# Effects of Nitrogen, Potassium and Organic Matter on Growth, Chemical Components and Seed Yields of IS 23585 Forage Sorghum Cultivar

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## Declaration

I declare that the research described in this thesis is that of the author, and has not previously been submitted either in whole or in part in support of an application for another degree or qualification at this or any other university or institution of learning.

Suradej Pholsen
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# Preface

The author obtained a B.Sc. in Plant Science from Khon Kaen University in March 1978 and an M.Sc. degree in Crop Production in 1983 from the Kasetsart University, Bangkok, Thailand. He was a staff member of the Department of Animal Science, Faculty of Agriculture, Khon Kaen University since 1995. He was previously a member of staff at Khon Kaen Agricultural College, Manjakiree, Khon Kaen for 18 years. At Khon Kaen University, he has been working as a lecturer in tropical pasture subjects and carrying out research work on pasture and range development. In 1998 he was permitted by the Department of Animal Science, Khon Kaen University to work towards a degree of Doctor of Philosophy at the University of Hertfordshire, College Lane, Hatfield, Herts, United Kingdom in collaboration with Khon Kaen University, Khon Kaen, Thailand.

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**To my beloved Father, Mother and Wife**

(Wichai, Chuam and Pimpaporn Pholsen)

# Contents

## Chapter 1

### Introduction

## Chapter 2

### Materials and Methods

## Chapter 3

### Experiment 1

### Effects of Low Application Rates of Nitrogen and Potassium on Growth, Chemical Components and Seed Yields of IS 23585 Forage Sorghum Cultivar, (*Sorghum bicolor* L. Moench) Grown on Yasothon soil series (Oxic Paleustults) in Rainy Season

## Chapter 3

### Experiment 2

### Effects of High Application Rates of Nitrogen and Potassium on Growth, Chemical Components and Seed Yields of IS 23585 Forage Sorghum Cultivar (*Sorghum bicolor* L. Moench) Grown on Yasothon Soil Series (Oxic Paleustults) in Rainy Season

## Chapter 4

### Experiment 3

### Effects of Nitrogen and Potassium on Growth, Chemical Components and Seed Yields of IS 23585 Forage Sorghum Cultivar, (*Sorghum bicolor* L. Moench) With a Basal Dressing of Cattle Manure During August and November 1999 Rainy Season

## Chapter 4

### Experiment 4

### Effects of Nitrogen and Potassium on Growth, Chemical Components and Seed Yields of IS 23585 Forage Sorghum Cultivar, (*Sorghum bicolor* L. Moench) With a Basal Dressing of Cattle Manure During Dry Season With Irrigation

## Chapter 5

### Experiment 5

### Effects of a Low Application Rate of Cattle Manure on Varying Ratios of Nitrogen and Potassium on Growth, Yields and Chemical Components of IS 23585 Forage Sorghum Cultivar (*Sorghum bicolor* L. Moench) Grown on Yasothon Soil Series (Oxic Paleustults) in Dry Season With Irrigation

## Chapter 5

### Experiment 6

### Effects of a High Application Rate of Cattle Manure on Varying Ratios of Nitrogen and Potassium on Growth, Yields and Chemical Components of IS 23585 Forage Sorghum Cultivar (*Sorghum bicolor* L. Moench) Grown on Yasothon Soil Series (Oxic Paleustults) in Rainy Season Without Irrigation

## Chapter 6

## Appendix

### Appendix A

### Appendix B

### Appendix C

**E1. Experiment 1**

### E2. Experiment 2

**E3. Experiment 3**

**E4. Experiment 4**

# List of Tables

## Chapter 3

### Experiment 1

## Chapter 3

### Experiment 2

## Chapter 4

### Experiment 3

## Chapter 4

### Experiment 4

**Chapter 5**

**Experiment 5**

**Chapter 5**

**Experiment 6**

## Chapter 6

General Discussion

# List of Plates and Figures

## Chapter 1

## Chapter 2

## Chapter 3

Experiment 1

## Chapter 3

### Experiment 2

## Chapter 4

### Experiment 3

## Chapter 4

### Experiment 4

## Chapter 5

### Experiment 5

## Chapter 5

### Experiment 6

# Abstract

Sorghum is considered to be of African origin and subsequently spread to most countries in tropical and subtropical regions. Sorghum has outstanding resistance against drought conditions. Grain and fodder from sorghum plants have been used for man's and animals' consumption respectively for many decades.

Experiments were conducted on Yasothon soil series (Oxic Paleustults) in Northeast Thailand, this is considered a poor soil. Growth parameters of sorghum were affected most by nitrogen chemical fertiliser followed by potassium chemical fertiliser. An increase in nitrogen level increased growth parameters and seed yields/ha of the sorghum plants whilst an increase in potassium also increased growth parameters and seed yields but to a lesser extent. High application rates of both nitrogen and potassium were required to achieve high total dry weights and seed yields/ha. Fermented cattle manure significantly increased growth parameters of the sorghum plants and soil properties were also improved by cattle manure. Total dry weights and seed yields/ha were affected most by seasons and treatments whilst seasons x treatments had highly significant effects on seed yields/ha but not total dry weights/ha. In terms of economic viewpoint, optimum application rates for nitrogen at a range of 300-450 kg N/ha and 100 kg $K_2O$/ha for potassium plus 40 tonnes/ha of fermented cattle manure were the recommended rates for optimum above ground total dry weight (15,940-26,282 kg/ha) and seed yield (5,047-6,374 kg/ha) of IS 23585 forage sorghum cultivar on Yasothon soil series.

An increase in nitrogen fertiliser application increased estimated crude protein (CP) of the sorghum plants whilst potassium did not. Both nitrogen and potassium had no significant effects on acid detergent fibre (ADF), neutral detergent fibre (NDF), and dry matter degradability (DMD). However, seasons had significant effects on CP, NDF, ADF, DMD and brix values. Treatments also had significant effects on all components except DMD, and brix values. Seasons x treatments had significant effects on all components except CP and brix values.

# Chapter 1

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## 1. Introduction

### 1.1 A Brief Historical Background and Classification of Sorghum (*Sorghum bicolor* L. Moench)

Sorghum is an annual plant, it belongs to Class Monocotyledoneae, Tribe: Andropogony, Family: Poaceae (Graminea) and Subfamily: Panicoideae. The genus Sorghum Moench is divided into four groups, they are: *Chaeotosorghum, Heterosorghum, Parasorghum, Stiposorghum,* and *Sorghum.*

*Sorghum bicolor* was brought into cultivation at the same time as many other West African crops. It is believed to have had domesticated around some 7000 years ago (Murdock, 1959). It has been advocated that sorghum cultivars reached India not earlier than 1500 BC and China by AD 900 (Harlan and Stemler, 1976). Sorghum was introduced to America and Australia around 100 years ago. The cultivation of sorghum has spread throughout the world due to its nutritious value both for fodder and grain. The major production countries of the world are America, India, Nigeria, China, and Mexico. However, sorghum is found in most subtropical and tropical regions. This C-4 Dicarboxylic Acid Pathway cereal plant can thrive in most tropical and subtropical climatic conditions since it has a high resistance to drought.

### 1.2 Importance of Sorghum in Agriculture

Sorghum plants have been considered as one of the most important cereal crops for human and animal food consumption. The importance of sorghum in terms of human consumption may be ranked after rice, wheat, maize and barley. It has been well advocated that sorghum plants could manifest high drought resistance and drought tolerance as reported by a number of workers, e.g. Whiteman and Wilson (1965); Seetharama *et al*, (1984); and Bennett *et al*, (1990). One outstanding characteristic of sorghum is that leaves and stalks are commonly coated with waxy materials, which will give some protection from heat in dry climatic conditions, and reduce transpiration rates. Sorghum normally has a large fibrous root system to support the erect stem and can adapt well in semi-arid areas where the optimum temperature could be upto 30 ° C and an annual rainfall ranged from 400-750 mm (Skerman and Riveros, 1990). Sorghum grains contribute to the human diet in many countries (particularly third world countries) as well as being used as animal feed. It has been reported that more than 1,000 million people in the semi-arid tropical zone use sorghum grains for their daily diet. Sorghum flour can be used to make many kinds of human food. For instance, Siwawej (1980) reported that sorghum flour together with 10 % tapioca starch produces the most acceptable noodles in Thailand. Da *et al.* (1981); and Scheuring *et al.* (1981) stated that *To^* made from sorghum has been used as a common food for the people in semi-arid Africa ranged from Senegal to Ethiopia, *Ugali* is a thick porridge popularly used in Eastern and Southern Africa (Mukuru *et al.*, 1981). *Ogi* or *Akamu* and *Tuwo* are the two main dishes of Nigeria (Obilana, 1981), whilst *Injera* is considered as the traditional bread of the Ethiopian people (Gebrekidan and Gebre Hiwot, 1981). *Kisra* is a thin pancake-like leavened bread of the Sudanese people (Ejeta, 1981), *Bogobe* is the sorghum meal of Botswana (Boling and Eisener, 1981), *Tortilla* is a daily food of Mexico and Latin America (Iruegas *et al.*, 1981), *Roti* is the most popular sorghum food in India as reported by Murty and Subramanian (1981); and Munck *et al.* (1981). The mixture of sorghum flour with other kinds of flour (cassava or rice) can be used to make many varieties of human food. Zou and Shi (2002) reported that in China sorghum grains have been used in making breads, cakes, dumplings and noodles. Sorghum grains can also be used to make liquor, brewing beer, refining sugar, monosodium glutamate, vinegar, alcohol, cosmetics, medicinal drugs, and even candy. In addition, sorghum plant materials are used in many ways, e.g. root and stalk as fuel, household mats, sun-hats. Sorghum stalks and leaves can also be used in making paper pulps and plywood.

## 1.3 World Sorghum Production

World sorghum harvests for grains slightly decreased from 1992 to 2001 (FAO, 2002 and Appendix A1.1), e.g. in 1992 and 1999, the harvested land areas were 46,863,000 and 40,863,000 ha, respectively. The land area being used for sorghum has decreased with time, e.g., in 2001 the harvested area was 41,574,000 ha. This was lower than the average figure for the past ten years (1992-2001). However, results show that the average sorghum yields per hectare did not change.

Major producers of sorghum include Africa (50.82 %), Asia (30.72 %), North and Central America (13.40 %) and most of the remainders are in South America and Oceania. Average grain yields/ha was differently attained, e.g., the average grain yield found in Africa was 837 kg/ha, whilst in Asia was up to 1,110 kg/ha, Oceania was higher, i.e., 2,369 kg/ha, South America has an average of 3,155 kg/ha, North and Central America attained an average figure of 3,613 kg/ha and over 4,000 kg/ha have been found in Europe.

## 1.4 Sorghum Cultivation in Thailand

Published work indicates that sorghum cultivation in Thailand began in 1962 and large collections of sorghum cultivars were carried out from 1962 to 1966 (Senanarong, 1977). During that period, Thailand received aid from several international organizations such as the Rockefeller Foundation, Texas Agricultural Experiment Station, Nebraska Experiment Station, Purdue University, and several US seed companies. Sorghum grain collections from overseas during that time consisted of composite types from East Africa, some segregating materials and hybrids from India, and some locally produced inbred lines such as the yellow endosperm feterita types derived from Indian collections. It was observed that some cultivars possess a lengthy stem with dark-red or brown grains. This includes IS 9181, and IS 8719 and the grains could be used for making beer (these cultivars are derived from Indian sorghum genotypes). The IS 9181 cultivar has also been used for silage making.

Research works on sorghum cultivars in Thailand started from 1962 by the coordinated research groups of the Department of Agriculture, Ministry of Agriculture and Kasetsart University with the assistance from the Rockefeller Foundation and the United States Agency for International Development (USAID) at Praphutthabat Agricultural Experiment Station in Lop Buri and Saraburi provinces and later the National Corn and Sorghum Research Center (Farm Suwan), located in Nakhonratchasima province, Northeast Thailand took charge of the programme in 1969 (Senanarong, 1977) under the management of Thailand National Corn and Sorghum Improvement Programme. Most of the research works focused on breeding, soil fertility, pathology, entomology, crop production, economics, extension, regional testing, utilisation and nutrition of the sorghum plants.

In 1973, a regional unit was set up in Khon Kaen Province to assist the Thailand National Corn and Sorghum Programme. The unit concentrated on a breeding programme and selection for new sorghum cultivars suitable for use in the cropping systems in Northeast Thailand. The initial work of the unit revealed that soil fertility was a serious problem due to soil heterogeneity, i.e. the growth of the sorghum plants within a given field was not evenly distributed. Since that time there have been some collaborative programmes with the International Crop Research Institute for the Semi-Arid Tropics known as ICRISAT. This was established in India (Patanothai, 1974 and 1980) and later the National Corn and Sorghum Improvement Programme had a collaborative project with the International Maize and Wheat Improvement Center known as CIMMYT (Renfro, 1983). In Thailand, four promising sorghum cultivars were subsequently released: U-Thong 1, Suphan Buri 60, KU 439 and KU 630 and at the same time four hybrid cultivars were also released, i.e. DK 54, DK 59, DK 64 and KU 8501.

At the beginning of sorghum cultivation in Thailand, sorghum cultivars were grown mostly in the Middle Plain areas: Lop Buri, Nakhon Sawan, Saraburi, Suphan Buri and Kanchana Buri provinces (Boonsue *et al.*, 1971). At present, sorghum for grain and fodder is grown in 13 provinces [Agricultural statistics of Thailand (1999 and 2000) and Appendix A1.2]. Growers of sorghum integrate this crop with other crops e.g. during early wet season from May to September, maize is the most likely crop; sorghum follows after the harvest of maize kernels.

Sorghum production in Thailand during the past decade decreased dramatically, i.e. from 1991 to 2000 the harvested areas decreased by 55.73% with a decrease in total grain production of 40.8 %. However, during the year 2000, grain yields per unit area of land have been increased by up to 24.90 %. The government now allows up to 108,000 ha per annum for sorghum production. Over the past decade, growers attained the total production of approximately 165 MT per year with the average grain yields of 1,537 kg/ha (Agricultural Economics News, 1999). The restriction on land area for sorghum cultivation was made according to the government agricultural policy where other competitive crops must occupy some of the land. The land area for the cultivation of sorghum in Thailand could be expanded in the near future when livestock production has been increased due to the high demand for milk and beef.

## 1.5 A Brief Botanical Description of Sorghum

### 1.5.1 Root

Sorghum belongs to the family Gramineae (Poaceae), the plant has two distinct root systems, i. e. firstly a single radicle from germination of the seed develops seminal roots to absorb water and nutrients during the early stage of growth and development. Seminal root systems are very temporary and finally cease. Secondly, fibrous root systems develop very quickly to replace seminal root systems permanently after the die off of the seminal root systems. The first fibrous root system develops from the lowest node of stem and later from upper nodes. Root primordia from aerial nodes produce adventitious roots as aerial roots. Aerial roots, which are closed to the soil surface, will elongate to penetrate into the soil to uptake nutrients and support the erect stem, and preventing lodging. The root system of the sorghum plant has almost twice as many secondary roots as maize at any stage of growth; this is likely to be a factor in drought tolerance (Miller, 1961; and Myers, 1980).

### 1.5.2 Stem

The stem or culm of sorghum is usually erect and tall with a height of 0.5 to 4.0 m. and 0.5 to 5.0 cm in diameter. The culm exhibits a series of nodes and internodes. Each node has a bud, which could develop to be a tiller or branch. Each node originates a leaf, whilst the inner portion of the stem initially has its juicy spongy pith with sweet or insipid taste; this becomes dry when grains have filled up (House, 1981).

### 1.5.3 Leaf

Sorghum leaves originate from each node and are arranged in two ranks on opposite sides of the stem. Each leaf consists of leaf sheath and leaf blade, divided by a ligule surrounding half of the stem. Leaf sheaths may have overlapping margins encircling the internode or internode above. The width of the leaf blade ranges from 1.5 to 13 cm and 30 to 135 cm in length. Leaf number varies from 7 to 30 leaves depending on the cultivar and its growth duration and environment. The uppermost internode bears the inflorescence, which is known as the peduncle (Murty *et al.*, 1994).

### 1.5.4 Inflorescence and Flower

Inflorescence of the sorghum plants normally sets on the peduncle with branching of several racemes. The racemes bear spikelets, which normally occur in pairs. There are sessile and fertile spikelets. Sessile spikelets are 3 to 10 mm (in length). The shape may be oval, elliptic or obovate with two glumes, i.e. lower and upper glumes. The glumes enclose two florets, the lower one is sterile and the upper one is fertile and perfect. The lower floret is presented by the sterile lower lemma, which partially enfolds the upper fertile lemma. The fertile lemma has a cleft at the apex and may have some awns. Another small thin membranous structure is called palea. The palea may be present or absent in some cultivars. Flower or floret of the sorghum plant sets on sessile spikelets. It consists of a single-celled ovary, with two long style pistils and feathery stigmas white, light yellow or pink in colour and four stamens. At the base of the ovule, adjacent to the upper fertile lemma, there are two lodicules and the filament with four lobes of anthers attach at the base of lodicules. Pedicelled spikelets are usually small, lanceolate and more pointed than sessile spikelets, consisting of only glumes and/or lemmas and normally sterile. Several spikelets set on one raceme. Several racemes set on a tertiary or secondary branch, which is attached to the primary branch and then rachis. The rachis is the central part of the axis of the inflorescence or panicle or head. The young inflorescence is forced up through the sheath of the flag leaf. The peduncle may be well exerted above the flag leaf or sometime the lower portion of the inflorescence may remain partly in the boot surrounded by the sheath of the flag leaf. The number of sessile spikelets per inflorescence varies with cultivars, ranged from 1,500 to 4,000 sessile spikelets (Murty *et al.*, 1994).

### 1.5.5 Seed

Seed or grain of sorghum varies in colour, shape and size. It normally consists of three main layers. They are outer seed coat or pericarp, endosperm and embryo. The pericarp consists of an epicarp, mesocarp and endocarp with cross and tube cells. The pericarp colour may be white, cream, lemon yellow, red, or brown. The shape of the seed can be spherical, oval, ellipsoidal, pear-shaped, or turtle-shaped with a flat surface on one side. Seed size being counted as 100-seed weight ranges from 0.75 to 7.50 g. The embryo or germ consists of two main parts, i.e. scutellum and embryonic axis. The embryonic axis consists of shoot and radicle, which will develop to be stem and root system, respectively. The endosperm consists of a layer of aleurone cells and an outer corneous endosperm surrounding a central floury or starchy endosperm. The stylar area is located opposite to the seed hilum. The stylar area corresponds to the portion of tissue to which the stylar was attached during development. Colour and pigmentation of the stylar can affect the appearance of this area. The hilum is a bridge of translocation of assimilates to the developing grains. When the seed matures, the bridge is cut off. The hylar areas turn to black at physiological maturity, i.e. the formation of black layer, an index sign of maturity of the sorghum grains (Murty *et al.*, 1994).

### 1.6 Growth and Development of Sorghum Plant

Sorghum plants have a range of phenotypic sizes and shapes depending on their origins, genetic variations, genetic make up for specific end use and environmental conditions where the crop plants are grown. However, all sorghum plants go through the same phases of life cycle, i.e, starting from seed germination to physiological maturity. Vanderlip (1972) divided the growth and development of the sorghum plants into three main phases. They include vegetative growth, reproductive growth, and grain filling stage. Germination of sorghum seed under field conditions results in emergence within a few days after sowing under well-prepared seedbed in warm moist soil conditions. The initial phase on vegetative growth or Growth Stage 1 (GS 1) starts from seed emergence followed by the development of radicle and roots and finally leaf growth occurs. GS 1 normally takes about 1 to 30 days after the sowing of seeds then the reproductive phase or Growth Stage 2 (GS 2) starts thereafter; it could be characterized by the differentiation of the growing point of the apical meristem into a floral meristem. The development of this phase starting from floral initiation, an emergence of flag leaf and the blooming up to the beginning of anthesis. GS 2 continues from GS 1 for another 30 days whilst the third or the final growth stage (GS 3) continues from GS 2, i.e. the sorghum plant has reached its grain filling stage. That is after anthesis, pollination and fertilisation occur. After fertilisation has taken place then the translocation of assimilates from source to sink starts. The stages in development of grains are early milk, milky then soft dough and hard dough, respectively. The grain dry down occurs when a decline in moisture content has taken place. That is water content in the sorghum grains is progressively replaced by the starch and other solid constituents. The accumulation of assimilates reaches maximum at the point of physiological maturity. This is the final stage of grain development. GS 3 stage takes 30 days after the GS 2. Faungfupong *et al.* (1986) measured leaf growth with time and grain yields of two sorghum cultivars being grown in Thailand in August 1986, the results showed that at 14, 28, 42, 56 and 70 days after sowing, the sorghum plants gave functional leaf number of 5.7, 6.4, 7.4, 10.6 and 9.6 leaves per plant, respectively with the grain yields of 3,713 kg/ha for Hegari cultivar and 4.8, 6.4, 8.3, 10.6 and 9.4 leaves per plant, respectively with grain yields of 4,619 kg/ha for KU 8501 cultivar. However, growth and development stages of the sorghum plants could be affected by environmental conditions, e.g. Kamoshita *et al.* (1998b) with a hybrid sorghum cultivar found that nitrogen stress delayed time to anthesis by 8 to 9 days, grain-filling duration was 3 to 4 days shorter and maturity was delayed by up to 5 days compared with added nitrogen at the rate of 240 kg N/ha.

## 1.7 Dry Matter Accumulation

Dry matter accumulation in sorghum parallels the growth stages and normally exhibits a typical sigmoid growth curve with some substantial growth after anthesis. Dry matter accumulation depends most on soil nutrient availability whilst seasonal pattern of nutrient uptake does not always give a reliable indication of nutrient demand, because the uptake is often limited by nutrient availability, particularly in the later part of the growing season (Myers and Asher, 1982). Anon (1974a) with three late maturity sorghum cultivars, i.e. Hegari, IS 8791, and TSS 7-5 under tropical rain fed areas in Thailand showed that dry matter accumulation of the three cultivars with time followed sigmoid growth curves.

A number of workers have linked both plant height and grain yield with photoperiod and especially number of days from sowing to flowering. e.g. Jan-orn *et al.* (1977) with Hegari sorghum cultivar, a late maturity cultivar showed sensitivity to photoperiod, when sowing date commenced closer to the shortest day-length of December 22 in Thailand. The results showed that grain yield, number of days to flowering and plant height decreased with sowing dates. Sowing of Hegari 122 was carried out on: 1/8/77, 16/8/77, 1/9/77, 16/9/77 and 3/10/77. The sorghum plants gave grain yields of 5,469, 5,063, 2,363, 1,269 and 1,200 kg/ha, respectively, with the number of days from sowing to flowering of 80, 74, 59, 57 and 56 days, respectively. At the same time the sorghum plants gave mean values of plant heights of 260, 245, 188, 172 and 130 cm, respectively. Whilst the results at another location, i.e. at Nakhon Sawan province with well distribution rainfall of 314.3

mm during growing period from 1st August to 30th October 1977. Hegari 122 cultivar gave grain yields of 9,169 kg/ha, with the average plant height of 244 cm and number of days from sowing to flowering of 67 days, whereas in Suphan Buri province (sowing before Nakhon Sawan for 1 week) Hegari cultivar gave 4,160 kg/ha of grain yields with the average plant height of 193 cm and number of days to flowering of 62 days.

The range of yields in the above trials indicate that other environmental factors are also important e.g. rainfall.

Faungfupong *et al.* (1977) showed that dry matter accumulation of Hegari cultivar being measured at 8, 14, 21, 28, 35, 42, 49, 56, 63, 70, 77, 84, 91, 98 and 105 days after emergence gave the above ground total dry matter of 0.1, 0.6, 4.4, 13.8, 20.5, 35.6, 68.8, 62.4, 101.2, 82.7, 93.4, 103.5, 98.6, 82.7 and 67.9 g/plant, respectively whilst that of KU 257 cultivar, the sorghum plants gave dry matter accumulation with respect to sowing dates of 0.1, 0.5, 4.2, 11.8, 16.7, 42.2, 50.1, 56.2, 71.0, 67.7, 73.6, 76.1, 79.1, 77.8 and 82.8 g/plant, respectively. Both data sets show a clear link between dry matter accumulation and time and a similar pattern but also emphasise differences between cultivars.

It has been advocated that dry matter accumulation of most sorghum plants follows a sigmoid curve (Kamoshita *et al.*, 1998b). They stated that sorghum plants always gave sigmoid regressions fitted to biomass accumulations. They further stated that factors affecting dry matter accumulation included soil fertility, fertilisers, climatic factors (seasonal differences, drought, temperature, humidity, soil moisture content), sunlight (light intensity, photoperiods), plant population and genetic traits of the sorghum plants. Seetharama *et al.* (1984) reported that water stress significantly decreased dry matter accumulation in sorghum plants even though the stress had been released by irrigation at 60 days after sowing. Rao *et al.* (1999) also found that water stress in sorghum when grown under rain-fed conditions greatly reduced biomass production in the final harvest.

Kamoshita *et al.* (1998b) showed that the increase in total biomass of hybrid sorghum plants from 53 to 99 days after sowing was linearly related to the cumulative radiation interception in both control and with nitrogen fertiliser of 240 kg N/ha, radiation use efficiency was 0.69 and 1.27 g/MJ, respectively. With application of 0 and 240 kg N/ha at 62 and 99 days after sowing the sorghum plants had cumulative radiation interception values of 428 and 560 MJ/m$^2$ and 1,016 and 1,320 MJ/m$^2$, respectively. Joshi *et al.* (1998) reported that leaf and root dry weights of sorghum increased gradually up to 75 days after sowing and then decreased with time, whereas stem dry weights increased throughout the vegetative and reproductive periods and ear-head dry weights also increased with time. During the period of 30 to 75 days after sowing, sorghum leaves accumulated more dry matter than the shoots and roots, thereafter shoots had higher dry matter followed by leaves, roots and ear-head, respectively. This indicates that assimilate partitioning changes with the growth stage, favouring leaves in the mid-growth period. Poonia *et al.* (1999) found that dry matter accumulation of sorghum gradually increased with stages of growth up to harvest at all rates of nitrogen application. The longer the duration of growth of the sorghum plants the higher the dry matter accumulation.

## 1.8 Total Dry Weights

Seetharama *et al.* (1984) reported on the seasonal biomass and grain yield of sorghum plants in various soil types and water stress treatments in semi-arid India from 1970 to 1978. They concluded that the higher biomass production in late maturity hybrids was attributed to the longer duration in growth extending the production and accumulation of assimilates rather than effects due to high leaf area indices (LAI), light interception and crop growth rates (CGR). Ockerby *et al.* (2001) reported that sorghum plant above ground dry weights at anthesis were reduced by both early and late water stress compared with controls. Berenguer and Faci (2001) found that the aerial dry matter production differed significantly at 171 days after sowing depending on irrigation amount. Rao *et al.* (1999) showed that water stress under rain-fed conditions greatly reduced dry matter production at the final harvest in sorghum hybrid CSH-9.

A number of workers have shown a strong link between cultivar and total biomass production. For example, Pholsen *et al.* (1998) with ten sorghum cultivars grown on Yasothon soil series (Oxic Paleustults) in Northeast Thailand, found that at 90 days after emergence, the sorghum plants gave dry matter yields ranging from 64.5 to 166.4 g/plant and at 160 days after emergence, dry matter yields ranging from 49.3 to 85.6 g/plant. Similarly, Areerak *et al.* (1999) with eight sorghum cultivars being sown post-rainy season, five of them were hybrids and three of them were pure lines. They showed that the hybrid KU 9501 cultivar gave the highest plant dry weight of 4,494 kg/ha whereas the rest of the four hybrids did not show any significant differences in plant dry weights (ranged: 3,689 to 3,788 kg/ha). The pure line SP 60 cultivar gave significantly higher dry weights than KU 439 and KU 630.

Pholsen *et al.* (2001) were unable to show any positive effects of fertiliser on whole plant biomass of IS 23585 sorghum cultivar grown on Yasothon soil series (Oxic Paleustults) in Northeast Thailand with the application of different rates of urea and potassium chloride (KCl) chemical fertilisers, i.e. 0+0, 62.5+50, 125+100 and 187.5+150 kg N+$K_2O$/ha. They did not find any significant differences due to treatments when the plant samples were taken at 82 days after emergence. The dry matter yields ranged from 51.04 to 64.97 g/plant. The explanation for this is probably that fertiliser levels were too low. This is a very poor soil, is very low in organic matter and has a sandy texture indicating a high leaching rate.

## 1.9 Stem Dry Weights

Stem growth of sorghum is important with respect to fodder yields. Peacock and Wilson (1984) state that stem dry weights of sorghum vary both with size and with the amount of stored carbohydrate. The marked variety differences that exist in stem storage capacity will also influence fodder value. Gibson and Schertz (1977) showed that in many high yield sorghum hybrids, stem dry weights decreased during grain filling stage, while Borrell *et al.* (2000b) showed that stem dry weights remained relatively constant (≈

400 g/m$^2$) throughout the grain-filling period for stay-green hybrids. Slight declines were found in intermediate hybrids particularly during the second half of the grain-filling period.

### 1.10 Leaf Dry Weights

Green leaf production is important with respect to quantity and quality of fodder and silage as well as carbon assimilation. Borrell *et al.* (2000a) carried out an experiment with hybrid sorghum cultivars, they found that during the first half of grain-filling period, green leaf dry weights remained relatively constant for AQL41/R69264 senescent hybrid and AQL41/RQL36, an intermediate hybrid, but increased with time for AQL41/RQL12, the stay-green hybrid cultivar. They found that by the period of mid grain filling, green leaf dry weight for the stay-green hybrid was 263 g/m$^2$ whilst that of the senescent hybrid was only 198 g/m$^2$. During late grain filling period, green leaf dry weight declined more rapidly for the senescent and intermediate hybrids compared with the stay-green hybrid. Stay-green hybrid had 167 and 56 g/m$^2$ greater leaf dry weight than that of the senescent and intermediate hybrid, respectively. They suggested that genetic traits of the cultivars had a great influence on number of leaves that stay green with time.

Pholsen *et al.* (2001) found that nitrogen application significantly increased leaf dry weights/plant of the IS 23585 sorghum cultivar grown on Yasothon soil series (Oxic Paleustults) in Northeast Thailand but the increase was only up to 125 kgN/ha. Higher nitrogen rates did not produce a further increase in leaf dry weights.

### 1.11 Grain Yields

Grain yields of sorghum could be considered as the most important final product since the sorghum grain can be used for human diet and also animal feed as well as being kept for sowing for the coming seasons. Tippayaruk *et al.* (1976) carried out experiments in six different locations in Thailand with twelve sorghum cultivars during the rainy season; the results showed that Hegari 182 gave the highest grain yields at four locations with the grain yields ranging from 2,549 to 5,362 kg/ha while of other two locations, Hegari

182 ranked the second and third. Ranking of grain yields in sorghum cultivars at Khon Kaen University Farm were different, i.e. KU 141 gave the highest grain yields followed by TSP 750 cultivar and Hegari 181 ranked the third with the grain yields of 4,576, 4,254 and 4,037 kg/ha and the number of days to flower of 72, 67 and 67 days after sowing, respectively. These results, and data from other workers, e.g. Chawanapong (1977); Chawanapong *et al.* (1980 and 1983); and Rungchang *et al.* (1983) all indicate that grain yield is very strongly linked to cultivar but that there is probably also an interaction with soil type, climate, nutrition and water availability. Data from more recent work gives some support to this view.

Thiraporn *et al.* (1986) grew eight sorghum cultivars in three locations in Thailand, they reported that Nakhon Sawan province field trial had an average grain yield of 4,086 kg/ha for all tested cultivars but KU 8501 was highest at 4,906 kg/ha. Nitrogen fertiliser application rates increased grain yields up to three fold under irrigation, nitrogen rates were 0 N to 240 kg N/ha. In contrast, Kamoshita *et al.* (1998a) with a sorghum experiment under rain-fed conditions, found no effect on grain yields due to nitrogen application. Holford *et al.* (1997) found a small effect due to nitrogen application but high nitrogen rates depressed grain yields. Borrell *et al.* (2000b) with nine sorghum hybrids grown under three levels of water supply, found that genotype and water regime interacted significantly with grain yield. Grain yield declined with increasing water deficit in the five senescent hybrids but was maintained constant under increasing water deficit for the four stay-green hybrids. Berenguer and Faci (2001) found that water regime significantly affected grain yields of sorghum at 171 days after sowing with up to 60% reduction at low irrigation levels. Rao *et al.* (1999) showed that grain yield in non-irrigated sorghum plants was decreased mainly by a reduction in grain number rather than by a decrease in grain size.

### 1.12 Seed Size

Thiraporn *et al.* (1980) carried out an experiment with seven sorghum cultivars in regional yield trials in Thailand. They found 1000-grain weights between 22.64 and 31.37 g indicating a very strong link between seed size and cultivar.

Berenguer and Faci (2001) found that irrigation levels significantly influenced 1,000-seed weights. Seed sizes were decreased with a decrease in the amount of irrigation water. Rao *et al.* (1999) also reported that water stress reduced 1000-grain weights of the short life cycle sorghum hybrid CSH-6 and its female parent 2219B. The decreases were as high as 26.5 and 65 % for irrigated and rain-fed conditions, respectively.

Chouhan and Dighe (1999) found that, in most cases, $N+P_2O_5$ (100+50 kg/ha) decreased 1000-seed weights to a small extent. In contrast, Pholsen *et al.* (2001) with IS 23585 sorghum cultivar grown on Oxic Paleustults soil in Northeast Thailand found that higher levels of both nitrogen and potassium (187.5+150 kg $N+K_2O$/ha) had no significant effect on seed size (1000-seed weights ranged from 30.05 to 32.33 g) and Kamoshita *et al.* (1998a) also showed that Nitrogen fertiliser application rates had little effect on grain size.

### 1.13 Leaf Areas and Leaf Area Indices (LAI)

Optimum radiant energy from the sun must be intercepted by leaf canopies, i.e. the crop plants should intercept at least 90 % of the incoming radiant energy; it has been established that in crop plants with vertical structure of leaves, LAI value should reach a maximum value between 8-10 (Birke, 1965; Suksri *et al.*, 1989; Suksri and Seripong, 1990; and Suksri, 1992, 1993, 1996, 1998 and 1999). Sorghum plants normally possess semi-erect leaves hence LAI (leaf area/plant divided by ground area) must be adjusted to reach an optimal value by an appropriate planting density, fertiliser and watering regime. This is to attain maximum output in relation to the incoming radiant energy and to suit the fertility level of soils.

Wilson and Eastin (1982) stated that leaf area (LA) is the basis of growth and yields of crop plants. For photoperiod sensitive crops, most of the LA produced is unlikely to persist until grain maturity, and may, therefore, be a major limitation to grain yield. LA per plant depends on genetic traits, number of leaves, rate of leaf expansion, sizes of leaves, and leaf senescence.

Tanaka (1974) stated that when nitrogen is a limiting factor for plant growth, an increase in nitrogen levels increased LAI up to certain rates of nitrogen where the crop plants attained optimum LAI. (An additional amount of phosphorus or potassium did not achieve this effect). Too a high rate of nitrogen application may result in an excessive amount of leaves, causing serious mutual shading, which may impose a ceiling on grain yield.

Seetharama *et al.* (1984) link LAI to water availability in sorghum. They reported that under well-irrigated conditions, LAI increased more rapidly with time and reached a maximum of 60 days after sowing and then decreased sharply with time. Water stress significantly depressed LAI but when the stress was released by giving irrigation water at 60 days after sowing, LAI increased up to 80 days after sowing and then decreased more rapidly with time. Kamoshita *et al.* (1998b) found that LAI of hybrid sorghum plants determined at 53 days after sowing for nitrogen treatment rates of 0 and 240 kg N/ha were 3.1 and 5.5, respectively. LAI decreased substantially from 53 days after sowing to the values of 1.8 and 2.3 at maturity for both nitrogen levels, respectively. LAI at maturity was higher for irrigated compared to rain-fed treatments. Leaf area indices increased with an increase in nitrogen application rates for both experiments. This work indicates a positive relationship between LAI and both nitrogen application rates and irrigation. Similarly, McCree and Davis (1974) found that when water stress occurred in sorghum plants it reduced the rate of leaf growth substantially. Water stress subsequently reduced the final leaf area through a reduction in both rates of cell division and expansion. Stout *et al.* (1978) also showed that water stress in sorghum affected the duration of leaf growth and they observed that there were some marked genetic differences within the tested cultivars; leaf growth of M35-1 cultivar continued with an increase in water stress whilst leaf growth of NK 300 cultivar reduced with time. Ockerby *et al.* (2001) reported that green leaf area of sorghum Buster cultivar at anthesis was reduced by water stress compared with the control treatment with values of 1,365 and 1,815 $cm^2$/plant, respectively. Rao *et al.* (1999) have grown sorghum under irrigated conditions. They found that both CSH-6 and CSH-9 sorghum hybrids, had significantly greater LA than their parents at 42 days after sowing. They have also grown sorghum under rain-fed conditions; LAI reached maximum at 42 days after sowing with a value of 5.33 for the short life cycle cultivar whilst the late maturity cultivar attained a maximum value of 6 at 42 days after sowing; thereafter LAI declined rapidly with time for all tested cultivars. The decline in LAI coincided with the time of anthesis of the sorghum plants.

### 1.14 Crop Growth Rate (CGR)

Crop growth rate may be defined as the accumulation of plant dry weight per unit land area within a given time of the growth period, i.e. a single figure of CGR must derive from two consecutive sampling periods. It signifies the efficiency of crop plants in accumulating assimilates regardless of respiration. CGR can be used as a useful tool to measure the changes in plant dry matter accumulation with time, the attained amounts of plant dry weight may indicate the efficiency of the crop plants in relation to time (Sestak *et al.,* 1971; Hunt, 1978; Bullock *et al.,* 1993; and Suksri, 1999).

Fischer and Wilson (1975) reported crop growth values for sorghum of 43.6 g/$m^2$/day with an average value for the whole crop cycle of 31 g/$m^2$/day. These figures were achieved with plant populations of 646,000 plants/ha and an average radiant energy of 26.5 MJ/$m^2$/day for the whole growth period. Borrell *et al.* (2000b) showed that there was no significant interaction between genotype and water regime on CGR and dry matter production in sorghum; averaged across hybrids, CGR for the whole 114 days of growth increased with water regime. CGR values were relatively low for water deficit treatments and the values attained were 14.4 g/$m^2$/day for terminal pre flowering, 16.6 g/$m^2$/day for post flowering and 17.9 g/$m^2$/day for no water deficit treatment. Genotypic variation in CGR was significantly different with the values ranged from 14.6 g/$m^2$/day for AQL39 / RQL36 genotype to 18.1 g/$m^2$/day for A35 / RQL36 genotype. Variations in biomass production were also found to be significant due to the variation in CGR values.

Rao *et al.* (1999) reported that water stress severely decreased CGR of sorghum. CGR values at seedling stage (11 to 21 days after sowing), pre-anthesis (24 days after sowing to anthesis) and post-anthesis (anthesis to maturity) for short life cycle hybrid CSH-6 were 2.05, 38.10 and 25.90 g/m$^2$/day when grown under irrigated conditions, respectively and 1.71, 5.25 and 10.10 g/m$^2$/day when grown under rain-fed conditions, respectively. For late maturity hybrid CSH-9, the CGR values were 2.08, 34.70 and 5.80 g/m$^2$/day under irrigated conditions, respectively and 1.53, 10.50 and 5.30 g/m$^2$/day under rain-fed conditions, respectively. They further stated that CGR value of CSH-6 had doubled from 5.25 g/m$^2$/day during pre-anthesis period to 10.1 g/m$^2$/day during the post-anthesis period due to its active sink of grain development. CGR of the late maturity hybrid, i.e. CSH-9 decreased by half from 10.50 to 5.30 g/m$^2$/day during the last two growth stages under rain-fed conditions.

## 1.15 Forage Quality

Forage or fodder quality for livestock production has a significant role in raising dairy, beef, and other cattle. Forage quality depends most on the content of carbohydrate, protein, minerals and $H_2O$ in its cells. In the tropics, the quality of forage feedstuff may not be as high as that of temperate areas where high soil fertility, soil moisture content and moderate amounts of radiant energy are the norm. In tropical areas, soil fertility is often poor coupled with inadequate soil moisture, although a high amount of radiant energy may be available throughout the year. Often, when forage crops are grown in a hot climate they may produce a high amount of fibrous tissues in leaves or stems with lower protein content and other essential nutrient elements, hence the forage may be relatively poor in terms of nutritive value.

T' Mannetje (1981) stated that Tropical pastures did not meet the nutritional requirements of ruminants for maximum production. The main limitations could be the availability of green feed (available for only half the year in most seasonal dry regions) as well as the low nutritive value during most of the active growth season. Butterworth (1985) reported that crude protein of 235 forage samples averaged 7.5% ± 3.5%, with a large number of them was under 7%, whereas 7% crude protein could be the level for zero live weight gain of ruminants. Crude protein content in most forage crops decreases when they reach maturity, due to more cell wall constituents (e.g. neutral detergent fibre, NDF). As the crude protein content decreased the NDF could be increased, hence digestibility could be relatively poor.

## 1.16 Chemical Components

### 1.16.1 Crude Protein (CP)

Dietary protein generally refers to crude protein (CP) content in the feedstuff. The convention to calculate CP in feedstuff is to multiply nitrogen by 6.25. This calculation is based on the assumption that the average N content of feedstuff is 16 g per 100 g of protein (NRC, 2001). Catchpoole (1962) found that crude protein in sorghum cv. Saccaline decreased with an increase in age of the crop plants. He took plant samples at 4, 6, 8, 10, 14 and 16 weeks after sowing, i.e. growth stages: no ear initiated, ear initiated, boot stage, early milk stage, early dough stage, hard dough stage and the final stage of growth. The results showed that the amounts of crude protein attained were 22.6, 14.0, 9.5, 7.3, 5.6, 4.2 and 4.8 %, respectively. CP values decreased more rapidly with advances in age of the sorghum plants. Asher and Cowie (1974) found that side dressing of 34 kg N/ha applied at the boot stage of sorghum cv. RS610 significantly increased grain nitrogen concentrations. The greatest effect on grain nitrogen content occurred when side dressing was applied at the anthesis stage. When nitrogen application was carried out only once at sowing stage at the rates of 0, 34, 112 and 336 kg N/ha, the grain nitrogen concentrations were 1.24, 1.06, 1.41 and 1.80 %, respectively. Whilst that of the side dressing at anthesis with one half of the total amount of fertiliser for each nitrogen rate, grain nitrogen had increased up to 1.35, 2.02, 2.03 and 2.68 %, respectively. He suggested that nitrogen losses through leaching could be enormous if nitrogen was applied only once at sowing period. In contrast, Meesawat *et al.* (1977) showed that an increase in nitrogen fertiliser rate from 112.5 to 225 kg N/ha did not significantly increase nitrogen content in leaves of the sorghum plants when determined at 60 days after sowing. They attained mean nitrogen percentages in leaves of 1.4 and 1.6 %, respectively for the two rates of nitrogen application.

Khajarern *et al.* (1977) carried out laboratory analysis on CP values of sorghum seeds of two cultivars i.e. TSS, IS 8719 E 173 by the procedure of proximate analysis. They prepared the sorghum seeds into three groups, i.e. TSS, IS 8719E 173, and the mixing half by half of the two cultivars. The results showed that the estimated crude protein contents of the three groups were 8.03, 9.40 and 8.40 %, respectively. They also found that protein contents of the cultivar of low protein content manifested some slight fluctuations but much greater with that of the high protein content cultivar, i.e. the IS 8719 E 173. The two cultivars were grown at Khon Kaen University Farm, Northeast Thailand. Devahuti *et al.* (1992) with forage sorghum showed that the red sorghum cultivar harvested at the periods of 45, 60 and 75 days after emergence gave the crude protein of 9.6, 8.1 and 6.6 % on dry weight basis, respectively. They suggested that CP values of the sorghum plants decreased substantially when the sorghum plants have advanced in age. Pholsen *et al.* (1998) reported that crude protein contents of ten sorghum cultivars determined at 90 days after emergence ranging from 4.60 to 6.79 %, IS 23585 cultivar gave CP content of 6.14 %.

Kamoshita *et al.* (1998a) showed that nitrogen content of a hybrid sorghum cultivar at maturity in both irrigated and rain-fed experiments was similar but increased with an increase in nitrogen fertiliser application rates and irrigation. The total nitrogen contents in irrigated sorghum were 4.96, 10.06 and 24.88 % whilst that of the rain-fed experiment were 4.37, 6.18 and 12.87 % for the rates of N application of 0, 60 and 240 kg/ha, respectively. Holford *et al.* (1997) carried out sorghum experiments in Australia and showed that in most experiments, sorghum grain protein responded well to N levels; in the southern region, the average protein responses were relatively high. The sorghum plants gave grain protein content of 6.78, 7.05, 7.36, 8.35 and 9.79 % with the applied chemical fertiliser rates of 0, 20, 40, 80 and 160 kg N/ha, respectively. The sorghum plants were grown under high rainfall (245 mm). In another experiment, nitrogen application rates gave relatively high CP values when sorghum plants were grown under low rainfall (169 mm). The attained CP values were 8.73, 8.81, 9.29, 9.86 and 10.38 % for nitrogen application rates of 0, 20, 40, 80 and 160 kg N/ha, respectively. In a pot experiment with forage sorghum, Singh and Singh (1998) reported that protein contents increased with an increase in nitrogen levels from 8.74, 9.14, 9.61 to 9.66 % with nitrogen rates of 0, 30, 60 and 120 mg/kg soil, respectively. Chouhan and Dighe (1999) found that higher levels of $N+P_2O_5$ increased nitrogen content in grain and straw of sorghum plants up to 80+40 kg $N+P_2O_5$ /ha. The application of $N+P_2O_5$ at the rates of 20+10, 40+20, 60+30, 80+40 and 100+50 kg $N+P_2O_5$ /ha gave grain nitrogen content of 2.27, 2.36, 2.44, 2.55 and 2.50 %, respectively and straw nitrogen content of 0.87, 0.93, 0.99, 1.08 and 1.03 %, respectively.

Patel (1998) reported that crude protein content in forage sorghum increased significantly with an increase in nitrogen levels. With the applied nitrogen fertiliser rates of 0, 25, 50 and 75 kg N/ha, the crude protein attained in the plant tissues were 352, 492, 654 and 783 kg/ha, respectively. Kamoshita *et al.* (1998b) showed that nitrogen in the plant tissues and in grains of the hybrid sorghum plants at maturity were over 3 times greater for the added 240 kg N/ha than that of the 0 kg N/ha. Similarly, Buxton *et al.* (1999) showed that nitrogen content found in the combination of sweet forage sorghum with the average values over the five-year period, significantly increased with an increase in nitrogen levels. When applied nitrogen fertiliser at the rates of 0, 70, 140 and 280 kg N/ha gave nitrogen content in both combined sorghum of 8.8, 10.0, 10.8 and 11.5 g/kg, respectively. When these figures were converted to the estimated crude protein, the values ranged from 55 to 72 g/kg. NRC (1984 and 1989) reported that crude proteins that reached the requirements for the total dietary range should be ranged from 70 g/kg for matured beef cattle to 190 g/kg for high-producing lactating dairy cattle. Pholsen *et al.* (2001) with IS 23585 sorghum cultivar grown on Oxic Paleustults soil, Northeast, Thailand found that higher levels of nitrogen application, in most cases, significantly increased CP of the sorghum plants. The attained CP values were 4.35, 4.83, 4.65 and 4.92 % for nitrogen rates of 0, 62.5, 125 and 187.5 kg N/ha, respectively. The measurements were carried out at 82 days after emergence. NRC (2001) reported that a matured lactating Holstein with a body weight of 680 kg requires daily dry matter intake of 20.3, 23.6, and 26.9 kg with CP % of 14.1, 15.2, and 16.0, to provide milk production of 25, 35 and 45 kg, respectively.

### 1.16.2 Neutral and Acid Detergent Fibres (NDF and ADF)

Carbohydrate content in feedstuff could be considered as the major source of energy for cattle to provide energy for rumen microbes and the host animal. Carbohydrates may be broadly classified as nonstructural carbohydrates and structural carbohydrates. Nonstructural carbohydrates could be found inside the cell of plants where pectin is included in non-fibrous carbohydrate but not in nonstructural carbohydrates. Both nonstructural and pectin are usually more digestible than structural carbohydrates. Structural carbohydrates could be found in plant cell walls. Sugars, starches, organic acids and other reserved carbohydrates such as fructans or fructosans make up the nonstructural carbohydrate fraction. They are the major sources of energy for cattle. Structural carbohydrates of plant cell walls are made of fibres. Crude fibre, neutral detergent fibre (NDF) and acid detergent fibre (ADF) are the most common measurable fibres used for routine feed analysis, but none of these fractions is chemically uniform. NDF embraces for the most part the plant cell wall and are sometimes referred to as the cell wall components or cell wall constituents. These consist primarily of cellulose, lignin, silica, hemicellulose and some protein. The differences among NDF (cell wall) components are in their (low) digestibility; they are entirely dependent on the microorganisms in the digestive tract for any digestion to be carried out. Lignin and silica are essentially indigestible even by microorganisms. Also, lignin has a curvilinear negative influence on cellulose and hemicellulose digestibility. NDF measures most of the structural components in plant cell, i.e. cellulose, hemicellulose and lignin. ADF does not include hemicellulose. Crude fibre does not quantitatively recover hemicellulose and lignin. NDF analysis is the best method that separates structural from nonstructural carbohydrates in plant cell and NDF measures most of the chemical compounds. It is generally considered to have comprised of fibre. Within the specific feedstuff, concentrations of NDF, ADF and crude fibre are highly correlated among these components, but for mixed diets contain different fibre sources. The correlations among the different measurements of fibre are the low values NDF. It is the best expression of fibre availability, but recommendations are given for ADF because of it is widely accepted by growers of cattle, whereas crude fibre is considered obsolete (Cullison, 1975; and NRC, 2001). Bacteria in the rumen of ruminants can digest NDF and ADF fibres (except lignin). After both fibres have been digested by bacteria then microbial proteins are formed, which can be absorbed in ruminal digestive tracts. Microbial proteins are synthesied to form proteins in animal cells. NDF and ADF could have been analyzed from detergent analysis by the method of Georing and Van Soest (1970). Structural carbohydrates (NDF and ADF) have been estimated from the aerial plant parts of sorghum because these are generally used to feed cattle in the forms of soilage, silage and hay. Devahuti *et al.* (1992) analysed in red sorghum and found that NDF in the plant tissues were 68.1, 73.3 and 68.6 % of dry matter, whilst ADF were 39.9, 40.1 and 40.5 % of dry matter at the cutting periods of 45, 60 and 75 days after emergence, respectively. Joshi *et al.* (1998) with forage sorghum found that there were more fibrous tissues in shoots than in leaves in all stages of growth and development. They analysed NDF and ADF content in leaves at 60, 75 and 90 days after sowing and the values were 682±1.2, 706±1.6 and 734±1.6 g/kg of dry matter of NDF, whilst ADF were 474±2.8, 463±3.7 and 456±2.8 g/kg of dry matter, respectively and NDF in shoots were 742±3.6, 759±0.8 and 766±1.6 g/kg of dry matter, whilst ADF values were 513±1.6, 531±4.1 and 526±0.8 g/kg of dry matter, respectively. Pholsen *et al.* (1998) reported that NDF contents in ten sorghum cultivars at 90 days after emergence ranged from 52.10 to 69.04 %, whilst IS 23585 cultivar gave the lowest values of NDF of 52.10 %. ADF content ranged from 26.05 to 37.08 %, whilst the lowest value of ADF content was 26.05 % for IS 23585 sorghum cultivar. In another experiment, Pholsen *et al.* (2001) found that in IS 23585 sorghum cultivar grown on Oxic Paleustults soil in Northeast Thailand, higher levels of nitrogen and potassium did not give significant differences in either NDF or

ADF content; they obtained NDF values ranged from 48.99 to 54.17 % and ADF values ranged from 28.28 to 31.59 %.

Buxton *et al.* (1999) found that higher rates of nitrogen fertiliser application significantly decreased both NDF and ADF content of sorghum plants. With applied nitrogen fertiliser rates of 0, 70, 140 and 280 kg N/ha, NDF content in both sweet and forage-combined sorghums were 588, 572, 564 and 560 g/kg, respectively and ADF values were 358, 353, 347 and 344 g/kg, respectively. It has been advocated by a number of workers, e.g. Buxton and Mertens (1995) that high NDF and ADF concentrations reduced digestibility and intake potential of forage crops by livestock. NRC (2001) reported that sorghum silage of 28.2 % dry matter contains CP of 9.1 %, NDF 60.7 %, ADF 38.7, lignin 6.5 % and ash 7.5 % on dry matter basis. Whilst from other work, NRC (2001) recommended minimum concentrations based on % dry matter of forage, NDF should ranged from 15 % to19 %, dietary NDF (25 to 33 %) and dietary ADF (17 to 21 %). Nutrient requirements for growing Holstein heifers using a model to predict target average daily needs to attain a mature body weight of 680 kg when dry matter intake rates were 5.2, 7.1 or 11.3 kg, were minimum NDF of 30 to 33 %, 30 to 33 % and 30 to 33 % and minimum ADF of 20 to 21 %, 20 to 21 % and 20 to 21 %, respectively.

### 1.16.3 Dry Matter Degradability (DMD)

Feeding value of forage to animals is directly linked to the digestibility of its nutrients, that is, the proportion of nutrients consumed, which is digested and absorbed by the animal as it passes through the alimentary tract. Following absorption into the bloodstream, the digested nutrients can be utilised for maintenance and production purposes (Frame, 1994). There are two main methods for the evaluation of forage digestibility, i.e. *in vivo* and *in vitro*. *In vivo* evaluation can be directly done by the total collection method of passing forage intake through digestive tracts until it ends up as dung. Percent digestibility of dry matter (DM) of forage is defined as the ratio of the difference between feed DM intake and DM of dung compared with feed DM intake in percentage. The indirect method (nylon bag technique), by incubation of nylon bags containing a 2.5-5.0 mm ground sample in the rumen for a fixed period of time was carried out. Degradability of the incubated sample can be evaluated by the loss of sample weights in the rumen while digestion occurs (Orskov *et al*, 1980). *In vitro* can be evaluated by Rumen Fluid-Pepsin and Pepsin-Cellulase method. Devahuti *et al.* (1992) analysed plant samples of red sorghum using the nylon bag technique and found that dry matter degradability (DMD) at 48 hours in the rumen was 64.1±14.16, 60±14.92 and 62.5±10.93% of dry matter at the cutting periods of 45, 60 and 75 days after emergence, respectively. Joshi *et al.* (1998) reported that *in vitro* DMD of forage sorghum was found to have decreased continuously both in leaves and shoots from 30 up to 90 days after sowing and slightly increased at 105 days after sowing. *In vitro* DMD of leaves and shoots at 60, 75 and 90 days after sowing were 552±2.0, 494±2.0 and 484± 3.0 g/kg of dry matter in leaves and were 504±3.0, 467±0.2 and 453±0.2 g/kg of dry matter in stems, respectively. These significant decreases of *in vitro* DMD of both leaves and stems with the advancement of plant age were mainly due to their corresponding increases in fibre contents of NDF, ADF and tannin content. Pholsen *et al.* (1998) reported that DMD at 48 hours in the rumen found with ten sorghum cultivars at 90 days after emergence ranged from 69.77 to 75.41 %; with IS 23585 cultivar, DMD was 73.16 %. Pholsen *et al.* (2001) found that with IS 23585 sorghum cultivar grown on Oxic Paleustults soil, Northeast Thailand, higher levels of nitrogen and potassium did not give significant differences in DMD percentages, with the values ranged from 66.29 to 71.97% at 48 hours incubated in the rumen.

### 1.16.4 Sugar Content or Brix values

Sugar content in most forage plants is the source of energy for anaerobic bacteria to produce lactic acid to aid in fermenting forage materials to attain silage. Catchpoole (1962) studied cutting periods on total sugar content in sorghum cv. Saccaline. He found that total sugar content was highest at early milk stage. He determined total sugar content at the ages of 6, 8, 10, 14, and 16 weeks after sowing, i.e. at the stages of growth of ear initiated, booting, early milky, early dough, hard dough and lower dead leaves stage. He found that total sugar content percentages were 8.6, 9.2, 18.1, 14.7, 7.6

and 6.1 of dry weight, respectively. Kraidej and Tippayaruk (1983) reported that sugar content in brix values of sweet sorghum cultivar Rio (from Indonesia) grown in rainy season at 67 days (50% flowering), 74 days (milk), 81 days (soft), 88 days (dough), 94 days (hard), 102 days (post ripe 1 wk.), 109 days (post ripe 2 wk.) and 116 days (post ripe 3 wk.) after sowing were 10.2, 11.6, 13.0, 13.0, 15.6, 15.8, 14.6 and 14.4%, respectively. Kraidej and Tippayarak (1983) with the same cultivar grown in a dry season reported that at 77 days (50% flowering), 87 days (early milk), 92 days (late milk), 97 days (dough), 104 days (hard dough), 111 days (ripe), 117 days (post ripe 1) and 116 days (post ripe 2) after sowing the sorghum plants attained brix values of 10.4, 12.2, 15.4, 13.8, 16.8, 19.2, 19.6 and 18.2%, respectively. Whilst for Rio cultivar (from USA) grown in a dry season, brix values were 12.2, 11.6, 15.4, 12.2, 16.4, 19.2, 19.6 and 18.2%, respectively. Pholsen *et al.* (2001) with IS 23585 sorghum cultivar grown on Oxic Paleustults soil, Northeast Thailand found that an increase in both nitrogen and potassium levels did not increase brix values of the sorghum plants. Nitrogen at the rates of 0, 62.5, 125 and 187.5 kg N/ha gave brix values of 10.91, 10.05, 10.14 and 8.73%, whilst potassium application at the rates of 0, 50, 100 and 150 kg/ha gave brix values of 10.74, 10.56, 9.04, and 9.49%, respectively. They suggested that a suitable ratio between N and K could have had some effects on brix values.

## 1.17 Environmental Conditions for Growth of Sorghum

Sorghum, (a C-4 dicarboxylic acid pathway plant) requires a more or less tropical climate with high environmental temperatures and adequate amounts of soil nutrients, soil moisture and radiant energy. Myers (1978) found that maximum grain yields of sorghum were 5.4 t/ha and total above ground dry matter yield of 15.5 t/ha with application of 150 kg N/ha (grown during October to April) and average rainfall of 989 mm. In a season with average rainfall of 855 mm, sorghum manifested a strong response to nitrogen application. He also stated that when sorghum was grown under average rainfall of 677 mm with 60 mm irrigation, vegetative growth was stimulated most by nitrogen up to 90 kg/ha during the first 56 days of growth. Higher rates of nitrogen application depressed yields when water stress occurred during the grain filling stage. An excessive amount of vegetative growth during the early growth period together with high nitrogen levels appeared to be major causes of yield depression especially if any water stress was apparent.

Rerkasem (1979) in a preliminary experiment in northern Thailand, two sorghum cultivars grown under rain-fed conditions with total fertiliser rates of 100-50-50 kg N-P-K/ha was used. He found that growth of both KU 141 and KU 300 cultivars were similar up to 68 days after sowing. KU 300 was earlier in flowering than KU 141. At final harvest KU 141 and KU 300 had grain yields of 1,016 and 1,617 kg/ha respectively. Soil water content decreased markedly from 16.0 % in the middle of October to 8.5 % in early November corresponding to the flowering period of KU 141. He stated that water stress at the end of the season might be the cause of the low yielding of KU 141. At the beginning of the season, when rainwater was not limited, both cultivars were comparable for dry matter production but at flowering period no rainfall occurred, hence grain yield for the late flowering cultivar (KU 141) was relatively reduced. Thiraporn (1979) stated that the earliness in flowering date of Hegari sorghum cultivar seemed to utilise the available soil moisture more efficiently than any other recommended cultivars when in 1979 rainy season in Thailand ceased in late September. Short life cycle sorghum cultivars seem to provide some advantages in grain yield, Chawanapong *et al.* (1979) showed that PB Hegari sorghum, a white seed coat cultivar, has been grown extensively by the Thai farmers for a number of years due to its short life cycle with high grain yield when compared with many other new cultivars. Most of the new recommended cultivars require an extended number of days until grain maturity unlike PB Hegari cultivar.

Jordan and Sullivan (1982) grew sorghum under low annual rainfall with low plant density per unit land area, i.e. with the aim of conserving sufficient soil moisture for grain filling. They found that this low annual rainfall severely reduced sorghum dry matter per unit land area and it was not appropriate to adopt the method to dry land conditions. Neild (1984) reported that most sorghum in the USA has been produced in a south-to-north-oriented region between 26 and 43°N latitude and 96 and 104°W longitude that constituted the southern half of the great plain. Precipitation average was 750 mm annually along the eastern border of this region and decreased to 400 mm in the west. The frost-free season averages 330 days in the south and decreases to 150 days in the north. Most of this region is too hot and too dry for a good yield of maize. He suggested that sorghum could be first sown about 10 March in southern Texas but not until about 23 May in the northern part of the growing region. Because of cooler temperatures in the north, the rate of crop development was slower than at other locations, even for the short life cycle hybrid. The early maturity hybrid-1125-GDD required 101 days to mature in the north (Armour) compared with 93 to 96 days for RS-671, the late-maturing cultivar at other locations.

Holford *et al.* (1997) working in the low rainfall northern region of Australia found that significant yield response to N levels occurred in 3 experiments only and N fertiliser tended to depress yields in 6 of the 22 experiments in the northern region. The results also revealed that only 4 out of the 18 southern experiments gave highly significant yield increase due to N levels. Rego *et al.* (1998) with sorghum cv. SPH-280 grown during the post-rainy season at ICRISAT, India with and without irrigation and with six rates of nitrogen fertiliser applied before sowing at rates of 0, 30, 60, 90, 120 and 150 kg N/ha found that leaf and panicle biomass were affected by nitrogen and water stress, but stem growth was unresponsive to nitrogen under irrigation. Leaf expansion was strongly influenced by both water stress and nitrogen application. The biomass Radiation Coefficient (*e*) for the main growth period was almost independent of nitrogen application at 1.3 to 1.4 g/MJ and was also independent of leaf nitrogen. The main source of the differences in yield was a decrease in radiation interception. At 150 kg N/ha under irrigation, the sorghum plants gave grain yield of 4.8 t/ha. Whilst under rain-fed treatment with 90 kg N/ha, the sorghum plants gave a grain yield of 3.2 t/ha. Rao *et al.* (1999) working with hybrid sorghum and their parents grown under irrigated and rain-fed field conditions found that severe water stress delayed flowering by more than a month for CSH-6 hybrid and its female parent, 2219B. The late maturity genotypes, both CSH-9 hybrid and its female parent 296B and male parent CS3541 were unable to complete their flowering stage under rain-fed conditions. Water stress induced asynchrony in flowering, due to the duration from first to last flowering; 10–15 days under irrigation and 30–35 days on rain-fed plots. Mastrorilli *et al.* (1999) showed that water stress decreased LAI more than stem growth and finally significantly reduced both final biomass and stalk production. Bordovsky *et al.* (1998) reported that average 11- year dryland sorghum grain yields with conventional and reduced tillage systems under rain-fed conditions were 2,569 and 2,512 kg/ha whilst under irrigation grain yields were 4,629 and 4,599 kg/ha, respectively. Water stress under rain-fed conditions significantly reduced sorghum grain yields irrespective of tillage system.

### 1.18 Soil Type for Growth of Sorghum

Myers and Asher (1982) reported that there are many soil types being used for the cultivation of sorghum such as Vertisols and Alfisols in India, Alfisols in Yemen, Mollisols in USA and Argentina, Vertisols in Mexico, Alfisols in Nigeria, Vertisols and Alfisols in Sudan and Vertisols in Australia. They stated that such a diversity of soil types revealed different levels of soil fertility. Some of them, particularly those found in most tropical areas had a poor level of soil nutrients and hence low crop yields per unit land area. The great soil group Paleustults belongs to suborder Ustults under the order of Ultisols (Soil Survey Staff, 1998). At worldwide level, Ultisols are currently estimated to cover about 11,054,000 km$^2$, which could be up to 8.5 % of the world total amount of soils for crop cultivation (ice-free land areas), and about 80 % of Ultisols are in tropical regions (Appendix A1.2.4). Suborder Ustults accounts for up to 3,870 Km$^2$ (3.0 %), approximately 35 % under the order Ultisols. Buol *et al.* (1997) reported that order Ultisols has low nutrient content, low base status with high subsoil acidity. When cropping on these soils, it is necessary to have an adequate quantity of lime, fertiliser and management talent available. It has been stated by West and Beinroth (2000) that Ultisols have base saturation <35 % in the lower part of the subsoil, associated properties include low pH, potentially high Al saturation, appreciable weathering and associated kaolinitic mineralogy, and in many cases, relatively high content of Fe and Al oxides and oxyhydroxides. Soil types being used in Thailand for maize and sorghum cultivation vary: e.g. Meksongsee (1971) reported that most soil types being used for maize production in Thailand were Grumusols and Rendzinas. These soil types could be found in Saraburi, Lop Buri, Nakhon Sawan and Nakhonratchasima provinces, while Redish Brown Lateritic soil could be found in Nakhonratchasima and Uthai Thani provinces. Brown Forest Soils could be found in Lop Buri and Petchabun provinces, whilst Grey Podzolic, Red Yellow Podzolic and Red Yellow Latosol could be found in some other provinces. Meesawat *et al.* (1977) reported that soil types where maize and sorghum plants have been grown continuously in Thailand consisted of about five major Great Soil Groups, i.e. Non Calcic Brown, Brown Forest; Grumusols, Renzinas and Reddish Brown Lateritic. With their fertility levels ranged from Non Calcic Brown > Brown Forest > Grumusols = Renzinas > Reddish Brown Lateritic.

Yasothon soil series being used for sorghum cultivation has been recognised as one of several major soil series of the great group of Oxic Paleustults in Northeast Thailand. The Department of Land Development, Ministry of Agriculture and Cooperatives of Thailand had classified Yasothon soil series into great group Oxic Paleustults. Yasothon soil series, one of the 72 soil series in Northeast Thailand has been ranked according to land area at number eighth. The members of Oxic Paleustults include Satuk Soil Series (1.8 %), Warin Soil Series (2.0 %), Seeque Soil Series (0.02 %), and Sungnern Soil Series (0.22 %). All of these soil series are found in Northeast Thailand (Keerati-kasikorn, 1984).

### 1.19 Soil Profile and Brief Description of Yasothon Soil Series (Oxic Paleustults). Only Ap and Bt1 horizons are included:

| | |
|---|---|
| Soil Name: | Yasothon soil series (Yt) |
| Profile Code Number: | NE-N-30/86 |
| Classification as of 1998: | Fine-loamy, siliceous, semi-active, |

isohyperthermic Typic Paleustults

Location: Ban Ton village, Muang District, Khon Kaen Province
Physiography: Upper part of peneplain
Parent material: Washed deposit from sandstone
Drainage: Well drained
Annual rainfall: 1,207.3 mm
Vegetation: Deterocarp and mixed deciduous forests
Described personnel: S. Cherchot

| **Horizon** | **Depth (cm)** | **Description** |
|---|---|---|
| Ap | 0-11 | Dark brown (7.7 YR4/2) and reddish brown (5YR4/3) sandy loam, weak to moderate fine and coarse subangular blocky structure; friable, slightly sticky, slightly plastic; many fine roots; slightly acid (field pH 6.5, 1:1 soil:water), clear, smooth boundary. |
| Bt1 | 11-35 | Reddish brown (5YR4/2) and dark reddish Brown (5YR3/4) sandy clay loam; weak medium and coarse subangular blocky structure; friable, slightly sticky, slightly plastic; patchy thin organic matter coating; many fine roots; medium acid (field pH 6.0, 1:1 soil:water); gradual, smooth boundary. |

## 1.20 Soil Properties of Yasothon Soil Series in Northeast Thailand

Panchaban (1976) had analysed some physical and chemical properties of Yasothon soil series before conducting his experiment on sorghum plants at Khon Kaen University Experimental Farm, Northeast Thailand. His results were:

Texture: Sandy loam with 75% sand, 7% clay and 18% silt

pH: 6.00 (1: 1, soil: $H_2O$ by volume)

5.10 (1: 1, soil: KCl)
6.15 (1: 5, soil: $H_2O$)
OM: 0.35%, P (Bray II): 10 ppm, BD: 1.50 g/cc, PD: 2.60 g/cc
EC: 0.006 millimhos/cm
Water content at field capacity (1/3 atm): 7.16%
Water content at permanent wilting point: 2.79%

Shelton *et al.* (1979) have also analysed soil properties of Yasothon soil series in Northeast Thailand and their results were:

| **Determined Items** | | |
|---|---|---|
| 1. Nitrate nitrogen (ppm) | | <1.0 |
| 2. Phosphorous (ppm) | | 17 |
| 3. Potassium (ppm) exchangeable | | 170 |
| 4. Calcium (ppm) exchangeable | | 290 |
| 5. Magnesium (ppm) exchangeable | | 86 |
| 6. pH (1:5, soil:water) | | 6.4 |
| 7. Iron (ppm) | DTPA | 13 |
| 8. Copper (ppm) | DTPA | 0.1 |
| 9. Manganese (ppm) | DTPA | 20 |
| 10. Zinc (ppm) | DTPA | 0.2 |
| 11. Sodium (ppm) | | 1.0 |
| 12. Chloride (ppm) | | 45 |
| 13. Conductivity (mmho/cm) | | 0.06 |
| 14. Organic carbon (%) | | 0.03 |
| 15. Sulphate sulphur (ppm) | | - |
| 16. Monocalcium (ppm) | | 2.5 |

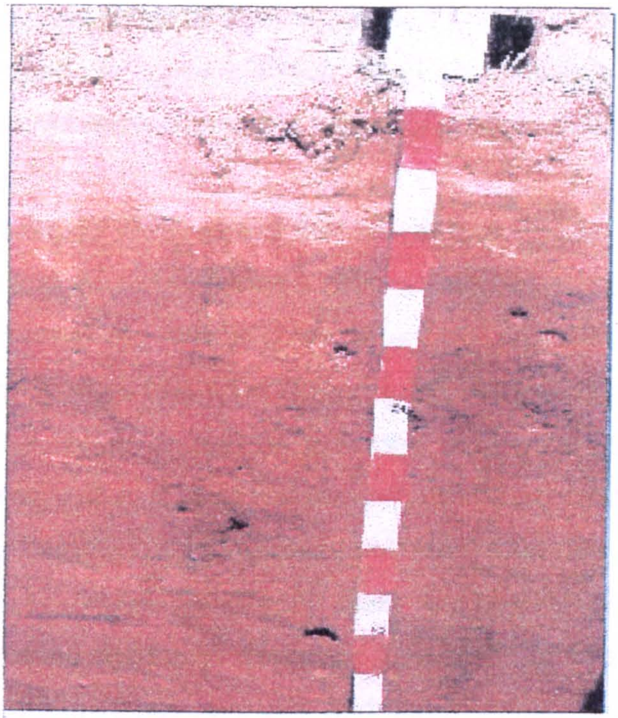

Plate 1 Soil profile of Yasothon soil series (Oxic Paleustults), one of the major soil series in Northeast Thailand (Suksri, 1999).

Some workers have carried out sorghum experiments on different soil series, e.g. Areerak *et al.* (1999) with five hybrids and three pure line sorghum cultivars sown at post-rainy season on five different soil series in Nakhon Sawan province, Thailand. They found, under different soil series, some significant differences in grain yields; e.g. with Thab Kwang soil series of sandy clay loam soil texture, pH value of 7.4 (1:1 soil:water by volume), organic matter of 2.43 % available P of 19 ppm, exchangeable K of 67 ppm and 637 mm rainfall. Results showed an average grain yield of 3,981 kg/ha, whilst on Wang Hai soil series of clay soil texture, pH value of 5.6 (1:1 soil:water by volume), organic matter of 1.59 % available P of 9 ppm, exchangeable K of 85 ppm and rainfall of 153 mm, average grain yield was only 738 kg/ha.

### 1. 21 Role of Organic Matter in Soil

Flaig (1974) stated that organic matter, in general, has a high cation exchange and water-holding capacity and the capacity to produce chelate cations. Larson and Clapp (1984) suggested that crop productivity could be increased through the mineralisation of plant materials in soils providing adequate nutrient supply during the period of organic matter decomposition.

Miller and Donahue (1990) stated that soil organic matter comes from living or dead plant and animal residues and is considered to be a very active and important fraction of the soil. A small amount of organic matter can modify soil physical properties and have a strong effect on biological and chemical properties. Soil organic matter provides some of the soil nitrogen, phosphorus and sulfur. It supplies the cementing substances for desirable soil aggregate formation and improves aeration, drainage and water-holding capacity. For maximum benefit, it must be readily decomposable and continuously replenished with fresh residues and manure. Microorganisms, particularly bacteria, actinomycetes and fungi usually decompose organic materials in soils. After active decomposition has taken place, organic matter residues are collectively called humus. Bacteria are heavy users of nitrogen, requiring one unit of nitrogen for each four or five units of carbon (4: 1 or 5: 1 of C: N ratio, organic-carbon: total-nitrogen ratio). The wider the C: N ratio, the lower the amount of nitrogen content, e.g. straw has a C: N ratio of 80 : 1; if it is incorporated into a soil low in nitrogen, the bacterial population will only slowly increase because the nitrogen supply for bacteria is limited. Plants grown on nitrogen deficient soils have reduced nitrogen availability for their roots because the soil microorganisms, which are more abundant and in more intimate contact, are able to use most available nitrogen before it can become accessible for the plant root surface and the same is true for phosphorus and sulfur inorganic residues and to a lesser extent for other nutrients. Miller and Donahue (1990) stated that typical composition of beef/dairy manure with respect to nitrogen, phosphorus, potassium, magnesium, sodium and total soluble salts ranged from 2 to 8, 0.2 to 1.0, 1 to 3, 1.0 to 1.5, 1 to 3 and 6 to 15 % on dry weight basis, respectively. Harris (1996) reported that in semi-arid Botswana with only 400 to 600 mm per annum of rainfall, soil could be too dry at or just after sowing and crops must be sown within two to seven days when 'windows of opportunity' present themselves after rainstorm, so kraal manure can be beneficial. Adding manure at a rate equivalent to 20 tonnes/ha increased growth and development of sorghum, with and without manure shoot dry weight at 25 days after sowing was 604 and 407 mg/plant, respectively. Meesawat *et al.* (1977) showed that the application of chicken manure at rates of 1, 2, 3, and 4 tonnes/ha produced greater grain yields of sorghum than the control and chemical fertiliser at the rate of 625-625 kg N-$P_2O_5$ kg/ha; application of 4 tonnes/ha of poultry manure only gave a maximum sorghum grain yield of 5,313 kg/ha. Franzluebbers *et al.* (1995) stated that vertical distribution of soil organic carbon and long-term and seasonal distribution of active soil carbon and nitrogen (i. e., microbial biomass and mineralisable carbon and nitrogen), were significantly affected by differences in (i) the length of fallow (ii) the placement of crop residues in the tillage system and (iii) the quantity and quality of crop roots and residues that were dependent upon crop sequence, tillage and nitrogen fertilisation regimes. Bordovsky *et al.* (1998) reported that yields of irrigated grain sorghum with crop residues added to the soil were higher each year than where the crop residues in the field had been removed after each harvest. Large significant differences were found in 4 of 8 years of the research study. Over 11 years average yields of grain sorghum with crop residues were much higher than those areas where the crop residues had been removed after each harvest.

Sommer (2001) reported that fresh deep litter gave higher dry matter and nitrogen yields in spring barley compared with no manure and any treated composts. The reasons were, composting reduced the first year fertiliser value of the deep litter and because losses of nitrogen during storage reduced the total ammoniacal nitrogen available to the crop plants.

### 1.22 Role of Nitrogen (N)

Nitrogen is one of the macronutrients available in nature in a very large quantity and is always presented in the atmosphere, the lithosphere and hydrosphere but the main reservoir is from atmosphere (Delwiche, 1983). Nitrogen is the most limiting nutrient in plant growth. It is a constituent of chlorophyll, plant proteins and nucleic acids. The important roles of nitrogen are protein and amino acid synthesis. It has been advocated by a number of workers that plants normally attain nitrogen in the forms of ammonium cation ($NH_4^+$) or nitrate anion ($NO_3^-$). Deficiency of nitrogen in plants causes stunted growth, chlorosis of the lower leaves starting from the leaf tip and spreading to the base and then to the leaf margin (Grundon *et al.*, 1987; Mengel and Kirkby, 1987; and Suksri, 1999).

Nitrogen requirement of crop plants has been determined in experiments carried out in different parts of the world involving different rates of nitrogen fertiliser application. Variable responses to nitrogen relate to differences in climatic, soil and genotypic factors across seasons and location. Asher and Cowie (1974) found that side dressing of 34 kg N/ha applied at the boot stage of sorghum cv. RS610 gave a highly significant effect in increasing yield, particularly at lower nitrogen treatments but only the highest rate of 336 kg N/ha left sufficient mineral nitrogen in the soil profile during grain filling stage, i.e. the application of nitrogen at planting period at the rates of 0, 34, 112 and 336 kg N/ha gave yields of 0.8, 1.1, 4.2 and 9.2 tonnes/ha in the treatments without side dressing and to 2.2, 2.0, 6.1 and 9.1 tonnes/ha with the application of 34 kg N/ha side dressing, respectively. Panichkul and Boon-ampol (1976) carried out experiments with sorghum cultivar IS 8719 grown on Roi-et soil series (Oxic Paleustults), all plots received basal dressing with 56.25 kg $K_2O$/ha and lime application to raise pH value to 7.5 with initial soil properties of 1.4% for OM, 11.0 ppm for available P and 72 ppm for exchangeable K. This work was done in a dry season with the use of irrigation where irrigation water was regularly applied eight times throughout the growing period. They found that an increase in nitrogen rates significantly increased grain yields up to 168.75 kg N/ha. Nitrogen chemical fertiliser was applied at the rates of 0, 25.25, 168.75 and 281.25 kg N/ha with grain yields of 1,912, 3,059, 3,936 and 4,140 kg/ha, respectively. Dry matter weights were 53.6, 83.5, 84.6 and 108.3 g/5 plants at 55 days and of 181.3, 286.7, 323.3 and 377.8 g/5 plants at 80 days, respectively. An increase in the amount of phosphorus from 56.25 to 112.50 kg $P_2O_5$/ha significantly decreased number of days to flowering from 69.1 down to 65.4 days, respectively.

In another sorghum experiment carried out with the use of irrigation system, Unkasam and Thawonmas (1976) grew three sorghum cultivars, IS 8719, TSS 7-5 and Hegari with six levels of nitrogen fertiliser on Chainat soil series with soil properties of: pH 5.8-6.0, soil organic matter of 1.85-2.94%, available soil P of 13-18 ppm and exchangeable K of 111-180 ppm. All plots received basal dressing for both $P_2O_5$ and $K_2O$ at the rate of 56.25 kg/ha for each fertiliser and the same initial rates of nitrogen fertiliser were applied to the stubble after the harvest of the main crop for ratoon yields. Their nitrogen rates were 0, 56.25, 112.50, 168.75, 225.00 and 281.25 kg N/ha with grain yields of the main crop of 1156, 3026, 4150, 4881, 5081 and 5319 kg/ha, respectively. Whilst that of ratoon, grain yields were 400, 1731, 3612, 4375, 4312 and 4312 kg/ha, respectively. However, both main and ratoon grain yields did not significantly increase beyond the application rate of 168.75 kg N/ha. Patanothai *et al.* (1976) tested 23 entries of sorghum cultivars grown on Yasothon soil series (Oxic Paleustults) at Khon Kaen University Experimental Farm, Northeast Thailand. All of the sorghum plants received chemical fertiliser at the rate of 106.25 kg N, $P_2O_5$, $K_2O$ kg/ha and sulfur dust at the rate of 25 kg/ha as banding prior to planting. At four weeks after planting, the sorghum plants were top-dressed with ammonium sulphate at the rate of 65.6 kg N/ha. They found that only a few lines performed consistently well across the Khon Kaen environment. It was found that the best six entries were 5 DX 61/6/2-2, 3 DX 57/14/4, Serena, TSP 750 (Late Hegari), 9 DX 3-2/3/2 and IS 8719 E 173 with average grain yields of 4,290, 4,270, 4,110, 3,530, 3,400 and 3,400 kg/ha, respectively, whilst the other 17 entries did not perform well in the Khon Kaen environments. In another experiment on selection basis, Patanothai *et al.* (1977) tested 46 pedigrees of sorghum plants at Khon Kaen under low soil fertility (no fertiliser application) and high fertility (added chemical fertiliser at the rates of 113.9 kg N/ha and 84.7 kg P/ha). They found that grain yields of the 46 entries ranged from 682 to 3,283 kg/ha at high fertility and 282 to 2,080 kg/ha at low fertility. The check cultivar (Late Hegari) gave grain yield of 1,034 and 1,424 in high and low fertility levels, respectively. The highest grain yield cultivar, i.e. 5 DX 142/4 gave grain yields of 3,283 and 1,789 kg/ha for both fertiliser levels, respectively whilst IS 8719 E 173 cultivar gave 2,182 and 2,080 kg/ha, respectively. They also found that some lines did not respond to both fertiliser treatments and they suggested that the poor response could have been partially due to the soil heterogeneity or the overriding effect of moisture stress due to an inadequate amount of rainfall during August to September. However, both control treatment cultivars, i.e. Late Hegari and IS 8719 E 173 gave the top yielding entries with grain yields of 3,093 and 2,966 kg/ha with number of days to flowering of 72 and 80 days from emergence, respectively. The Kasetsart University lines were the short life cycle cultivars.

Faungfupong *et al.* (1976) applied NPK chemical fertilisers at the rates of 0-0-0, 37-47-0, 72-94-0 and 112-141-0 kg N-P-K/ha; average sorghum grain yields were 2,239, 3,166, 3,551 and 3.169 kg/ha, respectively. The highest rate of chemical fertiliser failed to give the highest grain yield. They stated that to avoid risk on capital investment, NPK fertiliser at the rate of 37-43-0 kg/ha could be a recommended rate for farmers although the rate of 72-94-0 kg/ha gave the highest grain yield. Faungfupong and Yolprasarn (1977) reported that grain yields of sorghum did not increase significantly with an increase in both N and P fertilisers. Nitrogen and phosphorus chemical fertilisers at the rates of 0-0, 30-0, 30-30, 60-0, 60-30 and 60-60 kg N-P/ha gave sorghum grain yields of 2,340, 2,752, 2,592, 2,520, 2,634 and 2,534 kg/ha, respectively. They stated that the poor response of the sorghum plants to higher rates of fertiliser could be due to the drought conditions during the growing season. In contrast, Meesawat *et al.* (1977) reported that nitrogen fertiliser at a range of 18 to 36 kg N/ha significantly increased dry matter yields of sorghum. The dry matter yields at 20 days significantly increased from 11 to 15 g/5 plants and grain yields of both main crop and ratoon together were from 5,413 to 6,875 kg/ha for both nitrogen levels, respectively. Thiraporn *et al.* (1983) reported that the application of 16-20-0 of N-P-K complete chemical fertiliser at the rate of 300 kg/ha to sorghum plants at sowing, side dressing and 150 kg/ha at sowing plus topdressing with ammonium sulphate at the rate of 50 kg N/ha. They found that sorghum grain yields were 3,165, 3,234 and 3,684 kg/ha, respectively. The experiment was carried out on farmer's field during late rainy season of 1983 and they suggested that fertiliser application method being used for this experiment could be considered as the best method for growers of sorghum plants. In contrast, Ibrahim (1994) with Sudan grass (*Sorghum sudanense*) reported that the application of nitrogen fertiliser at the rates of 0 and 44 kg N/ha did not give any significant differences in plant dry weights for experiments carried out in 1992 whereas, the applied nitrogen rate of 88 kg N/ha significantly increased total plant dry weights for the experiment carried out in 1993. Muchow (1998) stated that part of yield variation was associated with differences in the capability of the soil to supply nitrogen and in the efficiency of recovery of applied nitrogen fertiliser; another component was nitrogen requirement for yield determination, which depended on the yield expectation in a given environment as being determined by climate, management and cultivar. The experiments were carried out in Australia in different locations, water levels and different rates of nitrogen application. He found that sorghum gave a linear relationship between grain yield and nitrogen supply of $r^2 = 0.73$ and between grain yield and nitrogen uptake of $r^2 = 0.98$. With high nitrogen supply but with water deficit, nitrogen uptake was higher than the minimum requirement for a given yield level, and NUE (N-use efficiency, defined as grain yield per-unit nitrogen uptake, maximizing it requires knowledge of the minimum N requirement for a given yield level) was lower; that was "luxury" nitrogen uptake. Luxury nitrogen uptake resulted in higher stem and grain nitrogen concentration at maturity. Buah *et al.* (1998) with 13 sorghum genotypes emphasize the importance of $NUE_1$ and $NUE_2$ for economic yield ($NUE_1$ was defined as the total above ground DM divided by total nitrogen content in the dry matter, g DM/g N and $NUE_2$ as grain yield divided by the total N content of the above ground plant, g grain/g N). They found that there was a significant linear response to nitrogen application for grain yield in both 1993 and 1994 experiments. The application of nitrogen at the rates of 0, 50 and 100 kg/ha gave grain yields of 1,983, 2,344 and 2,693 kg/ha with $NUE_1$ of 105.0, 87.5 and 78.4 g DM/g N for 1993 and of 5,275, 5,376 and 6,136 kg/ha with $NUE_1$ of 110.1, 101.7 and 94.4 g DM/g N for 1994 experiment, respectively. Nitrogen levels did not affect hundred seed weights of the sorghum plants. For 1993, hundred seed weights ranged from 1.61 to 1.75 g and in 1994 from 2.80 to 2.87 g. Nitrogen levels did not significantly affect $NUE_2$ in 1993 with the values ranging from 25.9 to 27.1 g grain/g N but nitrogen application in 1994 gave significant linear response; with rates of nitrogen of 0, 50 and 100kg/ha the values of $NUE_2$ were 53.3, 47.8 and 44.7 g grain/g N, respectively.

Singh and Singh, (1998) applied nitrogen in a pot experiment on forage sorghum at the rates of 0, 30, 60 and 120 mg N/kg soil. The results showed that dry matter yields significantly increased over the control treatment by 13.4, 23.3 and 26.9 %, respectively. Similarly, Patel (1998) with forage sorghum showed that an increase in nitrogen rates significantly increased dry matter yields. The applied nitrogen fertiliser rates were 0, 25, 50 and 75 kg N/ha with total dry matter yields of 4,073, 6,028, 8,169 and 9,281 kg/ha, respectively. Poonia *et al.* (1999) showed that at 60 and 90 days after sowing, the application of nitrogen at the rates of 0, 40, 80 and 120 kg/ha gave dry matter production of the sorghum plants of 18.82, 30.76, 35.79 and 36.38 g/plant and of 40.70, 58.90, 68.25 and 70.06 g/plant for both harvesting periods, respectively. Similarly, Franzluebbers *et al.* (1995) reported that an increase in nitrogen application from 0 to 9.0 g $N/m^2$ increased nitrogen uptake in stover and grain of sorghum from 2.15 to 2.43 g $N/m^2$ and from 2.64 to 6.98 g $N/m^2$ for conventional tillage, respectively. Chouhan and Dighe (1999) carried out an experiment on black clay soil with low available nitrogen and phosphorus but rich in potassium. They found that high levels of $N+P_2O_5$ increased grain yield and straw yield of the sorghum plants only up to 80+40 kg $N+P_2O_5$ /ha. Their rates of $N+P_2O_5$ were 20+10, 40+20, 60+30, 80+40 and 100+50 $N+P_2O_5$ kg/ha with grain yields of 995, 1,328, 1,574, 2,039 and 1,773 kg/ha, respectively and straw yields of 7,900, 7,818, 8,805, 11,010 and 9,957 kg/ha, respectively.

### 1.23 Role of Potassium (K)

Potassium is one of the major plant nutrients needed for growth and development. Potassium sources are primary and secondary clay minerals such as alkali felspars (4-15%), Ca-Na felspar (0-3%), Muscovite of K mica (7-11%), biotite of Mg mica (6-10%), illite (4-7%), vermiculite (0-2%), chlorite (0-1%) and 0-0.5 % for montmorillonite (Scheffer and Schachtschabel, 1982;

and Mengel and Kirkby, 1987). Potassium plays an important role in the translocation of assimilates from source to sink by its influences on electron ($e^-$) transport in the transport chain of crop plants (Overnell, 1975; Mengel and Kirkby, 1987; Grundon *et al.,* 1987; and Suksri, 1998 and 1999). Potassium is an enzyme activator, activating more than sixty different enzymes during metabolic processes. Potassium in soil can be utilised by plants in the form of the potassium cation ($K^+$) in soil solution, soil colloids and clay particles. Deficiency of potassium in sorghum plants causes stunted growth, interveinal chlorosis can be found near leaf margins followed by scorching and browning of older leaf tips, weak stem and shrivelled seeds also occur (Grundon *et al.,* 1987). In Nigeria, Heathcote (1973) reported that potassium produced maximum response for seed yield in sorghum up to 1,188 kg/ha and pointed out that the responses to potassium were much smaller in higher potassium status soils.

### 1.24 Balance of Nitrogen and Potassium in Crop Plants

Suksri and Wongwiwatchai (1988) reported that in cassava (*Manihot esculenta* Crantz) the top growth was promoted most by higher N, whilst higher K promoted tuber root growth, however, plant dry weights were similar for both high N and high K levels. Suksri (1999) highlighted some physiological effects due to the balance between nitrogen and potassium in some crop plants, e.g. the application of a higher level of N than K gave better quality fruits in star fruit plant, whilst higher level of K than N gave poor fruit quality, i.e. more tannin in fruits and the taste could be very poor. In jasmine rice (*Oryza sativa*) with a greater level of K than N, the palatability of the cooked rice could be extremely poor, i.e. the grains become hard without aromatic flavour. Tanaka and Yamaguchi (1972) with maize plants (*Zea mays* L.) reported that photosynthetic rate per unit leaf area (*po*) was correlated with nutrient content in maize leaves. *po* increased with an increase in nitrogen (N) and phosphorus (P) level, whilst *po* increase due to elevated potassium (K) was not more than 2%.

De Datta (1973) reported that in high-yielding rice in the Philippines, high rates of nitrogen increased the responses to applied potassium up to 60 kg

$K_2O$/ha but potassium at the rate of 90 kg $K_2O$/ha gave a similar grain yield of rice to that of 60 kg $K_2O$/ha. Anon (1973) with two sorghum cultivars, PB Hegari and IS 8719 E 173 applied with twelve rates of NPK fertilisers, grown under irrigation in dry season during January to April 1973 on paddy fields of Chainat province, Thailand. The results showed that an increase in the amount of potassium fertiliser from 0 to 18.75 kg $K_2O$/ha significantly increased the average grain yield from 2,078 to 2,258 kg/ha, whilst nitrogen rates of 75, 112.5, 150, 187.5 and 225 kg N/ha gave average grain yields of 730, 1,839, 2.222, 2,684 and 2,916 kg/ha, respectively. Anon (1974b) with three sorghum cultivars showed that the application of four levels of NPK fertilisers at the rates of 0-0-0, 50-50-25, 100-100-50 and 150-150-75 kg N-$P_2O_5$-$K_2O$/ha to PB Hegari, TSS 7-5 and IS 8719 E 173 cultivars in five locations in Thailand gave significantly increased grain yields only at the rates of 50-50-25 kg, whilst at higher rates the sorghum plants failed to respond to the added fertiliser.

Some workers have not found significant effects of N and K application, e.g. Faungfupong *et al.* (1979) with KU 257 sorghum cultivar grown on a farmer's field during late rainy season with the application of nitrogen and potassium fertilisers at N:K rates of 0-0, 5-0, 5-5, 10-0, 10-5 and 10-10 kg N-K/ha. The sorghum plants gave average grain yields of 2,450 2,656, 2,281, 2,525, 2,369 and 2,706 kg/ha, respectively. They found that the average grain yields at two locations did not significantly differ from one another. They stated that the initial amounts of N P K in soil of the two locations were probably adequately available. It seems likely since the applied rates were very low.

Buxton *et al.* (1999) with sweet and forage sorghum cultivars showed that the average potassium content in the plant tissues (five-year results) was decreased with an increase in nitrogen level. Similarly, Minson (1990) showed that with nitrogen fertiliser at rates of 0, 70, 140 and 280 kg N/ha the sorghum plants had potassium content of 14.1, 14.6, 13.3 and 13.1 g/kg, respectively.

### 1.25 Integrated Use of Farmyard Manure and NPK Chemical Fertilisers

Anon (1972) reported sorghum grain yields under field conditions at the Thailand National Corn and Sorghum Program (Suwan Farm), the soil was classified as Reddish Brown Laterite deficient in nitrogen and phosphorus (Asher *et al.*, 1970). Mean values of soil analysis during wet season between 1971 and 1972 revealed that pH values were 5.7 and 6.6, OM 2.62, 2.48%, available P of 19.70, 18.80 ppm, exchangeable K of 142, 330 ppm, and C.E.C 13.9, 14.2, respectively. The plots were applied with a compost contained 1.33% N, 1.3% $P_2O_5$ and 1.21% $K_2O$ at the rate of 12.5 t/ha, NPK complete chemical fertilisers at a rate of 62.5 kg/ha for each of N and $P_2O_5$, 75 kg $K_2O$/ha and slaked lime at a rate of 3,750 kg/ha. The results showed that there were no significant differences among the control, lime and compost plots. The lime plus NPK fertilisers and NPK fertilisers only plots showed significant increases in grain yields in both years when compared with the control treatment. Grain yields obtained from control, lime plus compost, lime plus NPK and NPK treated plots were 4,050, 4,394, 4,960 and 4,694 kg/ha in wet season of 1971, respectively and 1,951, 2,475, 2,956 and 2,994 kg/ha in wet season of 1972, respectively. The data show that in most cases grain yields in 1972 were up to 50% lower than in 1971 due to too much rainfall and clouds during the grain formation period. Ratnapradipa (1996) reported that maize kernel yields significantly increased with an increase in NPK fertilisers up to 46.8 kg/ha when grown on Satuk soil series (Oxic Paleustults) in Northeast Thailand, whilst fallow, green manure, Farm Yard Manure (FYM) and compost treated plots did not affect kernel yields of the maize plants, but FYM did improve some properties of the Satuk soil series. FYM at a rate of 20 t/ha, changed values of pH from 5.8 to 6.8, Soil OM from 5.9 to 10.5 g/kg, available soil P from 8.5 to 12.4 mg/kg, exchangeable soil K from 136 to 274 mg/kg and CEC from 1.8 to 2.9 cmol/kg compared with fallow plots.

Vaidya and Gabhane (1998) investigated sorghum-wheat crop sequences in a Vertisol soil field experiment with N : P : K ratio for sorghum of 120 : 60 : 50 kg/ha plus Farm Yard Manure (FYM) of 10 t/ha. The results indicated that the continuous application of fertilisers after six years decreased pH values by 0.05 to 0.1 units, which could possibly be the effect of ammoniacal fertiliser. Soil organic carbon increased with an increase in levels of NPK fertilisers, the lowest was found in control treatment (0.48 %), the highest in 100 % NPK+ 10 t FYM (0.90 %) and FYM alone was 0.75 %. They stated that the beneficial effect derived from the combination of NPK fertilisers with FYM on soil organic carbon content might be mainly due to the better root growth and more plant residues left in fertilised and manured plots. They also stated that the application of FYM in combination with the recommended dose of NPK fertilisers increased available soil N, P and K contents by 17.65, 13.33 and 8.00 % over NPK alone after the 7th cycle, respectively. They suggested that FYM may have reduced phosphate and potassium fixing capacity and enhanced the release of potassium due to the interaction of organic matter with clay particles.

### 1.26 Sorghum as a Forage Crop for Livestock Production in Thailand

Thailand is located in the tropical zone and has been recognised as an important producer of agricultural food products to feed the population of many countries around the world. Thailand has three seasons within a year, i.e. rainy season, cool season, and dry season. The dry season normally occurs from February to May with only a small amount of rainfall. The cool season, which normally occurs from November to the first half of February, can also be considered as a dry period of the year. The long dry period indicates that there is a huge requirement for fodder and silage as feedstuff for both dairy and beef cattle. Farmers have to prepare themselves well in advance in order to reserve adequate amounts of feedstuff for the periods without rainfall; they have to make silage or hay for that period of the year. Sorghum can be considered as a crop for such purposes so farmers need an adequate knowledge of all aspects of sorghum agronomics. Data on growth parameters and seed yield of forage sorghum cultivars are essential for farmers if livestock production in Thailand is to be expanded more rapidly with time.

Amongst forage crops for livestock production in Thailand, sorghum (*Sorghum bicolor* L. Moench) plays an important role in supplying nutritious livestock feed. Forage sorghum can be used in the forms of fodder or silage especially in the dry season when pasture and hays are inadequately available for both dairy and beef cattle. Sorghum can thrive in most environmental conditions in the semi-arid tropical regions since it has a high degree of drought tolerance (Whiteman and Wilson, 1965; and Seetharama *et al.*, 1984). Within the past decade, farmers in Thailand have realized how this crop can contribute to livestock production particularly, dairy production. Normally farmers harvest their forage sorghum when the crop reaches its milky stage and feed to their cattle as fodder whilst some could be kept as silage. Nutritive values of forage sorghum have been described by a number of workers, e.g. Lachmann *et al.* (1997); Joshi *et al.* (1998); Pholsen *et al.* (1998 and 2001); and Buxton *et al.* (1999).

Some pasture research experiments have been carried out, e.g. Khon Kaen University Pasture Improvement Project (Anon, 1981-82) and also Forage Legume Seed Production and Pasture Project of the Department of Livestock Development, Ministry of Agriculture and Cooperatives of Thailand (Manidool and Chantkam, 1986; Hare and Phaikaew, 1999). Nevertheless, feedstuffs for livestock remain inadequately available for the expansion of livestock production particularly in the dry season. Data on forage sorghum cultivars especially those well adapted to the environmental conditions are very limited; Pholsen *et al.*, (1998) carried out experiments on 10 forage sorghum cultivars and reported that IS 23585 was considered to be one of the best cultivars adapted well to Yasothon soil series (Oxic Paleustults) in Northeast Thailand. Therefore, this cultivar was chosen for further investigations, since it exhibited outstanding characteristics on both forage chemical components and grain yields. Other cultivars have been shown to be adapted well to other soil types, e.g. Rio, U-Thong and others (Suchato *et al.*, 1991; Agnal *et al.*, 1992; Powell and Hons, 1992; and Phaikaew *et al.*, 1992). Therefore, it is important for scientists in Thailand to search for more data on growth, yield, and chemical components of this forage sorghum (IS 23585), particularly the effects on growth due to soil fertility, chemical fertilisers in particular nitrogen and potassium and also organic amendment when carbon dioxide, water and radiant energy are at optimal levels for growth of the sorghum plants.

### 1.27 Summary and Discussion

Information found in the literature revealed that sorghum had been brought to cultivation around 7000 years ago. Its origin was probably West Africa and it has now been brought to several countries around the world for cultivation; this must be attributed to the nutritive value of the crop for both man and farm animals. As a cereal food for man, it ranks after wheat, barley and rice. This crop has outstanding drought tolerance and can thrive well in most tropical and subtropical areas; the crop could perform well in areas with low rainfall such as in some countries in Africa and Asia. Sorghum is well suited to most third world countries where the flour derived from its grain is used for making many kinds of daily food. However, it is not popular among other countries in the western world apart from being used as livestock feedstuff. The annual production of sorghum grain is highest in Africa followed by Asia, North and Central America and lowest in South America and Oceania. This may be attributable to the effect of climatic conditions, i.e. with the low annual rainfall, where other cereal crops such as wheat, barley and rice could not thrive on well hence the sorghum crop is used.

Sorghum has been cultivated in Thailand for many decades; Senanarong (1977) indicated that sorghum received attention from growers who started to cultivate the crop in 1962 when Thailand received some aid from international organisations. The Thai people have had more experience in growing rice rather than other cereal crops, since rice has been used as the main carbohydrate for their daily diets. However, the Thai people have now realised how important sorghum could be to the Thai economy, particularly when it comes to livestock production. Within this past decade sorghum has received less attention from growers due to competition from other cash crops such as maize, soybeans and groundnut. The current high demand for milk and beef in the Thai market has made Thai livestock producers look into the need to produce adequate amounts of feedstuff for their dairy and beef cattle. Livestock producers have learned to feed their herds with sorghum fodders, silage, and grains for mixed concentrate feedstuff.

Sorghum is grown for the harvest of grains for seed production and the harvest of fodder at milky stage for livestock feedstuff. Surplus fodder could be used to make silage for livestock when feedstuffs are inadequately available particularly in the dry season. In recent time, sorghum has gained interest from scientists of different disciplines such as plant breeders, plant physiologists, agronomists as well as ordinary farmers. Plant breeders have produced a number of new cultivars suitable to some specific locations, plant physiologists have looked at many aspects of crop performance in relation to environmental conditions whilst agronomists have studied crop yields with respect to methods of cultivation, e.g. Miller (1961); Boonsue *et al.* (1971); Vanderlip (1972); Senanarong (1977); Myers (1980); House (1981); Renfro (1983); Faungfupong *et al.* (1986); Poonia *et al.* (1999); Ockerby *et al.* (2001); Berenguer and Faci (2001); and many others have worked on sorghum. Most work has concentrated on growth and yield with respect to cultivars, soil fertility, fertiliser, day-length, water stress and even irrigation systems. Many other workers have investigated forage qualities with respect to growth environments, e.g. Catchpoole (1962); Fischer and Wilson (1975); Wilson and Eastin (1982); Seetharama *et al.* (1984); Buxton *et al.* (1999); and Rao *et al.* (1999). The reasons for such research activity must be partly attributed to the need to meet the demand in the expansion of livestock production apart from the need to increase the amount of carbohydrate and protein supply for man's daily diet where wheat, barley, rice and other cereal crops could not thrive due to drought or other adverse environmental conditions.

Some of the results found in the literature reveal that macronutrients particularly nitrogen and potassium play significant roles in fodder and grain yields; both nutrients are taken up by sorghum in large concentrations when high growth and yield is achieved. These two nutrients may be available in soils in a limited supply since most tropical soils are exposed to heavy rainfall and a high leaching rate could be occurring from year to year, apart from removal by crop cultivation. A large number of workers have emphasized the importance of nitrogen, e.g. Asher and Cowie (1974); Panichkul and Boon-ampol (1976); Unkasam and Thawonmas (1976); Delwiche (1983); Thiraporn *et al.* (1983); Ibrahim (1994); Muchow (1998); and Chouhan and Dighe (1999). There are also a number of published works on sorghum with respect to potassium application, e.g. Anon (1973, 1974a and 1974b); Panchaban (1976); Faungfupong *et al.* (1979); Minson (1990); and Buxton *et al.* (1999).

It has been recognized that most soils in tropical zones contain small amount of plant nutrients and minute amounts of organic matter due to high leaching rates and the rapid decomposition rate of organic materials as a result of high environmental temperature, hence some workers have emphasized their research experiments on the use of chemical fertilisers together with Farm Yard Manure and green manure, for instance, Anon (1972); Ratnapradipa (1996); and Vaidya and Gabhane (1998). It might be inferred that more research experiments should be carried out in the tropics with respect to the use of organic materials added to soils. This could be one of many methods of improving soil properties to increase crop production. It has been recognized that the amount of feedstuff for livestock production in Thailand is relatively inadequate compared with the need to expand the production of diary and beef cattle; and within the past decade, dairy and beef businesses have been increased more rapidly with time. Therefore, it is urgent for scientists to search for more production from sorghum, apart from pasture and other forage crops because of its potential to improve dairy and beef production.

## Objectives of This Research Work

To attain maximum output of forage sorghum in the very poor soil fertility of the Yasothon soil series (Oxic Paleustults), more experiments are needed on plant nutrition, especially with chemical fertilisers, particularly nitrogen and potassium. These two elements play a crucial role in growth of the crop plants, nitrogen has a significant role in the construction of amino acid compounds and proteins (Miller and Donahue, 1990; and Salisbury and Ross, 1992), whilst potassium has its role in electron ($e^-$) transport in the photosynthetic $e^-$ transport chain in supplying assimilates to sinks and other parts of the crop plants as stated by Overnell, (1975); and Suksri, (1998, 1999). In addition, the improvement of soil fertility with the use of soil amendments such as organic matter, crop residues and other sources, e.g. cattle manure, poultry manure is urgently needed. The aims of this investigation were as follows:

1.28.1 To use the Classical Growth Analysis Technique as a tool in measuring the changes in growth of the aerial plant parts of the sorghum (Sestak *et al.*, 1971; Hunt, 1978; Bullock *et al.*, 1993; and Suksri, 1999) with respect to the proposed treatments.

1.28.2 To analyse chemical components in sorghum plant tissues, i.e. crude protein, neutral and acid detergent fibres (NDF and NDF) in relation to effects of organic materials from cattle manure and a range of nitrogen and potassium chemical fertilisers.

1.28.3 To analyse dry matter degradability (DMD) of forage sorghum (Orskov *et al.*, 1980) at grain filling stage with respect to additions of organic materials from cattle manure and a range of both nitrogen and potassium fertiliser treatments.

1.28.4 To determine sorghum tissue sugar content by means of brix values of the sorghum plants at grain filling stage with respect to organic materials from cattle manure and a range of nitrogen and potassium treatments.

1.28.5 To be able to recommend appropriate environmental conditions with particular respect to nitrogen and potassium application rates and organic matter amendment in relation to Yasothon soil series (Oxic Paleustults) in Northeast Thailand for both high grain yields and forage quality and yields in sorghum.

# Chapter 2

## Materials and Methods

### 2.1 Introduction

Materials and methods for the six sorghum experiments are all reported in this chapter since in most cases there are similarities in the materials and methods being used. However, some of the experimental details for each experiment are described separately where there are differences.

### 2.2. Experiment 1

The experiment was carried out at the Experimental Farm, Faculty of Agriculture, Khon Kaen University, Khon Kaen, Northeast Thailand during the rainy season of 1997 during 6th July to 12th October 1997 to investigate the effect due to the varying nitrogen and potassium levels on growth, chemical components and seed yields of the sorghum (*Sorghum bicolor* L. Moench), IS 23585 cultivar. The sorghum plants were grown on Yasothon soil series (Oxic Paleustults). The experiment was laid out in a 4x4 factorial arranged in a randomised complete block design (RCBD) with four replications (Appendix F). Chemical fertiliser sources were urea (46 %N) for nitrogen (N) and potassium chloride (60 %$K_2O$) for potassium (K). Nitrogen rates being used were 0 ($N_0$), 62.5 ($N_1$), 125 ($N_2$), and 187.5 ($N_3$) kgN/ha whilst potassium fertiliser rates were 0 ($K_0$), 50 ($K_1$), 100 ($K_2$), and 150 ($K_3$) kg $K_2O$/ha. The combination of both N and K levels were all together 16 treatments, i.e. $N_0K_0$, $N_0K_1$, $N_0K_2$, $N_0K_3$, $N_1K_0$, $N_1K_1$, $N_1K_2$, $N_1K_3$, $N_2K_0$, $N_2K_1$, $N_2K_2$, $N_2K_3$, $N_3K_0$, $N_3K_1$, $N_3K_2$, and $N_3K_3$. The combination of both N and K fertilisers were evenly applied to the plots by hand at the sowing date.

Soil samples were collected from the plots before sowing of the sorghum seeds for their initial soil analysis data and at the final harvest for the final soil analysis data. All soil samples were analysed for pH values (1: 2.5, soil: water by volume) with the method of Black (1965); and Page *et al.* (1982), total soil nitrogen by Kjeldahl method (Black, 1965; and Page *et al.*, 1982), organic matter percentage by the method of Walkley and Black (Black, 1965;

and Page *et al.*, 1982), available phosphorus by the method of Bray II Extraction and Colorimetric (Bray and Kurtz, 1945; Murphy and Riley, 1962; and Page *et al.*, 1982), and extractable potassium by the method of $NH_4OAc$ Extraction and Flame photometry (Cottenie, 1980).

Two weeks before sowing, dolomite at the rate of 3,750 kg/ha was evenly applied to the soil by hand to increase the initial mean value of soil pH from 5.2 to approximately 6.3. The experimental field was ploughed twice followed by harrowing once. Each plot dimension being used was a 4 x 6 metres with a walking path of one metre between the plots. The plot was divided into 4 subplots and each subplot had an area of 3 x 2 metres (Appendix F). Triple super phosphate (approximately 46 % $P_2O_5$) chemical fertiliser was evenly applied to all plots by hand at the rate of 125 kg $P_2O_5$/ha before sowing. The distance between rows and within the rows was a 50 x 10 cm, respectively. Seeds of sorghum were sown directly into the soil by hand into seed drills together with the application of Carbofuran 3 %G insecticide at the rate of 37 kg/ha (Plate 2.1). After sowing, a spraying of Atrazine herbicide at the rate of 2.2 kg/ha was carried out to control pre-emergence of weeds. Three weeks after emergence, N and K fertilisers were applied to the crop plants and at the same time weeding was carried out mechanically using of hoes and the sorghum seedlings were thinned out leaving only one seedling per drill as well as ridging up the drill along the rows to cover above ground plant stems to approximately 8-10 cm.

Weeding was carried out twice at three weeks and six weeks after emergence. Weeding was no longer needed once the crop plants established sufficient leaf area per plant to cover the ground area (approximately 200-250 $cm^2$/plant). The technique of growth analysis was used to measure the changes in growth with time of the aerial plant parts of the sorghum plants (Sestak *et al.*, 1971; Hunt, 1978; Bullock *et al.*, 1993; and Suksri, 1999). The initial plant samples were taken at 52 days after emergence for the determinations of stem dry weights, leaf dry weights, and leaf areas/plant. Ten plant samples were cut at random from each subplot at approximately 15 cm above ground level of each subplot. The plant samples were separated into leaves, and stems for the determinations of leaf areas and dry weights (Plate 2.2). The second sampling period was carried out at 82 days after emergence for similar measurements as that of the first sampling period plus flower head dry weights. Seed head, seed yields and 1000-seed weights were taken at 93 days after emergence. The plants were oven dried at 60° C for 72 hours for dry weight determinations. Juice being squeezed from stems was measured individually for each plant of each replication for brix values (sugar contents). This was carried out at 82 days after emergence with the use of a Brix Meter, Atago N1, Japan with the brix ranges of 0~32 %. For dry weight determinations, the plant samples were oven dried at 80° C for 72 hours. Leaf area measurements being carried out with the use of fresh leaves were measured by the use of Leaf Area Meter (Model no. AAC-400, Hayashi Denko Co., Ltd., Japan).

For the analysis of chemical components and dry matter degradability, the plant samples were separated from those oven dried plant materials for dry weight determinations, i.e. the bunches of the whole plant materials were oven dried at 60 ° C for 72 hours. These plant samples of each plot were taken at the same time as that of the dry weight determinations, i.e. at 82 days after emergence when most of the grains reached their milky stage (Plate 2.3 and 2.4). The oven dried plant materials were ground to pass through a 1 mm screen grinder for the analysis of chemical components, i.e. the estimation of crude protein (CP) with the use of Kjeldahl method whilst neutral detergent fibre (NDF) and acid detergent fibre (ADF), the analyses were determined by the method of Georing and Van Soest (1970). Biological analysis for dry matter degradability (DMD) was carried out by the method of Nylon bag technique of Orskov *et al.* (1980). Details of each method of chemical components and biological analysis of dry matter degradability determinations are described in the Appendix D. Seed dry weights together with heads, seed yields alone and 1,000-seed weights were measured at 93 days after emergence.

All the data obtained were statistically analysed and the differences due to treatments were determined using Duncan's Multiple Range Test of means (DMRT) by MSTAT computer programme (Nissen, 1984).

Plate 2.1 Hand sowing of sorghum seeds.

Plate 2.2 Sorghum plant samples separated into stems, leaves, dead leaves, and heads of grains for the determinations of dry weights and leaf areas

Plate 2.3 Sorghum plants at milky stage.

Plate 2.4 Head of grains of sorghum plant at milky stage.

## 2.3 Experiment 2

This experiment was carried out as a follow up to Experiment 1 during 14th July to 4th November 1999. In Experiment 1 the rates of both nitrogen and potassium chemical fertilisers used were relatively low. Much higher rates of both nitrogen and potassium were used in this experiment. Materials and methods were similar to experiment 1 with the following additions/amendments:

1. Nitrogen chemical fertiliser rates were 0 ($N_0$), 150 ($N_1$), 300 ($N_2$), and 600 kg N/ha ($N_3$) and the potassium chemical fertiliser rates were 0 ($K_0$), 100 ($K_1$), 200 ($K_2$), and 400 kg $K_2O$/ha ($K_3$).
2. Growth analysis formulae (Sestak *et al.*, 1971; Hunt, 1978; Bullock *et al.*, 1993; and Suksri, 1999) being used for the determinations of crop growth rate (CGR), leaf area index (LAI), and leaf area duration (D) were:

Crop Growth Rate (CGR):

$$\mathrm{CGR} = \frac{W_2 - W_1}{T_2 - T_1} \times \frac{1}{P}$$

Where $W_1$ = Total dry weight at harvest 1

$W_2$ = Total dry weight at harvest 2,

$T_1$ = Time at harvest 1

$T_2$ = Time at harvest 2

P = Ground area

Units = Weight/ground area/time (e.g. g/$m^2$/week).

Leaf Area Index (LAI):

$$\mathrm{LAI} = \frac{A}{P}$$

Where A = Leaf area per plant

P = Ground area

LAI units = Dimensionless.

Leaf Area Duration (D)

$$D = \frac{A_2 + A_1}{2} x\, T_2 - T_1$$

Where $A_1$ = Leaf area at harvest 1

$A_2$ = Leaf area at harvest 2

$T_1$ = Time at harvest 1

$T_2$ = Time at harvest 2

D units = Leaf area. time ($m^2$.week)

The application of both nitrogen and potassium chemical fertilisers was carried out with three split applications, i.e. each of them was divided into three portions for the three respective applications, i.e. $N_1$ = 30, 90, 30, $N_2$ = 60, 180, 60 and $N_3$ = 120, 360, 120 kg N/ha for N application. For K, $K_1$ = 20, 60, 20, $K_2$ = 40, 120, 40 and $K_3$ = 80, 240, 80 kg $K_2O$/ha for K application. These N and K rates were applied together to the plots by hand, i.e. the first portion of both N and K was applied at 1 week after emergence and the second and third portions were applied at 6, and 8 weeks after emergence, respectively. The plant samples were taken at 2, 4, 6, 8, 10, and 12 weeks after emergence. The plant samples were used to determine dry weights, leaf areas, leaf area index, crop growth rate, leaf area duration, brix %, seed yields, and 1000-seed weights determinations. The obtained data were statistically analysed using a SAS Computer Programme (SAS, 1989).

## 2.4 Experiment 3

This experiment was carried out from 13th August to 22nd November 1999 with the aim of attaining better growth and yield by supplementing the application of both nitrogen and potassium fertilisers with fermented cattle manure since Yasothon soil series (Oxic Paleustults) is low in organic matter. Fertiliser treatments were the same as in Experiment 2.

To increase soil organic matter, the six-month fermented cattle manure at the rate of 40 tonnes/ha was used as a basal dressing to the experimental plots at two weeks before sowing. The manure was thoroughly applied to the soil by hand. The fermented cattle manure (approximately 30 % moisture contents) was also assayed for pH (1:10 manure: water by volume), organic matter (%), total nitrogen (%) using methods described in the Experiment 1 whilst phosphorous content (%) was determined by wet digestion using $H_2SO_4$ and colorimetric analysis (Murphy and Riley, 1962; and Page *et al.*, 1982). Total K (%) was determined by $H_2SO_4$ wet digestion and flame photometry (Cottennie, 1980).

The plant samples were taken at 3, 5, 7, 9 and 11 weeks after emergence.

### 2.5 Experiment 4

This was carried out from 22nd March to 29th June 2000. The materials and methods were similar to those of Experiment 3. except for the use of mini-sprinkler irrigation at the rate of 200 litres/hour (at a water pressure of 29 psi) for four hours, three times a week during the dry months of March until the first week of April when rainy season started (Plate 2.5 and Appendix B4.1 and B4.4 for meteorological data).

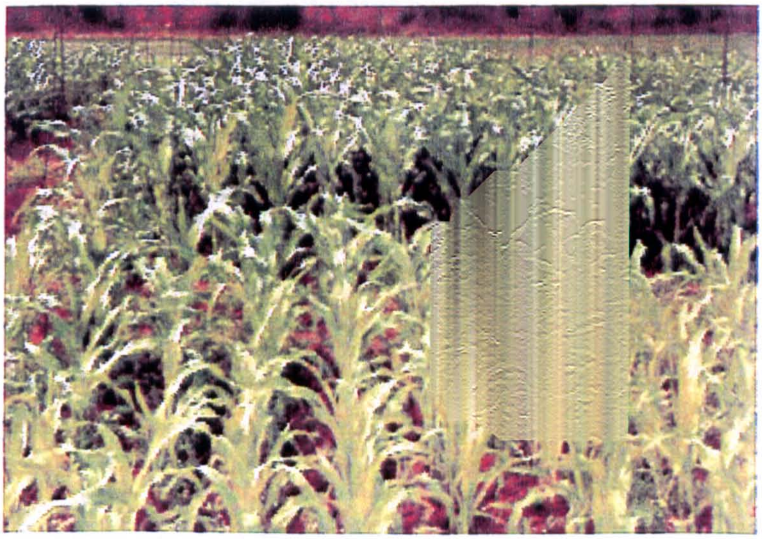

Plate 2.5 Sorghum plots in dry season showing overhead sprinkler system.

## 2.6 Experiment 5

This experiment was carried out from 14th March to 30th June 2001 (Appendix B5). The materials and methods used were similar to those of the Experiment 4 (irrigation was also used in this experiment) with the following amendments:

1. The experiment was laid in a randomised complete block design with four replications. The treatments being used were:
   T1 = Control #1
   T2 = Control #2
   T3 = Fermented cattle manure at the rate of 40 tonnes/ha
   T4 = Fermented cattle manure at the rate of 80 tonnes/ha
   T5 = Nitrogen fertiliser at the rate of 300 kg N/ha plus 100 kg $K_2O$/ha
   T6 = Nitrogen fertiliser at the rate of 300 kg N/ha plus 200 kg $K_2O$/ha
   T7 = Nitrogen fertiliser at the rate of 450 kg N/ha plus 100 kg $K_2O$/ha
   T8 = Nitrogen fertiliser at the rate of 450 kg N/ha plus 200 kg $K_2O$/ha
   T9 = Nitrogen fertiliser at the rate of 600 kg N/ha plus 100 kg $K_2O$/ha
   T10 = Nitrogen fertiliser at the rate of 600 kg N/ha plus 200 kg $K_2O$/ha
   T11 = Nitrogen fertiliser at the rate of 300 kg N/ha plus100 kg $K_2O$/ha plus cattle manure at the rate of 40 tonnes/ha
   T12 = Nitrogen fertiliser at the rate of 300 kg N/ha plus 200 kg $K_2O$/ha plus fermented cattle manure at the rate of 40 tonnes/ha
   T13 = Nitrogen fertiliser at the rate of 450 kg N/ha plus 100 kg $K_2O$/ha plus fermented cattle manure at the rate of 40 tonnes/ha
   T14 = Nitrogen fertiliser at the rate of 450 kg N/ha plus 200 kg $K_2O$/ha plus fermented cattle manure at the rate of 40 tonnes/ha
   T15 = Nitrogen fertiliser at the rate of 600 kg N/ha plus 100 kg $K_2O$/ha plus fermented cattle manure at the rate of 40 tonnes/ha
   T16 = Nitrogen fertiliser at the rate of 600 kg N/ha plus 200 kg $K_2O$/ha plus fermented cattle manure at the rate of 40 tonnes/ha

2. The plant samples were taken at 3, 5, 7, 9 and 11 weeks after emergence and the measurement methods were similar to those used in Experiment 4.

## 2.7 Experiment 6

This experiment was carried out from 24th July to 30th October 2001 at Khon Kaen University Experimental Farm, Khon Kaen Province, Thailand (Appendix B6). Materials and methods were similar to those of Experiment 5 except for the rates of fermented cattle manure used (80 tonnes/ha replaced the rate of 40 tonnes/ha) and only one control treatment was used. Irrigation was not used in this experiment because it was carried out in the rainy season. There were 14 treatments:

T1 = Control
T2 = Fermented cattle manure at the rate of 80 tonnes/ha
T3 = Nitrogen fertiliser at the rate of 300 kg N/ha plus 100 kg $K_2O$/ha
T4 = Nitrogen fertiliser at the rate of 300 kg N/ha plus 200kg $K_2O$/ha
T5 = Nitrogen fertiliser at the rate of 450 kg N/ha plus 100 kg $K_2O$/ha
T6 = Nitrogen fertiliser at the rate of 450 kg N/ha plus 200kg $K_2O$/ha
T7 = Nitrogen fertiliser at the rate of 600 kg N/ha plus 100 kg $K_2O$/ha
T8 = Nitrogen fertiliser at the rate of 600 kg N/ha plus 200kg $K_2O$/ha
T9 = Nitrogen fertiliser at the rate of 300 kg N/ha plus 100kg $K_2O$/ha plus cattle manure at the rate of 80 tonnes/ha
T10 = Nitrogen fertiliser at the rate of 300 kg N/ha plus 200kg $K_2O$/ha plus cattle manure at the rate of 80 tonnes/ha
T11 = Nitrogen fertiliser at the rate of 450 kg N/ha plus 100kg $K_2O$/ha plus cattle manure at the rate of 80 tonnes/ha
T12 = Nitrogen fertiliser at the rate of 450 kg N/ha plus 200kg $K_2O$/ha plus cattle manure at the rate of 80 tonnes/ha
T13 = Nitrogen fertiliser at the rate of 600 kg N/ha plus 100kg $K_2O$/ha plus cattle manure at the rate of 80 tonnes/ha
T14 = Nitrogen fertiliser at the rate of 600 kg N/ha plus 200kg $K_2O$/ha plus cattle manure at the rate of 80 tonnes/ha

# Chapter 3

## Experiment1

## Effects of Low Application Rates of Nitrogen and Potassium on Growth, Chemical Components and Seed Yields of IS 23585 Forage Sorghum Cultivar, (*Sorghum bicolor* L. Moench) Grown on Yasothon soil series (Oxic Paleustults) in Rainy Season

### 3.1 Introduction

Published data have indicated that sorghum plants could thrive on most soils even under severe drought conditions, i.e. with a few hundred millimeters of annual rainfall and some erratic rainfall patterns (Senanarong, 1977; and Bennett *et al.*,1990). However, to attain high fodder and grain yields, adequate soil moisture content, nutrients, radiant energy, carbon dioxide are all required and a suitable tropical temperature since sorghum is a C-4 dicarboxylic acid pathway plant requiring relatively high temperatures for optimal photosynthetic activity. High fodder and grain yields per unit land area also depend on the amounts of macronutrients taken up by the crop plants, particularly nitrogen and potassium. Nitrogen has a significant effect on top (especially leaf) growth of most crops whilst potassium is important for translocation of assimilates from source to sink; both nutrients are taken up by crop plants in a large quantity compared with phosphorous, magnesium and calcium (Overnell, 1975; Grundon *et al.*, 1987; Mengel and Kirkby, 1987; and Suksri, 1999). Tropical soils, in general, contain low amounts of both nitrogen and potassium as a result of high annual leaching rates and the previous cropping history. This is a particular case for Yasothon soil series, a member of the subgroup of Oxic Paleustults (Keerati-kasikorn, 1984; Suksri, 1999; and Chuasavathi and Trelo-ges, 2001). This soil series was chosen for this forage sorghum investigation due to its large amount of land area in Northeast Thailand and because it has been used for the cultivation of several crops for many decades. The aim of this investigation is to achieve high fodder and grain yield of sorghum on Yasothon soil series. Literature data on growth, yield, and forage chemical components, dry matter degradability and brix value with respect to this soil series is very limited for sorghum. Therefore, a series of experiments with the use of an IS 23585 forage sorghum cultivar, a promising cultivar attained from a previous experiment (Pholsen *et al.*, 1998). This was incorporated with a range of nitrogen and potassium chemical fertiliser treatments on Yasothon (Oxic Paleustults) soil.

**Materials and methods**: This section was given in chapter 2 on page 51. Nitrogen rates being used were 0 ($N_0$), 62.5 ($N_1$), 125 ($N_2$), and 187.5 ($N_3$) kgN/ha. Potassium fertiliser rates were 0 ($K_0$), 50 ($K_1$), 100 ($K_2$), and 150 ($K_3$) kg $K_2O$/ha. The combination of both N and K levels were all together 16 treatments, i.e. $N_0K_0$, $N_0K_1$, $N_0K_2$, $N_0K_3$, $N_1K_0$, $N_1K_1$, $N_1K_2$, $N_1K_3$, $N_2K_0$, $N_2K_1$, $N_2K_2$, $N_2K_3$, $N_3K_0$, $N_3K_1$, $N_3K_2$, and $N_3K_3$.

## 3.2 Results

### 3.2.1 Initial Soil Analysis Data of Yasothon Soil Series

The mean values for soil pH (1:2.5 soil: water by volume), organic matter %, total nitrogen %, available phosphorous (P) and extractable potassium (K) were 5.4, 0.69, 0.037, 35 ppm, and 38 ppm, respectively (Table 3.1).

Table 3.1 Initial soil analysis data of Yasothon soil series (Oxic Paleustults) of the plots at Khon Kaen University Experimental Farm, Northeast Thailand.

| Items | Blocks | | | | Averages |
|---|---|---|---|---|---|
| | I | II | III | IV | |
| pH (1:2.5) | 5.4 | 5.4 | 5.5 | 5.3 | 5.4 |
| Organic matter (%) | 0.62 | 0.68 | 0.74 | 0.72 | 0.69 |
| Total soil nitrogen (%) | 0.032 | 0.033 | 0.035 | 0.046 | 0.037 |
| Available phosphorus (ppm) | 30 | 34 | 37 | 40 | 35 |
| Extractable potassium (ppm) | 24 | 42 | 36 | 48 | 38 |

### 3.2.2 Soil Analysis Data at the Final Sampling Period

At the final sampling period, the results were 5.9-6.4, 0.68-0.97, 0.032-0.046, 61-75 ppm, and 44-90 ppm for soil pH, organic matter %, total soil nitrogen %, available phosphorous, and extractable potassium, respectively (Table 3.2). Generally, initial values (Table 3.1) are lower than final values (Table 3.2) but apart from pH and available phosphorus all values are relatively low.

Table 3.2 Soil analysis data of Yasothon soil series (Oxic Paleustults) of the plots at the final harvest for grains of the sorghum plants at Khon Kaen University Experimental Farm, Northeast Thailand.

| N levels | K levels |  |  |  | Average N |
|---|---|---|---|---|---|
|  | $K_0$ | $K_1$ | $K_2$ | $K_3$ |  |
|  |  | Soil pH (1:2.5) |  |  |  |
| $N_0$ | 5.9 | 6.1 | 6.0 | 6.0 | 6.0 |
| $N_1$ | 6.0 | 6.1 | 6.4 | 6.0 | 6.1 |
| $N_2$ | 6.2 | 6.1 | 6.0 | 6.1 | 6.1 |
| $N_3$ | 6.0 | 6.1 | 6.2 | 6.4 | 6.2 |
| Average K | 6.0 | 6.1 | 6.2 | 6.1 |  |
|  |  | Organic matter (%) |  |  |  |
| $N_0$ | 0.68 | 0.73 | 0.77 | 0.72 | 0.73 |
| $N_1$ | 0.76 | 0.97 | 0.87 | 0.84 | 0.86 |
| $N_2$ | 0.81 | 0.81 | 0.86 | 0.84 | 0.83 |
| $N_3$ | 0.72 | 0.89 | 0.76 | 0.69 | 0.77 |
| Average K | 0.74 | 0.85 | 0.82 | 0.77 |  |
|  |  | Total soil nitrogen (%) |  |  |  |
| $N_0$ | 0.0403 | 0.0410 | 0.0431 | 0.0424 | 0.0417 |
| $N_1$ | 0.0389 | 0.0368 | 0.0459 | 0.0403 | 0.0405 |
| $N_2$ | 0.0347 | 0.0396 | 0.0354 | 0.0319 | 0.0354 |
| $N_3$ | 0.0350 | 0.0392 | 0.0368 | 0.0333 | 0.0361 |
| Average K | 0.0372 | 0.0392 | 0.0403 | 0.0370 |  |
|  |  | Available phosphorous (ppm) |  |  |  |
| $N_0$ | 68 | 72 | 60 | 68 | 67.0 |
| $N_1$ | 69 | 65 | 67 | 68 | 67.3 |
| $N_2$ | 64 | 75 | 69 | 67 | 68.8 |
| $N_3$ | 75 | 70 | 73 | 61 | 69.8 |
| Average K | 69.0 | 70.5 | 67.3 | 66.0 |  |
|  |  | Extractable potassium (ppm) |  |  |  |
| $N_0$ | 44 | 63 | 63 | 90 | 65.0 |
| $N_1$ | 45 | 63 | 60 | 74 | 60.5 |
| $N_2$ | 44 | 51 | 64 | 70 | 57.3 |
| $N_3$ | 45 | 52 | 64 | 90 | 62.8 |
| Average K | 44.5 | 57.3 | 62.8 | 81.0 |  |

### 3.2.3 Stem Dry Weights, Leaf Dry Weights and Leaf Areas

At 52 days after emergence (1st harvest), the results show that an increase in nitrogen levels did not significantly increase stem dry weights, but leaf dry weights and leaf areas of the sorghum plants significantly increased with an increase in nitrogen levels with the mean values of 8.65 to 10.38 g/plant for leaf dry weights of $N_0$ and $N_3$ and with leaf areas of 1407 cm$^2$/plant for $N_0$ level and 1705 cm$^2$/plant for the $N_3$ level. However, an increase in potassium levels did not increase stem dry weights, leaf dry weights or leaf areas of the sorghum plants and there was no interaction between N and K levels recorded (Tables 3.3).

Table 3.3 Mean values of stem dry weights, leaf dry weights and leaf areas of the sorghum plants at 52 days after emergence as influenced by nitrogen and potassium levels, grown on Yasothon soil series (Oxic Paleustults). See Appendix E 1.1 for ANOVA.

| N levels | K levels | | | | Average N |
|---|---|---|---|---|---|
| | $K_0$ | $K_1$ | $K_2$ | $K_3$ | |
| | | Stem dry weights (g/pl) | | | |
| $N_0$ | 16.56 | 17.07 | 18.84 | 15.01 | 16.87 |
| $N_1$ | 16.81 | 15.11 | 16.75 | 20.43 | 17.28 |
| $N_2$ | 19.46 | 18.65 | 17.88 | 20.69 | 19.17 |
| $N_3$ | 16.72 | 17.94 | 24.93 | 19.59 | 19.80 |
| Average K | 17.39 | 17.19 | 19.60 | 18.93 | SE = ± 2.14 |
| | | Leaf dry weights (g/plant) | | | |
| $N_0$ | 8.34 | 8.56 | 9.63 | 8.05 | 8.65$^b$ |
| $N_1$ | 9.20 | 9.38 | 9.30 | 10.10 | 9.50$^{ab}$ |
| $N_2$ | 9.59 | 10.74 | 9.87 | 10.58 | 10.20$^a$ |
| $N_3$ | 9.59 | 10.64 | 11.14 | 10.16 | 10.38$^a$ |
| Average K | 9.18 | 9.83 | 9.99 | 9.72 | SE = ± 0.78 |
| | | Leaf areas (cm$^2$/plant) | | | |
| $N_0$ | 1472 | 1370 | 1567 | 1220 | 1407$^b$ |
| $N_1$ | 1504 | 1496 | 1480 | 1598 | 1520$^{ab}$ |
| $N_2$ | 1638 | 1669 | 1583 | 1693 | 1646$^a$ |
| $N_3$ | 1535 | 1685 | 2000 | 1598 | 1705$^a$ |
| Average K | 1537 | 1555 | 1658 | 1527 | SE = ± 138.50 |

Letters indicate significant differences of Duncan's Multiple Range Test (DMRT) at P = 0.05.
SE = Standard error of means.

### 3.2.4 Total Dry Weights, Stem Dry Weights, Leaf Dry Weights, Flower Head Dry Weights and Leaf Areas

At 82 days after emergence (2nd harvest), total dry weights, stem dry weights, leaf dry weights, flower head dry weights and leaf areas per plant were unaffected by both nitrogen and potassium levels (Table 3.4). The highest value of total dry weight (64.97 g/plant) was for $N_3K_1$ treatment. These data contrast with initial sampling period (Table 3.3) when the sorghum plants did show some significant leaf growth responses to increases in nitrogen levels.

Table 3.4 Mean values of total dry weights, stem dry weights, leaf dry weights, leaf areas and flower head dry weights of the sorghum plants at 82 days after emergence as influenced by nitrogen and potassium levels, grown on Yasothon soil series (Oxic Paleustults). See Appendix E 1.2 for Analysis of variance (ANOVA).

| N levels | K levels | | | | Average N |
|---|---|---|---|---|---|
| | $K_0$ | $K_1$ | $K_2$ | $K_3$ | |
| | | Total dry weights (g/plant) | | | |
| $N_0$ | 53.36 | 63.07 | 57.39 | 55.43 | 57.31 |
| $N_1$ | 52.52 | 63.85 | 58.94 | 51.06 | 56.59 |
| $N_2$ | 55.14 | 52.35 | 54.46 | 56.67 | 54.66 |
| $N_3$ | 59.99 | 64.97 | 51.04 | 55.46 | 57.87 |
| Average K | 55.25 | 61.06 | 55.46 | 54.66 | SE = ± 5.66 |
| | | Stem dry weights (g/plant) | | | |
| $N_0$ | 33.64 | 39.96 | 35.88 | 36.33 | 36.45 |
| $N_1$ | 33.46 | 41.01 | 35.51 | 32.27 | 35.56 |
| $N_2$ | 34.82 | 32.94 | 34.87 | 36.36 | 34.75 |
| $N_3$ | 38.32 | 40.68 | 32.42 | 33.57 | 36.25 |
| Average K | 35.06 | 38.65 | 34.67 | 34.63 | SE = ± 3.59 |
| | | Leaf dry weights (g/plant) | | | |
| $N_0$ | 5.95 | 8.02 | 5.86 | 6.36 | 6.55 |
| $N_1$ | 6.23 | 7.72 | 7.01 | 6.27 | 6.81 |
| $N_2$ | 5.94 | 6.45 | 6.91 | 7.34 | 6.66 |
| $N_3$ | 7.86 | 8.22 | 7.36 | 7.63 | 7.77 |
| Average K | 6.50 | 7.60 | 6.79 | 6.90 | SE = ± 0.83 |
| | | Flower head dry weights (g/plant) | | | |
| $N_0$ | 13.78 | 15.12 | 15.65 | 12.75 | 14.33 |
| $N_1$ | 12.83 | 15.12 | 16.42 | 15.52 | 14.97 |
| $N_2$ | 14.39 | 12.96 | 12.68 | 12.92 | 13.24 |
| $N_3$ | 13.82 | 16.07 | 11.27 | 14.26 | 13.86 |
| Average K | 13.70 | 14.82 | 14.01 | 13.86 | SE = ± 1.78 |
| | | Leaf areas ($cm^2$/plant) | | | |
| $N_0$ | 1278 | 1721 | 1259 | 1365 | 1406 |
| $N_1$ | 1339 | 1658 | 1505 | 1347 | 1462 |
| $N_2$ | 1275 | 1386 | 1448 | 1576 | 1421 |
| $N_3$ | 1687 | 1766 | 1582 | 1640 | 1669 |
| Average K | 1395 | 1633 | 1449 | 1482 | SE = ± 179.03 |

SE = Standard error of means.

### 3.2.5 Relationship Between Total Fertiliser Addition and Total Dry Weights of the Sorghum Plants

The result showed that total fertiliser addition in terms of the combined effects of N and K was not significantly associated with total dry weights. $R^2$ of 0.016 indicated that 1.6 % of the variation in the mean total dry weight was accounted for by the linear function of the total fertiliser addition (Fig. 3.1).

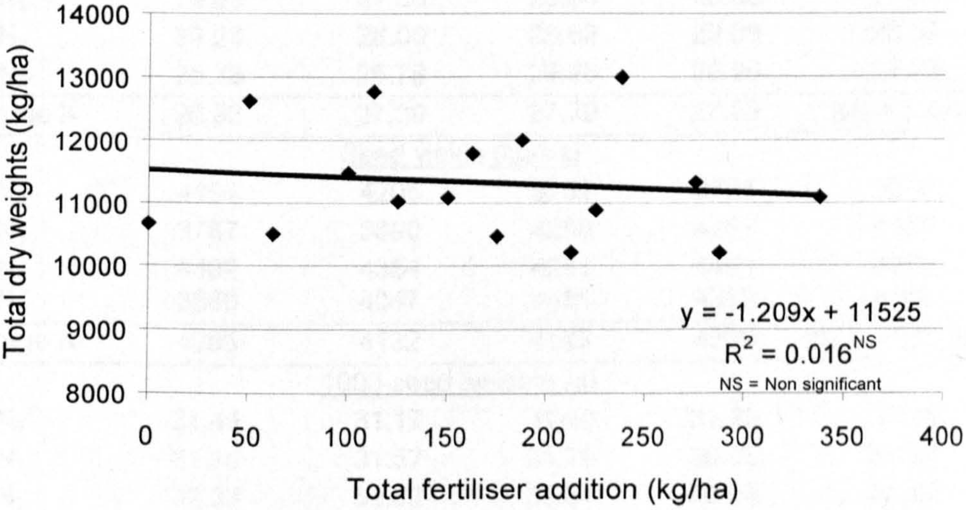

Fig. 3.1 Relationship between total fertiliser addition and total dry weights of the sorghum plants at 82 days after emergence, grown on Yasothon soil series (Oxic Paleustults), Northeast Thailand.

### 3.2.6 Seed Head Dry Weights, Seed Yields and 1000-Seed Weights

At the final sampling period, 93 days after emergence (3rd harvest), the results showed that seed head dry weights, seed yields/ha and 1000-seed weights of the sorghum plants were not significantly affected by either nitrogen or potassium levels. Maximum seed head dry weight of 29.38 g/plant was in $N_2K_3$ treatment, seed yield of 4491 kg/ha in $N_2K_3$ treatment and the maximum 1000-seed weight of 32.33 g in $N_2K_0$ treatment (Table 3.5). In particular, the additional amounts of both nitrogen and potassium fertilisers had no significant effect on the growth parameters of the sorghum plants and also on seed yield. Seed yields attained for this work were ranging from 3735 to 4491 kg/ha for $N_0K_3$ and $N_2K_3$ treatments, respectively.

Table 3.5 Mean values of seed head dry weights, seed yields and 1000-seed weights of the sorghum plants at 93 days after emergence as influenced by nitrogen and potassium levels, grown on Yasothon soil series (Oxic Paleustults). See Appendix E 1.3 for ANOVA.

| N levels | K levels | | | | Average N |
|---|---|---|---|---|---|
| | $K_0$ | $K_1$ | $K_2$ | $K_3$ | |
| | | Seed head dry weights (g/pl) | | | |
| $N_0$ | 27.75 | 27.39 | 24.68 | 24.50 | 26.06 |
| $N_1$ | 24.63 | 27.50 | 28.38 | 28.38 | 27.22 |
| $N_2$ | 29.23 | 28.00 | 28.88 | 29.38 | 28.87 |
| $N_3$ | 25.73 | 26.78 | 29.25 | 29.25 | 27.75 |
| Average K | 26.83 | 27.39 | 27.79 | 27.88 | SE = ± 1.08 |
| | | Seed yields (kg/ha) | | | |
| $N_0$ | 4194 | 4205 | 3781 | 3735 | 3979 |
| $N_1$ | 3787 | 3890 | 4298 | 4297 | 4068 |
| $N_2$ | 4402 | 4384 | 4211 | 4491 | 4372 |
| $N_3$ | 3880 | 4047 | 4481 | 4312 | 4180 |
| Average K | 4066 | 4132 | 4193 | 4209 | SE = ± 276.68 |
| | | 1000-seed weights (g) | | | |
| $N_0$ | 31.44 | 31.17 | 31.50 | 31.39 | 31.38 |
| $N_1$ | 31.25 | 31.57 | 31.78 | 30.96 | 31.39 |
| $N_2$ | 32.33 | 31.92 | 31.31 | 30.05 | 31.40 |
| $N_3$ | 32.19 | 31.05 | 32.22 | 31.53 | 31.75 |
| Average K | 31.80 | 31.43 | 31.70 | 30.98 | SE = ± 0.67 |

SE = Standard error of means.

### 3.2.7 Relationship Between Total Fertiliser Addition and Seed Yields of the Sorghum Plants

The result showed that total fertiliser addition in terms of the combined effects of N and K was not significantly associated with seed yields. $R^2$ of 0.203 indicated that 20.3 % of the variation in the mean seed yield was accounted for by the linear function of the total fertiliser addition (Fig. 3.2).

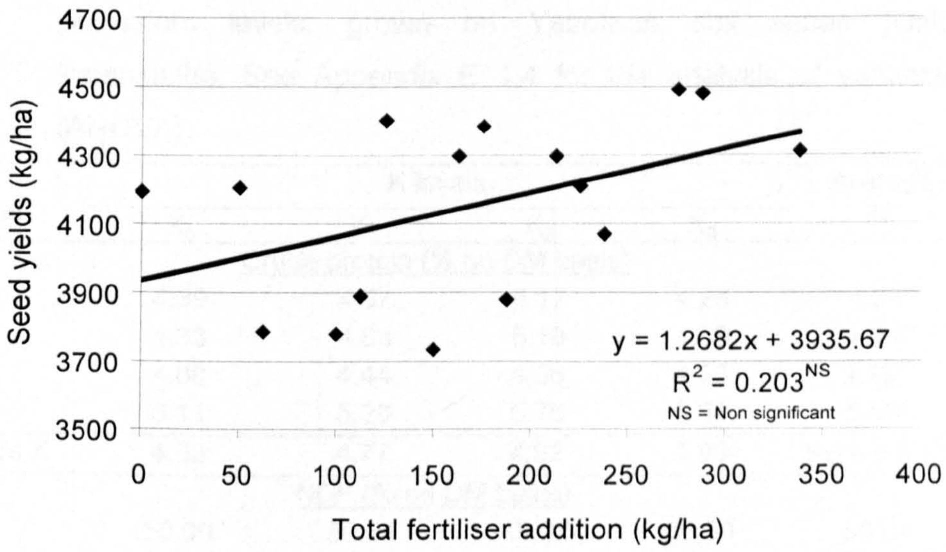

Fig. 3.2 Relationship between total fertiliser addition and seed yields of the sorghum plants, grown on Yasothon soil series (Oxic Paleustults), Northeast Thailand.

### 3.2.8 Crude Protein (CP) Contents, Neutral Detergent Fibre (NDF) and Acid Detergent Fibre (ADF) Contents, Dry Matter Degradability (DMD) and Brix Values at 2nd Harvest (82 days after emergence)

The results showed that the crude protein percentages on dry matter basis significantly increased from 4.35 to 5.69 % for $N_0$ and $N_3$ levels, respectively. Values for NDF, and ADF on dry matter basis, the results showed that these chemical components were unaffected by an increase in the amounts of both nitrogen and potassium added to the soil (Table 3.6). Nitrogen and potassium levels had no significant effects on DMD in rumen for measurements at 24 and 48 hours whilst brix percentages, in general, decreased with an increase in both N and K levels (Table 3.7). Brix percentages were similar for $N_0$ to $N_2$ and became least at $N_3$ level, i.e. the highest N level significantly decreased brix value. An increase in K levels significantly decreased brix values with the mean values ranging from 9.04 to 10.74 for $K_2$ and $K_0$, respectively.

Table 3.6 Mean values of estimated crude protein, neutral detergent fibre (NDF) and acid detergent fibre (ADF) contents of the sorghum plants at 82 days after emergence as influenced by nitrogen and potassium levels, grown on Yasothon soil series (Oxic Paleustults). See Appendix E 1.4 for the analysis of variance (ANOVA).

| N levels | K levels | | | | Average N |
|---|---|---|---|---|---|
| | $K_0$ | $K_1$ | $K_2$ | $K_3$ | |
| | | Crude protein (% on DM basis) | | | |
| $N_0$ | 4.39 | 4.57 | 4.17 | 4.26 | 4.35$^{b}$ |
| $N_1$ | 4.33 | 4.83 | 5.19 | 4.98 | 4.83$^{ab}$ |
| $N_2$ | 4.86 | 4.44 | 4.56 | 4.73 | 4.65$^{ab}$ |
| $N_3$ | 6.11 | 5.26 | 5.76 | 5.64 | 5.69$^{a}$ |
| Average K | 4.92 | 4.77 | 4.92 | 4.90 | SE = ± 0.31 |
| | | NDF (% on DM basis) | | | |
| $N_0$ | 50.00 | 50.62 | 49.04 | 50.50 | 50.04 |
| $N_1$ | 49.25 | 49.37 | 54.17 | 51.50 | 51.07 |
| $N_2$ | 50.68 | 51.20 | 51.04 | 48.99 | 50.48 |
| $N_3$ | 53.34 | 52.35 | 53.61 | 54.11 | 53.35 |
| Average K | 50.82 | 50.89 | 51.97 | 51.28 | SE = ± 1.90 |
| | | ADF (% on DM basis) | | | |
| $N_0$ | 29.52 | 28.95 | 29.32 | 28.70 | 29.12 |
| $N_1$ | 28.83 | 29.49 | 30.94 | 29.45 | 29.69 |
| $N_2$ | 29.90 | 30.23 | 30.53 | 28.28 | 29.74 |
| $N_3$ | 30.94 | 30.54 | 30.64 | 31.59 | 30.93 |
| Average K | 29.80 | 29.80 | 30.36 | 29.51 | SE = ± 1.18 |

Letters indicate significant differences of DMRT at probability of 0.05.
SE = Standard error of means.

Table 3.7 Mean values of dry matter degradability values (DMD) at 24 and 48 hours and brix values of the sorghum plants at 82 days after emergence as influenced by nitrogen and potassium levels, grown on Yasothon soil series (Oxic Paleustults). See Appendix E 1.4 for ANOVA.

| N levels | K levels | | | | Average N |
|---|---|---|---|---|---|
| | $K_0$ | $K_1$ | $K_2$ | $K_3$ | |
| | | DMD at 24 hours (% on DM basis) | | | |
| $N_0$ | 55.51 | 54.92 | 56.84 | 53.81 | 55.27 |
| $N_1$ | 56.26 | 57.12 | 55.16 | 57.54 | 56.52 |
| $N_2$ | 58.46 | 56.24 | 56.57 | 54.42 | 56.42 |
| $N_3$ | 53.22 | 54.69 | 53.24 | 52.98 | 53.53 |
| Average K | 55.86 | 55.74 | 55.45 | 54.69 | SE = ± 2.26 |
| | | DMD at 48 hours (% on DM basis) | | | |
| $N_0$ | 67.88 | 68.79 | 66.34 | 66.29 | 67.32 |
| $N_1$ | 69.65 | 67.44 | 66.58 | 70.83 | 68.62 |
| $N_2$ | 71.97 | 66.76 | 65.27 | 67.95 | 67.99 |
| $N_3$ | 66.37 | 68.19 | 68.22 | 66.76 | 67.38 |
| Average K | 68.97 | 67.79 | 66.60 | 67.96 | SE = ± 1.86 |
| | | Brix (%) | | | |
| $N_0$ | 11.97 | 11.48 | 10.13 | 10.08 | $10.91^{a}$ |
| $N_1$ | 11.19 | 10.37 | 8.99 | 9.65 | $10.05^{a}$ |
| $N_2$ | 10.49 | 11.47 | 7.76 | 10.81 | $10.14^{a}$ |
| $N_3$ | 9.30 | 8.90 | 9.28 | 7.44 | $8.73^{b}$ |
| Average K | $10.74^{a}$ | $10.56^{ab}$ | $9.04^{c}$ | $9.49^{bc}$ | SE = ± 0.83 |

Letters indicate significant differences of DMRT at probability of 0.05.
SE = Standard error of means.

### 3.3 Discussion

At 52 days after emergence (1st harvest), the results show that an increase in nitrogen levels did not increase stem dry weights. However, leaf dry weights and leaf areas of the sorghum plants were increased with an increase in nitrogen levels. An increase in potassium levels did not increase stem dry weights, leaf dry weights or leaf areas of the sorghum plants and no interaction between N and K levels was found. These results indicate that at least some of the nitrogen levels being used have improved leaf growth of the sorghum plants whilst potassium did not show any signs of improvement on growth parameters tested. This may be partly attributed to a high leaching rate due to the high amount of rainfall during the months of August and September 1997 with values of 175.3 and 110 mm, respectively (Appendix B1.2 and B1.3). The loss of soil nitrogen due to leaching under heavy rainfall conditions could ranged from 50-80 kg N/ha annually as stated by Miller and Donahue (1990) whilst other nutrients could have leached out of the soil particles also at a high rate (Vomel, 1965/66; Muller *et. al.*, 1985; and Mengel and Kirkby, 1987). Yasothon soil series being used for the present work is also low in organic matter percentage, normally less than 0.8% (Suksri, 1998, and 1999). However, this could not fully explain the differences between the N and K treatments, unless unit residual N has a greater effect on growth than unit residual K. This in fact could be the explanation since the positive effect of N is mainly on leaf growth parameters and it is well established, e.g., Tanaka (1974); Wild (1988); and Kamoshita *et al.* (1998b), that nitrogen is the key macronutrient for leaf growth and development in crop plants. Another reason could have been the erratic rainfall pattern where the sorghum plants did not receive evenly distributed rainwater throughout the growth period hence soil moisture content could have been inadequate at different periods of growth (cf. Appendix B1.2 for meteorological data). Water stress affecting growth of crop plants has been reported by a number of workers, e.g. McCree and Davis (1974); Stout *et al.* (1978); Roa *et al.* (1999); and Ockerby *et al.* (2001).

At 82 days after emergence (2nd harvest), total dry weights, stem dry weights, leaf dry weights, flower head dry weights and leaf areas per plant were unaffected by both nitrogen and potassium levels; the additional amounts of both nitrogen and potassium had no significant effect on the growth parameters of the sorghum plants. At the first harvest (52 days) the sorghum plants did show some significant leaf growth responses to an increase in nitrogen levels. The differences in response to the fertiliser treatments between harvest 1 and harvest 2 could be partly attributable to the low extractable value of soil potassium as found at the final soil sampling and also it may be partly attributable to the depletion of soil nitrogen and potassium with time and also the high leaching rate of soil nutrients as reported by Geleta *et al.,* (1994). However, the final soil analysis revealed higher levels of both soil N and K than the initial ones, so drought conditions may have had some effects on growth of the sorghum plants. There had been high amounts of rainfall in September and until the second week of October (Appendix B1.3 and B1.4), but later a drought period occurred during the last two weeks of October, so the sorghum plants were severely affected by water stress for a certain period of time. The rates of both nitrogen and potassium fertilisers given to the sorghum plants could have been too low. However, total dry weights per unit ground area were similar to those reported by Rao *et al.* (1999) for irrigated plants. The final mean values of both soil nitrogen and extractable potassium were lower than the critical values as reported by Shelton *et al.* (1979), this may have been partly due to leaching losses which would have reduced N and K availability to the sorghum plants. The decline in leaf growth at the later growth stage could possibly be due to the imbalance between nitrogen and potassium and partly due to the advance in plant age. Both soil nitrogen and extractable potassium levels were lower than the critical values particularly the potassium (44-90 ppm for soil K and 0.0347-0.0410 % for soil N) by the end of the experiment. Faungfupong *et al.* (1980) grew sorghum KU 257 variety at Nakonratchasima, Saraburi and Lopburi provinces, (the Central Plain area of Thailand) and found that an addition amount of nitrogen and potassium up to 62.5 kg N and K/ha had no effect on growth and yield of sorghum because these application rates were too low. Jaisil *et al.* (1980) grew different varieties of sorghum at Khon Kaen Province, Northeast Thailand; they reported that seed yields of the sorghum varieties tested did not respond to the application of nitrogen up to 132.3 kg N/ha. Their seed yields ranged from 1923 to 4618 kg/ha, which were in many cases lower than in the present work. The lowest sorghum seed yield of four varieties grown in nine provinces of Northeast Thailand were reported by Thiraporn (1980) with the average seed yields ranging from 1151 to 1860 kg/ha. The poor response to nitrogen and potassium of the sorghum plants in the present experiment could be due to the low amounts of soil nitrogen and potassium available to the sorghum plants particularly in the later part of the growing season as a result of both leaching losses and drought. The results of the present work were similar to the work reported by Myers and Asher, (1982); and Seetharama *et al.* (1984) for sorghum and pearl millet.

At the final (3rd) harvest 93 days after emergence, the results showed that seed head dry weights, seed yields and 1000-seed weights of the sorghum plants were unaffected by either nitrogen or potassium levels (Table 3.5). In particular, the additional amounts of both nitrogen and potassium fertilisers had no significant effect on the important agronomic parameter, seed yield. This may be due to the low rates of both nitrogen and potassium being applied to the soil and/or the depletion of soil nutrients due to leaching, since the levels of both nitrogen and extractable potassium at the final harvest were relatively low as previously discussed. Seed yields attained in this work ranged from 3735 to 4491 kg/ha which were similar to those reported by Bordovsky *et al.*, (1998) being harvested and grown under conventional tillage and also similar to the results reported by Rao *et al.* (1999) for irrigated sorghum plants.

The results on the analysis of brix values, chemical components and DMD at 82 days after emergence (2nd Harvest) showed that nitrogen and potassium had some effects on brix percentages, i.e. higher levels of nitrogen and potassium decreased brix percentages of the sorghum plants, whilst increasing nitrogen levels increased crude protein (Tables 3.6 and 3.7). These results confirm the work reported by Buxton *et al.* (1999). Potassium levels failed to promote brix percentages; this may be attributable to the imbalance between nitrogen and potassium added to the soil resulting in low values of brix % or perhaps the drought conditions during the last part of the growth period have had the effect (cf. Appendix B1.3). Buxton *et al.,* (1999) pointed out that high level of nitrogen depressed the uptake of potassium in the plant tissues while the values of NDF, ADF, and DMD were not affected by nitrogen or potassium levels. This could possibly be due to the depletion of soil nutrients and perhaps also partly due to the drought conditions during the first half of the dry season as previously discussed. DMD values were not influenced by the levels of nitrogen or potassium but the digestible values increased with an increase in number of hours of digestion. The similar values of DMD could possibly be due to an inadequate amount of soil nitrogen available to the sorghum plants. This could have produced tough tissue particularly in stems. These results are in agreement with Pholsen *et al.* (1998).

### 3.4 Summary

At 52 days after emergence (1st Harvest), leaf dry weights and leaf areas of the sorghum plants significantly increased with an increase in nitrogen levels whilst potassium levels had no significant effect. By the 2nd harvest (82 days), there were no significant effects of nitrogen or potassium levels on total dry weights, stem dry weights, leaf dry weights, flower head dry weights or even leaf areas. This may have been due to the depletion of soil nutrients as a result of leaching and/or a drought period or inadequate fertilizer application rates. Brix percentages decreased, whilst %CP increased with an increase in nitrogen levels but potassium had no significant effect. Nitrogen and potassium levels had no significant effects on NDF, ADF percentages of the sorghum plants. DMD % increased with an increase in number of hours of digestion.

At the final harvest (93 days after emergence), seed head dry weights, seed yields and 1000-seed weights were unaffected by the increased levels of both N and K.

It was concluded that nitrogen and potassium chemical fertiliser levels used in the present experiment may have been too low resulting in relatively little effect on growth and yields of the sorghum plants. In order to test this hypothesis a further experiment on growth, chemical components and yield of the sorghum plants using higher rates of both N and K is required. The experiment should be conducted in rainy season of the same period of the year and the same measurement methods should be used.

## Experiment 2

## Effects of High Application Rates of Nitrogen and Potassium on Growth, Chemical Components and Seed Yields of IS 23585 Forage Sorghum Cultivar (*Sorghum bicolor* L. Moench) Grown on Yasothon Soil Series (Oxic Paleustults) in Rainy Season

### 3.5 Introduction

It was concluded from the previous experiment that the nitrogen and potassium levels applied did not produce major effects on the growth parameters and chemical components of the sorghum plants and it was suggested that the levels used were too low for optimum growth of sorghum in relation to the fertility level of Yasothon soil series (Oxic Paleustults). This view is confirmed by a number of workers who have carried out experiments in Thailand using similar application rates of N and K, e.g. Faungfupong *et al.* (1980); Jaisil *et al.* (1980); Seetharama *et al.* (1984); and Pholsen *et al.* (2001). These workers have also noted the high leaching rate of soil nutrients due to heavy tropical rainfall. In this experiment both N and K application rates are increased in order to establish suitable rates of both fertilisers with respect to the fertility level of Yasothon soil series to obtain maximum growth and yield.

**Materials and methods:** This section was given in chapter 2 on page 57. High application rates of nitrogen chemical fertiliser rates were 0 ($N_0$), 150 ($N_1$), 300 ($N_2$), and 600 kg N/ha ($N_3$); and potassium chemical fertiliser rates were 0 ($K_0$), 100 ($K_1$), 200 ($K_2$), and 400 kg $K_2O$/ha ($K_3$).

### 3.6 Results

### 3.6.1 Initial Soil Analysis Data of Yasothon Soil Series

For initial values of soil properties before the sowing of the sorghum seeds, the results showed that soil property ranges of soil pH (1: 2.5 soil: water by volume), organic matter %, total soil nitrogen %, available phosphorous and extractable potassium were 5.4, 0.69, 0.0356, 41.5 ppm, and 60.3 ppm, respectively (Table 3.8).

Table 3.8 Initial soil analysis data of Yasothon soil series (Oxic Paleustults) before the sowing of the sorghum seeds at Khon Kaen University Experimental Farm, Northeast Thailand.

| Items | Blocks | | | | Averages |
|---|---|---|---|---|---|
| | I | II | III | IV | |
| PH (1:2.5) | 5.3 | 5.4 | 5.6 | 5.5 | 5.4 |
| Organic matter (%) | 0.61 | 0.67 | 0.69 | 0.79 | 0.69 |
| Total soil nitrogen (%) | 0.0308 | 0.0340 | 0.0389 | 0.0387 | 0.0356 |
| Available phosphorus (ppm) | 41 | 38 | 35 | 52 | 41.5 |
| Extractable potassium (ppm) | 55 | 55 | 64 | 67 | 60.3 |

### 3.6.2 Soil Analysis Data at the Final Sampling Period

At the final harvest values for soil pH (1:2.5 soil:water by volume), organic matter %, total soil nitrogen %, available phosphorous and extractable potassium were 5.5-6.1, 0.73-0.90, 0.0366-0.0432, 44-65 ppm, and 28-94 ppm, respectively (Table 3.9). Generally, initial values (Table 3.8) are similar to final values (Table 3.9) apart from available phosphorus and extractable potassium at high application rates ($K_2$ and $K_3$) all values are relative low.

Table 3.9 Soil analysis data of Yasothon soil series (Oxic Paleustults) in the sorghum plots after the final harvest of Experiment 2 at Khon Kaen University Experimental Farm, Northeast Thailand during 1999 rainy season.

| N levels | K levels | | | | Average N |
|---|---|---|---|---|---|
| | $K_0$ | $K_1$ | $K_2$ | $K_3$ | |
| | | Soil pH (1:1) | | | |
| $N_0$ | 5.9 | 6.0 | 6.1 | 6.1 | 6.0 |
| $N_1$ | 6.1 | 6.1 | 5.8 | 6.0 | 6.0 |
| $N_2$ | 5.9 | 5.6 | 5.7 | 6.0 | 5.8 |
| $N_3$ | 6.0 | 5.5 | 5.6 | 5.8 | 5.7 |
| Average K | 6.0 | 5.8 | 5.8 | 6.0 | |
| | | Organic matter (%) | | | |
| $N_0$ | 0.82 | 0.84 | 0.78 | 0.89 | 0.83 |
| $N_1$ | 0.82 | 0.82 | 0.85 | 0.78 | 0.82 |
| $N_2$ | 0.73 | 0.78 | 0.77 | 0.90 | 0.80 |
| $N_3$ | 0.83 | 0.79 | 0.83 | 0.77 | 0.81 |
| Average K | 0.80 | 0.81 | 0.81 | 0.84 | |
| | | Total soil nitrogen (%) | | | |
| $N_0$ | 0.0396 | 0.0387 | 0.0406 | 0.0385 | 0.0394 |
| $N_1$ | 0.0382 | 0.0417 | 0.0390 | 0.0385 | 0.0394 |
| $N_2$ | 0.0366 | 0.0432 | 0.0376 | 0.0408 | 0.0396 |
| $N_3$ | 0.0399 | 0.0406 | 0.0417 | 0.0373 | 0.0399 |
| Average K | 0.0386 | 0.0411 | 0.0397 | 0.0388 | |
| | | Available phosphorus (ppm) | | | |
| $N_0$ | 56 | 56 | 62 | 56 | 57.5 |
| $N_1$ | 65 | 59 | 55 | 49 | 57.0 |
| $N_2$ | 44 | 54 | 55 | 56 | 52.3 |
| $N_3$ | 49 | 53 | 50 | 64 | 54.0 |
| Average K | 53.5 | 55.5 | 55.5 | 56.3 | |
| | | Extractable potassium (ppm) | | | |
| $N_0$ | 50 | 43 | 77 | 94 | 66.0 |
| $N_1$ | 33 | 42 | 58 | 79 | 53.0 |
| $N_2$ | 28 | 38 | 50 | 76 | 48.0 |
| $N_3$ | 37 | 38 | 62 | 79 | 54.0 |
| Average K | 37.0 | 40.3 | 61.8 | 82.0 | |

### 3.6.3 Total Dry Weights, Stem Dry Weights, Leaf Dry Weights, Dead Leaf Dry Weights, Head Dry Weights, Leaf Areas, Leaf Area Indices (LAI), Crop Growth Rates (CGR), Leaf Area Duration (D), Brix Values, Seed Yields and 1000-Seed Weights

The results for total dry weights, stem dry weights, leaf dry weights, leaf areas and LAI at the initial sampling period (2 weeks after emergence) showed that an increase in nitrogen level significantly increased these parameters. The increases in total dry weights/ha ranged from 111 to 156 kg/ha for $N_0$ to $N_3$, respectively. An increase in potassium level significantly decreased total dry weights/ha at higher K concentrations, $K_2$ and $K_3$ (Table 3.10). LAI increased from 0.27 to 0.37 with increasing nitrogen application ($N_0$ to $N_3$) while potassium had little or no effect on LAI. The pattern for other parameters in table 3.10 was similar. The effects due to nitrogen were relatively greater than for potassium.

At the second sampling period at 4 weeks after emergence, the results showed that an increase in N level significantly increased total dry weights/plant. There were no significant effects of increased potassium levels (Table 3.11). Similar trends were found for stem dry weights, leaf dry weights, leaf areas, LAI and CGR. That is nitrogen had some significant effects for all measured parameters while K did not.

For the third sampling period at 6 weeks after emergence, the results showed that total dry weights of the sorghum plants ranged from 3663 to 6997 kg/ha for $N_0$ and $N_3$, respectively while total dry weights ranged from 5380 to 5829 kg/ha for $K_0$ and $K_2$, respectively. The increases in N levels significantly increased total dry weights/ha while increases in K did not significantly increase total dry weights (Table 3.12). A similar trend was found with the stem dry weights, leaf dry weights, leaf areas, LAI and CGR. The overall trend shown by the data in Table 3.12 is very similar to harvest 2 (Table 3.11); a marked positive effect of increasing N levels on all parameters but no significant effects of increased K.

Table 3.10 Mean values of total dry weights, stem dry weights, leaf dry weights, leaf areas and leaf area indices of the sorghum plants at 2 weeks after emergence as influenced by nitrogen and potassium levels grown on Yasothon soil series (Oxic Paleustults). See Appendix E2.1 for ANOVA.

| N levels | K levels | | | | Average N |
|---|---|---|---|---|---|
| | $K_0$ | $K_1$ | $K_2$ | $K_3$ | |
| | | Total dry weights (kg/ha) | | | |
| $N_0$ | 110 | 112 | 117 | 103 | $111^{d}$ |
| $N_1$ | 136 | 131 | 120 | 119 | $127^{c}$ |
| $N_2$ | 139 | 170 | 134 | 129 | $141^{b}$ |
| $N_3$ | 158 | 167 | 142 | 156 | $156^{a}$ |
| Average K | $136^{ab}$ | $143^{a}$ | $129^{b}$ | $127^{b}$ | SE = ±8.04 |
| | | Stem dry weights (g/plant) | | | |
| $N_0$ | 0.17 | 0.16 | 0.18 | 0.15 | $0.16^{d}$ |
| $N_1$ | 0.20 | 0.19 | 0.17 | 0.17 | $0.18^{c}$ |
| $N_2$ | 0.20 | 0.24 | 0.21 | 0.18 | $0.21^{b}$ |
| $N_3$ | 0.25 | 0.24 | 0.23 | 0.26 | $0.25^{a}$ |
| Average K | $0.20^{ab}$ | $0.21^{a}$ | $0.20^{ab}$ | $0.19^{b}$ | SE = ±0.01 |
| | | Leaf dry weights (g/plant) | | | |
| $N_0$ | 0.39 | 0.40 | 0.41 | 0.37 | $0.39^{c}$ |
| $N_1$ | 0.48 | 0.47 | 0.44 | 0.43 | $0.45^{b}$ |
| $N_2$ | 0.49 | 0.56 | 0.47 | 0.47 | $0.50^{a}$ |
| $N_3$ | 0.54 | 0.59 | 0.48 | 0.52 | $0.53^{a}$ |
| Average K | $0.48^{ab}$ | $0.51^{a}$ | $0.45^{b}$ | $0.45^{b}$ | SE = ±0.03 |
| | | Leaf areas (cm$^2$/plant) | | | |
| $N_0$ | 133 | 136 | 141 | 126 | $134^{c}$ |
| $N_1$ | 166 | 161 | 150 | 147 | $156^{b}$ |
| $N_2$ | 170 | 195 | 163 | 161 | $172^{a}$ |
| $N_3$ | 187 | 205 | 165 | 180 | $184^{a}$ |
| Average K | $164^{ab}$ | $174^{a}$ | $155^{b}$ | $154^{b}$ | SE = ±10.75 |
| | | Leaf area indices | | | |
| $N_0$ | 0.27 | 0.27 | 0.28 | 0.25 | $0.27^{c}$ |
| $N_1$ | 0.33 | 0.32 | 0.30 | 0.29 | $0.31^{b}$ |
| $N_2$ | 0.34 | 0.39 | 0.33 | 0.32 | $0.34^{a}$ |
| $N_3$ | 0.37 | 0.41 | 0.33 | 0.36 | $0.37^{a}$ |
| Average K | $0.33^{ab}$ | $0.35^{a}$ | $0.31^{b}$ | $0.31^{b}$ | SE = ±0.02 |

Letters indicate significant differences of DMRT at probability of 0.05.
SE = Standard error of means.

Table 3.11 Mean values of total dry weights, stem dry weights, leaf dry weights, leaf areas, leaf area indices and crop growth rates of the sorghum plants at 4 weeks after emergence as influenced by nitrogen and potassium levels grown on Yasothon soil series (Oxic Paleustults). See Appendix E2.2 for ANOVA.

| N levels | K levels | | | | Average N |
|---|---|---|---|---|---|
| | $K_0$ | $K_1$ | $K_2$ | $K_3$ | |
| Total dry weights (kg/ha) | | | | | |
| $N_0$ | 934 | 1026 | 1178 | 1105 | 1061$^{c}$ |
| $N_1$ | 1385 | 1339 | 1379 | 1421 | 1381$^{b}$ |
| $N_2$ | 1639 | 1804 | 1654 | 1865 | 1741$^{a}$ |
| $N_3$ | 1635 | 1666 | 1677 | 1725 | 1676$^{a}$ |
| Average K | 1398 | 1459 | 1472 | 1529 | SE = ±93.52 |
| Stem dry weights (g/plant) | | | | | |
| $N_0$ | 1.63 | 1.78 | 2.15 | 1.86 | 1.85$^{c}$ |
| $N_1$ | 2.54 | 2.37 | 2.40 | 2.50 | 2.46$^{b}$ |
| $N_2$ | 3.07 | 3.32 | 3.01 | 3.39 | 3.20$^{a}$ |
| $N_3$ | 3.17 | 2.90 | 3.11 | 3.39 | 3.14$^{a}$ |
| Average K | 2.60 | 2.59 | 2.67 | 2.78 | SE = ±0.19 |
| Leaf dry weights (g/plant) | | | | | |
| $N_0$ | 3.04 | 3.35 | 3.74 | 3.67 | 3.45$^{c}$ |
| $N_1$ | 4.39 | 4.32 | 4.49 | 4.61 | 4.45$^{b}$ |
| $N_2$ | 5.13 | 5.70 | 5.26 | 5.94 | 5.51$^{a}$ |
| $N_3$ | 5.00 | 5.43 | 5.27 | 5.24 | 5.24$^{a}$ |
| Average K | 4.39 | 4.70 | 4.69 | 4.86 | SE = ±0.03 |
| Leaf areas (cm$^2$/plant) | | | | | |
| $N_0$ | 809 | 893 | 997 | 977 | 919$^{c}$ |
| $N_1$ | 1169 | 1151 | 1196 | 1227 | 1186$^{b}$ |
| $N_2$ | 1366 | 1519 | 1402 | 1583 | 1467$^{a}$ |
| $N_3$ | 1333 | 1447 | 1404 | 1396 | 1395$^{a}$ |
| Average K | 1169 | 1253 | 1250 | 1296 | SE = ±79.19 |
| Leaf area indices | | | | | |
| $N_0$ | 1.62 | 1.79 | 1.99 | 1.95 | 1.84$^{c}$ |
| $N_1$ | 2.34 | 2.30 | 2.39 | 2.45 | 2.37$^{b}$ |
| $N_2$ | 2.73 | 3.04 | 2.80 | 3.17 | 2.94$^{a}$ |
| $N_3$ | 2.67 | 2.89 | 2.81 | 2.79 | 2.79$^{a}$ |
| Average K | 2.34 | 2.51 | 2.50 | 2.59 | SE = ±0.16 |
| Crop growth rates # 1 (g/m$^2$/week) | | | | | |
| $N_0$ | 41.19 | 45.69 | 53.03 | 50.10 | 47.50$^{c}$ |
| $N_1$ | 62.46 | 60.37 | 62.91 | 65.12 | 62.72$^{b}$ |
| $N_2$ | 75.00 | 82.13 | 75.94 | 86.80 | 79.97$^{a}$ |
| $N_3$ | 73.87 | 74.97 | 76.74 | 78.44 | 76.00$^{a}$ |
| Average K | 63.13 | 65.79 | 67.15 | 70.11 | SE = ±4.80 |

Letters indicate significant differences of DMRT at probability of 0.05.
SE = Standard error of means.

Table 3.12 Mean values of total dry weights, stem dry weights, leaf dry weights, leaf areas, leaf area indices and crop growth rates of the sorghum plants at 6 weeks after emergence as influenced by nitrogen and potassium levels grown on Yasothon soil series (Oxic Paleustults). See Appendix E2.3 for ANOVA.

| N levels | K levels | | | | Average N |
|---|---|---|---|---|---|
| | $K_0$ | $K_1$ | $K_2$ | $K_3$ | |
| | | Total dry weights (kg/ha) | | | |
| $N_0$ | 3220 | 3624 | 3970 | 3837 | $3663^{d}$ |
| $N_1$ | 4978 | 5241 | 5811 | 5345 | $5344^{c}$ |
| $N_2$ | 6112 | 6468 | 6241 | 6195 | $6254^{b}$ |
| $N_3$ | 7211 | 7239 | 7295 | 6241 | $6997^{a}$ |
| Average K | 5380 | 5643 | 5829 | 5405 | SE = ±310.42 |
| | | Stem dry weights (g/plant) | | | |
| $N_0$ | 5.48 | 6.24 | 6.62 | 6.00 | $6.09^{d}$ |
| $N_1$ | 10.78 | 11.76 | 14.34 | 12.91 | $12.45^{c}$ |
| $N_2$ | 15.44 | 17.06 | 16.76 | 15.45 | $16.18^{b}$ |
| $N_3$ | 18.46 | 18.96 | 19.24 | 16.58 | $18.31^{a}$ |
| Average K | 12.54 | 13.51 | 14.24 | 12.74 | SE = ±0.98 |
| | | Leaf dry weights (g/plant) | | | |
| $N_0$ | 10.62 | 11.88 | 13.23 | 13.19 | $12.23^{c}$ |
| $N_1$ | 14.11 | 14.45 | 14.72 | 13.82 | $14.27^{b}$ |
| $N_2$ | 15.12 | 15.28 | 14.45 | 15.53 | $15.09^{b}$ |
| $N_3$ | 17.60 | 17.24 | 17.24 | 14.63 | $16.67^{a}$ |
| Average K | 14.36 | 14.71 | 14.91 | 14.29 | SE = ±0.82 |
| | | Leaf areas ($cm^2$/plant) | | | |
| $N_0$ | 2698 | 3018 | 3360 | 3349 | $3106^{c}$ |
| $N_1$ | 3583 | 3669 | 3738 | 3509 | $3625^{b}$ |
| $N_2$ | 3841 | 3881 | 3669 | 3944 | $3833^{b}$ |
| $N_3$ | 4469 | 4378 | 4378 | 3715 | $4235^{a}$ |
| Average K | 3648 | 3736 | 3786 | 3629 | SE = ±209.42 |
| | | Leaf area indices | | | |
| $N_0$ | 5.40 | 6.04 | 6.72 | 6.70 | $6.21^{c}$ |
| $N_1$ | 7.17 | 7.34 | 7.48 | 7.02 | $7.25^{b}$ |
| $N_2$ | 7.68 | 7.76 | 7.34 | 7.89 | $7.67^{b}$ |
| $N_3$ | 8.94 | 8.76 | 8.76 | 7.43 | $8.47^{a}$ |
| Average K | 7.30 | 7.47 | 7.57 | 7.26 | SE = ±0.42 |
| | | Crop growth rates # 2 ($g/m^2$/week) | | | |
| $N_0$ | 114.31 | 129.92 | 139.62 | 136.62 | $130.11^{d}$ |
| $N_1$ | 179.62 | 195.11 | 221.62 | 196.18 | $198.13^{c}$ |
| $N_2$ | 223.66 | 233.18 | 229.34 | 216.49 | $225.66^{b}$ |
| $N_3$ | 278.79 | 278.63 | 280.92 | 225.80 | $266.03^{a}$ |
| Average K | 199.09 | 209.21 | 217.87 | 193.77 | SE = ±15.31 |

Letters indicate significant differences of DMRT at probability of 0.05.
SE = Standard error of means.

At the fourth sampling period 8 weeks after emergence, the results showed that total dry weights significantly increased with an increase in N level up to $N_2$ only with values of 5,330, 9,244, and 10,881 kg/ha for $N_0$, $N_1$, and $N_2$, respectively while an increase in K level did not significantly increase total dry weights/ha (Table 3.13). Stem dry weights also increased with an increase in N level up to $N_2$. Increase in N level also significantly increased leaf dry weights while K increased these only up to $K_1$. A similar trend was found with leaf areas and LAI. Maximum LAI of 9.25 was achieved at the highest level of N ($N_3$). An increase in K significantly increased leaf areas and LAI up to $K_1$ only. K had relatively small effects on leaf growth. CGR values were also significantly increased with an increase in N level but K had no significant effect on CGR values.

At the fifth sampling period 10 weeks after emergence, the results showed that total dry weights/ha increased with an increase in N level up to $N_2$ only with values of 6,507, 12,264, and 13,942 kg/ha for $N_0$, $N_1$, and $N_2$, respectively whilst an increase in K level increased total dry weights/ha only up to K1 whilst the highest level of K depressed total dry weights significantly. Stem dry weights per plant were increased with an increase in N level up to $N_2$ level only, the highest level of N significantly depressed stem dry weights. K increased stem dry weights only at $K_2$. Leaf dry weights significantly increased with an increase in N level up to $N_2$; $N_2$ was similar to the $N_3$ level. However, K had no effect on leaf dry weights per plant, i.e. an increase in K level did not increase leaf dry weights/plant (Table 3.14). High N levels significantly increased dead leaf dry weights whilst these were similar at all levels of K. Increasing N significantly increased head dry weights/plant whilst K significantly increased these up to $K_1$ level only. Similar results to those for leaf dry weights/plant were found for leaf areas/plant, i.e. K failed to increase leaf areas per plant while N increased up to $N_2$; $N_3$ slightly depressed leaf areas. Leaf areas/plant ranged from 1,194 to 2,438 cm$^2$/plant for $N_0$ and $N_2$, respectively (Table 3.15). At this stage of growth, LAI values were much lower than the fourth sampling period (Table 3.13) with values of 2.39, 4.14, and 4.88 for $N_0$, $N_1$, and $N_2$, respectively. An increase in N level significantly increased LAI up to $N_2$ level only while K had no effect on LAI value. The results for CGR showed that CGR significantly increased with an increase in both N and K levels but only up to $N_1$ and $K_1$; values were 58.85 and 151.00 g/m$^2$/plant for N0 and $N_1$, and 103.86 and 127.93 g/m$^2$/plant for $K_0$ and $K_1$. An increase in N level significantly increased D of the sorghum plants whilst K did not. The results on brix values indicated that, an increase in K level significantly increased brix percentages of the sorghum plants but a reverse was found with an increase in N level. Brix values ranged from 8.97 to 11.73 for $K_0$ and $K_3$, respectively whilst N had values ranged from 9.99 to11.27 for $N_3$ and $N_0$, respectively. N depressed brix percentages whilst K slightly increased them.

Table 3.13 Mean values of total dry weights, stem dry weights, leaf dry weights, leaf areas, leaf area Indices and crop growth rates of the sorghum plants at 8 weeks after emergence as influenced by nitrogen and potassium levels, grown on Yasothon soil series (Oxic Paleustults). See Appendix E2.4 for ANOVA.

| . N levels | K levels | | | | Average N |
|---|---|---|---|---|---|
| | $K_0$ | $K_1$ | $K_2$ | $K_3$ | |
| | | Total dry weights (kg/ha) | | | |
| $N_0$ | 4957 | 5631 | 5394 | 5340 | 5330$^{c}$ |
| $N_1$ | 9662 | 9445 | 9199 | 8672 | 9244$^{b}$ |
| $N_2$ | 10126 | 10319 | 11283 | 11798 | 10881$^{a}$ |
| $N_3$ | 11083 | 10927 | 10602 | 10920 | 10883$^{a}$ |
| Average K | 8957 | 9080 | 9119 | 9182 | SE = ±308.52 |
| | | Stem dry weights (g/plant) | | | |
| $N_0$ | 16.02 | 16.93 | 16.59 | 16.95 | 16.62$^{c}$ |
| $N_1$ | 31.69 | 30.49 | 29.32 | 25.84 | 29.33$^{b}$ |
| $N_2$ | 33.59 | 32.87 | 37.21 | 39.49 | 35.79$^{a}$ |
| $N_3$ | 36.69 | 34.35 | 33.15 | 34.32 | 34.63$^{a}$ |
| Average K | 29.50 | 28.66 | 29.07 | 29.15 | SE = ±1.27 |
| | | Leaf dry weights (g/plant) | | | |
| $N_0$ | 8.76 | 11.22 | 10.38 | 9.75 | 10.03$^{d}$ |
| $N_1$ | 16.62 | 16.74 | 16.86 | 16.52 | 16.89$^{c}$ |
| $N_2$ | 17.04 | 18.72 | 19.20 | 19.50 | 18.62$^{b}$ |
| $N_3$ | 18.72 | 20.28 | 19.86 | 20.28 | 19.79$^{a}$ |
| Average K | 15.29$^{b}$ | 16.74$^{a}$ | 16.53$^{a}$ | 16.76$^{a}$ | SE = ±0.51 |
| | | Leaf areas (cm$^{2}$/plant) | | | |
| $N_0$ | 2047 | 2622 | 2425 | 2278 | 2343$^{d}$ |
| $N_1$ | 3883 | 3911 | 3897 | 4093 | 3946$^{c}$ |
| $N_2$ | 3981 | 4373 | 4486 | 4556 | 4349$^{b}$ |
| $N_3$ | 4373 | 4738 | 4640 | 4738 | 4622$^{a}$ |
| Average K | 3571$^{b}$ | 3911$^{a}$ | 3862$^{a}$ | 3916$^{a}$ | SE = ±118.47 |
| | | Leaf area indices | | | |
| $N_0$ | 4.09 | 5.24 | 4.85 | 4.56 | 4.69$^{d}$ |
| $N_1$ | 7.77 | 7.82 | 7.79 | 8.19 | 7.89$^{c}$ |
| $N_2$ | 7.96 | 8.75 | 8.97 | 9.11 | 8.70$^{b}$ |
| $N_3$ | 8.75 | 9.48 | 9.28 | 9.48 | 9.25$^{a}$ |
| Average K | 7.14$^{b}$ | 7.82$^{a}$ | 7.72$^{a}$ | 7.83$^{a}$ | SE = ±0.24 |
| | | Crop growth rates # 3 (g/m$^{2}$/week) | | | |
| $N_0$ | 86.83 | 100.33 | 71.21 | 75.14 | 83.37$^{c}$ |
| $N_1$ | 234.20 | 210.20 | 169.40 | 166.33 | 195.03$^{b}$ |
| $N_2$ | 200.69 | 192.56 | 252.08 | 280.13 | 231.36$^{a}$ |
| $N_3$ | 193.58 | 184.38 | 165.35 | 233.95 | 194.31$^{b}$ |
| Average K | 178.82 | 171.87 | 164.51 | 188.88 | SE = ±19.41 |

Letters indicate significant differences of DMRT at probability of 0.05. SE=Std error.

Table 3.14 Mean values of total dry weights, stem dry weights, leaf dry weights, dead leaf dry weights and head dry weights of the sorghum plants at 10 weeks after emergence as influenced by nitrogen and potassium levels, grown on Yasothon soil series (Oxic Paleustults) See Appendix E2.5 for ANOVA.

| N levels | K levels | | | | Average N |
|---|---|---|---|---|---|
| | $K_0$ | $K_1$ | $K_2$ | $K_3$ | |
| | | Total dry weights (kg/ha) | | | |
| $N_0$ | 5854 | 6745 | 7210 | 6221 | $6507^d$ |
| $N_1$ | 10954 | 12809 | 12918 | 12378 | $12264^c$ |
| $N_2$ | 13833 | 13720 | 14351 | 13863 | $13942^a$ |
| $N_3$ | 13496 | 13282 | 13781 | 13069 | $13407^b$ |
| Average K | $11034^c$ | $11639^{ab}$ | $12065^a$ | $11383^{bc}$ | SE = ±357.11 |
| | | Stem dry weights (g/plant) | | | |
| $N_0$ | 19.23 | 21.71 | 23.75 | 19.76 | $21.11^d$ |
| $N_1$ | 35.63 | 41.07 | 42.56 | 40.42 | $39.92^c$ |
| $N_2$ | 45.96 | 44.32 | 47.72 | 47.15 | $46.28^a$ |
| $N_3$ | 43.77 | 40.04 | 44.22 | 41.02 | $42.76^b$ |
| Average K | $36.15^b$ | $37.28^b$ | $39.56^a$ | $37.09^b$ | SE = ±1.36 |
| | | Leaf dry weights (g/plant) | | | |
| $N_0$ | 5.74 | 6.90 | 6.67 | 5.22 | $6.13^c$ |
| $N_1$ | 10.52 | 11.06 | 10.57 | 10.36 | $10.63^b$ |
| $N_2$ | 12.92 | 11.88 | 12.78 | 12.51 | $12.52^a$ |
| $N_3$ | 12.31 | 12.07 | 11.82 | 12.02 | $12.06^a$ |
| Average K | 10.37 | 10.48 | 10.46 | 10.03 | SE = ±0.49 |
| | | Dead leaf dry weights (g/plant) | | | |
| $N_0$ | 2.38 | 2.80 | 2.90 | 2.48 | $2.64^c$ |
| $N_1$ | 3.14 | 3.06 | 3.10 | 3.25 | $3.14^b$ |
| $N_2$ | 3.18 | 3.43 | 2.98 | 3.12 | $3.18^b$ |
| $N_3$ | 3.96 | 4.03 | 3.94 | 3.79 | $3.93^a$ |
| Average K | 3.16 | 3.33 | 3.23 | 3.16 | SE = ±0.20 |
| | | Head dry weights (g/plant) | | | |
| $N_0$ | 1.92 | 2.32 | 2.73 | 3.65 | $2.65^c$ |
| $N_1$ | 5.48 | 8.86 | 8.36 | 7.86 | $7.64^b$ |
| $N_2$ | 7.11 | 8.98 | 8.29 | 6.54 | $7.73^b$ |
| $N_3$ | 7.44 | 8.27 | 8.92 | 8.52 | $8.29^a$ |
| Average K | $5.49^b$ | $7.11^a$ | $7.08^a$ | $6.64^a$ | SE = ±0.35 |

Letters indicate significant differences of DMRT at probability of 0.05.
SE = Standard error of means.

Table 3.15 Mean values of leaf areas, leaf area indices, crop growth rates, leaf area duration and brix values of the sorghum plants at 10 weeks after emergence as influenced by nitrogen and potassium levels, grown on Yasothon soil series (Oxic Paleustults). See Appendix E2.5 for ANOVA.

| N levels | K levels | | | | Average N |
|---|---|---|---|---|---|
| | $K_0$ | $K_1$ | $K_2$ | $K_3$ | |
| | | Leaf areas (cm$^2$/plant) | | | |
| $N_0$ | 1117 | 1343 | 1299 | 1017 | 1194$^{c}$ |
| $N_1$ | 2049 | 2155 | 2057 | 2018 | 2070$^{b}$ |
| $N_2$ | 2516 | 2313 | 2488 | 2436 | 2438$^{a}$ |
| $N_3$ | 2397 | 2351 | 2302 | 1341 | 2348$^{a}$ |
| Average K | 2020 | 2040 | 2036 | 1953 | SE = ±95.11 |
| | | Leaf area indices | | | |
| $N_0$ | 2.24 | 2.69 | 2.60 | 2.03 | 2.39$^{c}$ |
| $N_1$ | 4.10 | 4.31 | 4.11 | 4.04 | 4.14$^{b}$ |
| $N_2$ | 5.03 | 4.63 | 4.98 | 4.87 | 4.88$^{a}$ |
| $N_3$ | 4.80 | 4.70 | 4.60 | 4.68 | 4.70$^{a}$ |
| Average K | 4.04 | 4.08 | 4.07 | 3.91 | SE = ±0.19 |
| | | Crop growth rates # 4 (g/m$^2$/week) | | | |
| $N_0$ | 44.86 | 55.70 | 90.77 | 44.08 | 58.85$^{c}$ |
| $N_1$ | 64.60 | 168.19 | 185.92 | 185.29 | 151.00$^{a}$ |
| $N_2$ | 185.33 | 170.05 | 153.43 | 130.28 | 153.02$^{a}$ |
| $N_3$ | 120.67 | 117.77 | 158.95 | 107.44 | 126.21$^{b}$ |
| Average K | 103.86$^{b}$ | 127.93$^{ab}$ | 147.27$^{a}$ | 110.02$^{b}$ | SE = ±16.66 |
| | | leaf area duration(m$^2$.week) | | | |
| $N_0$ | 1.24 | 1.46 | 1.50 | 1.44 | 1.41$^{d}$ |
| $N_1$ | 1.95 | 1.98 | 1.99 | 1.98 | 1.98$^{c}$ |
| $N_2$ | 2.11 | 2.21 | 2.18 | 2.28 | 2.19$^{b}$ |
| $N_3$ | 2.30 | 2.37 | 2.33 | 2.22 | 2.30$^{a}$ |
| Average K | 1.90 | 2.00 | 2.00 | 1.98 | SE = ±0.06 |
| | | Brix (%) | | | |
| $N_0$ | 10.09 | 11.07 | 11.52 | 12.38 | 11.27$^{a}$ |
| $N_1$ | 9.38 | 11.15 | 11.24 | 11.48 | 10.81$^{ab}$ |
| $N_2$ | 8.78 | 10.60 | 10.62 | 11.74 | 10.43$^{bc}$ |
| $N_3$ | 7.64 | 10.14 | 10.85 | 11.32 | 9.99$^{c}$ |
| Average K | 8.97$^{c}$ | 10.74$^{b}$ | 11.06$^{b}$ | 11.73$^{a}$ | SE = ±0.34 |

Letters indicate significant differences of DMRT at probability of 0.05.
SE = Standard error of means.

### 3.6.4 Relationship Between Total fertiliser Addition and Total Dry Weights of the Sorghum Plants

The result showed that total fertiliser addition in terms of the combined effects of N and K was significantly associated with total dry weights. $R^2$ of 0.40 indicated that 40 % of the variation in the mean total dry weight was accounted for by the linear function of the total fertiliser addition (Fig. 3.3).

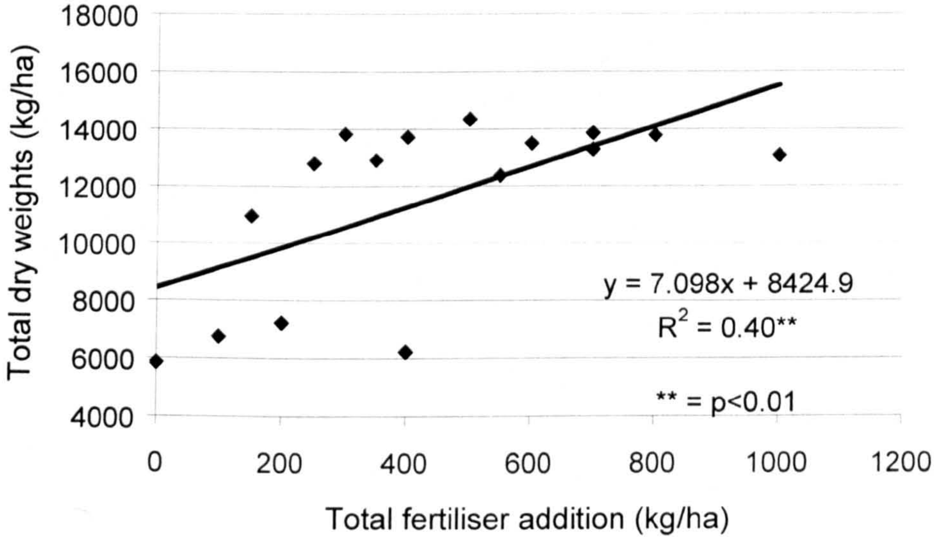

Fig. 3.3 Relationship between total fertiliser addition and total dry weights of the sorghum plants at 10 weeks after emergence grown on Yasothon soil series (Oxic Paleustults), Northeast Thailand.

### 3.6.5 Relationship Between Total Fertiliser Addition and Seed Yields of the Sorghum Plants

The result showed that total fertiliser addition in terms of the combined effects of N and K was significantly associated with seed yields. $R^2$ of 0.50 indicated that 50 % of the variation in the mean seed yield was accounted for by the linear function of the total fertiliser addition (Fig. 3.4).

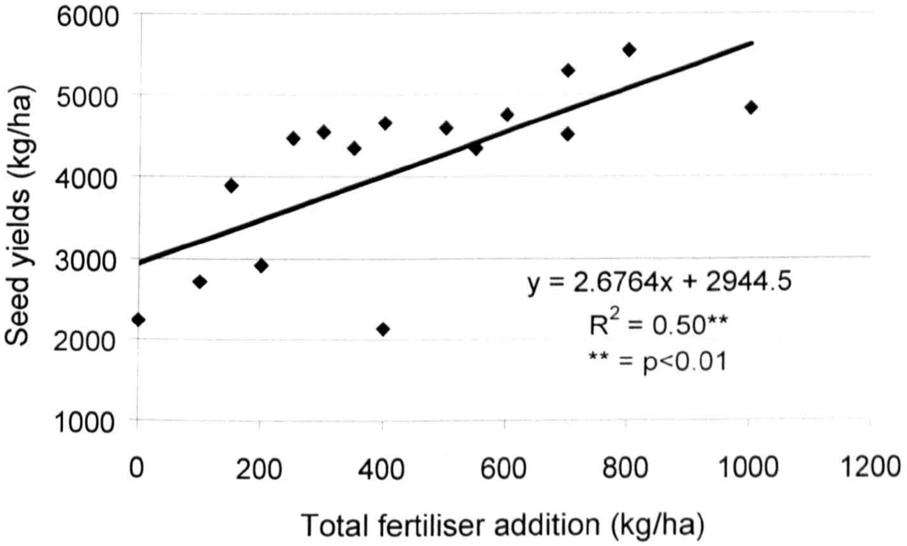

Fig. 3.4 Relationship between total fertiliser addition and seed yields of the sorghum plants grown on Yasothon soil series (Oxic Paleustults), Northeast Thailand.

### 3.6.6 Relationship Between Leaf area duration (D) and Total Dry Weights at 10 Weeks After Emergence of the Sorghum Plants

The result showed that D was significantly associated with total dry weights. $R^2$ of 0.92 indicated that 92 % of the variation in the mean total dry weight was accounted for by the linear function of the D value (Fig. 3.5).

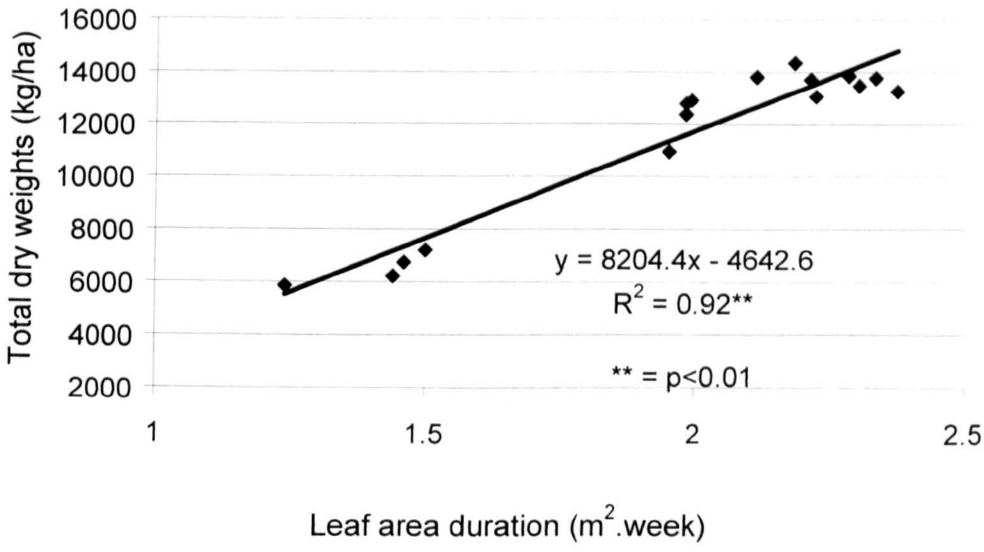

Fig. 3.5 Relationship between leaf area duration and total dry weights of the sorghum plants at 10 weeks after emergence as influenced by the combined effects of nitrogen and potassium application rates grown on Yasothon soil series (Oxic Paleustults).

For the sixth sampling period at 12 weeks after emergence, the results showed that an increase in N level increased total dry weights of the sorghum plants although $N_2$ was similar to $N_3$ whilst the effect due to K showed that, an increase in K level significantly increased total dry weights/ha only at $K_2$ (Table 3.16). Total dry weights were highest with $N_3$ (16,095 kg/ha) whilst $K_2$ attained the highest value of 14,142 kg/ha. Nitrogen levels had greater effects on total dry weights than the potassium levels. A similar trend was found with stem dry weights/plant, i.e. an increase in N level significantly increased stem dry weights whilst K level showed an increase only at $K_2$. N significantly increased leaf dry weights in all tested levels whilst K had some effect on leaf dry weight/plant only up to $K_1$. N had a greater effect than K on leaf growth. For dead leaf dry weights, the results showed that an increase in N level increased dead leaf dry weights/plant up to $N_2$ whilst K gave somewhat inconsistent results, i.e. dead leaf dry weights, in most cases, were similar for all levels of K.

The results showed that an increase in N level significantly increased head dry weights the values ranging from 10.54 to 24.05 g/plant for $N_0$ and $N_3$, respectively whilst an increase in K significantly increased head dry weights/plant up to $K_1$ level only (18.99 and 19.96 g/plant for $K_0$ and $K_1$, respectively). A similar trend was found with leaf areas, i.e. an increase in N level significantly increased leaf areas of the sorghum plants whilst K did so only up to $K_1$. Leaf areas/plant significantly increased with an increase in N levels with the values ranging from 1,031 to 2,187 cm$^2$/plant for $N_0$ and $N_3$, respectively. An increase in K levels significantly increased leaf areas/plant up to $K_1$ only (1,549 and 1,675 cm$^2$/plant for $K_0$ and $K_1$, respectively).

A similar trend to that for leaf areas/plant was found with LAI, i.e. LAI values were significantly increased with increases in N level but K only up to $K_1$ (Table 3.17). At this final stage of growth, LAI values were relatively low the highest value was 4.37 for $N_3$ level and 3.35 for $K_1$. The results for crop growth rates (CGR) showed that an increase in N level significantly increased CGR, whilst an increase in K level significantly increased CGR only up to $K_2$ with a small decline at the $K_3$ level. CGR values ranged from 45.49 to 175.06 g/m$^2$/week for $N_0K_1$ and $N_3K_2$, respectively. With D, D values were ranging from 1.44 to 2.82 m$^2$.week for $N_0K_0$ and $N_3K_1$, respectively. N significantly increased D whilst K did not. For brix %, the results showed that an increased in K level increased brix % of the sorghum plants with the values ranging from 4.74 to 7.23% for $K_0$ and $K_3$, respectively. K significantly promotes brix values whilst N reduced brix percentages at $N_2$ and $N_3$.

An increase in N significantly increased dry seed head yields, whilst K significantly increased this parameter only up to $K_1$ level. This trend was also found with seed yields/ha, i.e. an increase in N level significantly increased seed yields of the sorghum plants whilst K did so only up to $K_1$ level. Seed yields ranged from 2,505 to 5,110 kg/ha for $N_0$ and $N_3$, respectively whilst K gave only 3,859 to 4,288 kg/ha for $K_0$ and $K_1$, respectively. N had a greater effect on seed yields than K (Table 3.18). For 1000-seed weights, the results showed that an increase in N level significantly increased seed size of the sorghum plants only up to $N_1$ level. Similarly K had its effect on seed size only up to $K_1$. Further levels of both N and K did not increase 1000-seed weights of the sorghum plants.

Table 3.16 Mean values of total dry weights, stem dry weights, leaf dry weights, dead leaf dry weights, head dry weights and leaf areas of the sorghum plants at 12 weeks after emergence as influenced by nitrogen and potassium levels grown on Yasothon soil series (Oxic Paleustults). See Appendix E2.6 for ANOVA.

| N levels | K levels | | | | Average N |
|---|---|---|---|---|---|
| | $K_0$ | $K_1$ | $K_2$ | $K_3$ | |
| | | Total dry weights (kg/ha) | | | |
| $N_0$ | 7044 | 7655 | 8277 | 7626 | 7650$^{c}$ |
| $N_1$ | 12901 | 14596 | 14461 | 14126 | 14021$^{b}$ |
| $N_2$ | 15397 | 15577 | 16543 | 15724 | 15810$^{a}$ |
| $N_3$ | 15699 | 15538 | 17282 | 15860 | 16095$^{a}$ |
| Average K | 12760$^{b}$ | 13341$^{b}$ | 14142$^{a}$ | 13333$^{b}$ | SE = ±425.02 |
| | | Stem dry weights (g/plant) | | | |
| $N_0$ | 15.44 | 17.01 | 19.38 | 17.93 | 17.44$^{c}$ |
| $N_1$ | 32.82 | 37.05 | 37.19 | 34.27 | 35.34$^{b}$ |
| $N_2$ | 39.43 | 39.26 | 43.75 | 41.33 | 40.94$^{a}$ |
| $N_3$ | 38.93 | 38.45 | 43.46 | 39.07 | 39.98$^{a}$ |
| Average K | 31.65$^{b}$ | 32.94$^{b}$ | 35.95$^{a}$ | 33.15$^{b}$ | SE = ±1.41 |
| | | Leaf dry weights (g/plant) | | | |
| $N_0$ | 4.23 | 4.73 | 4.90 | 4.44 | 4.57$^{d}$ |
| $N_1$ | 5.86 | 6.23 | 6.33 | 7.27 | 6.43$^{c}$ |
| $N_2$ | 8.15 | 8.96 | 8.64 | 9.68 | 8.86$^{b}$ |
| $N_3$ | 9.25 | 9.78 | 9.90 | 9.87 | 9.70$^{a}$ |
| Average K | 6.87$^{b}$ | 7.43$^{a}$ | 7.44$^{a}$ | 7.81$^{a}$ | SE = ±0.35 |
| | | Dead leaf dry weights (g/plant) | | | |
| $N_0$ | 5.57 | 5.73 | 5.95 | 5.53 | 5.69$^{b}$ |
| $N_1$ | 5.28 | 6.70 | 6.66 | 6.03 | 6.16$^{ab}$ |
| $N_2$ | 6.97 | 6.96 | 7.11 | 5.97 | 6.75$^{a}$ |
| $N_3$ | 7.33 | 6.12 | 7.31 | 6.22 | 6.75$^{a}$ |
| Average K | 6.29$^{ab}$ | 6.38$^{ab}$ | 6.76$^{a}$ | 5.94$^{b}$ | SE = ±0.40 |
| | | Head dry weights (g/plant) | | | |
| $N_0$ | 9.98 | 10.81 | 11.16 | 10.23 | 10.54$^{c}$ |
| $N_1$ | 20.55 | 22.98 | 22.13 | 23.07 | 22.18$^{b}$ |
| $N_2$ | 22.45 | 22.72 | 23.21 | 21.65 | 22.51$^{b}$ |
| $N_3$ | 22.99 | 23.34 | 25.75 | 224.14 | 24.05$^{a}$ |
| Average K | 18.99$^{b}$ | 19.96$^{a}$ | 20.56$^{a}$ | 19.77$^{ab}$ | SE = ±0.58 |
| | | Leaf areas (cm$^2$/plant) | | | |
| $N_0$ | 955 | 1066 | 1105 | 1000 | 1031$^{d}$ |
| $N_1$ | 1321 | 1411 | 1427 | 1638 | 1449$^{c}$ |
| $N_2$ | 1836 | 2019 | 1948 | 2182 | 1996$^{b}$ |
| $N_3$ | 2086 | 2205 | 2231 | 2225 | 2187$^{a}$ |
| Average K | 1549$^{b}$ | 1675$^{a}$ | 1678$^{a}$ | 1761$^{a}$ | SE = ±79.29 |

Letters indicate significant differences of DMRT at probability of 0.05.
SE = Standard error of means.

Table 3.17 Mean values of leaf area indices, crop growth rates, leaf area duration and brix values of the sorghum plants at 12 weeks after emergence as influenced by nitrogen and potassium levels grown on Yasothon soil series (Oxic Paleustults). See Appendix E2.6 for ANOVA.

| N levels | K levels | | | | Average N |
|---|---|---|---|---|---|
| | $K_0$ | $K_1$ | $K_2$ | $K_3$ | |
| | | Leaf area indices | | | |
| $N_0$ | 1.91 | 2.13 | 2.21 | 2.00 | $2.06^{d}$ |
| $N_1$ | 2.64 | 2.82 | 2.86 | 3.28 | $2.90^{c}$ |
| $N_2$ | 3.67 | 4.04 | 3.90 | 4.37 | $3.99^{b}$ |
| $N_3$ | 4.17 | 4.41 | 4.46 | 4.45 | $4.37^{a}$ |
| Average K | $3.10^{b}$ | $3.35^{a}$ | $3.36^{a}$ | $3.52^{a}$ | SE = ±0.16 |
| | | Crop growth rates # 5 ($g/m^2$/week) | | | |
| $N_0$ | 59.50 | 45.49 | 53.33 | 70.21 | $57.13^{c}$ |
| $N_1$ | 97.37 | 89.33 | 77.18 | 87.41 | $87.82^{b}$ |
| $N_2$ | 78.22 | 92.87 | 109.58 | 93.04 | $93.43^{b}$ |
| $N_3$ | 110.14 | 112.78 | 175.06 | 139.55 | $134.38^{a}$ |
| Average K | $86.31^{b}$ | $85.12^{b}$ | $103.79^{a}$ | $97.55^{ab}$ | SE = ±11.31 |
| | | Leaf area duration ($m^2$.week) | | | |
| $N_0$ | 1.44 | 1.70 | 1.74 | 1.64 | $1.63^{d}$ |
| $N_1$ | 2.29 | 2.34 | 2.33 | 2.35 | $2.32^{c}$ |
| $N_2$ | 2.54 | 2.64 | 2.62 | 2.74 | $2.64^{b}$ |
| $N_3$ | 2.74 | 2.82 | 2.79 | 2.68 | $2.76^{a}$ |
| Average K | 2.25 | 2.37 | 2.37 | 2.35 | SE = ±0.07 |
| | | Brix (%) | | | |
| $N_0$ | 4.71 | 6.22 | 7.33 | 8.04 | $6.57^{a}$ |
| $N_1$ | 5.38 | 6.33 | 6.65 | 7.72 | $6.52^{a}$ |
| $N_2$ | 4.80 | 5.92 | 6.02 | 6.44 | $5.79^{b}$ |
| $N_3$ | 4.08 | 5.21 | 5.42 | 6.72 | $5.36^{b}$ |
| Average K | $4.74^{d}$ | $5.92^{c}$ | $6.36^{b}$ | $7.23^{a}$ | SE = ±0.30 |

Letters indicate significant differences of DMRT at probability of 0.05.
SE = Standard error of means.

Table 3.18 Mean values of dry seed head yields, seed yields, and 1000-seed weights of the sorghum plants as influenced by nitrogen and potassium levels grown on Yasothon soil series (Oxic Paleustults). See Appendix E2.6 for ANOVA.

| N levels | K levels | | | | Average N |
|---|---|---|---|---|---|
| | $K_0$ | $K_1$ | $K_2$ | $K_3$ | |
| | | Dry seed head yields (kg/ha) | | | |
| $N_0$ | 2456 | 2985 | 3102 | 2344 | $2722^d$ |
| $N_1$ | 4275 | 4913 | 4785 | 4774 | $4687^c$ |
| $N_2$ | 4995 | 5115 | 4044 | 4958 | $5028^b$ |
| $N_3$ | 5220 | 5820 | 6084 | 5306 | $5610^a$ |
| Average K | $4237^b$ | $4708^a$ | $4756^a$ | $4345^b$ | SE = ±208.11 |
| | | Seed yields (kg/ha) | | | |
| $N_0$ | 2237 | 2719 | 2927 | 2135 | $2505^d$ |
| $N_1$ | 3894 | 4474 | 4358 | 4348 | $4268^c$ |
| $N_2$ | 4549 | 4659 | 4594 | 4515 | $4579^b$ |
| $N_3$ | 4754 | 5301 | 5550 | 4833 | $5110^a$ |
| Average K | $3859^b$ | $4288^a$ | $4357^a$ | $3958^b$ | SE = ±196.28 |
| | | 1000-seed weights (g) | | | |
| $N_0$ | 27.21 | 29.14 | 27.64 | 27.47 | $27.86^b$ |
| $N_1$ | 28.36 | 29.78 | 29.39 | 29.89 | $29.36^a$ |
| $N_2$ | 28.19 | 29.07 | 29.09 | 30.88 | $29.31^a$ |
| $N_3$ | 28.72 | 30.66 | 32.13 | 29.07 | $30.14^a$ |
| Average K | $28.12^b$ | $29.66^a$ | $29.56^a$ | $29.33^{ab}$ | SE = ±0.89 |

Letters indicate significant differences of DMRT at probability of 0.05.
SE = Standard error of means.

### 3.6.7 Relationship Between Leaf area duration (D) and Seed Yields

The result showed that D was significantly associated with seed yields. $R^2$ of 0.94 indicated that 94 % of the variation in the mean seed yield was accounted for by the linear function of the D value (Fig. 3.6).

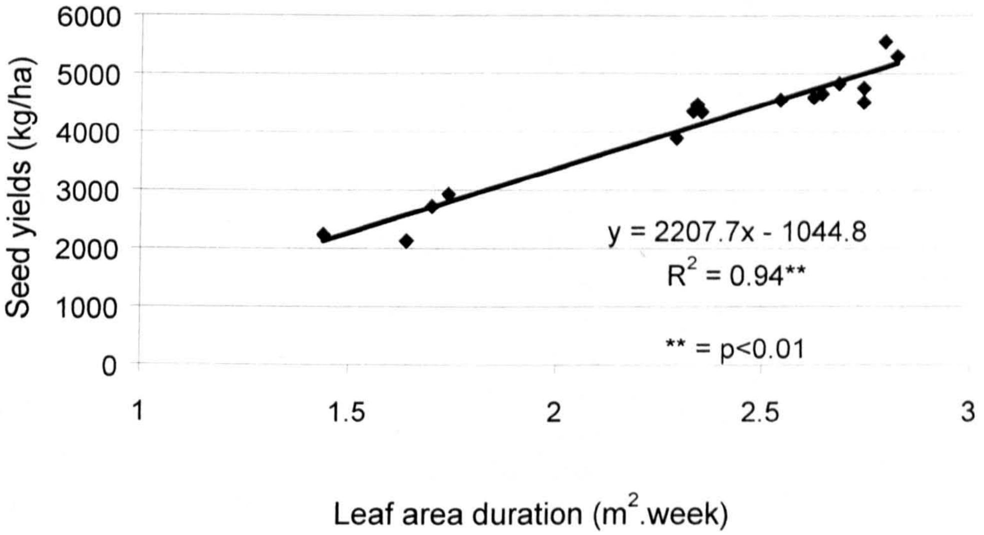

Fig. 3.6 Relationship between leaf area duration and seed yields of the sorghum plants at 12 weeks after emergence as influenced by the combined effects of nitrogen and potassium application rates, grown on Yasothon soil series (Oxic Paleustults), Khon Kaen University, Northeast Thailand.

### 3.6.8 Crude Protein (CP) Contents, Neutral Detergent Fibre (NDF) and Acid Detergent Fibre (ADF) Contents and Dry Matter Degradability (DMD)

Sorghum plant tissue analysis on the estimated CP contents revealed that an increase in N level significantly increased CP contents of the sorghum plants although the values at $N_2$ were similar to $N_3$ level; K had no effect on CP contents (Table 3.19). There were no significant effects of N or K levels on NDF, ADF, and DMD of the sorghum plants.

**Table 3.19** Mean values of estimated crude protein, neutral detergent fibre (NDF) acid detergent fibre (ADF) contents and dry matter degradability (DMD) of the sorghum plants at 10 weeks after emergence as influenced by nitrogen and potassium fertilisers. See Appendix E2.7 for ANOVA.

| N levels | K levels | | | | Average N |
|---|---|---|---|---|---|
| | $K_0$ | $K_1$ | $K_2$ | $K_3$ | |
| | | Crude protein (% on DM basis) | | | |
| $N_0$ | 4.36 | 4.37 | 4.56 | 5.31 | $4.65^c$ |
| $N_1$ | 7.48 | 7.08 | 7.61 | 7.60 | $7.44^b$ |
| $N_2$ | 8.79 | 8.67 | 8.04 | 8.32 | $8.46^a$ |
| $N_3$ | 9.22 | 9.18 | 9.29 | 8.76 | $9.11^a$ |
| Average K | 7.46 | 7.32 | 7.38 | 7.50 | SE = ±0.49 |
| | | NDF (% on DM basis) | | | |
| $N_0$ | 61.58 | 59.86 | 62.50 | 64.81 | 61.44 |
| $N_1$ | 60.94 | 60.34 | 61.23 | 61.72 | 61.06 |
| $N_2$ | 61.17 | 61.85 | 62.24 | 63.30 | 62.14 |
| $N_3$ | 60.57 | 61.37 | 62.04 | 61.46 | 61.36 |
| Average K | 61.06 | 60.86 | 62.00 | 62.07 | SE = ±1.09 |
| | | ADF (% on DM basis) | | | |
| $N_0$ | 35.83 | 34.54 | 36.40 | 35.37 | 35.53 |
| $N_1$ | 34.90 | 35.15 | 35.22 | 36.19 | 35.36 |
| $N_2$ | 34.83 | 34.92 | 34.82 | 36.94 | 35.38 |
| $N_3$ | 34.74 | 34.73 | 36.04 | 34.94 | 35.11 |
| Average K | 35.07 | 34.83 | 35.62 | 35.86 | SE = ±0.88 |
| | | Dry matter degradability (%) | | | |
| $N_0$ | 67.12 | 70.41 | 68.06 | 69.82 | 68.85 |
| $N_1$ | 69.37 | 67.25 | 70.44 | 70.88 | 69.48 |
| $N_2$ | 68.21 | 67.59 | 69.38 | 69.08 | 68.57 |
| $N_3$ | 69.64 | 70.17 | 67.94 | 69.16 | 69.23 |
| Average K | 68.58 | 68.86 | 69.95 | 69.73 | SE = ±1.34 |

Letters indicate significant differences of DMRT at probability of 0.05.
SE = Standard error of means.

## 3.7 Discussion

It was found that the rates of chemical fertilisers nitrogen (N) and potassium (K) used in Experiment I were relatively low and inadequate for the growth of the sorghum plants (Pholsen *et al.*, 2001). Therefore, the experiment was repeated with higher rates of both nitrogen and potassium. At the initial sampling period (2 weeks after emergence) the results showed that an increase in nitrogen level significantly increased total dry weights, stem dry weights, leaf dry weights, leaf areas and leaf area indices of the sorghum plants; an increase in potassium levels had very little positive and small negative effects. The results indicated that nitrogen had a much greater effect on growth of the sorghum plants during the early growth period than potassium. Suksri (1999) stated that nitrogen plays a significant role on vegetative growth of most crop plants.

At the second sampling period (4 weeks after emergence) the growth parameters of the sorghum plants significantly increased in all levels of N although $N_3$ was similar to $N_2$ in all cases. The results suggested that at $N_3$, this level of N could have slightly depressed the growth of the sorghum plants perhaps due to high concentration of N around the root zone, whilst K failed to significantly increase the growth of the crop plants at any level.

By the third sampling period at 6 weeks after emergence, the results showed that an increase in N level significantly increased total dry weights, stem dry weights, leaf dry weights, leaf area, and leaf area indices of the sorghum plants whilst slight increases with increasing K were not statistically significant. The results indicated that N had a significant effect on all the growth parameters listed in Table 3.12 i.e. vegetative growth has been promoted most by nitrogen and not by K.

At this stage of growth, the sorghum plants had attained relatively high LAI values (e.g. 8.5 for $N_3$). Values of this order are likely to be close to maximum LAI for optimal light interception for leaf canopies with a vertical leaf structure. LAI values of approximately 8-10 could be considered maximum for vertical leaf structure of the sorghum plants. Matsushima

(1976) with rice and Suksri (1992) with a maize (*Zea mays* L.) cultivar reported that with this type of leaf structure, LAI should reach maximum values at a range from 8-10.

An increase in N level significantly increased CGR of the sorghum plants whilst K did not. The results indicated that N had a very significant positive effect on CGR of the sorghum plants, whilst K had no significant effect.

At 8 weeks after emergence, the results showed that an increase in N level significantly increased total dry weights, stem dry weights only up to the $N_2$ level (Table 3.13). This could be attributed to depletion of soil nitrogen; the data for soil analysis at the end of the experimental period tend to support this view. Another reason for the depletion of soil nutrients could be due to a high leaching rate of soil nutrients since Yasothon soil series contains a large amount of sandy particles. The leaching of soil nutrients has been reported by a number of workers, e.g. Cooke (1972); Mengel and Kirkby (1987); Miller and Donahue (1990); Loiseau *et al.* (2001); and Sommer (2001). Leaf dry weights increased with increases in N level but K increased these only up to $K_1$. The results indicated that nitrogen had a much greater effect on leaf growth, whilst K had only some slight effect (Russel, 1988). LAI reached its highest mean value of 9.25 for $N_3$ level. LAI values for K treatments were much lower. These results suggested that LAI nearly reaches the maximum value for growth in the $N_3$ treatment and the influence of K on LAI is secondary (Tanaka, 1974; Kamoshita *et al.*, 1998a; and Suksri, 1999)

The differences in total dry weights, stem dry weights, leaf dry weights, leaf areas, LAI and CGR of the sorghum plants (Table 3.14 and 3.15) at the fifth sampling period (10 weeks after emergence) could have been attributed partly to both the advance in age of the sorghum plants and the re-translocation of assimilates to the grain. At this stage of growth, it was found that large amounts of dead leaf dry material were accumulated. The re-translocation of assimilates to grain could have been affected by leaf age, i.e. aging leaves may have re-translocated some nitrogen to grains resulting in premature aging of lower leaves as reported by Evans (1971); and Suksri (1991). An increase in N level significantly increased head dry weights of seeds whilst K did so only up to $K_1$. LAI values decreased with time from the fourth to the fifth sampling periods, but LAI remained influenced by the N levels (Wolfe *et al.*, 1988; and Tollenaar and Aquiler, 1992). These results indicate that N prolonged the life of leaves whilst K had no effect at this stage. These results are in agreement with the work of Kamoshita *et al.* (1998b).

The results for crop growth rates showed that an increase in N level significantly increased CGR of the sorghum plants at all harvests whilst K had some significant effect only at 10 and 12 weeks after emergence. This indicates that CGR was influenced most by N throughout the growth period whilst K has a significant influence only in the latter part, i.e. grain filling stage where more of the assimilates were moving to grains.

The results for leaf area duration (D) at 10 weeks after emergence show that D significantly increased with an increase in N level, i. e. N had a significant effect on leaf growth and prolonged life of leaves, whilst K did not. These results confirm the work reported by Mengel and Kirkby (1987), Suksri (1999).

At 12 weeks after emergence, total dry weights/ha, stem dry weights, leaf dry weights, dead leaf dry weights, head dry weights, leaf areas/plant, LAI and CGR of the sorghum plants (Table 3.16, 3.17) were significantly affected by both N and K levels but in most cases the positive effect of increasing N is greater. This may be a reflection of the growth stage and the transition from vegetative to reproductive growth. That is more assimilates were re-translocated to the grains (Prioul *et al.*, 1990).

The results for brix values at most harvests indicate that an increase in N level significantly decreased brix values whilst an increase in K level increased brix values significantly, i.e. N had a negative effect on brix values whilst K increased sugar contents as reported by Suksri (1999).

The results for 1000-seed weights (Table 3.18) showed that N and K had some similar effects on seed size, both significantly increasing seed size only up to the first level ($N_1$ and $K_1$). Seed size could possibly be partly controlled by the genotype of the cultivar, which may have more influence than fertiliser levels (Samphantharak *et al.*, 1983; and Lertprasertrat *et al.*, 1998). By this final harvest some of the growth parameters have declined with time due to aging yet a similar trend as that of the previous sampling periods on the effects of N and K levels is still evident. For example, leaf area duration (D), is significantly improved by N but not by K since the positive effect on N is only on leaf growth and it is well established (Tanaka, 1974; Wild, 1988; and Kamoshita, 1998b). The results also showed that an increase in D correlated with increased total dry weights and seed yields of the sorghum plants. These two parameters also show a significant positive link with N and K application rates.

Seed yields and total dry weights/ha of the $N_3K_2$ treatment were much better than the rest. These results were similar to the work reported by Suksri (1991) with castor bean plants.

The results for crude protein contents (Table 3.19) showed that an increase in N level significantly increased CP of the sorghum tissues whilst K had no significant effect. Both N and K levels had no effect on NDF, ADF, and DMD of the sorghum tissues. These results were similar to work reported by Devahuti *et al.* (1992); Phaikaew *et al.* (1992); and Pholsen *et al.* (1998 and 2001).

Yasothon soil series (Oxic Paleustults) contains relatively low percentages of organic matter and a high proportion of sandy particles; the growth and yield of the sorghum plants could be affected by these poor conditions of the soil environment where the water holding capacity is relatively poor and the leaching rate high. It was, therefore, decided to repeat this experiment with the addition of cattle manure to provide organic matter. This could help to explain the effects due to the application of N and K on the poor Yasothon soil series. The addition of a high rate of fermented cattle manure could improve both soil organic matter and water-holding capacity of Yasothon soil.

# Chapter 4

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## Experiment 3

## Effects of Nitrogen and Potassium on Growth, Chemical Components and Seed Yields of IS 23585 Forage Sorghum Cultivar, (*Sorghum bicolor* L. Moench) With a Basal Dressing of Cattle Manure During August and November 1999 Rainy Season

### 4.1 Introduction

A repeat of Experiment 2 was carried out but with the application of fermented cattle manure at the rate of 40 tonnes/ha being used as a basal dressing with the aim that the application of cattle manure to the soil could possibly both improve soil properties and fertiliser effects for the growth of the sorghum plants since Yasothon series has a very low organic matter percentage as reported by Suksri (1999); and Chuasavathi and Trelo-ges (2001). The application of cattle manure as a soil amendment will increase the percentage of soil organic matter and provide better water holding capacity especially when solar radiation and air temperatures are high. This should help the sorghum plants meet any stress causes by evapotranspiration processes. The fermented cattle manure could also improve other soil properties of the Yasothon soil series. It has been advocated by a number of workers that organic soil amendment materials markedly improve soil conditions, e.g. Miller and Donahue (1990); Suksri (1991) and (1999); and Chuasavathi and Tre-loges (2001).

**Materials and methods:** This section was given in chapter 2 on page 58. Treatments were the same as in Experiment 2 apart from application of 40 tonnes/ha of cattle manure as basal dressing.

## 4.2 Results

### 4.2.1 Initial Soil Analysis Data of Yasothon Soil Series

The soil analysis before the sowing of the sorghum seeds revealed that mean values of soil pH, organic matter %, nitrogen %, available soil phosphorous, and extractable potassium were 5.4, 0.73, 0.042, 35.5 ppm, and 33.5 ppm, respectively (Table 4.1).

Table 4.1 Initial soil analysis data of Yasothon soil series (Oxic Paleustults) the sowing of sorghum seeds (Experiment 3) at Khon Kaen University Experimental Farm, Northeast Thailand in rainy season 1999.

| Items | Blocks | | | | Averages |
|---|---|---|---|---|---|
| | I | II | III | IV | |
| pH (1:2.5) | 5.5 | 5.5 | 5.4 | 5.0 | 5.4 |
| Organic matter (%) | 0.75 | 0.68 | 0.70 | 0.79 | 0.73 |
| Total soil N (%) | 0.0334 | 0.0320 | 0.0303 | 0.0728 | 0.0421 |
| Available P (ppm) | 29 | 26 | 39 | 48 | 35.5 |
| Extractable K (ppm) | 48 | 26 | 21 | 39 | 33.5 |

### 4.2.2 Soil Analysis Data at the Final Sampling Period

After the final harvest of the sorghum plants, the values for soil pH, organic matter %, total soil nitrogen % (N), available soil phosphorous (P) and extractable soil potassium (K) were in the ranges of 5.4-6.2, 079-0.99, 0.037-0.046, 46-66 ppm, and 32-123 ppm, respectively (Table 4.2). Generally, initial values (Table 4.1) are similar to final values (Table 4.2) apart from available phosphorus and extractable potassium at high application rates ($K_2$ and $K_3$) all values are relative low.

Table 4.2 Soil analysis data of Yasothon soil series (Oxic Paleustults) after the final harvest for grains (experiment 3) at Khon Kaen University Experimental Farm, Northeast Thailand during rainy season of 1999.

| N lvels | K levels | | | | Average N |
|---|---|---|---|---|---|
| | $K_0$ | $K_1$ | $K_2$ | $K_3$ | |
| | Soil pH (1:1 soil: water by volume) | | | | |
| $N_0$ | 5.6 | 5.8 | 5.8 | 6.1 | 5.8 |
| $N_1$ | 5.9 | 5.7 | 5.9 | 6.2 | 5.9 |
| $N_2$ | 5.9 | 5.7 | 6.2 | 6.0 | 6.0 |
| $N_3$ | 5.5 | 5.8 | 5.4 | 5.8 | 5.6 |
| Average K | 5.7 | 5.8 | 5.8 | 6.0 | |
| | Organic matter (%) | | | | |
| $N_0$ | 0.85 | 0.82 | 0.94 | 0.95 | 0.89 |
| $N_1$ | 0.89 | 0.80 | 0.84 | 0.89 | 0.86 |
| $N_2$ | 0.79 | 0.99 | 0.90 | 0.87 | 0.89 |
| $N_3$ | 0.84 | 0.89 | 0.85 | 0.89 | 0.87 |
| Average K | 0.84 | 0.88 | 0.88 | 0.90 | |
| | Total soil nitrogen (%) | | | | |
| $N_0$ | 0.0383 | 0.0390 | 0.0415 | 0.0425 | 0.0403 |
| $N_1$ | 0.0424 | 0.0462 | 0.0429 | 0.0404 | 0.0430 |
| $N_2$ | 0.0366 | 0.0396 | 0.0448 | 0.0390 | 0.0400 |
| $N_3$ | 0.0403 | 0.0417 | 0.0413 | 0.0404 | 0.0409 |
| Average K | 0.0394 | 0.0416 | 0.0426 | 0.0406 | |
| | Available phosphorus (ppm) | | | | |
| $N_0$ | 62 | 53 | 59 | 64 | 59.4 |
| $N_1$ | 64 | 53 | 62 | 64 | 60.8 |
| $N_2$ | 55 | 60 | 54 | 46 | 53.8 |
| $N_3$ | 52 | 49 | 49 | 66 | 54.0 |
| Average K | 58.3 | 53.8 | 56.0 | 60.0 | |
| | Extractable potassium (ppm) | | | | |
| $N_0$ | 32 | 63 | 75 | 123 | 73.3 |
| $N_1$ | 33 | 45 | 50 | 102 | 57.5 |
| $N_2$ | 29 | 44 | 66 | 76 | 53.8 |
| $N_3$ | 32 | 47 | 55 | 85 | 54.8 |
| Average K | 31.5 | 49.8 | 61.5 | 96.5 | |

### 4.2.3 Total Dry Weights, Stem Dry Weights, Leaf Dry Weights, Dead Leaf Dry Weights, Head Dry Weights, Leaf Areas, Leaf Area Indices (LAI), Crop Growth Rates (CGR), Leaf Area Duration (D), Brix Values, Seed Yields and 1000-Seed Weights

At 3 weeks after emergence, the results showed that an increase in N level significantly increased total dry weights of the sorghum plants with the values of 825, 951, 1,187, and 1,397 kg/ha for $N_0$ to $N_3$, respectively (Table 4.3). Whilst an increase in K level significantly increased total dry weights of the sorghum plants but to a lesser extent compared with the effect due to N levels, e.g. total dry weights of $K_2$ were similar to $K_3$. A similar trend as that for the total dry weights/ha was attained with stem dry weights, leaf dry weights, leaf areas/plant, and LAI of the sorghum plants, i.e. an increase in N level significantly increased stem dry weights, leaf dry weights, leaf areas and LAI values of the sorghum plants. An increase in K level also significantly increased all of the measured parameters of the sorghum plants but to a lesser extent than that for nitrogen.

For the second sampling period at 5 weeks after emergence, the results showed that total dry weights/ha of the sorghum plants significantly increased with an increase in N level and also with an increase in K level but to a lesser extent. $N_0$ up to $N_3$ gave mean values of total dry weights of 2,924, 3,140, 3,622, and 3,896 kg/ha, respectively whilst $K_0$ up to $K_3$ had the values of 3,268, 3,332, 3,458, and 3,524 kg/ha, respectively (Table 4.4). A similar trend as that for total dry weights was found with stem dry weights, leaf dry weights, leaf areas/plant and LAI with increasing N but increasing K had a small effect on stem dry weights only. Crop growth rates significantly increased up to $N_2$ but were not significantly changed by increases in K level.

The results attained at the third sampling period at 7 weeks after emergence showed that an increase in N level significantly increased total dry weights/ha of the sorghum plants with the values of 4,440, 6,249, 6,938, and 8,384 kg/ha for $N_0$, $N_1$, $N_2$, and $N_3$, respectively (Table 4.5). An increase in K significantly increased total dry weights/ha of the sorghum plants only up to $K_2$ level. An increase in N level significantly increased stem dry weights, leaf dry weights/ha, leaf areas per plant, and LAI of the sorghum plants. Increasing K levels had a similar effect but only up to $K_2$. N had a greater effect on the growth parameters of the sorghum plants than K. An increase in N level significantly increased crop growth rates (CGR), whilst K had a smaller effect, up to $K_1$ only.

Table 4.3 Mean values of total dry weights, stem dry weights, leaf dry weights, leaf areas and leaf area indices of the sorghum plants at 3 weeks after emergence as influenced by nitrogen and potassium levels, grown on Yasothon soil series (Oxic Paleustults). See Appendix E3.1 for ANOVA.

| N levels | K levels | | | | Average N |
|---|---|---|---|---|---|
| | $K_0$ | $K_1$ | $K_2$ | $K_3$ | |
| | | Total dry weights (kg/ha) | | | |
| $N_0$ | 631 | 838 | 876 | 956 | $825^{d}$ |
| $N_1$ | 919 | 966 | 950 | 969 | $951^{c}$ |
| $N_2$ | 1101 | 1180 | 1170 | 1298 | $1187^{b}$ |
| $N_3$ | 1335 | 1361 | 1396 | 1495 | $1397^{a}$ |
| Average K | $997^{c}$ | $1086^{b}$ | $1098^{ab}$ | $1180^{a}$ | SE = ±60.17 |
| | | Stem dry weights (g/plant) | | | |
| $N_0$ | 0.71 | 0.97 | 1.10 | 1.19 | $0.99^{d}$ |
| $N_1$ | 1.19 | 1.27 | 1.20 | 1.23 | $1.22^{c}$ |
| $N_2$ | 1.60 | 1.74 | 1.53 | 1.55 | $1.61^{b}$ |
| $N_3$ | 1.78 | 1.84 | 1.86 | 2.10 | $1.90^{a}$ |
| Average K | $1.32^{b}$ | $1.46^{a}$ | $1.42^{ab}$ | $1.52^{a}$ | SE = ±0.08 |
| | | Leaf dry weights (g/plant) | | | |
| $N_0$ | 2.45 | 3.23 | 3.28 | 3.60 | $3.14^{d}$ |
| $N_1$ | 3.41 | 3.57 | 3.55 | 3.62 | $3.54^{c}$ |
| $N_2$ | 3.91 | 4.17 | 4.33 | 4.94 | $4.34^{b}$ |
| $N_3$ | 4.90 | 4.97 | 5.13 | 5.37 | $5.09^{a}$ |
| Average K | $3.67^{c}$ | $3.99^{bc}$ | $4.07^{ab}$ | $4.38^{a}$ | SE = ±0.23 |
| | | Leaf areas ($cm^2$/plant) | | | |
| $N_0$ | 665 | 877 | 891 | 977 | $853^{d}$ |
| $N_1$ | 926 | 968 | 966 | 984 | $961^{c}$ |
| $N_2$ | 1063 | 1133 | 1175 | 1343 | $1179^{b}$ |
| $N_3$ | 1331 | 1351 | 1394 | 1460 | $1384^{a}$ |
| Average K | $996^{c}$ | $1082^{bc}$ | $1107^{ab}$ | $1191^{a}$ | SE = ±63.53 |
| | | Leaf area indices | | | |
| $N_0$ | 1.33 | 1.75 | 1.78 | 1.96 | $1.71^{d}$ |
| $N_1$ | 1.85 | 1.94 | 1.93 | 1.97 | $1.92^{c}$ |
| $N_2$ | 2.13 | 2.27 | 2.35 | 2.69 | $2.36^{b}$ |
| $N_3$ | 2.66 | 2.70 | 2.79 | 2.92 | $2.77^{a}$ |
| Average K | $1.99^{c}$ | $2.17^{bc}$ | $2.21^{ab}$ | $2.39^{a}$ | SE = ±0.13 |

Letters indicate significant differences of DMRT at probability of 0.05.
SE = Standard error of means.

Table 4.4 Mean values of total dry weights, stem dry weights, leaf dry weights, leaf areas, leaf area indices and crop growth rates of the sorghum plants at 5 weeks after emergence as influenced by nitrogen and potassium levels, grown on Yasothon soil series (Oxic Paleustults). See Appendix E3.2 for ANOVA.

| N levels | K levels | | | | Average N |
|---|---|---|---|---|---|
| | $K_0$ | $K_1$ | $K_2$ | $K_3$ | |
| | Total dry weights (kg/ha) | | | | |
| $N_0$ | 2793 | 2843 | 2975 | 3085 | $2924^{d}$ |
| $N_1$ | 3058 | 3072 | 3235 | 3193 | $3140^{c}$ |
| $N_2$ | 3448 | 3578 | 3738 | 3725 | $3622^{b}$ |
| $N_3$ | 3773 | 3835 | 3883 | 4093 | $3896^{a}$ |
| Average K | $3268^{b}$ | $3332^{ab}$ | $3458^{ab}$ | $3524^{a}$ | SE = ±137.02 |
| | Stem dry weights (g/plant) | | | | |
| $N_0$ | 5.87 | 6.11 | 6.83 | 7.15 | $6.49^{c}$ |
| $N_1$ | 7.10 | 7.13 | 7.25 | 7.39 | $7.22^{b}$ |
| $N_2$ | 7.89 | 8.01 | 8.79 | 8.58 | $8.32^{a}$ |
| $N_3$ | 8.49 | 8.63 | 8.64 | 8.96 | $8.68^{a}$ |
| Average K | $7.34^{b}$ | $7.47^{b}$ | $7.88^{a}$ | $8.02^{a}$ | SE = ±0.28 |
| | Leaf dry weights (g/plant) | | | | |
| $N_0$ | 8.09 | 8.10 | 8.05 | 8.28 | $8.13^{c}$ |
| $N_1$ | 8.19 | 8.25 | 8.93 | 8.58 | $8.49^{c}$ |
| $N_2$ | 9.35 | 9.88 | 9.90 | 10.05 | $9.80^{b}$ |
| $N_3$ | 10.38 | 10.55 | 10.78 | 11.50 | $10.80^{a}$ |
| Average K | 9.00 | 9.20 | 9.42 | 9.60 | SE = ±0.44 |
| | Leaf areas (cm$^2$/plant) | | | | |
| $N_0$ | 1927 | 1930 | 1918 | 1971 | $1937^{c}$ |
| $N_1$ | 1951 | 1965 | 2126 | 2043 | $2021^{c}$ |
| $N_2$ | 2227 | 2352 | 2358 | 2394 | $2333^{b}$ |
| $N_3$ | 2472 | 2513 | 2567 | 2739 | $2573^{a}$ |
| Average K | 2144 | 2190 | 2242 | 2287 | SE = ±105.75 |
| | Leaf area indices | | | | |
| $N_0$ | 3.86 | 3.86 | 3.83 | 3.94 | $3.87^{c}$ |
| $N_1$ | 3.90 | 3.93 | 4.25 | 4.09 | $4.04^{c}$ |
| $N_2$ | 4.45 | 4.71 | 4.72 | 4.79 | $4.67^{b}$ |
| $N_3$ | 4.95 | 5.03 | 5.14 | 5.48 | $5.15^{a}$ |
| Average K | 4.29 | 4.38 | 4.49 | 4.58 | SE = ±0.21 |
| | Crop growth rates# 1 (g/m$^2$/week) | | | | |
| $N_0$ | 108.10 | 100.21 | 104.92 | 106.46 | $104.92^{b}$ |
| $N_1$ | 106.98 | 105.47 | 114.23 | 111.18 | $109.47^{b}$ |
| $N_2$ | 117.36 | 119.86 | 128.39 | 121.36 | $121.74^{a}$ |
| $N_3$ | 121.89 | 123.69 | 124.31 | 129.90 | $124.95^{a}$ |
| Average K | 113.58 | 112.31 | 117.96 | 117.23 | SE = ±6.73 |

Letters indicate significant differences of DMRT at probability of 0.05.
SE = Standard error of means.

Table 4.5 Mean values of total dry weights, stem dry weights, leaf dry weights, leaf areas, leaf area indices and crop growth rates of the sorghum plants at 7 weeks after emergence as influenced by nitrogen and potassium levels, grown on Yasothon soil series (Oxic Paleustults). See Appendix E3.3 for ANOVA.

| N levels | K levels | | | | Average N |
|---|---|---|---|---|---|
| | $K_0$ | $K_1$ | $K_2$ | $K_3$ | |
| | | Total dry weights (kg/ha) | | | |
| $N_0$ | 4207 | 4326 | 4627 | 4599 | 4440$^{d}$ |
| $N_1$ | 5929 | 6293 | 6428 | 6346 | 6249$^{c}$ |
| $N_2$ | 6622 | 6804 | 7256 | 7070 | 6938$^{b}$ |
| $N_3$ | 7865 | 8054 | 8698 | 8918 | 8384$^{a}$ |
| Average K | 6156$^{b}$ | 6369$^{b}$ | 6752$^{a}$ | 6733$^{a}$ | SE = ±212.07 |
| | | Stem dry weights (g/plant) | | | |
| $N_0$ | 10.82 | 11.66 | 13.13 | 12.85 | 12.12$^{d}$ |
| $N_1$ | 17.54 | 18.41 | 18.70 | 18.57 | 18.31$^{c}$ |
| $N_2$ | 19.39 | 20.13 | 22.42 | 21.67 | 20.90$^{b}$ |
| $N_3$ | 23.99 | 24.76 | 27.25 | 27.34 | 25.84$^{a}$ |
| Average K | 17.94$^{b}$ | 18.74$^{b}$ | 20.38$^{a}$ | 20.11$^{a}$ | SE = ±0.86 |
| | | Leaf dry weights (g/plant) | | | |
| $N_0$ | 10.22 | 8.98 | 10.01 | 10.15 | 9.84$^{d}$ |
| $N_1$ | 12.11 | 13.06 | 13.44 | 13.16 | 12.94$^{c}$ |
| $N_2$ | 13.72 | 13.90 | 13.86 | 13.69 | 13.79$^{b}$ |
| $N_3$ | 15.33 | 15.51 | 16.24 | 17.26 | 16.09$^{a}$ |
| Average K | 12.85$^{b}$ | 12.86$^{b}$ | 13.39$^{ab}$ | 13.57$^{a}$ | SE = ±0.45 |
| | | Leaf areas (cm$^{2}$/plant) | | | |
| $N_0$ | 2303 | 2248 | 2255 | 2287 | 2273$^{d}$ |
| $N_1$ | 2729 | 2942 | 3028 | 2965 | 2916$^{c}$ |
| $N_2$ | 3091 | 3130 | 3123 | 3084 | 3107$^{b}$ |
| $N_3$ | 3454 | 3494 | 3659 | 3888 | 3624$^{a}$ |
| Average K | 2894$^{b}$ | 2954$^{ab}$ | 3016$^{ab}$ | 3056$^{a}$ | SE = ±100.65 |
| | | Leaf areas indices | | | |
| $N_0$ | 4.61 | 4.50 | 4.51 | 4.58 | 4.55$^{d}$ |
| $N_1$ | 5.46 | 5.88 | 6.06 | 5.93 | 5.83$^{c}$ |
| $N_2$ | 6.18 | 6.26 | 6.25 | 6.17 | 6.22$^{b}$ |
| $N_3$ | 6.91 | 6.99 | 7.32 | 7.78 | 7.25$^{a}$ |
| Average K | 5.79$^{b}$ | 5.91$^{ab}$ | 6.04$^{ab}$ | 6.12$^{a}$ | SE = ±0.20 |
| | | Crop growth rates # 2 (g/m$^{2}$/week) | | | |
| $N_0$ | 70.70 | 74.18 | 82.60 | 75.70 | 75.80c |
| $N_1$ | 143.55 | 160.90 | 159.66 | 157.65 | 155.44$^{b}$ |
| $N_2$ | 158.73 | 161.33 | 175.90 | 167.25 | 165.80$^{b}$ |
| $N_3$ | 204.60 | 210.93 | 240.75 | 241.28 | 224.39$^{a}$ |
| Average K | 144.40$^{b}$ | 151.84$^{ab}$ | 164.73$^{a}$ | 160.47$^{ab}$ | SE = ±12.31 |

Letters indicate significant differences of DMRT at probability of 0.05.
SE = Standard error of means.

For the fourth sampling period at 9 weeks after emergence, the results showed that an increase in N level significantly increased total dry weights/ha of the sorghum plants with values ranged from 6,527 to 12,312 kg/ha for $N_0$ and $N_3$, respectively. K significantly increased total dry weights up to $K_2$ level only with the values ranged from 9,028 to 9,805 kg/ha for $K_0$ and $K_2$, respectively (Table 4.6). N had a greater effect on total dry weights of the sorghum plants than K. Similar results were found with stem dry weights/plant, leaf dry weights/plant, and head dry weights/plant, i.e. N had significantly greater effects on these measured parameters than K. Dead leaf dry weights were also significantly increased with an increase in N level while K level had a smaller effect.

An increase in N level significantly increased leaf areas/plant with mean values of 1,351, 1,937, 2,058, and 2,418 $cm^2$/plant for $N_0$, $N_1$, $N_2$, and $N_3$, respectively (Table 4.7). An increase in K level also significantly increased leaf areas/plant but to a smaller extent, and up to $K_1$ level only. An increase in N level significantly increased LAI values while K did so only up to $K_2$ level. CGR significantly increased with an increase in N level whilst K levels had no significant effect. An increase in K level significantly increased brix % of the sorghum plants but only up to $K_2$ level. An increase in N level significantly increased the brix % up to $N_1$ level only.

For the fifth sampling period at 11 weeks after emergence, the results showed that an increase in N level significantly increased total dry weights/ha of the sorghum plants with mean values of 8,265, 11,278, 12,705, and 15,018 kg/ha for $N_0$, $N_1$, $N_2$, and $N_3$, respectively (Table 4.8). An increase in K level significantly increased total dry weights/ha of the sorghum plants but only up to $K_2$ level. N had much greater effect on total dry weights/ha than K. An increase in N level significantly increased stem dry weights/plant with the mean values ranging from 21.48 to 39.42 g/plant for $N_0$ and $N_3$, respectively. K had a small effect up to $K_1$ level only. Leaf dry weights/plant were also significantly increased with an increase in N level; K had an effect only up to $K_2$ level and a slightly decrease was found with $K_3$ level. Leaf areas/plant significantly increased with an increase in N level whilst K did only up to $K_2$. Nitrogen had a greater effect on leaf areas/plant than K.

The results showed that an increase in N level significantly increased dead leaf dry weights/plant with the mean values ranging from 2.11 to 3.96 g/plant for $N_0$ and $N_3$, respectively, whilst K had a significant effect only up to $K_2$.

Head dry weights/plant significantly increased with an increase in N level with the values ranging from 11.97 to 21.04 g/plant for $N_0$ and $N_3$, respectively. An increase in K level also significantly increased head dry weights/plant with the values ranging from 15.36 to 17.86 g/plant for $K_0$ and $K_3$, respectively.

A similar trend to that for leaf areas/plant was found with LAI, i.e. an increase in N level significantly increased LAI of the sorghum plants whilst K level did so only up to $K_2$. N had much greater effect on LAI than K (Table 4.9). The results for crop growth rates (CGR) showed that an increase in N or K level significantly increased CGR only up to $N_1$ or $K_1$. An increase in N level significantly increased leaf area duration (D) with mean values ranging from 1.35 to 2.10 $m^2$.week for $N_0$ and $N_3$, respectively. An increase in K level also significantly increased D but only up to $K_2$ with the values ranging from 1.65 to 1.78 $m^2$.week for $K_0$ and $K_2$, respectively. Brix values were influenced by N level only at $N_3$, whilst K had a significant effect only up to $K_2$.

An increase in N level significantly increased dry seed head yields/ha only up to $N_1$ whilst K level had no significant effect. A similar trend was found with seed yields/ha and 1000-seed weights, i.e. N significantly increased these parameters only up to $N_1$ whilst K had no significant effects (Table 4.10).

Table 4.6 Mean values of total dry weights, stem dry weights, leaf dry weights, dead leaf dry weights, and head dry weights of the sorghum plants at 9 weeks after emergence as influenced by nitrogen and potassium levels, grown on Yasothon soil series (Oxic Paleustults). See Appendix E3.4 for ANOVA.

| N levels | K levels | | | | Average N |
|---|---|---|---|---|---|
| | $K_0$ | $K_1$ | $K_2$ | $K_3$ | |
| Total dry weights (kg/ha) | | | | | |
| $N_0$ | 6104 | 6101 | 6865 | 7036 | $6527^{d}$ |
| $N_1$ | 8377 | 8531 | 9188 | 9192 | $8822^{c}$ |
| $N_2$ | 10091 | 10260 | 10168 | 10534 | $10263^{b}$ |
| $N_3$ | 11539 | 11945 | 12998 | 12765 | $12312^{a}$ |
| Average K | $9028^{b}$ | $9209^{b}$ | $9805^{a}$ | $9882^{a}$ | SE = ±291.78 |
| Stem dry weights (g/plant) | | | | | |
| $N_0$ | 19.85 | 19.85 | 22.58 | 24.10 | $21.59^{d}$ |
| $N_1$ | 27.49 | 26.99 | 29.82 | 29.38 | $28.42^{c}$ |
| $N_2$ | 32.87 | 34.07 | 32.89 | 34.31 | $33.54^{b}$ |
| $N_3$ | 37.99 | 38.96 | 41.37 | 41.32 | $39.91^{a}$ |
| Average K | $29.55^{b}$ | $29.97^{b}$ | $31.67^{a}$ | $32.28^{a}$ | SE = ±1.05 |
| Leaf dry weights (g/plant) | | | | | |
| $N_0$ | 6.09 | 6.02 | 6.94 | 6.40 | $6.36^{d}$ |
| $N_1$ | 8.41 | 9.28 | 9.28 | 9.49 | $9.12^{c}$ |
| $N_2$ | 9.51 | 9.48 | 9.61 | 10.15 | $9.69^{b}$ |
| $N_3$ | 10.44 | 11.31 | 12.15 | 11.62 | $11.38^{a}$ |
| Average K | $8.61^{b}$ | $9.02^{ab}$ | $9.50^{a}$ | $9.42^{a}$ | SE = ±0.33 |
| Dead leaf dry weights (g/plant) | | | | | |
| $N_0$ | 1.98 | 2.10 | 2.12 | 1.95 | $2.04^{d}$ |
| $N_1$ | 2.33 | 2.80 | 2.89 | 3.12 | $2.79^{c}$ |
| $N_2$ | 3.35 | 3.42 | 3.37 | 3.27 | $3.35^{b}$ |
| $N_3$ | 3.27 | 3.56 | 4.15 | 4.26 | $3.81^{a}$ |
| Average K | $2.73^{b}$ | $2.97^{ab}$ | $3.13^{a}$ | $3.15^{a}$ | SE = ±0.20 |
| Head dry weights (g/plant) | | | | | |
| $N_0$ | 2.60 | 2.55 | 2.70 | 2.74 | $2.65^{d}$ |
| $N_1$ | 3.67 | 3.60 | 3.95 | 3.98 | $3.80^{c}$ |
| $N_2$ | 4.73 | 4.34 | 4.98 | 4.95 | $4.75^{b}$ |
| $N_3$ | 6.01 | 5.90 | 7.33 | 6.63 | $6.47^{a}$ |
| Average K | $4.25^{c}$ | $4.10^{c}$ | $4.74^{a}$ | $4.57^{ab}$ | SE = ±0.31 |

Letters indicate significant differences of DMRT at probability of 0.05.
SE = Standard error of means.

Table 4.7 Mean values of leaf areas, leaf area indices, crop growth rates and brix values of the sorghum plant at 9 weeks after emergence as influenced by nitrogen and potassium levels, grown on Yasothon soil series (Oxic Paleustults). See Appendix E3.4 for ANOVA.

| N levels | K levels | | | | Average N |
|---|---|---|---|---|---|
| | $K_0$ | $K_1$ | $K_2$ | $K_3$ | |
| | | Leaf areas (cm$^2$/plant) | | | |
| $N_0$ | 1294 | 1278 | 1475 | 1358 | $1351^{d}$ |
| $N_1$ | 1788 | 1971 | 1973 | 2017 | $1937^{c}$ |
| $N_2$ | 2021 | 2014 | 2041 | 2156 | $2058^{b}$ |
| $N_3$ | 2218 | 2403 | 2582 | 2468 | $2418^{a}$ |
| Average K | $1830^{b}$ | $1917^{ab}$ | $2018^{a}$ | $2000^{a}$ | SE = ±70.72 |
| | | Leaf area indices | | | |
| $N_0$ | 2.59 | 2.56 | 2.95 | 2.72 | $2.71^{d}$ |
| $N_1$ | 3.58 | 3.94 | 3.95 | 4.04 | $3.88^{c}$ |
| $N_2$ | 4.04 | 4.03 | 4.08 | 4.32 | $4.12^{b}$ |
| $N_3$ | 4.43 | 4.81 | 5.17 | 4.94 | $4.84^{a}$ |
| Average K | $3.66^{b}$ | $3.84^{ab}$ | $4.04^{a}$ | $4.01^{a}$ | SE = ±0.14 |
| | | Crop growth rates # 3 (g/m$^2$/week) | | | |
| $N_0$ | 94.84 | 88.76 | 111.92 | 121.82 | $104.34^{d}$ |
| $N_1$ | 122.41 | 111.90 | 137.98 | 142.32 | $128.65^{c}$ |
| $N_2$ | 173.46 | 172.77 | 145.63 | 173.20 | $166.27^{b}$ |
| $N_3$ | 183.71 | 194.55 | 215.34 | 192.32 | $196.48^{a}$ |
| Average K | 143.61 | 142.00 | 152.72 | 157.42 | SE = ±16.82 |
| | | Brix (%) | | | |
| $N_0$ | 10.57 | 10.62 | 10.84 | 11.88 | $10.98^{b}$ |
| $N_1$ | 12.88 | 13.43 | 13.63 | 13.63 | $13.39^{a}$ |
| $N_2$ | 13.20 | 13.40 | 13.80 | 13.39 | $13.45^{a}$ |
| $N_3$ | 13.57 | 13.66 | 13.86 | 13.38 | $13.62^{a}$ |
| Average K | $12.56^{b}$ | $12.78^{ab}$ | $13.03^{a}$ | $13.07^{a}$ | SE = ±0.32 |

Letters indicate significant differences of DMRT at probability of 0.05.
SE = Standard error of means.

Table 4.8 Mean values of total dry weights, stem dry weights, leaf dry weights, dead leaf dry weights, head dry weights and leaf areas of the sorghum plants at 11 weeks after emergence as influenced by nitrogen and potassium levels, grown on Yasothon soil series (Oxic Paleustults). See Appendix E3.5 for ANOVA.

| N levels | K levels | | | | Average N |
|---|---|---|---|---|---|
| | $K_0$ | $K_1$ | $K_2$ | $K_3$ | |
| | | Total dry weights (kg/ha) | | | |
| $N_0$ | 7517 | 8085 | 8469 | 8990 | 8265$^{d}$ |
| $N_1$ | 10223 | 10761 | 11735 | 12391 | 11278$^{c}$ |
| $N_2$ | 12135 | 12590 | 12882 | 13214 | 12705$^{b}$ |
| $N_3$ | 13770 | 14885 | 16198 | 15219 | 15018$^{a}$ |
| Average K | 10911$^{c}$ | 11580$^{b}$ | 12321$^{a}$ | 12454$^{a}$ | SE = ±280.52 |
| | | Stem dry weights (g/plant) | | | |
| $N_0$ | 19.75 | 20.30 | 21.25 | 23.29 | 21.48$^{d}$ |
| $N_1$ | 26.74 | 27.33 | 30.85 | 32.43 | 29.34$^{c}$ |
| $N_2$ | 33.27 | 33.61 | 33.38 | 34.41 | 33.67$^{b}$ |
| $N_3$ | 36.03 | 39.33 | 41.87 | 40.43 | 39.42$^{a}$ |
| Average K | 28.95$^{b}$ | 30.14$^{a}$ | 31.84$^{a}$ | 32.64$^{a}$ | SE = ±0.88 |
| | | Leaf dry weights (g/plant) | | | |
| $N_0$ | 5.35 | 6.23 | 6.59 | 6.29 | 6.12$^{d}$ |
| $N_1$ | 7.37 | 7.66 | 8.46 | 8.53 | 8.01$^{c}$ |
| $N_2$ | 8.27 | 8.64 | 9.27 | 9.44 | 8.91$^{b}$ |
| $N_3$ | 9.91 | 10.88 | 11.72 | 10.23 | 10.69$^{a}$ |
| Average K | 7.73$^{c}$ | 8.35$^{b}$ | 9.01$^{a}$ | 8.62$^{ab}$ | SE = ±0.39 |
| | | Dead leaf dry weights (g/plant) | | | |
| $N_0$ | 1.78 | 2.05 | 2.11 | 2.48 | 2.11$^{d}$ |
| $N_1$ | 2.39 | 2.45 | 2.50 | 2.68 | 2.51$^{c}$ |
| $N_2$ | 2.64 | 2.71 | 2.96 | 3.21 | 2.88$^{b}$ |
| $N_3$ | 3.33 | 3.80 | 4.45 | 4.25 | 3.96$^{a}$ |
| Average K | 2.54$^{b}$ | 2.75$^{b}$ | 3.01$^{a}$ | 3.16$^{a}$ | SE = ±0.17 |
| | | Head dry weights (g/plant) | | | |
| $N_0$ | 10.71 | 11.86 | 12.40 | 12.89 | 11.97$^{d}$ |
| $N_1$ | 14.62 | 16.37 | 16.88 | 18.32 | 16.55$^{c}$ |
| $N_2$ | 16.51 | 17.99 | 18.80 | 19.01 | 18.08$^{b}$ |
| $N_3$ | 19.59 | 20.42 | 22.95 | 21.20 | 21.04$^{a}$ |
| Average K | 15.36$^{c}$ | 16.66$^{b}$ | 17.76$^{ab}$ | 17.86$^{a}$ | SE = ±0.78 |
| | | Leaf areas (cm$^2$/plant) | | | |
| $N_0$ | 1162 | 1353 | 1433 | 1368 | 1329$^{d}$ |
| $N_1$ | 1603 | 1665 | 1839 | 1854 | 1740$^{c}$ |
| $N_2$ | 1797 | 1878 | 2015 | 2053 | 1936$^{b}$ |
| $N_3$ | 2154 | 2364 | 2548 | 2224 | 2323$^{a}$ |
| Average K | 1679$^{c}$ | 1815$^{b}$ | 1959$^{a}$ | 1875$^{ab}$ | SE = ±85.89 |

Letters indicate significant differences of DMRT at probability of 0.05.
SE = Standard error of means.

Table 4.9 Mean values of leaf area indices, crop growth rates, leaf area duration and brix values of the sorghum plants at 11 weeks after emergence as influenced by nitrogen and potassium levels, grown on Yasothon soil series (Oxic Paleustults). See Appendix E3.5 for ANOVA.

| N levels | K levels | | | | Average N |
|---|---|---|---|---|---|
| | $K_0$ | $K_1$ | $K_2$ | $K_3$ | |
| Leaf area indices | | | | | |
| $N_0$ | 2.33 | 2.71 | 2.87 | 2.74 | $2.66^d$ |
| $N_1$ | 3.21 | 3.33 | 3.68 | 3.71 | $3.48^c$ |
| $N_2$ | 3.59 | 3.76 | 4.03 | 4.11 | $3.87^b$ |
| $N_3$ | 4.31 | 4.73 | 5.10 | 4.45 | $4.65^a$ |
| Average K | $3.36^c$ | $3.63^b$ | $3.92^a$ | $3.75^{ab}$ | SE = ±0.17 |
| Crop growth rates # 4 ($g/m^2$/week) | | | | | |
| $N_0$ | 70.67 | 99.19 | 80.17 | 97.73 | $86.94^b$ |
| $N_1$ | 92.29 | 111.50 | 127.39 | 159.98 | $122.79^a$ |
| $N_2$ | 102.17 | 116.54 | 135.69 | 134.00 | $122.10^a$ |
| $N_3$ | 111.58 | 147.02 | 159.99 | 122.75 | $135.34^a$ |
| Average K | $94.18^b$ | $118.56^a$ | $125.81^a$ | $128.62^a$ | SE = ±13.23 |
| Leaf area duration ($m^2$.week) | | | | | |
| $N_0$ | 1.31 | 1.32 | 1.44 | 1.34 | $1.35^d$ |
| $N_1$ | 1.56 | 1.63 | 1.68 | 1.66 | $1.63^c$ |
| $N_2$ | 1.75 | 1.81 | 1.83 | 1.87 | $1.82^b$ |
| $N_3$ | 1.98 | 2.05 | 2.16 | 2.19 | $2.10^a$ |
| Average K | $1.65^b$ | $1.70^b$ | $1.78^a$ | $1.77^a$ | SE = ±0.04 |
| Brix (%) | | | | | |
| $N_0$ | 10.05 | 10.92 | 11.55 | 14.18 | $11.68^b$ |
| $N_1$ | 11.89 | 12.07 | 12.46 | 11.50 | $11.98^{ab}$ |
| $N_2$ | 12.72 | 11.32 | 12.14 | 12.24 | $12.11^{ab}$ |
| $N_3$ | 11.95 | 12.84 | 13.51 | 12.50 | $12.70^a$ |
| Average K | $11.65^c$ | $11.79^c$ | $12.42^{ab}$ | $12.61^a$ | SE = ±0.48 |

Letters indicate significant differences of DMRT at probability of 0.05.
SE = Standard error of means.

Table 4.10 Mean values of dry seed head yields, seed yields and 1000-seed weights of the sorghum plants as influenced by nitrogen and potassium levels, grown on Yasothon soil series (Oxic Paleustults). See Appendix E3.5 for ANOVA.

| N levels | K levels | | | | Average N |
|---|---|---|---|---|---|
| | $K_0$ | $K_1$ | $K_2$ | $K_3$ | |
| | | Dry seed head yields (kg/ha) | | | |
| $N_0$ | 3884 | 4239 | 4502 | 4516 | $4285^b$ |
| $N_1$ | 5205 | 6110 | 5545 | 5279 | $5535^a$ |
| $N_2$ | 5765 | 5517 | 6408 | 6170 | $5965^a$ |
| $N_3$ | 5848 | 5890 | 6663 | 5783 | $6046^a$ |
| Average K | 5176 | 5439 | 5780 | 5437 | SE = ±455.62 |
| | | Seed yields (kg/ha) | | | |
| $N_0$ | 3379 | 3688 | 3916 | 3929 | $3728^b$ |
| $N_1$ | 4528 | 5315 | 4824 | 4593 | $4815^a$ |
| $N_2$ | 5016 | 4800 | 5575 | 5368 | $5190^a$ |
| $N_3$ | 5096 | 5124 | 5797 | 5031 | $5262^a$ |
| Average K | 4505 | 4732 | 5028 | 4730 | SE = ±369.49 |
| | | 1000-seed weights (g) | | | |
| $N_0$ | 31.75 | 30.53 | 30.49 | 30.81 | $30.90^b$ |
| $N_1$ | 33.82 | 35.10 | 33.72 | 33.69 | $34.08^a$ |
| $N_2$ | 33.97 | 34.51 | 35.16 | 34.44 | $34.52^a$ |
| $N_3$ | 34.27 | 35.18 | 34.23 | 33.91 | $34.40^a$ |
| Average K | 33.45 | 33.83 | 33.40 | 33.21 | SE = ±0.74 |

Letters indicate significant differences of DMRT at probability of 0.05.
SE = Standard error of means.

### 4.2.4 Crude Protein (CP) Contents, Neutral Detergent Fibre (NDF) and Acid Detergent Fibre (ADF) Contents, and Dry Matter Degradability (DMD)

The results showed that, in general, an increase in N level significantly increased CP percentages of the sorghum plants with mean values ranged from 5.08 to 8.73 % for $N_0$ and $N_3$, respectively. K had no effect on CP %. N and K levels had no effect on NDF, ADF, and DMD of the sorghum plants (Table 4.11).

Table 4.11 Mean values of the estimated crude protein, neutral detergent fibre (NDF), acid detergent fibre (ADF) contents and dry matter degradability of the sorghum plants at 10 weeks after emergence as influenced by nitrogen and potassium levels, grown on Yasothon soil series (Oxic Paleustults). See Appendix E3.6 for ANOVA.

| N levels | K levels | | | | Average N |
|---|---|---|---|---|---|
| | $K_0$ | $K_1$ | $K_2$ | $K_3$ | |
| | | Crude protein (% on DM basis) | | | |
| $N_0$ | 5.30 | 4.95 | 4.90 | 5.17 | $5.08^{c}$ |
| $N_1$ | 7.84 | 7.02 | 7.82 | 8.01 | $7.67^{b}$ |
| $N_2$ | 7.90 | 8.27 | 8.12 | 8.05 | $8.09^{ab}$ |
| $N_3$ | 9.32 | 8.56 | 8.44 | 8.60 | $8.73^{a}$ |
| Average K | 7.59 | 7.20 | 7.32 | 7.46 | SE = ±0.49 |
| | | NDF (% on DM basis) | | | |
| $N_0$ | 62.49 | 61.17 | 62.32 | 63.71 | 62.42 |
| $N_1$ | 61.51 | 62.00 | 62.43 | 62.38 | 62.08 |
| $N_2$ | 61.36 | 61.21 | 60.83 | 62.67 | 61.52 |
| $N_3$ | 63.37 | 62.03 | 61.49 | 62.22 | 62.28 |
| Average K | 62.18 | 61.60 | 61.77 | 62.75 | SE = ±0.95 |
| | | ADF (% on DM basis) | | | |
| $N_0$ | 35.78 | 35.63 | 35.47 | 36.74 | 35.91 |
| $N_1$ | 34.83 | 35.02 | 35.01 | 35.32 | 35.05 |
| $N_2$ | 35.17 | 34.53 | 34.75 | 37.13 | 35.40 |
| $N_3$ | 36.48 | 34.93 | 34.43 | 35.22 | 35.27 |
| Average K | 35.57 | 35.03 | 34.92 | 36.10 | SE = ±0.75 |
| | | Dry matter degradability (%) | | | |
| $N_0$ | 68.89 | 70.51 | 69.43 | 69.18 | 69.50 |
| $N_1$ | 68.88 | 68.92 | 71.04 | 69.52 | 69.59 |
| $N_2$ | 70.38 | 69.77 | 71.07 | 68.92 | 70.04 |
| $N_3$ | 70.78 | 69.63 | 71.51 | 71.33 | 70.81 |
| Average K | 69.73 | 69.71 | 70.76 | 69.74 | SE = ±1.00 |

Letters indicate significant differences of DMRT at probability of 0.05.
SE = Standard error of means.

### 4.2.5 Relationship Between Total Fertiliser Addition and Total Dry Weights of the Sorghum Plants

The result showed that total fertiliser addition in terms of the combined effects of N and K was significantly associated with total dry weights. $R^2$ of 0.81 indicated that 81 % of the variation in the mean total dry weight was accounted for by the linear function of the total fertiliser addition (Fig. 4.1).

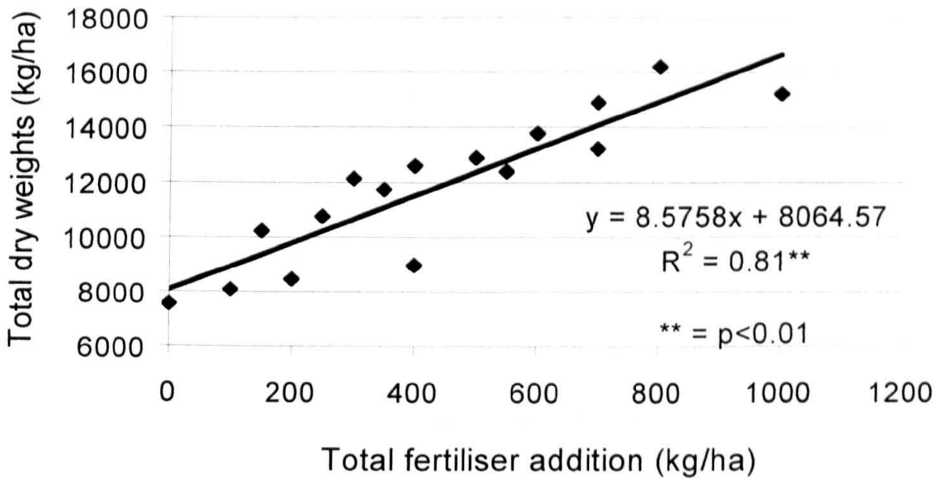

Fig. 4.1 Relationship between total fertiliser addition and total dry weights of the sorghum plants measured at 11 weeks after emergence, grown on Yasothon soil series (Oxic Paleustults), Northeast Thailand.

### 4.2.6 Relationship Between Total Fertiliser Addition and Seed Yields of the Sorghum Plants

The result showed that total fertiliser addition in terms of the combined effects of N and K was significantly associated with seed yields. $R^2$ of 0.47 indicated that 47 % of the variation in the mean seed yield was accounted for by the linear function of the total fertiliser addition (Fig. 4.2).

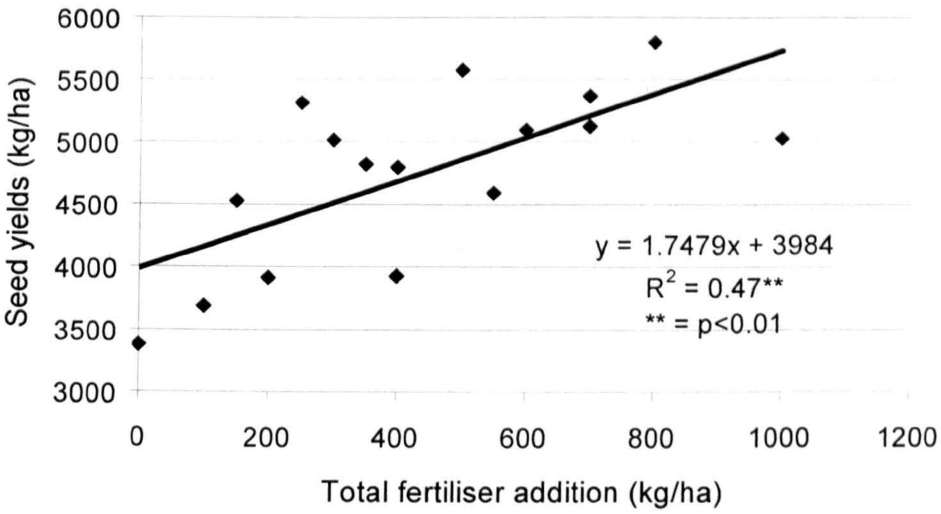

Fig. 4.2 Relationship between total fertiliser addition and seed yields of the sorghum plants grown on Yasothon soil series (Oxic Paleustults), Northeast Thailand.

### 4.2.7 Relationship Between Leaf Area Duration (D) and Total Dry Weights and the Relationship Between D and Seed Yields

The result showed that D was significantly associated with total dry weights. $R^2$ of 0.96 indicated that 96 % of the variation in the mean total dry weight was accounted for by the linear function of the D value (Fig. 4.3). A similar result as that of the relationship between total dry weights and D was found with the relationship between seed yields and D, i.e. D was significantly associated with seed yields. $R^2$ of 0.71 indicated that 71 % of the variation in the mean seed yield was accounted for by the linear function of the D value (Fig. 4.4). The longer the duration of the living leaves (D) the greater the amounts of total dry weights/ha and seed yields/ha of the sorghum plants.

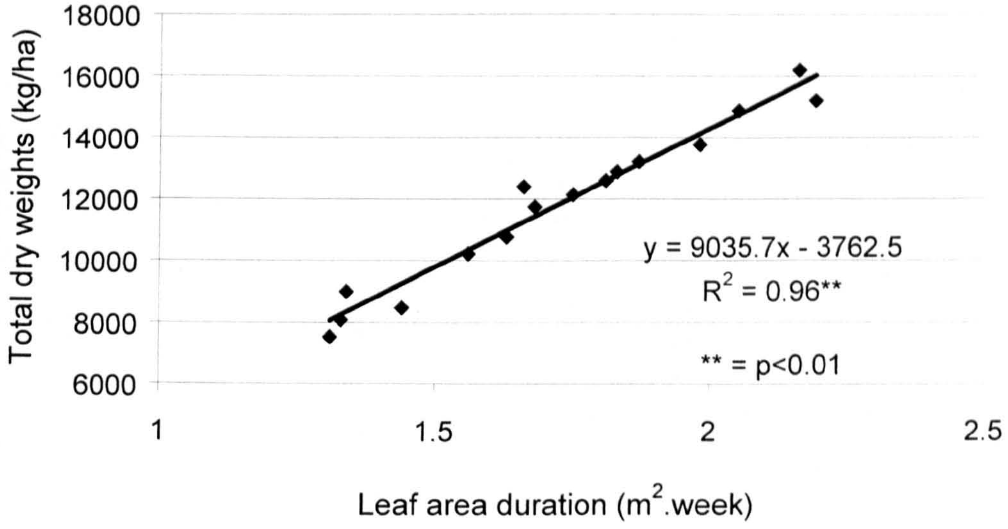

Fig. 4.3 Relationship between leaf area duration and total dry weights of the sorghum plants at 11 weeks after emergence as influenced by the combined effects of nitrogen and potassium application rates, grown on Yasothon soil series (Oxic Paleustults).

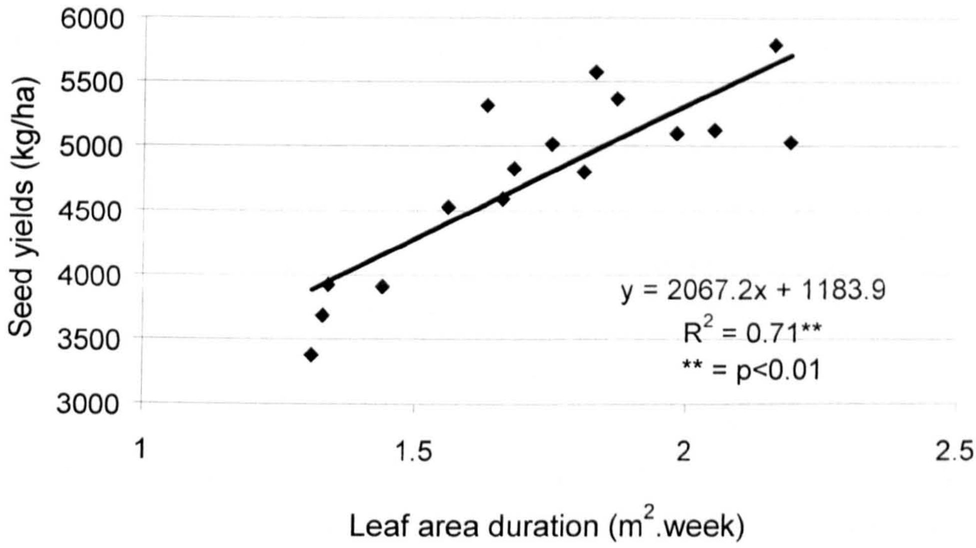

Fig. 4.4 Relationship between leaf area duration and seed yields of the sorghum plants as influenced by of the combined effects nitrogen and potassium application rates, grown on Yasothon soil series (Oxic Paleustults).

## 4.3 Discussion

During the early growth period of the sorghum plants, the results indicated that an increase in N level significantly increased total dry weights/ha, stem dry weights, leaf dry weights, leaf areas/plant and leaf area indices of the sorghum plants, whilst the increases in K levels also significantly increased all these measured parameters of the sorghum plants, but to a relatively smaller extent. This trend in growth of the sorghum plants due to the effect of both N and K was found in all three sampling periods (3, 5, 7 weeks after emergence). The results suggested that N had a greater effect on total dry weights, stem dry weights, leaf dry weights, leaf areas, CGR and LAI of the sorghum plants than K. The effects on most measured parameters due to nitrogen could be attributable to its direct effects since this element has its significant role on vegetative growth, whilst potassium has more indirect effects, i.e. its important role lies on the translocation of assimilates from source to sink. The results on the effect of nitrogen confirm the work reported by Ibrahim (1994); Buah *et al.* (1998); Poonia *et al.* (1999); and Suksri (1999).

When the sorghum plants had produced individual heads of seeds at 9 weeks after emergence, the results showed that an increase in N level significantly increased total dry weights/ha, stem dry weights/plant, leaf dry weights/plant, leaf areas/plant, LAI, head dry weights and brix %, whilst an increase in K level significantly increased all these measurement parameters mostly only up to $K_2$ level. The results suggested that N had greater effects on growth of the sorghum plants than K. This trend in growth was found in all subsequent sampling periods. Leaf growth both leaf areas/plant and LAI reached maximum at 7 weeks after emergence thereafter leaf areas and LAI declined more rapidly with time when the crop plants reached 9 weeks after emergence although LAI values remained corresponding to N levels, i.e., an increase in N level significantly increased LAI values. The decline in leaf areas and LAI could have been attributed to the plants aging so some lower leaves had become its senescent; re-translocation of nitrogen to younger leaves and to grains of the sorghum plants could also be a factor. At this stage of growth, the sorghum plants had initiated flower heads and dead leaf dry weights (from lower leaves) started to accumulate. The results suggested that some nitrogen could have moved to grains (hence lower leaves died off); another reason for this could be the advance in age of the sorghum plants and also inadequate amount of soil moisture at this point with growth cycle (Suksri, 1978 and 1999). Dead leaf dry weights significantly increased with an increase in N level. This could be attributable to the translocation of nitrogen from aging leaves to sink (grains) as previously discussed. The re-translocation of assimilates to sink has been reported by Evans (1975); Pate (1980); Mengel and Kirkby (1987); and Suksri *et al.*, (1991 and 1999). It was found that CGR significantly increased with an increase in N level whilst K had no effect. The results indicated that nitrogen had the significant effect on the production of assimilates in the sorghum plants (Prioul *et al.*, 1990; and Tollenaar and Dwyer, 1998).

At 11 weeks after emergence, total dry weights/ha of the sorghum plants were significantly increased with an increase in N level whilst K had a similar result but to lesser extent. Similar trends were also shown in the results for stem dry weights, leaf dry weights, dead leaf dry weights, leaf areas, LAI and head dry weights/plant. Dead leaf dry weights/plant significantly increased with an increase in N level, i.e. the higher the N level the greater the dead leaf dry weights/plant. The greater amounts of dead leaf dry weights/plant can possibly be attributable to an inadequate amount of soil moisture when the transpiration rate of leaves was relatively high and a high environmental temperature coincided with high leaf areas/plant (Appendix B3.1) (Begonia *et al.*, 1987; and Wolfe *et al.*, 1988). Head dry weights, leaf areas and LAI were significantly increased with an increase in N levels, whilst K had a lesser effect. The results indicated that both N and K had their significant effects on growth of the sorghum plants, but that influence of N overall was greater (Unkasam and Thawonmas, 1976; Chouhan and Dighe, 1999; and Poonia *et al.*, 1999).

At 11 weeks after emergence, the results showed that N and K had significant effects on CGR only at $N_1$ and $K_1$. Similarly, N level had a small effect on grain yields of the sorghum plants, whilst K did not. This trend was also found with 1000-seed dry weights, i.e. N slightly increased seed size ($N_1$ only) whilst K did not. A similar result was also found with brix values, i.e., N had a small effect on brix value whilst K had greater effects but only with higher K level ($K_2$). N had significant effect on the estimated crude protein (CP %) percentages, i.e. an increase in N level significantly increased CP %. However, both N and K had no effect on NDF, ADF, and DMD contents. This could have been attributed to perhaps the inadequate amounts of soil moisture content in the latter part of the rainy season (Appendix B3.1) resulting in the high fibre contents in the plant tissues. It could possibly be inferred that if the sorghum plants had received an adequate amount of soil moisture throughout the growth period then DMD values should be relatively high, hence fodder quality could be improved (Frame, 1994; Buxton and Mertens, 1995; and Joshi *et al.*, 1998).

The results show that an increase in the amount of both N and K fertilisers significantly increased total dry weights/ha of the sorghum plants. Therefore, the significant effect on growth of the sorghum plants is a combined one rather than due to either N or K alone (Tanaka, 1966; De Datta, 1973; and Suksri, 1999). A similar result was also shown between amount of fertilisers added to the soil and seed yields but to a lesser extent. A highly significant effect due to an increase in D on total dry weights/ha was attained, i.e. the greater the D values the better the total dry weights/ha of the sorghum plants. The results suggested that the prolonged life of leaves had a tremendous effect on fodder yields of the sorghum plants (Begonia *et al.*, 1987). Another significant effect due to D on seed yields was attained, i.e. an increase in D increased seed yields/ha of the sorghum plants. The results indicated that the longer the "stay green" of leaves the greater the seed yields of the sorghum plants. Seed yields and total dry weights/ha of the sorghum plants of the $N_3K_2$ treatment were better than the rest (Borrell *et al.*, 2000b).

The results of this experiment (Experiment 3) revealed that seed yields of the sorghum plants with respect to N and K fertliser levels added to the soil were better than in the previous experiment (Experiment 2) presumably due to the application of a basal dressing of fermented cattle manure, i.e. in Experiment 3 an application of $N_1$, $N_2$ and $N_3$ gave seed yields of 4,815, 5,190 and 5,262 kg/ha, respectively whilst Experiment 2 were 4,268, 4,579 and 5,110 kg/ha, respectively. With K application, in Experiment 3, seed yields were 4,732, 5,028 and 4,730 kg/ha in $K_1$, $K_2$ and $K_3$, respectively. Whilst in Experiment 2, seed yields were 4,288, 4,357 and 3,958 kg/ha, respectively. Experiment 3 was rain-fed; the pattern of response may well be different in the dry season. It was, therefore, decides to repeat Experiment 3 in the dry season with the use of irrigation water. This was to justify the effects due to the application of N, K and basal cattle manure on growth and yields of the sorghum plants when total radiant energy and environmental temperatures could be relatively greater than in the wet season (Suksri, 1999).

## Experiment 4

## Effects of Nitrogen and Potassium on Growth, Chemical Components and Seed Yields of IS 23585 Forage Sorghum Cultivar, (*Sorghum bicolor* L. Moench) With a Basal Dressing of Cattle Manure During Dry Season With Irrigation

### 4.4 Introduction

The results of the previous experiment (Experiment 3), when the work was carried out during rainy season under rain-fed conditions with the use of fermented cattle manure as an organic foundation for growth of the sorghum plants, the results revealed that the growth of the sorghum plants due to the application of both nitrogen and potassium chemical fertilisers was much better than that of the first two experiments. Rainy season normally provides adequate amount of rainwater for the growth of crop plants unless a drought period has occurred, which does happen in some years. During recent past years rainy season has had a lesser amount of radiant energy from the sun than that of the dry season due to cloud cover with lower day and night temperatures than the dry season; this had affected the growth of many crop plants by delaying maturity (Suksri *et al.*, 1991). Dry season in Northeast Thailand normally provides a high amount of radiant energy due to the lack of cloud cover (Suksri, 1978).

Under drought conditions, a number of growers in Thailand cannot supply adequate amount of fodders and silage to their herds of livestock and rely most on concentrate feedstuffs and hays. Therefore, agronomic data on growth and crop yield of sorghum produced in dry season with the use of irrigation water should be of significant interest and value to livestock and farmers. Another reason to repeat Experiment 3 is to investigate if the results are repeatable when the growing season is changed. Growing fodder sorghum in dry season could be important in producing adequate amounts of fresh fodder as feedstuffs to feed livestock (apart from or in addition to hays, silage and concentrate rations) during each hot or dry season of the year. Sorghum fodders produced in hot season could help in the expansion of livestock production particularly dairy cattle since the Thai people have a current interest in expanding their dairy farming in most of the regions of the country particularly northeastern region where it represents one third of both the population and the land areas (National statistic office, 2003). In hot season, most of the water reservoirs in each region have normally released large amounts of irrigation water to growers of the many crop plants such as rice, soybean, maize, sorghum and orchard trees. Given a share of this irrigation water, green fodders of sorghum or maize could be always available for diary farming regardless of the season.

**Materials and Methods:** This section was given in chapter 2 on page 59. Treatments were the same as Experiment 3 (a repeat of Experiment 3 in dry season).

## 4.5 Results

### 4.5.1 Initial Soil Analysis Data of Yasothon Soil Series

The initial soil analysis data of soil properties of Yasothon soil series (Oxic Paleustults) showed that mean values of soil pH, organic matter %, total soil nitrogen %, available phosphorus and exchangeable potassium were 6.1, 0.603, 0.035, 21.24 ppm, and 45.01 ppm, respectively (Table 4.12).

Table 4.12 Initial soil analysis data of Yasothon soil series (Oxic Paleustults) of the plots before the sowing of sorghum seeds at Khon Kaen University Experimental Farm, Northeast Thailand during dry season of the Year 2000.

| Items | Blocks | | | | Averages |
|---|---|---|---|---|---|
| | I | II | III | IV | |
| pH (1:2.5 soil:water) | 6.1 | 6.1 | 6.1 | 6.2 | 6.1 |
| Organic matter (%) | 0.599 | 0.608 | 0.591 | 0.614 | 0.603 |
| Total soil nitrogen (%) | 0.033 | 0.032 | 0.036 | 0.040 | 0.035 |
| Available phosphorus (ppm) | 21.64 | 21.71 | 21.09 | 20.54 | 21.24 |
| Extractable potassium (ppm) | 44.04 | 45.98 | 43.40 | 46.63 | 45.01 |

### 4.5.2 Soil Analysis Data at the Final Sampling Period

The soil analysis carried out after the final harvest of the sorghum plants, showed that soil pH, organic matter %, total soil nitrogen %, available phosphorus, and extractable potassium were in the ranges of 6.0-6.8, 0.525-0.686, 0.030-0.047, 25.26-47.07 ppm, and 40.34-92.58 ppm, respectively (Table 4.13). Generally, initial values (Table 4.12) are similar to final values (Table 4.13) apart from pH, available phosphorus and extractable potassium at the highest rate ($K_3$) all values are relative low.

**Table 4.13** Soil analysis data of the sorghum plots of Yasothon soil series (Oxic Paleustults) after the final harvest for grains of the sorghum plants at Khon Kaen University Experimental Farm, Northeast Thailand during dry season of the Year 2000.

| N levels | K levels | | | | Average N |
|---|---|---|---|---|---|
| | $K_0$ | $K_1$ | $K_2$ | $K_3$ | |
| | | Soil pH (1:2.5 soil:water by volume) | | | |
| $N_0$ | 6.1 | 5.7 | 6.5 | 6.8 | 6.3 |
| $N_1$ | 6.3 | 6.5 | 6.1 | 6.4 | 6.3 |
| $N_2$ | 6.5 | 6.2 | 6.5 | 6.4 | 6.4 |
| $N_3$ | 6.2 | 6.0 | 6.1 | 6.0 | 6.1 |
| Average K | 6.3 | 6.1 | 6.3 | 6.4 | |
| | | Organic matter (%) | | | |
| $N_0$ | 0.613 | 0.597 | 0.638 | 0.621 | 0.617 |
| $N_1$ | 0.613 | 0.613 | 0.629 | 0.525 | 0.595 |
| $N_2$ | 0.638 | 0.686 | 0.718 | 0.678 | 0.680 |
| $N_3$ | 0.646 | 0.579 | 0.678 | 0.581 | 0.626 |
| Average K | 0.628 | 0.623 | 0.666 | 0.601 | |
| | | Total soil nitrogen (%) | | | |
| $N_0$ | 0.036 | 0.043 | 0.045 | 0.030 | 0.039 |
| $N_1$ | 0.044 | 0.039 | 0.046 | 0.043 | 0.043 |
| $N_2$ | 0.047 | 0.039 | 0.045 | 0.042 | 0.043 |
| $N_3$ | 0.042 | 0.043 | 0.036 | 0.041 | 0.041 |
| Average K | 0.042 | 0.041 | 0.043 | 0.039 | |
| | | Available phosphorus (ppm) | | | |
| $N_0$ | 37.06 | 29.27 | 36.61 | 36.17 | 34.78 |
| $N_1$ | 26.59 | 25.93 | 29.04 | 28.60 | 27.54 |
| $N_2$ | 31.94 | 31.05 | 35.28 | 27.48 | 31.44 |
| $N_3$ | 30.83 | 25.26 | 47.07 | 43.96 | 36.78 |
| Average K | 31.61 | 27.88 | 37.00 | 34.05 | |
| | | Extractable potassium (ppm) | | | |
| $N_0$ | 43.28 | 51.12 | 61.49 | 92.58 | 62.12 |
| $N_1$ | 45.94 | 56.31 | 51.12 | 77.04 | 57.60 |
| $N_2$ | 40.76 | 51.12 | 40.34 | 66.67 | 49.72 |
| $N_3$ | 51.12 | 51.12 | 51.12 | 56.31 | 52.42 |
| Average K | 45.28 | 52.42 | 51.02 | 73.15 | |

### 4.5.3 Total Dry Weights, Stem Dry Weights, Leaf Dry Weights, Dead Leaf Dry Weights, Head Dry Weights, Leaf Areas, Leaf Area Indices (LAI), Crop Growth Rates (CGR), Leaf Area Duration (D), Brix Values, Seed Yields and 1000-Seed Weights.

The results showed that an increase in N level significantly increased total dry weights of the sorghum plants 3 weeks after emergence, although the highest level of nitrogen ($N_3$) was statistically similar to that of $N_2$ with average values of 400, 501, 537, and 549 kg/ha for $N_0$, $N_1$, $N_2$, and $N_3$, respectively (Table 4.14). An increase in K level did not significantly increase total dry weights/ha of the sorghum plants. A similar trend was also found with stem dry weights, leaf dry weights, leaf areas per plant and LAI, i.e. N had a very significant effect on all measured parameters while K levels showed no significant effect.

For the second sampling period at 5 weeks after emergence, the results showed that an increase in N level significantly increased total dry weights/ha of the sorghum plants and the effects due to an increase in N level were clearer than at the initial sampling period. Total mean dry weights/ha ranged from 2,135 to 3,317 kg/ha for $N_0$ and $N_3$, respectively (Table 4.15). An increase in K level did not significantly increase total dry weights/ha of the sorghum plants. A similar trend was found with stem dry weights and leaf dry weights, i.e. N had a significant positive effect, whilst K had little or no effect. Dead leaf dry weights per plant were similar for all levels of K except the highest but an increase in N level significantly increased dead leaf dry weights/plant only up to $N_1$.

The results showed that leaf areas/plant increased with an increase in N level with mean values of 1,628, 2,096, 2,216, and 2,257 cm$^2$/plant for $N_0$, $N_1$, $N_2$, and $N_3$, respectively (Table 4.16). Similarly, an increase in K level significantly increased leaf areas/plant of the sorghum plants but to a lesser degree. This trend was also found with LAI but LAI values in all levels of N and K were sub-optimal at this growth stage. Crop growth rate (CGR) significantly increased with an increase in N level up to $N_1$ but was not significantly increased with increases in K.

For the third sampling period at seven weeks after emergence, the results showed that an increase in N level significantly increased total dry weights/ha of the sorghum plants with mean values of 4,610, 7,278, 7,505, and 8,375 kg/ha for $N_0$, $N_1$, $N_2$, and $N_3$, respectively (Table 4.17). On the other hand, an increase in K level did not significantly increase total dry weights/ha. A similar trend was found with stem dry weights/plant, i.e. N promoted stem dry weights/plant whilst K did not.

Leaf dry weights per plant increased with an increase in N level although the differences found between $N_1$ to $N_3$ were not statistically significant (mean values were 7.59, 12.10, 12.54, and 12.73 g/plant for $N_0$, $N_1$, $N_2$, and $N_3$, respectively). An increase in K level did not significantly increase leaf dry weights/plant. Dead leaf dry weights/plant were somewhat inconsistently shown; an increase in N level significantly decreased dead leaf dry weights/plant up to $N_1$ level, whilst $N_0$ and $N_3$ levels were similar. Dead leaf dry weights were unaffected by an increase in K level.

An increase in N level significantly increased leaf areas/plant up to $N_1$ only whilst an increase in K level did not significantly increase leaf areas/plant. A similar trend was found with LAI. LAI of the sorghum plants at this stage of growth were higher than for the second sampling period (Table 4.18), but still sub-optimal. An increase in N level significantly increased CGR although CGR values of $N_1$ and $N_2$ were similar with the highest value at $N_3$ level. Increases in K level had no significant effect on CGR.

**Table 4.14** Mean values of total dry weights, stem dry weights, leaf dry weights, leaf areas and leaf area indices of the sorghum plants at 3 weeks after emergence as influenced by nitrogen and potassium levels, grown on Yasothon soil series (Oxic Paleustults). See Appendix E4.1 for ANOVA.

| N levels | K levels | | | | Average N |
|---|---|---|---|---|---|
| | $K_0$ | $K_1$ | $K_2$ | $K_3$ | |
| | | Total dry weights (kg/ha) | | | |
| $N_0$ | 382 | 398 | 400 | 420 | $400^{c}$ |
| $N_1$ | 445 | 508 | 517 | 532 | $501^{b}$ |
| $N_2$ | 535 | 535 | 536 | 542 | $537^{a}$ |
| $N_3$ | 544 | 539 | 550 | 562 | $549^{a}$ |
| Average K | 476 | 495 | 501 | 514 | SE = ±23.20 |
| | | Stem dry weights (g/plant) | | | |
| $N_0$ | 0.39 | 0.41 | 0.41 | 0.44 | $0.41^{c}$ |
| $N_1$ | 0.51 | 0.53 | 0.54 | 0.57 | $0.54^{b}$ |
| $N_2$ | 0.58 | 0.60 | 0.61 | 0.61 | $0.60^{a}$ |
| $N_3$ | 0.62 | 0.62 | 0.64 | 0.64 | $0.63^{a}$ |
| Average K | 0.53 | 0.54 | 0.55 | 0.57 | SE = ±0.03 |
| | | Leaf dry weights (g/plant) | | | |
| $N_0$ | 1.52 | 1.58 | 1.59 | 1.66 | $1.59^{c}$ |
| $N_1$ | 1.72 | 2.01 | 2.04 | 2.10 | $1.97^{b}$ |
| $N_2$ | 2.09 | 2.07 | 2.07 | 2.11 | $2.09^{ab}$ |
| $N_3$ | 2.09 | 2.08 | 2.11 | 2.17 | $2.11^{a}$ |
| Average K | 1.86 | 1.94 | 1.95 | 2.01 | SE = ±0.09 |
| | | Leaf areas (cm$^2$/plant) | | | |
| $N_0$ | 512 | 530 | 533 | 556 | $533^{c}$ |
| $N_1$ | 577 | 673 | 686 | 703 | $660^{b}$ |
| $N_2$ | 702 | 696 | 694 | 707 | $700^{ab}$ |
| $N_3$ | 702 | 697 | 708 | 728 | $709^{a}$ |
| Average K | 623 | 649 | 655 | 674 | SE = ±30.76 |
| | | Leaf area indices | | | |
| $N_0$ | 1.02 | 1.06 | 1.07 | 1.11 | $1.07^{c}$ |
| $N_1$ | 1.16 | 1.35 | 1.37 | 1.41 | $1.32^{b}$ |
| $N_2$ | 1.40 | 1.39 | 1.39 | 1.42 | $1.40^{ab}$ |
| $N_3$ | 1.41 | 1.39 | 1.42 | 1.46 | $1.42^{a}$ |
| Average K | 1.25 | 1.30 | 1.31 | 1.35 | SE = ±0.06 |

Letters indicate significant differences of DMRT at probability of 0.05.
SE = Standard error of means.

**Table 4.15** Mean values of total dry weights, stem dry weights, leaf dry weights and dead leaf dry weights of the sorghum plants at 5 weeks after emergence as influenced by nitrogen and potassium levels, grown on Yasothon soil series (Oxic Paleustults). See Appendix E4.2 for ANOVA.

| N levels | K levels | | | | Average N |
|---|---|---|---|---|---|
| | $K_0$ | $K_1$ | $K_2$ | $K_3$ | |
| | | Total dry weights (kg/ha) | | | |
| $N_0$ | 2012 | 2104 | 2143 | 2280 | $2135^{d}$ |
| $N_1$ | 2887 | 2931 | 2963 | 3065 | $2962^{c}$ |
| $N_2$ | 2977 | 3088 | 3321 | 3226 | $3153^{b}$ |
| $N_3$ | 3258 | 3316 | 3324 | 3368 | $3317^{a}$ |
| Average K | 2784 | 2860 | 2938 | 2985 | SE = ±111.24 |
| | | Stem dry weights (g/plant) | | | |
| $N_0$ | 4.58 | 4.76 | 4.95 | 5.17 | $4.87^{d}$ |
| $N_1$ | 7.23 | 7.24 | 7.43 | 7.64 | $7.39^{c}$ |
| $N_2$ | 7.45 | 7.89 | 8.46 | 8.24 | $8.01^{b}$ |
| $N_3$ | 8.65 | 8.71 | 8.79 | 8.87 | $8.76^{a}$ |
| Average K | 6.98 | 7.15 | 7.41 | 7.48 | SE = ±0.33 |
| | | Leaf dry weights (g/plant) | | | |
| $N_0$ | 5.05 | 5.29 | 5.29 | 5.78 | $5.35^{c}$ |
| $N_1$ | 6.70 | 6.72 | 6.85 | 7.28 | $6.89^{b}$ |
| $N_2$ | 6.90 | 7.12 | 7.60 | 7.51 | $7.28^{a}$ |
| $N_3$ | 7.22 | 7.40 | 7.43 | 7.63 | $7.42^{a}$ |
| Average K | $6.47^{b}$ | $6.63^{b}$ | $6.79^{ab}$ | $7.05^{a}$ | SE = ±0.26 |
| | | Dead leaf dry weights (g/plant) | | | |
| $N_0$ | 0.43 | 0.47 | 0.48 | 0.45 | $0.46^{b}$ |
| $N_1$ | 0.51 | 0.68 | 0.54 | 0.41 | $0.54^{a}$ |
| $N_2$ | 0.53 | 0.42 | 0.55 | 0.38 | $0.47^{ab}$ |
| $N_3$ | 0.42 | 0.48 | 0.40 | 0.34 | $0.41^{b}$ |
| Average K | $0.47^{a}$ | $0.51^{a}$ | $0.49^{a}$ | $0.40^{b}$ | SE = ±0.05 |

Letters indicate significant differences of DMRT at probability of 0.05.
SE = Standard error of means.

**Table 4.16** Mean values of leaf areas, leaf area indices and crop growth rates of the sorghum plants at 5 weeks after emergence as influenced by nitrogen and potassium levels, grown on Yasothon soil series (Oxic Paleustults). See Appendix E4.2 for ANOVA.

| N levels | K levels | | | | Average N |
|---|---|---|---|---|---|
| | $K_0$ | $K_1$ | $K_2$ | $K_3$ | |
| | | Leaf areas (cm²/plant) | | | |
| $N_0$ | 1536 | 1609 | 1609 | 1758 | $1628^{c}$ |
| $N_1$ | 2038 | 2050 | 2083 | 2214 | $2096^{b}$ |
| $N_2$ | 2100 | 2167 | 2310 | 2285 | $2216^{a}$ |
| $N_3$ | 2196 | 2250 | 2261 | 2320 | $2257^{a}$ |
| Average K | $1968^{b}$ | $2019^{b}$ | $2066^{ab}$ | $2144^{a}$ | SE = ±78.40 |
| | | Leaf area indices | | | |
| $N_0$ | 3.07 | 3.22 | 3.22 | 3.52 | $3.26^{c}$ |
| $N_1$ | 4.08 | 4.10 | 4.17 | 4.43 | $4.20^{b}$ |
| $N_2$ | 4.20 | 4.34 | 4.62 | 4.57 | $4.43^{a}$ |
| $N_3$ | 4.39 | 4.50 | 4.52 | 4.64 | $4.51^{a}$ |
| Average K | $3.94^{b}$ | $4.04^{b}$ | $4.13^{ab}$ | $4.29^{a}$ | SE = ±0.16 |
| | | Crop growth rates # 1 (g/cm²/week) | | | |
| $N_0$ | 81.48 | 85.29 | 87.13 | 93.01 | $86.73^{c}$ |
| $N_1$ | 122.10 | 121.17 | 122.28 | 126.64 | $123.05^{b}$ |
| $N_2$ | 122.11 | 127.65 | 139.23 | 134.17 | $130.79^{ab}$ |
| $N_3$ | 135.71 | 138.87 | 138.71 | 140.28 | $138.39^{a}$ |
| Average K | 115.35 | 118.25 | 122.84 | 123.53 | SE = ±5.57 |

Letters indicate significant differences of DMRT at probability of 0.05.
SE = Standard error of means.

Table 4.17 Mean values of total dry weights, stem dry weights, leaf dry weights and dead leaf dry weights of the sorghum plants at 7 weeks after emergence as influenced by nitrogen and potassium levels, grown on Yasothon soil series (Oxic Paleustults). See Appendix E4.3 for ANOVA.

| N levels | K levels | | | | Average N |
|---|---|---|---|---|---|
| | $K_0$ | $K_1$ | $K_2$ | $K_3$ | |
| | | Total dry weights (kg/ha) | | | |
| $N_0$ | 4341 | 4442 | 4753 | 4903 | $4610^{c}$ |
| $N_1$ | 7172 | 7314 | 7512 | 7113 | $7278^{b}$ |
| $N_2$ | 7494 | 7579 | 7393 | 7553 | $7505^{b}$ |
| $N_3$ | 8156 | 8736 | 8585 | 8024 | $8375^{a}$ |
| Average K | 6791 | 7018 | 7061 | 6898 | SE = ±299.46 |
| | | Stem dry weights (g/plant) | | | |
| $N_0$ | 13.53 | 13.92 | 15.12 | 15.57 | $14.54^{c}$ |
| $N_1$ | 23.40 | 23.37 | 24.03 | 23.13 | $23.48^{b}$ |
| $N_2$ | 24.00 | 24.27 | 24.27 | 24.46 | $24.25^{b}$ |
| $N_3$ | 28.20 | 29.31 | 28.59 | 26.82 | $28.23^{a}$ |
| Average K | 22.28 | 22.72 | 23.00 | 22.50 | SE = ±1.00 |
| | | Leaf dry weights (g/plant) | | | |
| $N_0$ | 7.36 | 7.47 | 7.78 | 7.77 | $7.60^{b}$ |
| $N_1$ | 11.62 | 12.36 | 12.77 | 11.66 | $12.10^{a}$ |
| $N_2$ | 12.63 | 12.89 | 12.07 | 12.55 | $12.54^{a}$ |
| $N_3$ | 11.78 | 13.42 | 13.40 | 12.33 | $12.73^{a}$ |
| Average K | 10.85 | 11.54 | 11.51 | 11.08 | SE = ±0.54 |
| | | Dead leaf dry weights (g/plant ) | | | |
| $N_0$ | 0.82 | 0.82 | 0.87 | 0.99 | $0.88^{a}$ |
| $N_1$ | 0.84 | 0.84 | 0.76 | 0.77 | $0.80^{b}$ |
| $N_2$ | 0.85 | 0.74 | 0.63 | 0.76 | $0.75^{b}$ |
| $N_3$ | 0.80 | 0.96 | 0.94 | 0.97 | $0.92^{a}$ |
| Average K | 0.83 | 0.84 | 0.80 | 0.87 | SE = ±0.05 |

Letters indicate significant differences of DMRT at probability of 0.05.
SE = Standard error of means.

**Table 4.18** Mean values of leaf areas, leaf area indices and crop growth rates of the sorghum plants at 7 weeks after emergence as influenced by nitrogen and potassium levels, grown on Yasothon soil series (Oxic Paleustults). See Appendix E4.3 for ANOVA.

| N levels | K levels | | | | Average N |
|---|---|---|---|---|---|
| | $K_0$ | $K_1$ | $K_2$ | $K_3$ | |
| | | Leaf areas (cm$^2$/plant) | | | |
| $N_0$ | 1823 | 1852 | 1927 | 1926 | $1882^{b}$ |
| $N_1$ | 2882 | 3065 | 3165 | 2891 | $3001^{a}$ |
| $N_2$ | 3131 | 3196 | 2992 | 3109 | $3107^{a}$ |
| $N_3$ | 2921 | 3325 | 3320 | 3057 | $3156^{a}$ |
| Average K | 2689 | 2860 | 2851 | 2746 | SE = ±135.04 |
| | | Leaf area indices | | | |
| $N_0$ | 3.65 | 3.71 | 3.86 | 3.85 | $3.77^{b}$ |
| $N_1$ | 5.77 | 6.13 | 6.33 | 5.78 | $6.00^{a}$ |
| $N_2$ | 6.26 | 6.39 | 5.99 | 6.22 | $6.21^{a}$ |
| $N_3$ | 5.84 | 6.65 | 6.64 | 6.12 | $6.31^{a}$ |
| Average K | 5.38 | 5.72 | 5.71 | 5.49 | SE = ±0.27 |
| | | Crop growth rates # 2 (g/m$^2$/week) | | | |
| $N_0$ | 116.48 | 116.92 | 130.50 | 131.12 | $123.76^{c}$ |
| $N_1$ | 214.26 | 219.12 | 227.46 | 202.37 | $215.80^{b}$ |
| $N_2$ | 225.87 | 224.57 | 203.60 | 216.37 | $217.60^{b}$ |
| $N_3$ | 244.88 | 270.96 | 263.04 | 232.80 | $252.92^{a}$ |
| Average K | 200.37 | 207.89 | 206.15 | 195.67 | SE = ±17.28 |

Letters indicate significant differences of DMRT at probability of 0.05.
SE = Standard error of means.

At the fourth sampling period (9 weeks after emergence), the results showed that an increase in N level significantly increased total dry weights/ha up to $N_2$ level (Table 4.19), whilst an increase in K significantly increased total dry weights/ha between $K_0$ and $K_2$. An increase in N level significantly increased stem dry weights/plant but only up to $N_2$, whilst an increase in K level did not significantly increase stem dry weights/plant.

A clearer effect due to an increase in N level was found with leaf dry weights/plant, i.e. an increase in N level significantly increased leaf dry weights/plant; an increase in K level significantly increased leaf dry weights/plant but only up to $K_2$. N had a greater effect on leaf dry weights/plant than K. The results showed that an increase in N level significantly increased dead leaf dry weights/plant only at $N_1$ level and further increases did not significantly increase dead leaf dry weights of the sorghum plants. K had no significant effect.

Head dry weights were significantly increased with an increase in N level but up to $N_2$. K had no effect on head dry weights/plant.

The results indicated that an increase in N level significantly increased leaf areas/plant with mean values of 1,922, 2,595, 3,099, and 3,279 cm$^2$/plant for $N_0$, $N_1$, $N_2$, and $N_3$, respectively (Table 4.20). An increase in K level also significantly increased leaf areas/plant up to $K_2$ level only. N had a greater effect on leaf areas/plant than K. A similar trend was shown by LAI, i.e. an increase in N and K levels significantly increased LAI up to $N_2$ and $K_2$. LAI values followed a similar pattern as that of leaf areas/plant. With the highest values in both cases being linked to N rather than K.

An increase in N level significantly increased CGR of the sorghum plants up to $N_2$ level. Increase in K had no significant effect on CGR. In contrast, brix values significantly increased with an increase in K level whilst an increase in N level significantly decreased brix values. Brix values ranged from 8.37 to 6.96 for $N_0$ and $N_3$, respectively and from 6.95 to 8.42 for $K_0$ and $K_3$, respectively.

Table 4.19 Mean values of total dry weights, stem dry weights, leaf dry weights, dead leaf dry weights and head dry weights of the sorghum plants at 9 weeks after emergence as influenced by nitrogen and potassium levels, grown on Yasothon soil series (Oxic Paleustults). See Appendix E4.4 for ANOVA.

| N levels | K levels | | | | Average N |
|---|---|---|---|---|---|
| | $K_0$ | $K_1$ | $K_2$ | $K_3$ | |
| | | Total dry weights (kg/ha) | | | |
| $N_0$ | 7597 | 7572 | 8216 | 8406 | 7948$^c$ |
| $N_1$ | 11168 | 12589 | 12535 | 12641 | 12233$^b$ |
| $N_2$ | 13438 | 13660 | 13510 | 13954 | 13641$^a$ |
| $N_3$ | 13949 | 13692 | 14289 | 14174 | 14026$^a$ |
| Average K | 11538$^b$ | 11878$^{ab}$ | 12138$^a$ | 12294$^a$ | SE = ±384.56 |
| | | Stem dry weights (g/plant) | | | |
| $N_0$ | 24.30 | 24.38 | 26.51 | 27.66 | 25.71$^c$ |
| $N_1$ | 36.86 | 41.78 | 41.46 | 41.62 | 40.43$^b$ |
| $N_2$ | 43.86 | 44.40 | 43.91 | 44.91 | 44.27$^a$ |
| $N_3$ | 45.15 | 45.41 | 45.83 | 46.71 | 45.78$^a$ |
| Average K | 37.54 | 38.99 | 39.43 | 40.23 | SE = ±1.35 |
| | | Leaf dry weights (g/plant ) | | | |
| $N_0$ | 8.72 | 9.64 | 10.15 | 9.55 | 9.52$^d$ |
| $N_1$ | 11.57 | 13.16 | 13.46 | 13.21 | 12.85$^c$ |
| $N_2$ | 15.05 | 15.14 | 15.45 | 15.73 | 15.34$^b$ |
| $N_3$ | 16.19 | 14.70 | 17.61 | 16.45 | 16.24$^a$ |
| Average K | 12.88$^c$ | 13.16$^{bc}$ | 14.17$^a$ | 13.74$^{ab}$ | SE = ±0.49 |
| | | Dead leaf dry weights (g/plant) | | | |
| $N_0$ | 3.45 | 2.40 | 2.82 | 3.22 | 2.97$^b$ |
| $N_1$ | 4.77 | 4.89 | 4.72 | 5.19 | 4.89$^a$ |
| $N_2$ | 4.92 | 5.33 | 4.75 | 5.36 | 5.09$^a$ |
| $N_3$ | 5.08 | 4.95 | 4.77 | 4.26 | 4.77$^a$ |
| Average K | 4.56 | 4.39 | 4.27 | 4.51 | SE = ±0.28 |
| | | Head dry weights (g/plant) | | | |
| $N_0$ | 1.52 | 1.44 | 1.60 | 1.60 | 1.54$^c$ |
| $N_1$ | 2.64 | 3.12 | 3.04 | 3.19 | 3.00$^b$ |
| $N_2$ | 3.36 | 3.44 | 3.44 | 3.78 | 3.51$^a$ |
| $N_3$ | 3.32 | 3.40 | 3.24 | 3.46 | 3.36$^a$ |
| Average K | 2.71 | 2.85 | 2.83 | 3.01 | SE = ±0.16 |

Letters indicate significant differences of DMRT at probability of 0.05.
SE = Standard error of means.

Table 4.20 Mean values of leaf areas, leaf area indices, crop growth rates and brix values of the sorghum plants at 9 weeks after emergence as influenced by nitrogen and potassium levels, grown on Yasothon soil series (Oxic Paleustults). See Appendix E4.4 for ANOVA.

| N levels | K levels | | | | Average N |
|---|---|---|---|---|---|
| | $K_0$ | $K_1$ | $K_2$ | $K_3$ | |
| | | Leaf areas (cm$^2$/plant) | | | |
| $N_0$ | 1761 | 1947 | 2050 | 1930 | $1922^{d}$ |
| $N_1$ | 2336 | 2658 | 2719 | 2668 | $2595^{c}$ |
| $N_2$ | 3040 | 3057 | 3120 | 3177 | $3099^{b}$ |
| $N_3$ | 3270 | 2969 | 3556 | 3322 | $3279^{a}$ |
| Average K | $2602^{c}$ | $2658^{bc}$ | $2861^{a}$ | $2774^{ab}$ | SE = ±99.09 |
| | | Leaf area indices | | | |
| $N_0$ | 3.52 | 3.89 | 4.10 | 3.86 | $3.84^{c}$ |
| $N_1$ | 4.67 | 5.32 | 5.44 | 5.34 | $5.19^{b}$ |
| $N_2$ | 6.08 | 6.12 | 6.24 | 6.36 | $6.20^{a}$ |
| $N_3$ | 6.54 | 5.94 | 7.11 | 6.64 | $6.56^{a}$ |
| Average K | $5.20^{b}$ | $5.32^{bc}$ | $5.72^{a}$ | $5.55^{ab}$ | SE = ±0.20 |
| | | Crop growth rates # 3 (g/plant/week) | | | |
| $N_0$ | 162.79 | 156.46 | 173.15 | 175.19 | $166.90^{c}$ |
| $N_1$ | 199.80 | 263.76 | 251.15 | 276.43 | $247.79^{b}$ |
| $N_2$ | 297.17 | 304.05 | 305.87 | 320.04 | $306.78^{a}$ |
| $N_3$ | 289.67 | 247.78 | 285.17 | 307.47 | $282.52^{a}$ |
| Average K | 237.36 | 243.01 | 253.84 | 269.78 | SE = ±24.22 |
| | | Brix (%) | | | |
| $N_0$ | 7.45 | 7.52 | 8.59 | 9.93 | $8.37^{a}$ |
| $N_1$ | 6.95 | 7.44 | 7.70 | 8.08 | $7.54^{b}$ |
| $N_2$ | 6.98 | 7.17 | 7.49 | 7.95 | $7.40^{b}$ |
| $N_3$ | 6.42 | 6.72 | 6.97 | 7.72 | $6.96^{c}$ |
| Average K | $6.95^{c}$ | $7.21^{c}$ | $7.69^{b}$ | $8.42^{a}$ | SE = ±0.29 |

Letters indicate significant differences of DMRT at probability of 0.05.
SE = Standard error of means.

At the fifth sampling period (11 weeks after emergence), the results showed that total dry weights/ha of the sorghum plants significantly increased with an increase in N level up to $N_2$ with values of 11,686, 17,328 and 19,431 kg/ha for $N_0$, $N_1$, and $N_2$ respectively (Table 4.21). There were no statistical differences due to an increase in K level on total dry weights/ha of the sorghum plants. Similarly, an increase in N level significantly increased stem dry weights/plant whilst K had no significant effect.

The results showed that an increase in N level significantly increased leaf dry weights/plant up to $N_2$ whilst K did not. Leaf dry weights/plant ranged from 6.84 to 13.74 g/plant for $N_0$ and $N_2$, respectively. The results on dead leaf dry weights/plant indicated that an increase in N level significantly increased dead leaf dry weights/plant. The effect due to K was somewhat inconsistent, i.e. a high amount of dead leaf was found with $K_0$ and became smaller with $K_1$ and $K_2$ and then $K_3$ was similar to $K_0$. Head dry weights significantly increased with an increase in N but only up to $N_2$ level. An increase in K level significantly increased head dry weights/plant but only at the highest ($K_3$) level.

The results on leaf areas/plant revealed that an increase in N level significantly increased leaf areas/plant up to $N_2$ only (values of 1,190, 1,981, and 2,390 $cm^2$/plant for $N_0$, $N_1$and $N_2$) (Table 4.22). An increase in K level did not significantly increase leaf areas/plant. A similar result was found with both LAI and CGR i.e. an increase in N level significantly increased LAI and CGR of the sorghum plants whilst K did not. Leaf area duration significantly increased with an increase in both N and K levels, but the effect of N was greater at the higher application rates. Brix values were significantly decreased with increasing N, while increasing K level had a positive effect on brix % up to $K_2$.

Table 4.21 Mean values of total dry weights, stem dry weights, leaf dry weights, dead leaf dry weights and head dry weights of the sorghum plants at 11 weeks after emergence as influenced by nitrogen and potassium levels. See Appendix E4.5 for ANOVA.

| N levels | K levels | | | | Average N |
|---|---|---|---|---|---|
| | $K_0$ | $K_1$ | $K_2$ | $K_3$ | |
| | | Total dry weights (kg/ha) | | | |
| $N_0$ | 9579 | 11027 | 12720 | 13419 | $11686^{c}$ |
| $N_1$ | 16759 | 17344 | 17618 | 17589 | $17328^{b}$ |
| $N_2$ | 18950 | 19290 | 19486 | 19999 | $19431^{a}$ |
| $N_3$ | 20546 | 19932 | 20929 | 20791 | $20550^{a}$ |
| Average K | 16459 | 16898 | 17688 | 17950 | SE = ±928.01 |
| | | Stem dry weights (g/plant) | | | |
| $N_0$ | 33.81 | 40.77 | 45.54 | 45.37 | $41.37^{c}$ |
| $N_1$ | 58.02 | 58.77 | 59.46 | 58.59 | $58.71^{b}$ |
| $N_2$ | 61.93 | 63.31 | 63.77 | 64.17 | $63.30^{ab}$ |
| $N_3$ | 66.99 | 65.15 | 69.81 | 69.46 | $67.85^{a}$ |
| Average K | 55.19 | 57.00 | 59.65 | 59.40 | SE = ±3.25 |
| | | Leaf dry weights (g/plant) | | | |
| $N_0$ | 5.60 | 6.16 | 7.68 | 7.92 | $6.84^{c}$ |
| $N_1$ | 9.92 | 11.64 | 11.84 | 12.16 | $11.39^{b}$ |
| $N_2$ | 12.56 | 13.60 | 14.48 | 14.32 | $13.74^{a}$ |
| $N_3$ | 14.32 | 14.32 | 14.40 | 14.48 | $14.38^{a}$ |
| Average K | 10.60 | 11.43 | 12.10 | 12.22 | SE = ±1.04 |
| | | Dead leaf dry weights (g/plant) | | | |
| $N_0$ | 3.31 | 2.83 | 3.77 | 4.79 | $3.68^{b}$ |
| $N_1$ | 4.79 | 3.60 | 4.08 | 4.28 | $4.19^{ab}$ |
| $N_2$ | 4.86 | 4.42 | 3.34 | 5.00 | $4.41^{a}$ |
| $N_3$ | 5.28 | 4.86 | 3.99 | 3.97 | $4.53^{a}$ |
| Average K | $4.56^{a}$ | $3.93^{b}$ | $3.80^{b}$ | $4.51^{a}$ | SE = ±0.36 |
| | | Head dry weights (g/plant) | | | |
| $N_0$ | 5.18 | 5.39 | 6.61 | 9.02 | $6.55^{c}$ |
| $N_1$ | 11.07 | 12.72 | 12.72 | 12.92 | $12.36^{b}$ |
| $N_2$ | 15.41 | 15.12 | 15.85 | 16.50 | $15.72^{a}$ |
| $N_3$ | 16.15 | 15.34 | 16.45 | 16.05 | $16.00^{a}$ |
| Average K | $11.95^{b}$ | $12.14^{b}$ | $12.91^{ab}$ | $13.62^{a}$ | SE = ±0.79 |

Letters indicate significant differences of DMRT at probability of 0.05.
SE = Standard error of means.

**Table 4.22** Mean values of leaf areas, leaf area indices, crop growth rates, leaf area duration and brix values of the sorghum plants at 11 weeks after emergence as influenced by nitrogen and potassium levels, grown on Yasothon soil series (Oxic Paleustults). See Appendix E4.5 for ANOVA.

| N levels | K levels | | | | Average N |
|---|---|---|---|---|---|
| | $K_0$ | $K_1$ | $K_2$ | $K_3$ | |
| | | Leaf areas ($\mathrm{cm^2}$/plant) | | | |
| $N_0$ | 974 | 1072 | 1336 | 1378 | 1190$^{c}$ |
| $N_1$ | 1726 | 2025 | 2059 | 2115 | 1981$^{b}$ |
| $N_2$ | 2185 | 2366 | 2519 | 2491 | 2390$^{a}$ |
| $N_3$ | 2491 | 2491 | 2505 | 2519 | 2502$^{a}$ |
| Average K | 1844 | 1989 | 2105 | 2126 | SE = ±181.26 |
| | | Leaf area indices | | | |
| $N_0$ | 1.95 | 2.14 | 2.67 | 2.75 | 2.38$^{c}$ |
| $N_1$ | 3.45 | 4.05 | 4.12 | 4.23 | 3.96$^{b}$ |
| $N_2$ | 4.37 | 4.73 | 5.04 | 4.98 | 4.78$^{a}$ |
| $N_3$ | 4.98 | 4.98 | 5.01 | 5.04 | 5.00$^{a}$ |
| Average K | 3.69 | 3.98 | 4.21 | 4.25 | SE = ±0.36 |
| | | Crop growth rates # 4 (g/plant/week) | | | |
| $N_0$ | 99.07 | 172.79 | 225.21 | 250.61 | 186.92$^{c}$ |
| $N_1$ | 279.54 | 237.79 | 254.18 | 247.40 | 254.73$^{b}$ |
| $N_2$ | 275.63 | 281.50 | 298.78 | 302.25 | 289.54$^{ab}$ |
| $N_3$ | 329.85 | 312.02 | 332.01 | 330.87 | 326.19$^{a}$ |
| Average K | 246.02 | 251.03 | 277.55 | 282.78 | SE = ±43.28 |
| | | Leaf area duration ($\mathrm{m^2}$.week) | | | |
| $N_0$ | 1.17 | 1.24 | 1.31 | 1.32 | 1.26$^{d}$ |
| $N_1$ | 1.68 | 1.83 | 1.87 | 1.84 | 1.81$^{c}$ |
| $N_2$ | 1.94 | 1.99 | 2.01 | 2.03 | 1.99$^{b}$ |
| $N_3$ | 2.00 | 2.03 | 2.15 | 2.07 | 2.06$^{a}$ |
| Average K | 1.70$^{c}$ | 1.77$^{b}$ | 1.84$^{a}$ | 1.82$^{ab}$ | SE = ±0.04 |
| | | Brix (%) | | | |
| $N_0$ | 11.17 | 12.80 | 14.05 | 14.71 | 13.18$^{a}$ |
| $N_1$ | 10.99 | 11.86 | 12.40 | 12.35 | 11.90$^{b}$ |
| $N_2$ | 11.04 | 11.27 | 12.13 | 12.77 | 11.80$^{bc}$ |
| $N_3$ | 10.47 | 11.27 | 11.64 | 11.98 | 11.34$^{c}$ |
| Average K | 10.92$^{c}$ | 11.80$^{b}$ | 12.56$^{a}$ | 12.95$^{a}$ | SE = ±0.33 |

Letters indicate significant differences of DMRT at probability of 0.05.
SE = Standard error of means.

At the sixth sampling period (13 weeks after emergence), the results showed that an increase in N level also significantly increased total dry weights/ha of the sorghum plants with the values of 13,851, 20,370, 22,211, and 23,731 kg/ha for $N_0$, $N_1$, $N_2$, and $N_3$, respectively (Table 4.23). An increase in K level significantly increased total dry weights/ha but the effect of K was somewhat less than the effect due to N, i.e. N had a greater effect on total dry weights/ha of the sorghum plants than K. Stem dry weights/plant also significantly increased with an increase in N level whilst an increase in K level had no effect on stem growth. A similar result was also attained for leaf growth, i.e. an increase in N level significantly increased leaf dry weights/plant whilst K had no significant effect.

The results also showed that an increase in N level significantly increased dead leaf dry weights/plant of the sorghum plants, whilst K did not. An increase in N level significantly increased head dry weights/plant only up to $N_1$ whilst further increases did not increase head dry weights/plant. An increase in K level significantly increased head dry weights/plant at the higher concentrations, especially $K_3$.

The results showed that an increase in N level significantly increased leaf areas/plant (1,276, 2,064, 2,398, and 2,612 $cm^2$/plant for $N_0$, $N_1$, $N_2$, and $N_3$, respectively) (Table 4.24). Leaf areas/plant for all levels of N at this sampling period were, in most cases, slightly greater than that of the fifth sampling period. There were no significant differences due to an increase in K level on leaf areas/plant. A similar result was found with LAI, i.e. LAI significantly increased with an increase in N level but not with K.

An increase in N level significantly increased CGR of the sorghum plants but with a degree of inconsistency, in general, N appears to promote CGR whilst K had no significant effect.

An increase in N level significantly increased D with the values ranging from 1.51 to 2.57 $m^2$.week for $N_0$ and $N_3$, respectively. An increase in K level significantly increased D up to $K_2$ level. N appeared to have a greater effect on D than K.

An increase in N level significantly increased dry seed head yields/ha (4,084, 6,953, 7,970, and 8,595 kg/ha for $N_0$, $N_1$, $N_2$, and $N_3$, respectively). An increase in K level also significantly increased dry seed head yields/ha but the increase was up to $K_2$ level only (Table 4.25).

An increase in N level significantly increased seed yields/ha (values ranged from 3,442 to 7,244 kg/ha for $N_0$ and $N_3$, respectively). An increase in K level also significantly increased seed yields/ha up to $K_2$ level. With 1000-seed weights, the results showed that an increase in N level significantly increased seed weight (size) of the sorghum plants only up to $N_1$ level whilst K had no significant effect on seed size.

Table 4.23 Mean values of total dry weights, stem dry weights, leaf dry weights, dead leaf dry weights and head dry weights of the sorghum plants at 13 weeks after emergence as influenced by nitrogen and potassium levels, grown on Yasothon soil series (Oxic Paleustults). See Appendix E4.6 for ANOVA.

| N levels | K levels | | | | Average N |
|---|---|---|---|---|---|
| | $K_0$ | $K_1$ | $K_2$ | $K_3$ | |
| | | Total dry weights (kg/ha) | | | |
| $N_0$ | 11858 | 13404 | 14607 | 15536 | 13851$^{d}$ |
| $N_1$ | 19514 | 20645 | 20724 | 20596 | 20370$^{c}$ |
| $N_2$ | 21894 | 22020 | 22187 | 22743 | 22211$^{b}$ |
| $N_3$ | 23258 | 23397 | 23976 | 24294 | 23731$^{a}$ |
| Average K | 19131$^{b}$ | 19867$^{ab}$ | 20374$^{a}$ | 20792$^{a}$ | SE = ±818.30 |
| | | Stem dry weights (g/plant) | | | |
| $N_0$ | 38.64 | 44.62 | 47.32 | 46.46 | 44.26$^{d}$ |
| $N_1$ | 54.63 | 61.47 | 62.62 | 61.81 | 60.13$^{c}$ |
| $N_2$ | 66.13 | 67.68 | 66.18 | 66.82 | 66.70$^{b}$ |
| $N_3$ | 69.75 | 69.81 | 72.57 | 74.58 | 71.68$^{a}$ |
| Average K | 57.29 | 60.90 | 62.17 | 62.42 | SE = ±2.98 |
| | | Leaf dry weights (g/plant) | | | |
| $N_0$ | 6.23 | 6.73 | 6.77 | 7.55 | 6.82$^{d}$ |
| $N_1$ | 10.98 | 10.93 | 11.06 | 11.14 | 11.03$^{c}$ |
| $N_2$ | 12.83 | 12.50 | 12.91 | 13.00 | 12.81$^{b}$ |
| $N_3$ | 14.15 | 13.08 | 13.82 | 14.77 | 13.96$^{a}$ |
| Average K | 11.05 | 10.81 | 11.14 | 11.62 | SE = ±0.53 |
| | | Dead leaf dry weights (g/plant) | | | |
| $N_0$ | 4.35 | 4.63 | 5.46 | 4.90 | 4.84$^{c}$ |
| $N_1$ | 5.00 | 5.18 | 5.18 | 5.27 | 5.16$^{c}$ |
| $N_2$ | 6.38 | 5.55 | 5.27 | 6.20 | 5.85$^{b}$ |
| $N_3$ | 6.75 | 6.57 | 6.20 | 6.93 | 6.61$^{a}$ |
| Average K | 5.62 | 5.48 | 5.53 | 5.83 | SE = ±0.47 |
| | | Head dry weights (g/plant) | | | |
| $N_0$ | 10.08 | 11.05 | 13.49 | 18.77 | 13.35$^{b}$ |
| $N_1$ | 26.98 | 25.65 | 24.77 | 24.76 | 25.54$^{a}$ |
| $N_2$ | 24.13 | 24.38 | 26.57 | 27.71 | 25.70$^{a}$ |
| $N_3$ | 25.64 | 27.55 | 27.32 | 25.19 | 26.43$^{a}$ |
| Average K | 21.71$^{b}$ | 22.16$^{b}$ | 23.04$^{ab}$ | 24.11$^{a}$ | SE = ±0.97 |

Letters indicate significant differences of DMRT at probability of 0.05.
SE = Standard error of means.

Table 4.24 Mean values of leaf areas, leaf area indices, crop growth rates and leaf area duration of the sorghum plants at 13 weeks after emergence as influenced by nitrogen and potassium levels, grown on Yasothon soil series (Oxic Paleustults). See Appendix E4.6 for ANOVA.

| N levels | K levels | | | | Average N |
|---|---|---|---|---|---|
| | $K_0$ | $K_1$ | $K_2$ | $K_3$ | |
| | | Leaf areas (cm$^2$/plant) | | | |
| $N_0$ | 1166 | 1259 | 1267 | 1413 | 1276$^d$ |
| $N_1$ | 2054 | 2046 | 2070 | 2085 | 2064$^c$ |
| $N_2$ | 2402 | 2340 | 2417 | 2433 | 2398$^b$ |
| $N_3$ | 2649 | 2448 | 2587 | 2765 | 2612$^a$ |
| Average K | 2068 | 2023 | 2085 | 2174 | SE = ±100.08 |
| | | Leaf area indices | | | |
| $N_0$ | 2.33 | 2.52 | 2.53 | 2.83 | 2.55$^d$ |
| $N_1$ | 4.11 | 4.09 | 4.14 | 4.17 | 4.13$^c$ |
| $N_2$ | 4.82 | 4.68 | 4.84 | 4.87 | 4.80$^b$ |
| $N_3$ | 5.30 | 4.90 | 5.17 | 5.53 | 5.23$^a$ |
| Average K | 4.14 | 4.05 | 4.17 | 4.35 | SE = ±0.20 |
| | | Crop growth rates # 5 (g/plant/week) | | | |
| $N_0$ | 113.99 | 118.83 | 94.31 | 105.88 | 108.25$^c$ |
| $N_1$ | 137.75 | 165.01 | 155.28 | 150.34 | 152.10$^{ab}$ |
| $N_2$ | 147.17 | 136.53 | 135.06 | 137.18 | 138.99$^b$ |
| $N_3$ | 135.62 | 173.34 | 152.38 | 175.16 | 159.13$^a$ |
| Average K | 133.63 | 148.43 | 134.26 | 142.14 | SE = ±13.40 |
| | | Leaf area duration(m$^2$.week) | | | |
| $N_0$ | 1.39 | 1.47 | 1.56 | 1.60 | 1.51$^d$ |
| $N_1$ | 2.06 | 2.23 | 2.28 | 2.26 | 2.21$^c$ |
| $N_2$ | 2.40 | 2.46 | 2.50 | 2.53 | 2.47$^b$ |
| $N_3$ | 2.51 | 2.52 | 2.66 | 2.59 | 2.57$^a$ |
| Average K | 2.09$^b$ | 2.17$^{ab}$ | 2.25$^a$ | 2.25$^a$ | SE = ±0.06 |

Letters indicate significant differences of DMRT at probability of 0.05.
SE = Standard error of means.

Table 4.25 Mean values of dry seed head yields, seed yields and 1000-seed weights of the sorghum plants as influenced by nitrogen and potassium levels, grown on Yasothon soil series (Oxic Paleustults). See Appendix E4.6 for ANOVA.

| N levels | K levels | | | | Average N |
|---|---|---|---|---|---|
| | $K_0$ | $K_1$ | $K_2$ | $K_3$ | |
| | | Dry seed head yields (kg/ha) | | | |
| $N_0$ | 3737 | 3774 | 4369 | 4454 | $4084^d$ |
| $N_1$ | 6477 | 6885 | 7089 | 7361 | $6953^c$ |
| $N_2$ | 7650 | 7800 | 8160 | 8269 | $7970^b$ |
| $N_3$ | 8259 | 8483 | 9027 | 8612 | $8595^a$ |
| Average K | $6531^b$ | $6736^{ab}$ | $7161^a$ | $7174^a$ | SE = ±313.24 |
| | | Seed yields (kg/ha) | | | |
| $N_0$ | 3149 | 3181 | 3682 | 3754 | $3442^d$ |
| $N_1$ | 5459 | 5803 | 5975 | 6204 | $5860^c$ |
| $N_2$ | 6447 | 6574 | 6877 | 6969 | $6717^b$ |
| $N_3$ | 6960 | 7149 | 7608 | 7258 | $7244^a$ |
| Average K | $5504^b$ | $5677^{ab}$ | $6036^a$ | $6046^a$ | SE = ±264.02 |
| | | 1000-seed weights (g) | | | |
| $N_0$ | 24.37 | 23.15 | 24.83 | 27.28 | $24.91^b$ |
| $N_1$ | 26.28 | 26.20 | 25.96 | 27.06 | $26.38^a$ |
| $N_2$ | 27.06 | 26.95 | 29.79 | 26.81 | $27.65^a$ |
| $N_3$ | 26.82 | 26.54 | 27.39 | 27.96 | $27.18^a$ |
| Average K | 26.13 | 25.71 | 26.99 | 27.28 | SE = ±0.94 |

Letters indicate significant differences of DMRT at probability of 0.05.

### 4.5.4 Crude Protein (CP) Contents, Neutral Detergent Fibre (NDF) and Acid Detergent Fibre (ADF) Contents, and Dry Matter Degradability (DMD)

The results showed that an increase in N level significantly increased CP of the sorghum plants (values of 5.25, 7.74, 8.93, and 9.71 % for $N_0$, $N_1$, $N_2$, and $N_3$, respectively) (Table 4.26). An increase in K level did not increase CP, i.e. N had a very significant effect on CP content whilst K had no significant effect. N and K levels had no significant effect on NDF, ADF, and DMD of the sorghum plants.

**Table 4.26** Mean values of estimated crude protein, neutral detergent fibre (NDF), acid detergent fibre (ADF) contents and dry matter degradability of the sorghum plants at 10 weeks after emergence as influenced by nitrogen and potassium levels, grown on Yasothon soil series (Oxic Paleustults). See Appendix E4.7 for ANOVA.

| N levels | K levels | | | | Average N |
|---|---|---|---|---|---|
| | $K_0$ | $K_1$ | $K_2$ | $K_3$ | |
| | Crude protein (% on DM basis) | | | | |
| $N_0$ | 4.91 | 5.19 | 5.35 | 5.56 | $5.25^d$ |
| $N_1$ | 8.32 | 7.30 | 8.07 | 7.25 | $7.74^c$ |
| $N_2$ | 8.99 | 9.07 | 8.80 | 8.87 | $8.93^b$ |
| $N_3$ | 9.56 | 9.97 | 9.68 | 9.62 | $9.71^a$ |
| Average K | 7.95 | 7.88 | 7.98 | 7.83 | SE = ±0.23 |
| | NDF (% on DM basis) | | | | |
| $N_0$ | 73.63 | 75.94 | 73.06 | 73.62 | 74.06 |
| $N_1$ | 72.53 | 72.64 | 74.21 | 72.57 | 72.99 |
| $N_2$ | 72.75 | 76.25 | 72.44 | 74.05 | 73.87 |
| $N_3$ | 75.33 | 74.39 | 74.09 | 74.31 | 74.53 |
| Average K | 73.56 | 74.81 | 73.45 | 73.64 | SE = ±1.26 |
| | ADF (% on DM basis) | | | | |
| $N_0$ | 45.13 | 44.21 | 42.05 | 43.31 | 43.68 |
| $N_1$ | 42.63 | 41.66 | 41.24 | 42.16 | 41.92 |
| $N_2$ | 43.20 | 45.42 | 41.58 | 44.26 | 43.62 |
| $N_3$ | 44.65 | 44.45 | 42.90 | 42.52 | 43.63 |
| Average K | 43.90 | 43.94 | 41.94 | 43.06 | SE = ±1.24 |
| | Dry matter degradability (%) | | | | |
| $N_0$ | 46.67 | 47.36 | 51.63 | 49.65 | 48.83 |
| $N_1$ | 53.34 | 50.59 | 49.97 | 50.56 | 51.12 |
| $N_2$ | 53.52 | 47.24 | 53.08 | 51.59 | 51.36 |
| $N_3$ | 48.91 | 51.45 | 51.43 | 51.92 | 50.93 |
| Average K | 50.61 | 49.16 | 51.53 | 50.93 | SE = ±1.80 |

Letters indicate significant differences of DMRT at probability of 0.05.
SE = Standard error of means.

### 4.5.5 Relationship Between Total Fertiliser Addition and Total Dry Weights of the Sorghum Plants

The result showed that total fertiliser addition in terms of the combined effects of N and K was significantly associated with total dry weights. $R^2$ of 0.63 indicated that 63 % of the variation in the mean total dry weight was accounted for by the linear function of the total fertiliser addition (Fig. 4.5).

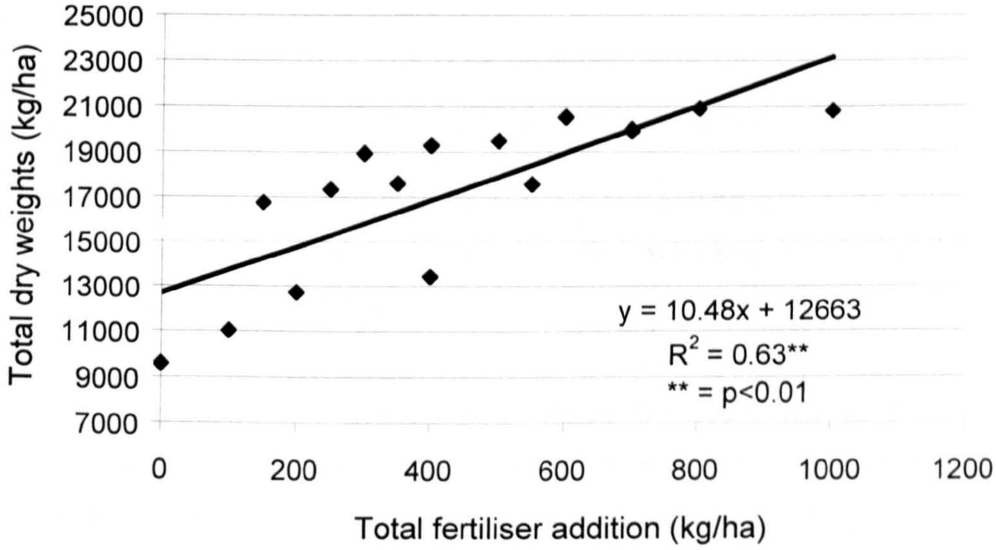

Fig. 4.5 Relationship between total fertiliser addition and total dry weights of the sorghum plants harvested at 11 weeks after emergence, grown on Yasothon soil series (Oxic Paleustults), Northeast Thailand.

### 4.5.6 Relationship Between Total Fertiliser Addition and Seed Yields of the Sorghum Plants

The result showed that total fertiliser addition in terms of the combined effects of N and K was significantly associated with seed yields. $R^2$ of 0.63 indicated that 63 % of the variation in the mean seed yield was accounted for by the linear function of the total fertiliser addition (Fig. 4.6).

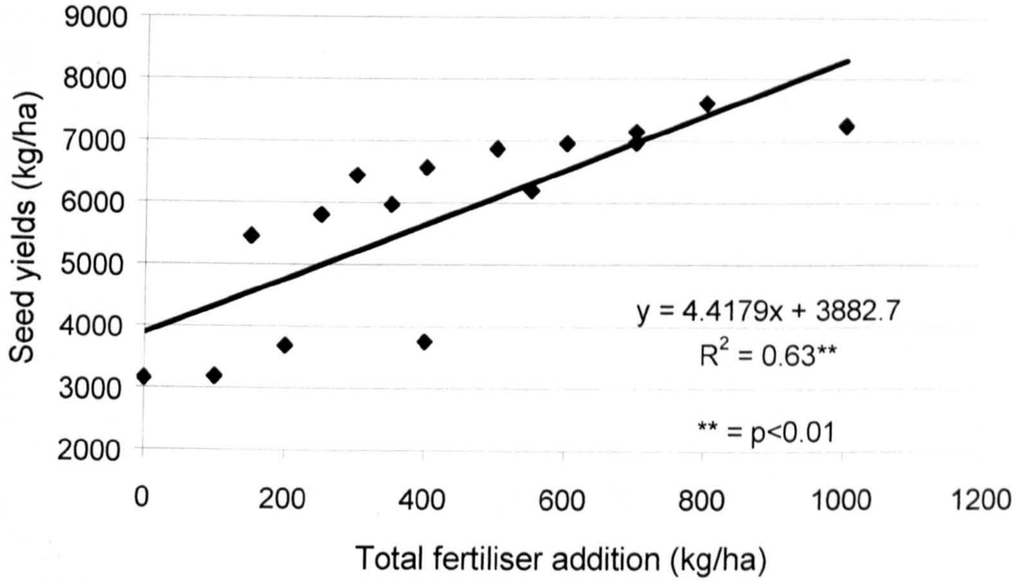

Fig. 4.6 Relationship between total fertiliser addition and seed yields of the sorghum plants grown on Yasothon soil series (Oxic Paleustults), Northeast Thailand.

### 4.5.7 Relationship Between Leaf Area Duration (D) and Total Dry Weights and the Relationship Between D and Seed Yields

The result showed that D was significantly associated with total dry weights. $R^2$ of 0.97 indicated that 97 % of the variation in the mean total dry weight was accounted for by the linear function of the D value (Fig. 4.7). A similar result as that of the relationship between total dry weights and D was found with the relationship between seed yields and D. $R^2$ of 0.99 indicated that 99 % of the variation in the mean seed yield was accounted for by the linear function of the D value (Fig. 4.8).

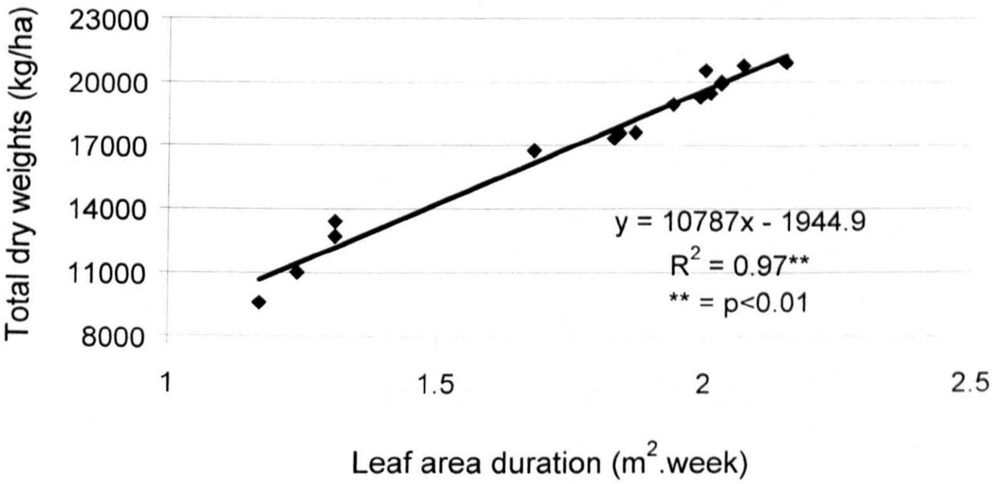

Fig. 4.7 Relationship between leaf area duration and total dry weights of the sorghum plants at 11 weeks after emergence as influenced by the combined effects of nitrogen and potassium application rates, grown on Yasothon soil series (Oxic Paleustults).

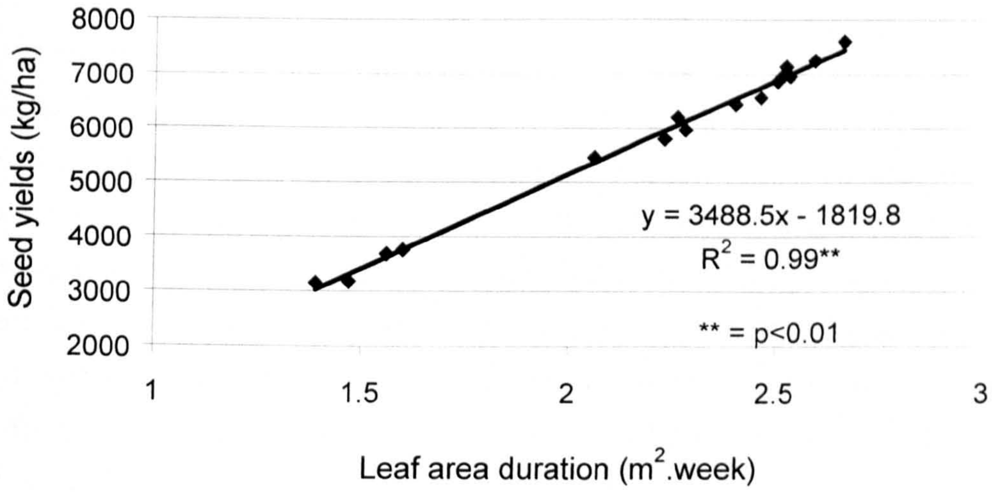

Fig. 4.8 Relationship between leaf area duration and seed yields of the sorghum plants as influenced by the combined effects of nitrogen and potassium application rates, grown on Yasothon soil series (Oxic Paleustults).

## 4.6 Combined Analysis of Total Dry Weights and Seed Yields

### 4.6.1 Introduction

In order to further investigate possible effects of changing the sowing period, location, and the application of fermented cattle manure in relation to nitrogen and potassium levels on total dry weights and seed yields/ha of the sorghum plants, some results on growth and yields of the sorghum plants were used for combined analysis calculations (Gomez and Gomez, 1984). This was to justify more clearly the effects due to time of sowing of seeds, location and manure application in relation to nitrogen and potassium levels added to the soil.

### 4.6.2 Results

#### 4.6.2.1 Combined Analysis on Seed Yields of the Sorghum Plants Between Experiment 2 and Experiment 3

The results on combined analysis calculations on seed yields between the two experiments showed that there were some highly significant effects due to Location, Location x Nitrogen, and Nitrogen application alone whilst the effect due to potassium was significant only at the 5 % level (Table 4.27). There were no significant interactions found on Location x Potassium, Location x Nitrogen x Potassium, and the interaction between Nitrogen x Potassium. Therefore, seed yields depend most on Location, the interaction between Location and Nitrogen, and Nitrogen application alone whilst potassium had a secondary significant effect on seed yields of the sorghum plants. Seed yields significantly increased with an increase in N level up to $N_2$ whilst K up to only $K_1$ with seed yields of 4,884 and 4,510 kg/ha, respectively. $N_2K_1$ gave a seed yield of 4,729 kg/ha but the highest seed yield was with $N_3K_2$; a seed yield of 5,674 kg/ha.

Table 4.27 Combined analysis of means of seed yields of the sorghum plants between Experiment 2 and Experiment 3, grown on Yasothon soil series (Oxic Paleustults) at Khon Kaen University, Thailand. ANOVA (n=16).

| N levels | K levels | | | | Average N |
|---|---|---|---|---|---|
| | $K_0$ | $K_1$ | $K_2$ | $K_3$ | |
| | | Seed yields (kg/ha) | | | |
| $N_0$ | 2808 | 3203 | 3422 | 3032 | $3116^{c}$ |
| $N_1$ | 4211 | 4895 | 4591 | 4470 | $4542^{b}$ |
| $N_2$ | 4783 | 4729 | 5084 | 4942 | $4884^{a}$ |
| $N_3$ | 4925 | 5212 | 5674 | 4932 | $5186^{a}$ |
| Average K | $4182^{c}$ | $4510^{ab}$ | $4693^{a}$ | $4344^{bc}$ | |

Letters indicate significant differences of DMRT at probability of 0.05.

| Items | Significant levels | | | | | | | CV | Std |
|---|---|---|---|---|---|---|---|---|---|
| | L | L x N | L x K | L x N x K | N | K | N x K | (%) | Error(±) |
| Seed yields | ** | ** | NS | NS | ** | * | NS | 14.11 | 312.74 |

** = Probability ≤ 0.01. * = Probability ≤ 0.05. NS = Non Significant.

CV = Coefficient of variations. Std Error = Standard error of means.

L = Location. N = Nitrogen. K = Potassium.

### 4.6.2.2 Combined Analysis on Total Dry Weights of the Sorghum Plants Between Experiment 3 and Experiment 4

The combined analysis on total dry weights/ha between Experiment 3 and Experiment 4 showed that there were some highly significant effects due to sowing Season, sowing Season x Nitrogen, Nitrogen and Potassium alone on total dry weights/ha of the sorghum plants whilst the effects due to sowing Season x Potassium, sowing Season x Nitrogen x Potassium and N x K had no significant effect on total dry weights/ha of the sorghum plants (Table 4.28). Therefore, nitrogen and potassium had some highly significant effects on total dry weights/ha of the sorghum plants and also the sowing season. Total dry weights/ha significantly increased with an increase in N level and the highest N ($N_3$) level had a total dry weight of 17,784 kg/ha, whilst an increase in K level significantly increased total dry weights up to $K_2$

only with a value of 15,005 kg/ha. The $N_3K_2$ treatment gave the highest total dry weight of 18,536 kg/ha.

Table 4.28 Combined analysis of means of total dry weights of the sorghum plants at 11 weeks after emergence between Experiment 3 (rainy season 1999) and Experiment 4 (dry season 2000) as affected by nitrogen and potassium levels grown on Yasothon soil series (Oxic Paleustults) and ANOVA (n=16).

| N levels | K levels | | | | Average N |
|---|---|---|---|---|---|
| | $K_0$ | $K_1$ | $K_2$ | $K_3$ | |
| | Total dry weights (kg/ha) | | | | |
| $N_0$ | 8548 | 9556 | 10594 | 11204 | $9976^d$ |
| $N_1$ | 13419 | 14.53 | 14677 | 14990 | $14303^c$ |
| $N_2$ | 15542 | 15940 | 16184 | 16607 | $16068^b$ |
| $N_3$ | 17158 | 17408 | 18536 | 18005 | $17784^a$ |
| Average K | $13685^b$ | $14239^b$ | $15005^a$ | $15202^a$ | |

Letters indicate significant differences of DMRT at probability of 0.05.

| Items | Significant levels | | | | | | | CV | Std |
|---|---|---|---|---|---|---|---|---|---|
| | S | S x N | S x K | S x N x K | N | K | N x K | (%) | Error(±) |
| Total dry weights | ** | ** | NS | NS | ** | ** | NS | 9.43 | 685.52 |

** = Probability ≤ 0.01. NS = Non Significant.

CV = Coefficient of variations. Std Error = Standard error of means.

S = Season. N = Nitrogen. K = Potassium.

### 4.6.2.3 Combined Analysis on Seed Yields of the Sorghum Plants Between Experiment 3 and Experiment 4

The results showed that there were some highly significant effects on the effect due to sowing Season alone, sowing Season x Nitrogen, Nitrogen and Potassium individually whilst the effects due to Sowing Season x Potassium, Sowing season x Nitrogen x Potassium, and Nitrogen x Potassium had no significant effect on seed yields of the sorghum plants (Table 4.29). Therefore, seed yields of the sorghum plants depend most on sowing season, Sowing season and Nitrogen interaction, and both Nitrogen and Potassium alone. Seed yields significantly increased up to $N_2$ but $N_3$ level gave the highest seed yield/ha of 6,253 kg/ha, whilst an increase in K level significantly increased seed yields up to $K_2$ with a seed yield of 5,532 kg/ha. The best treatment was found with $N_3K_2$ with the value of 6,702 kg/ha.

Table 4.29 Combined analysis of means of seed yields of the sorghum plants between Experiment 3 in rainy season 1999 and Experiment 4 in dry season 2000 as influenced by nitrogen and potassium levels grown on Yasothon soil series (Oxic Paleustults) and ANOVA (n=16).

| N levels | K levels | | | | Average N |
|---|---|---|---|---|---|
| | $K_0$ | $K_1$ | $K_2$ | $K_3$ | |
| | | Seed yields (kg/ha) | | | |
| $N_0$ | 3264 | 3434 | 3799 | 3841 | $3585^c$ |
| $N_1$ | 4993 | 5559 | 5400 | 5398 | $5338^b$ |
| $N_2$ | 5732 | 5686 | 6226 | 6168 | $5953^a$ |
| $N_3$ | 6028 | 6137 | 6702 | 6145 | $6253^a$ |
| Average K | $5004^b$ | $5204^{ab}$ | $5532^a$ | $5388^a$ | |

Letters indicate significant differences of DMRT at probability of 0.05.

| Items | Significant levels | | | | | | | CV | Std |
|---|---|---|---|---|---|---|---|---|---|
| | S | S x N | S x K | S x N x K | N | K | N x K | (%) | Error(±) |
| Seed yields | ** | ** | NS | NS | ** | ** | NS | 12.75 | 336.74 |

** = Probability ≤ 0.01. NS = Non Significant.

CV = Coefficient of variations. Std Error = Standard error of means.

S = Season. N = Nitrogen. K = Potassium.

## 4.7 Discussion

The initial soil analysis data showed that mean pH value was at a reasonable level (6.1), however, soil organic matter % was relatively low (0.6%). This was also found with soil nitrogen %, and extractable potassium, whilst soil available phosphorus was presumably adequate for the growth of the crop plants (Shelton *et al.*, 1979; Mengel and Kirkby, 1987; and Suksri 1999). At the final harvest of the sorghum plants, soil phosphorus and potassium were much higher than the initial values (soil organic matter was similar to the initial value). These results suggest a rapid decomposition rate of the cattle manure applied. This is probably due to the high environmental temperature in the dry season increasing activities of microorganisms as reported by Ratnapradipa (1996) with maize plants grown on the sub soil group Satuk soil series, which belongs to the same great soil group as Yasothon. The data for soil analysis at the final harvest indicated that the sorghum plants had adequate amounts of soil nutrients for optimum growth.

With this dry season experiment, the results showed that during the initial growing period, the growth of the sorghum plants was facilitated well by the use of overhead sprinkler irrigation where the plants received irrigation water for 3 times/week for the period of five weeks before rainwater was available to the sorghum plants (Appendix B5.3). The effect due to nitrogen showed that an increase in N level significantly increased total dry weights/ha, stem dry weights, leaf dry weights, and leaf areas/plant and LAI whilst K had no effect. This could be attributed to the greater effect of nitrogen on vegetative growth of the crop plants. Suksri and Wongwiwatchai (1988) stated that top growth of cassava (*Manihot esculenta* Crantz) grown on Yasothon soil was promoted most by the higher levels of nitrogen chemical fertiliser rather than potassium chemical fertiliser. This case could possibly be applied to many kinds of crop plants including sorghum. A clearer effect due to an increase in N level was found with the subsequent sampling periods, i.e. nitrogen promoted top growth of the sorghum plants whilst potassium did not (Suksri, 1992 and 1999). However, dead leaf dry weights of the sorghum plants were accumulating from the second sampling period. This could be attributable to an inadequate amount of soil moisture rather than leaf senescence when the sorghum plants had been grown for less than five weeks; another reason for this could be the high environmental air temperature particularly during daytime where the temperature exceeded 38 $^{0}$ C in April 2001 hence the plants required high amounts of soil water in order to cope with the high evapo-transpiration rate and associated leaf cooling (Appendix B5.2). During the fifth week the results also indicated that an increase in both N and K levels significantly increased leaf dry weights but K seems to be less effective when compared with nitrogen. The results suggested that both N and K fertilisers had significant effects on vegetative growth during the period when the sorghum plants reached the juvenile stage. Therefore, it seems likely that the sorghum plants required large amounts of both N and K at this stage of growth and development but with a higher requirement for N than for K. At this stage LAI values only ranged from 3.07 to 4.64. These are relatively low values and presumably 100 % light interception would have been possible by the leaf canopy. Hence there was no competition for radiant energy among leaves at this stage. The sorghum plants were relatively young and had not attained the maximum LAI yet. The maximum LAI for this type of leaf structure in the semi-arid tropical zone should range from 8 -10 as stated by Suksri (1991, 1992, and 1999). At this level of LAI, 90 % of light interception could be fairly distributed among the leaf canopies of the sorghum plants. In this experiment, maximum LAI was attained when the sorghum plants reached the age of nine weeks after emergence with the maximum value of 7.11. This value could be considered as a sub-optimal value for growth the sorghum plants.

A high value of LAI may have some negative effects on growth of some crop plants, e.g. Tanaka (1966) with tropical rice (*Oryza stiva* L.) pointed out that under high plant density, the rice plants were unable to utilise high amounts of nitrogen hence reflecting interaction between high mutual shading LAI values and other limiting factors could be the amount of solar radiation and the genotype of the rice plants. Tanaka's experiment was carried out in Japan (under lower light intensity) unlike the condition at Khon Kaen, Thailand where high radiant energy was available in the dry season under clear sky conditions. A similar finding was reported by the work of van

Oosterom *et al.* (2001). They showed that when the value of LAI of the sorghum plants exceeded 2-3 then nitrogen contents in the sorghum stover declined. This suggested that nitrogen utilisation by the sorghum plants could be affected by a high LAI in spite of a low amount of radiant energy. However, the results on CP contents of the sorghum plants found with the present work did not show any good agreement with this finding. When LAI values were between 3.8-6.5, the CP % significantly increased with an increase in N level. The values of LAI attained with this experiment were much greater than those reported by Areerak *et al.* (1999) but similar to those of Mastrorilli *et al.* (1999). However, LAI values of this experiment were sub-optimal (maximum value of 7.11 in $N_3K_2$ at 9 weeks after emergence), which were not approaching maximum value for high crop growth and yields as reported by Birke (1965); and Suksri (1999).

In most of the sampling periods, the results revealed that an increase in N level significantly increased total dry weights/ha, stem dry weights/plant, leaf areas/plant, LAI, and CGR of the sorghum plants. This could have been attributed to the significant effect of nitrogen as previously discussed whilst an increase in K level did increase total dry weights/ha, stem dry weights/plant, LAI, and CGR of the sorghum plants but to a lesser extent. This could be attributable to the fact that potassium has its significant role in assisting in the translocation of the assimilates from source to sink, i.e. K has no direct effect on photosynthesis but assists in loading and unloading of the assimilates from the sources and temporary sinks to the storage organs (sink). Many workers have emphasised that potassium (K) has its significant role on the translocation of assimilates from source to sink, e.g. Overnell (1975); Mengel and Kirkby (1987); and Suksri (1998 and 1999). They pointed out that potassium has its direct influence on electron ($e^-$) transport in the photosynthetic $e^-$ transport chain, hence a rapid unloading in the plant tissues could have been assisted by potassium. When the sorghum plants had advanced in age (after 9 weeks after emergence), the results revealed that total dry weights/ha due to $N_3$ level showed a slight decline. This could have been attributable partly to an inadequate amount of soil moisture by this growth stage (Appendix B5.3-B5.4), also the aging of leaves and the availability of soil nutrients as a result of the inadequate soil moisture could be contributing factors. Finally, N level ($N_3$) may have been too high for this period of growth in the dry season. Nevertheless, the results did show that an increase in N level significantly increased leaf areas/plant whilst an increase in K level also increased leaf areas/plant but to a lesser extent. Therefore, both N and K had significant effects on leaf growth but N had the highest effect when compared with the effect due to K. However, the increases in leaf areas/plant due to K did not prolong until the final sampling period, whilst N did (Kamoshita *et al.*, 1998a). CGR values were significantly increased with an increase in N but not K levels. In contrast, N did not promote brix values of the sorghum plants but K did (Experiment 4 only). These results indicated that nitrogen fertilisers could possibly have a negative effect on the brix %. K promoted brix values of the sorghum plants, whilst N did not (Mengel and Kirkby, 1987; and Suksri, 1999). These results were different from Experiment 3 where both N and K increased brix %. This may be attributable to the differences in soil moisture regime. It was found that the sorghum plants of Experiment 3 were exposed to drought conditions more than Experiment 4 (Appendix B2.2, B2.3, B2.4 and B3.1). An increase in N level significantly increased dead leaf dry weights, whilst K had no effect. This may be attributable to the re-translocation of nitrogen to seeds (Evans, 1975; and Suksri, 1998) resulting in the death of lower aging leaves, also inadequate soil moisture and the advance in age of the sorghum plants (Begonia *et al.*, 1987; Wolfe *et al.*, 1988; and Mastrorilli *et al.*, 1999).

Seed yields/ha of the sorghum plants significantly increased with an increase in both N and K levels but K had a slightly smaller effect than N. The highest seed yields and total dry weights/ha of the sorghum plants were found with the $N_3K_2$ and $N_3K_3$ treatments both treatments gave a similar level of seed yields and total dry weights/ha of the sorghum plants. Seed yields were much higher than Experiment 3 and those reported by Bordosky *et al.* (1998); Roa *et al.* (1999); and Pholsen *et al.* (2001). This must be attributable partly to the amounts of rainwater, which was greater for Experiment 4 than Experiment 3 as previously discussed. Nitrogen fertiliser increased seed size only up to $N_1$, whilst K did not. Similarly, an increase in

N level significantly increased CP % of the sorghum plants whilst K did not. Both N and K had no significant effect on NDF, ADF, and DMD of the sorghum plants. DMD values were lower than those reported by Kalbande and Thomas (1997), whilst CP values found with this work were greater than those reported by Phaikaew *et al.* (1992). Significant relationships have been established between the amounts of N and K fertilisers added to the soil and total dry weights/ha, seed yields/ha, leaf area duration and total dry weights/ha, leaf area duration and grain yields/ha of the sorghum plants. The longer the duration of living leaves (D) the better the total dry weights/ha and grain yields/ha of the sorghum plants. However, D value at 11 weeks after emergence of Experiment 3 was lower than that of Experiment 4. This must be attributable to the differences in the amounts of rainwater, which was greater for Experiment 4 than that of Experiment 3. It may be possible that drought conditions could have decreased photosynthesis rate of Experiment 3 resulting in lower CGR of Experiment 3 than that of Experiment 4. Thus greater total dry weights and seed yields/ha of Experiment 4 were greater than that of Experiment 3. Some combined analysis data carried out with previous experiments and the present experiment may be useful to explain the effects due to both N and K levels in relation to the changes in sowing season of the year and other differences between the experiments.

The combined analyses of Experiment 2 & 3 and Experiment 3 & 4 showed that the location had a significant effect on growth and seed yields of the sorghum plants in addition to nitrogen and potassium chemical fertilisers added to the soil. The results indicated a relative deterioration of Yasothon soil series (Oxic Paleustults) due perhaps to the previous crop cultivation, leaching and the depletion of organic matter percentages. Hence high annual application rates of both nitrogen and potassium were needed in order to obtain better growth and seed yields of the sorghum plants. The highly significant differences found due to the location on seed yields of the sorghum plants could be at least partly attributed to the application of 40 tonnes/ha of fermented cattle manure (Experiment 3 and 4) which would have contributed a considerable amount of soil organic matter and some minerals to the soil in the experimental plots (Meesawat *et al.*, 1977; Harris, 1996; and Vaidya and Gabhane, 1998).

The combined analysis on total dry weights/ha data indicated that total dry weights/ha of the sorghum plants were highly influenced by season where hot or dry season gave much greater total dry weights and seed yields/ha than that of the wet season experiment i.e., total dry weights and seed yields of Experiment 4 were 20,929 and 9,027 kg/ha for $N_3K_2$, whilst in Experiment 3 were 16,198 and 5,797 kg/ha, respectively. The differences in seed yields must presumably be attributable to the amount of total radiant energy from the sun (the total amount of radiant energy in the dry season would have been much greater than that of the rainy season). Another reason for this could possibly have been attributed to the adequate amount of soil moisture content of dry season, which may have been greater than that of the rainy season especially during the critical early vegetative growth stages where a great deal of rainwater was available to the plants (Appendix B2.4, B3.1, B4.3 and B4.4) (Suksri, 1978 and 1999). The application of water from overhead mini sprinkler irrigation at the rate of 200 litres/hour, each lasted four hours for three times per week and could have provided an adequate amount of soil moisture content for the early growth period of the sorghum plants and later the sorghum plants attained water from rainfall. From sowing of seeds until the third sampling, the amount of rainwater for Experiment 4 was 485.7 mm (Appendix B4.1, B4.2 and B4.3) compared with Experiment 3 where the sorghum plants received rainwater alone, which was only 177.5 mm (Appendix B2.2 B2.3 and B2.4), although the environmental temperature during daytime was extremely high (reaching the highest value of 39 $^{\circ}$ C). Therefore, in general, nitrogen had significant effects on the growth parameters of the sorghum plants, which were greater than potassium but the results from the combined analysis revealed that both nutrients had a highly significant effect on total dry weights and seed yields/ha. The results show that sorghum could provide adequate amounts of fresh fodder for dairy and beef cattle in the hot or dry season provided that irrigation water is available; seed multiplication for the next season could also be carried out.

## 4.8 Conclusions

The application of fermented cattle manure as a basal dressing to Yasothon soil series (Oxic Paleustults) made it possible to find some clearer effects of the application of nitrogen and potassium chemical fertilisers than in the previous experiments, i.e. an increase in nitrogen level significantly increased total dry weights/ha, stem dry weights/plant, leaf dry weights/plant, leaf areas/plant, LAI, CGR, D and CP contents of the sorghum plants. Increasing potassium levels also gave some significant effects on growth parameters but to a lesser extent when compared to the effect due to nitrogen application. The main role of potassium is probably in the translocation of assimilates from source to sink. It also promotes sugar contents (brix %) in the sorghum plant tissues and increases fibrous tissues.

Seed yields significantly increased with an increase in nitrogen level whilst potassium had a smaller effect on seed yields. However, nitrogen and potassium had no effect on NDF, ADF, and DMD of the sorghum plants. Some significant relationships were also found between D and total dry weights/ha, and between D and seed yields of the sorghum plants.

Following on from the results of Experiments 1 to 4, some further experiments were designed with different ratios of N and K fertilisers. It had been found that N in the range of 300-600 kg N/ha and K in the range of 100-200 kg$K_2O$/ha seemed most appropriate for growth and yield of the sorghum plants. A number treatments incorporating different combinations of N and K within these ranges with and without cattle manure were devised with the aim of establishing the optimum N: K: Manure combination. Treatments were:

T1 = Control 1.
T2 = Control 2.
T3 = Cattle manure alone at the rate of 40 tonnes/ha.
T4 = Cattle manure alone at the rate of 80 tonnes/ha.
T5 = Ratio between N:K of 300:100 (N:$K_2O$/ha).
T6 = Ratio between N:K of 300:200 (N:$K_2O$/ha).
T7 = Ratio between N:K of 450:100 (N:$K_2O$/ha).

T8 = Ratio between N:K of 450:200 (N:$K_2O$/ha).

T9 = Ratio between N:K of 600:100 (N:$K_2O$/ha).

T10 = Ratio between N:K of 600:200 (N:$K_2O$/ha).

T11 = Ratio between N:K of 300:100 (N:$K_2O$/ha) plus cattle manure 40 t/ha.

T12 = Ratio between N:K of 300:200 (N:$K_2O$/ha) plus cattle manure 40 t/ha

T13 = Ratio between N:K of 450:100 (N:$K_2O$/ha) plus cattle manure 40 t/ha.

T14 = Ratio between N:K of 450:200 (N:$K_2O$/ha) plus cattle manure 40 t/ha.

T15 = Ratio between N:K of 600:100 (N:$K_2O$/ha) plus cattle manure 40 t/ha.

T16 = Ratio between N:K of 600:200 (N:$K_2O$/ha) plus cattle manure 40 t/ha.

The design being used was a randomized complete block design (RCBD) with 4 replications and forms the basis for Experiment 5.

# Chapter 5

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## Experiment 5

## Effects of a Low Application Rate of Cattle Manure and Varying Ratios of Nitrogen and Potassium on Growth, Yields and Chemical Components of IS 23585 Forage Sorghum Cultivar (*Sorghum bicolor* L. Moench) Grown on Yasothon Soil Series (Oxic Paleustults) in Dry Season With Irrigation

### 5.1 Introduction

The results of the previous experiments (Experiment 1 to Experiment 4) showed that Yasothon soil series requires large amount of nitrogen and potassium chemical fertilisers for optimum growth and seed yields of sorghum and that the results were much better when fermented cattle manure was added to the soil as a basal dressing at a rate of 40 tonnes/ha when compared with the results of the initial two experiments (which were carried out without the use of fermented cattle manure). The best treatment on the basis of a combined analysis between the second and the third and also between the third and the fourth experiments was $N_3K_2$ treatment. The seed yields/ha between the second and third experiments were 5,674 kg/ha and the total dry weights and seed yields/ha between the third and fourth experiments were 18536 kg and 6702 kg, respectively.

Therefore, to confirm the effects due to both nitrogen and potassium levels together with fermented cattle manure added to the soil further investigation was carried out with different rates and/or ratios of nitrogen and potassium chemical fertilisers plus the application of fermented cattle manure as a basal dressing.

**Materials and methods:** This section was given in chapter 2 on page 60.

## 5.2 Results

### 5. 2.1 Initial Soil Analysis Data of Yasothon Soil Series

For initial soil analysis data, the results showed that mean values of soil pH, organic matter %, total soil nitrogen %, available phosphorous and extractable potassium were 4.93 (1:2.5 soil: water by volume), 0.62, 0.041, 65 ppm, and 48 ppm, respectively (Table 5.1).

Table 5.1 Initial soil analysis data of Yasothon soil series (Oxic Paleustults) before the plots were used for the sowing of sorghum seeds at Khon Kaen University Experimental Farm, Northeast Thailand.

| Items | Blocks | | | | Averages |
|---|---|---|---|---|---|
| | I | II | III | IV | |
| pH (1:2.5 soil:water) | 4.70 | 4.80 | 5.10 | 5.10 | 4.93 |
| Organic matter (%) | 0.65 | 0.60 | 0.62 | 0.62 | 0.62 |
| Total soil nitrogen (%) | 0.0423 | 0.0401 | 0.0408 | 0.0408 | 0.041 |
| Available phosphorus (ppm) | 65 | 50 | 69 | 75 | 65 |
| Extractable potassium (ppm) | 46 | 48 | 51 | 47 | 48 |

### 5.2.2 Soil Analysis Data at the Final Sampling Period

During the final harvest of the sorghum plants, the results showed that soil pH were in a range of 4.9-5.3, 5.9-6.2, 5.0-5.2, and 6.1-6.4 for control, cattle manure, chemical fertilisers, and chemical fertilisers plus cattle manure, respectively. Organic matter percentages were in a range of 0.72-0.76, 1.13-1.68, 0.67-0.79 and 0.85-0.94 for control, cattle manure, chemical fertilisers, and chemical fertilisers plus cattle manure, respectively. Nitrogen % of 0.0331-0.0379, 0.0565-0.0642, 0.0579-0.0661, and 0.0668-0.0753 for control, cattle manure, chemical fertilisers, and chemical fertilisers plus cattle manure, respectively. Available phosphorous of 54-60, 56-70, 55-68, and 73-80 ppm for control, cattle manure, chemical fertilisers, and chemical fertilisers plus cattle manure, respectively. Extractable potassium of 41-45, 52-63, 43-59, and 74-78 ppm for control, cattle manure, chemical fertilisers, and chemical fertilisers plus cattle manure, respectively (Table 5.2). The values in Table 5.2 were generally higher than the initial values especially in the cattle manure treatments (T11-T16).

Table 5.2 Soil analysis data of Yasothon soil series (Oxic Paleustults) of the experimental plots after the final harvest for grains of the sorghum plants at Khon Kaen University Experimental Farm, Northeast Thailand in dry season 2001.

| Treatments | pH (1:2.5) | Organic matter (%) | Total N (%) | Available P (ppm) | Extractable K (ppm) |
|---|---|---|---|---|---|
| 1. Control # 1 | 4.9 | 0.76 | 0.0379 | 54 | 41 |
| 2. Control # 2 | 5.3 | 0.72 | 0.0331 | 60 | 45 |
| 3. CM 40 t/ha | 5.9 | 1.13 | 0.0565 | 70 | 52 |
| 4. CM 80 t/ha | 6.2 | 1.68 | 0.0642 | 56 | 63 |
| 5. 300N : 100K kg/ha | 5.1 | 0.76 | 0.0579 | 68 | 43 |
| 6. 300N : 200K kg/ha | 5.1 | 0.77 | 0.0586 | 55 | 51 |
| 7. 450N : 100K kg/ha | 5.2 | 0.76 | 0.0579 | 67 | 43 |
| 8. 450N : 200K kg/ha | 5.0 | 0.79 | 0.0594 | 67 | 52 |
| 9. 600N : 100K kg/ha | 5.0 | 0.67 | 0.0634 | 63 | 45 |
| 10. 600N : 200K kg/ha | 5.1 | 0.72 | 0.0661 | 67 | 59 |
| 11. 300N : 100K+CM | 6.4 | 0.91 | 0.0753 | 80 | 78 |
| 12. 300N : 200K+CM | 6.1 | 0.94 | 0.0668 | 73 | 77 |
| 13. 450N : 100K+CM | 6.3 | 0.88 | 0.0738 | 79 | 74 |
| 14. 450N : 200K+CM | 6.2 | 0.85 | 0.0723 | 77 | 77 |
| 15. 600N : 100K+CM | 6.1 | 0.86 | 0.0731 | 78 | 78 |
| 16. 600N : 200K+CM | 6.3 | 0.87 | 0.0686 | 74 | 74 |

K = $K_2O$. CM = Cattle manure at the rate of 40 tonnes/ha.

### 5.2.3 Total Dry Weights, Stem Dry Weights, Leaf Dry Weights, Head Dry Weights, Leaf Areas, Leaf Area Indices (LAI), Crop Growth Rates (CGR), Leaf Area Duration (D), Seed Yields and 1000-Seed Weights

For the initial sampling period at 3 weeks after emergence, the results showed that total dry weights/ha of the sorghum plants ranged from 92 to 263 kg/ha for control #1 (T1) and the 600 kg N/ha plus 200 kg $K_2O$/ha plus 40 tonnes/ha of fermented cattle manure (T16), respectively. Total dry weights/ha of all fertiliser treated plants were significantly greater than those of the control treatments. The treatment with added fermented cattle manure at 40 tonnes/ha was similar to the control treatments (Table 5.3). Treatment 4 (cattle manure at the rate of 80 tonnes/ha) was significantly greater than both (T3) and the control treatments. An increase in the amounts of chemical fertilisers both N and K and fermented cattle manure (T11-T16) further increased total dry weights/ha of the sorghum plants. Similar trends as for total dry weights/ha were also found with stem dry weights, leaf dry weights, leaf areas/plant and also LAI. The highest rates of both chemical fertilisers and fermented cattle manure (T16) gave the highest values for all measured parameters. LAI values at this early growth stage were relatively small ranging from 0.26 to 0.75 for control #1 and T16, respectively.

Table 5.3 Mean values of total dry weights, stem dry weights, leaf dry weights, leaf areas and leaf area indices of the sorghum plants at 3 weeks after emergence as influenced by cattle manure, chemical fertilisers nitrogen and potassium, grown on Yasothon soil series (Oxic Paleustults), and ANOVA (n=16).

| Treatments | Total dry weights (kg/ha) | Stem dry weights (g/plant) | Leaf dry weights (g/plant) | Leaf areas ($cm^2$/plant) | Leaf area indices |
|---|---|---|---|---|---|
| 1. Control # 1 | $92^{g}$ | $0.14^{ij}$ | $0.32^{g}$ | $129^{f}$ | $0.26^{g}$ |
| 2. Control # 2 | $103^{g}$ | $0.18^{hi}$ | $0.34^{g}$ | $136^{f}$ | $0.27^{g}$ |
| 3. CM 40 t/ha | $102^{g}$ | $0.13^{j}$ | $0.38^{g}$ | $153^{f}$ | $0.31^{g}$ |
| 4. CM 80 t/ha | $162^{ef}$ | $0.19^{h}$ | $0.63^{def}$ | $250^{de}$ | $0.50^{def}$ |
| 5. 300N : 100K kg/ha | $144^{f}$ | $0.20^{gh}$ | $0.53^{f}$ | $209^{e}$ | $0.42^{f}$ |
| 6. 300N : 200K kg/ha | $147^{f}$ | $0.19^{gh}$ | $0.55^{ef}$ | $218^{e}$ | $0.44^{ef}$ |
| 7. 450N : 100K kg/ha | $177^{de}$ | $0.27^{ef}$ | $0.62^{def}$ | $248^{de}$ | $0.50^{def}$ |
| 8. 450N : 200K kg/ha | $188^{de}$ | $0.28^{def}$ | $0.66^{cde}$ | $263^{cd}$ | $0.53^{cde}$ |
| 9. 600N : 100K kg/ha | $215^{bc}$ | $0.32^{bcd}$ | $0.76^{bc}$ | $302^{bc}$ | $0.61^{bc}$ |
| 10. 600N : 200K kg/ha | $228^{b}$ | $0.35^{ab}$ | $0.79^{b}$ | $314^{b}$ | $0.63^{b}$ |
| 11. 300N : 100K+CM | $163^{def}$ | $0.22^{gh}$ | $0.59^{def}$ | $236^{de}$ | $0.48^{def}$ |
| 12. 300N : 200K+CM | $168d^{def}$ | $0.24^{fg}$ | $0.61^{def}$ | $241^{de}$ | $0.48^{def}$ |
| 13. 450N : 100K+CM | $190^{cd}$ | $0.29^{cde}$ | $0.67^{cd}$ | $265^{cd}$ | $0.53^{cd}$ |
| 14. 450N : 200K+CM | $214^{bc}$ | $0.33^{bc}$ | $0.75^{bc}$ | $299^{bc}$ | $0.60^{bc}$ |
| 15. 600N : 100K+CM | $238^{b}$ | $0.36^{ab}$ | $0.83^{b}$ | $333^{b}$ | $0.67^{ab}$ |
| 16. 600N : 200K+CM | $263^{a}$ | $0.38^{a}$ | $0.94^{a}$ | $374^{a}$ | $0.75^{a}$ |
| Significant level | ** | ** | ** | ** | ** |
| CV (%) | 9.94 | 11.89 | 11.41 | 11.36 | 11.46 |
| Std. Error (±) | 8.67 | 0.01 | 0.04 | 14.09 | 0.03 |

Letters within the same column indicate significant differences of DMRT at probability of 0.05.

K = $K_2O$. CM = Cattle manure at the rate of 40 tonnes/ha.

** = Probability ≤ 0.01. CV = Coefficient of variations.

Std. Error = Standard error of means.

By the second sampling period at 5 weeks after emergence, total dry weights/ha, stem dry weights and leaf dry weights/plant showed some clear effects due the application of fermented cattle manure at the rates of 40 and 80 tonnes/ha, i.e. these growth parameters were significantly greater than those of the control treatments and the 80 tonnes rate (T4) was greater than T3. Nitrogen and potassium chemical fertilisers and fermented cattle manure separately (T5-T10) and together (T11-T16) further increased total dry weights/ha, stem dry weights and leaf dry weights/plant of the sorghum plants (Table 5.4). Total dry weights/ha ranged from 651 for control (T1) to 2,965 kg/ha at the highest level of both chemical N and K fertilisers plus 40 tonnes/ha of fermented cattle manure (T16), respectively, although total dry weights/ha of T15 were similar to T16 but stem dry weights of T16 were significantly greater than T15. In general, the increases in the application rates of both N and K and particularly N significantly increased growth parameters of the sorghum plants; this effect was further enhanced by the contribution of the fermented cattle manure (T11-T16).

A similar trend as that for total dry weights/ha was also found with leaf areas, LAI and CGR, i.e. higher levels of both N and K plus fermented cattle manure progressively and significantly increased these measured parameters of the sorghum plants. The ranges of leaf areas, LAI and CGR from the control treatments up to the highest N and K chemical fertilisers plus 40 tonnes/ha of fermented cattle maure (T16) were large (742-2,614, 1.49-5.23 and 27.95-135.10) and highly significant (Table 5.5). At this stage of growth, LAI values had not reached optimum. The data in Table 5.5 also show that in most cases the higher K application rate (200 kg$K_2O$/ha) has no significant effect with or without cattle manure.

Table 5.4 Mean values of total dry weights, stem dry weights and leaf dry weights of the sorghum plants at 5 weeks after emergence as influenced by cattle manure, chemical fertilisers nitrogen and potassium, grown on Yasothon soil series (Oxic Paleustults), and ANOVA (n=16).

| Treatments | Total dry weights (kg/ha) | Stem dry weights (g/plant) | Leaf dry weights (g/plant) |
|---|---|---|---|
| 1. Control # 1 | $651^{i}$ | $0.84^{k}$ | $2.42^{h}$ |
| 2. Control # 2 | $681^{i}$ | $0.86^{k}$ | $2.55^{h}$ |
| 3. CM 40 t/ha | $910^{h}$ | $1.36^{j}$ | $3.19^{g}$ |
| 4. CM 80 t/ha | $1285^{g}$ | $1.79^{i}$ | $4.63^{f}$ |
| 5. 300N : 100K kg/ha | $1465^{f}$ | $2.34^{h}$ | $4.99^{ef}$ |
| 6. 300N : 200K kg/ha | $1491^{f}$ | $2.43^{g}$ | $5.03^{ef}$ |
| 7. 450N : 100K kg/ha | $1963^{d}$ | $3.46^{f}$ | $6.36^{d}$ |
| 8. 450N : 200K kg/ha | $2007^{d}$ | $3.56^{ef}$ | $6.47^{d}$ |
| 9. 600N : 100K kg/ha | $2342^{c}$ | $3.79^{de}$ | $7.92^{ab}$ |
| 10. 600N : 200K kg/ha | $2394^{c}$ | $3.97^{d}$ | $8.01^{ab}$ |
| 11. 300N : 100K+CM | $1601^{ef}$ | $2.76^{g}$ | $5.25^{ef}$ |
| 12. 300N : 200K+CM | $1665^{e}$ | $2.83^{g}$ | $5.50^{e}$ |
| 13. 450N : 100K+CM | $2417^{bc}$ | $4.89^{c}$ | $7.02^{c}$ |
| 14. 450N : 200K+CM | $2567^{b}$ | $5.00^{c}$ | $7.84^{b}$ |
| 15. 600N : 100K+CM | $2875^{a}$ | $5.99^{b}$ | $8.38^{ab}$ |
| 16. 600N : 200K+CM | $2965^{a}$ | $6.29^{a}$ | $8.54^{a}$ |
| Significant level | ** | ** | ** |
| CV (%) | 6.13 | 5.76 | 6.80 |
| Std. Error (±) | 56.08 | 0.09 | 0.20 |

Letters in the same column indicate significant differences of DMRT at probability of 0.05.

K = $K_2O$. CM = Cattle manure at the rate of 40 tonnes/ha.

** = Probability $\leq 0.01$. CV = Coefficient of variations.

Std. Error = Standard error of means.

Table 5.5 Mean values of leaf areas, leaf area indices and crop growth rate of the sorghum plants at 5 weeks after emergence as influenced by cattle manure, chemical fertilisers nitrogen and potassium, grown on Yasothon soil series (Oxic Paleustults), and ANOVA (n=16).

| Treatments | Leaf areas ($cm^2$/plant) | Leaf area indices | Crop growth rates ($g/m^2$/week) |
|---|---|---|---|
| 1. Control # 1 | $742^h$ | $1.49^h$ | $27.95^i$ |
| 2. Control # 2 | $782^h$ | $1.56^h$ | $28.89^i$ |
| 3. CM 40 t/ha | $977^g$ | $1.96^g$ | $40.36^h$ |
| 4. CM 80 t/ha | $1419^f$ | $2.84^f$ | $56.15^g$ |
| 5. 300N : 100K kg/ha | $1529^{ef}$ | $3.06^{ef}$ | $66.02^f$ |
| 6. 300N : 200K kg/ha | $1540^{ef}$ | $3.08^{ef}$ | $67.20^{ef}$ |
| 7. 450N : 100K kg/ha | $1948^d$ | $3.90^d$ | $89.30^d$ |
| 8. 450N : 200K kg/ha | $1983^d$ | $3.97^d$ | $90.94^d$ |
| 9. 600N : 100K kg/ha | $2427^{ab}$ | $4.86^{ab}$ | $106.36^d$ |
| 10. 600N : 200K kg/ha | $2453^{ab}$ | $4.91^{ab}$ | $108.31^c$ |
| 11. 300N : 100K+CM | $1609^e$ | $3.22^{ef}$ | $71.94^{ef}$ |
| 12. 300N : 200K+CM | $1684^e$ | $3.37^e$ | $74.87^e$ |
| 13. 450N : 100K+CM | $2207^c$ | $4.42^c$ | $111.35^{bc}$ |
| 14. 450N : 200K+CM | $2402^b$ | $4.80^b$ | $117.65^b$ |
| 15. 600N : 100K+CM | $2568^{ab}$ | $5.14^{ab}$ | $131.84^a$ |
| 16. 600N : 200K+CM | $2614^a$ | $5.23^a$ | $135.10^a$ |
| Significant level | ** | ** | ** |
| CV (%) | 6.80 | 6.80 | 6.72 |
| Std. Error (±) | 61.34 | 0.12 | 2.78 |

Letters in the same column indicate significant differences of DMRT at probability of 0.05.

K = $K_2O$. CM = Cattle Manure at the rate of 40 tonnes/ha.

** = Probability ≤ 0.01. CV = Coefficient of variations.

Std. Error = Standard error of means.

The results from the third sampling period at 7 weeks after emergence showed that the sorghum plants had reached the juvenile period where total dry weights/ha ranged from 3,802 to 8,769 kg/ha for T1 and T16, respectively. The differences due to treatments were large and highly significant with respect to increases in N and cattle manure applications in most cases (Table 5.6). The highest biomass was achieved with 400 kg N/ha plus cattle manure (T15 andT16). As in the previous harvest, the higher K application rates (200 kg$K_2O$/ha) had no significant effect in most cases. A similar trend to that of total dry weights/ha was found with stem and leaf dry weights/plant.

A similar trend to that already shown for dry biomass (Table 5.6) was also found with leaf areas, LAI and CGR, i.e. all fertiliser treated plants produced much greater leaf areas, LAI, and CGR than the control treatments and the differences were large and highly significant (Table 5.7). Leaf areas ranged from 2,132 to 3,792 $cm^2$/plant for T1 and T16, respectively, whilst LAI values ranged from 4.26 to 7.59 for T1 and T16, respectively. CGR values ranged from 157.56 to 290.23 $g/m^2$/week for T1 and T16, respectively. In most cases the higher (200 kg$K_2O$/ha) K rate did not improve any of these parameters and the effect of the highest N rate (600 kg N/ha) was marginal when compared with the 450 kg N/ha treatment.

**Table 5.6** Mean values of total dry weights, stem dry weights and leaf dry weights of the sorghum plants at 7 weeks after emergence as influenced by cattle manure, chemical fertilisers nitrogen and potassium, grown on Yasothon soil series (Oxic Paleustults), and ANOVA (n=16).

| Treatments | Total dry weights (kg/ha) | Stem dry weights (g/plant) | Leaf dry weights (g/plant) |
|---|---|---|---|
| 1. Control # 1 | 3802$^{g}$ | 8.23$^{g}$ | 10.78$^{f}$ |
| 2. Control # 2 | 3844$^{g}$ | 8.27$^{g}$ | 10.96$^{ef}$ |
| 3. CM 40 t/ha | 4879$^{f}$ | 12.70$^{f}$ | 11.70$^{e}$ |
| 4. CM 80 t/ha | 6028$^{e}$ | 14.99$^{e}$ | 15.16$^{d}$ |
| 5. 300N : 100K kg/ha | 6508$^{d}$ | 17.33$^{d}$ | 15.21$^{d}$ |
| 6. 300N : 200K kg/ha | 6497$^{d}$ | 17.54$^{d}$ | 14.95$^{d}$ |
| 7. 450N : 100K kg/ha | 6659$^{d}$ | 17.98$^{d}$ | 15.33$^{d}$ |
| 8. 450N : 200K kg/ha | 6779$^{d}$ | 18.28$^{d}$ | 15.61$^{d}$ |
| 9. 600N : 100K kg/ha | 7400$^{c}$ | 20.36$^{c}$ | 16.65$^{c}$ |
| 10. 600N : 200K kg/ha | 7394$^{c}$ | 20.41$^{c}$ | 16.56$^{c}$ |
| 11. 300N : 100K+CM | 6768$^{d}$ | 18.38$^{d}$ | 15.47$^{d}$ |
| 12. 300N : 200K+CM | 6728$^{d}$ | 18.23$^{d}$ | 15.41$^{d}$ |
| 13. 450N : 100K+CM | 8008$^{b}$ | 21.81$^{b}$ | 18.23$^{b}$ |
| 14. 450N : 200K+CM | 8060$^{b}$ | 22.02$^{b}$ | 18.29$^{ab}$ |
| 15. 600N : 100K+CM | 8703$^{a}$ | 24.54$^{a}$ | 18.98$^{ab}$ |
| 16. 600N : 200K+CM | 8769$^{a}$ | 24.67$^{a}$ | 19.18$^{a}$ |
| Significant level | ** | ** | ** |
| CV (%) | 4.08 | 5.20 | 3.86 |
| Std. Error (±) | 136.31 | 0.46 | 0.30 |

Letters in the same column indicate significant differences of DMRT at probability of 0.05.

K = $K_2O$. CM = Cattle manure at the rate of 40 tonnes/ha.

** = Probability ≤ 0.01. CV = Coefficient of variations.

Std. Error = Standard error of means.

Table 5.7 Mean values of leaf areas, leaf area indices and crop growth rate of the sorghum plants at 7 weeks after emergence as influenced by cattle manure, chemical fertilisers nitrogen and potassium, grown on Yasothon soil series (Oxic Paleustults), and ANOVA (n=16).

| Treatments | Leaf areas ($cm^2$/plant) | Leaf area indices | Crop growth rates ($g/m^2$/week) |
|---|---|---|---|
| 1. Control # 1 | $2132^{f}$ | $4.26^{f}$ | $157.56^{f}$ |
| 2. Control # 2 | $2166^{ef}$ | $4.33^{ef}$ | $158.17^{f}$ |
| 3. CM 40 t/ha | $2314^{e}$ | $4.63^{e}$ | $198.49^{e}$ |
| 4. CM 80 t/ha | $2996^{d}$ | $5.99^{d}$ | $237.16^{d}$ |
| 5. 300N : 100K kg/ha | $3008^{d}$ | $6.02^{d}$ | $252.17^{cd}$ |
| 6. 300N : 200K kg/ha | $2957^{d}$ | $5.91^{d}$ | $250.33^{cd}$ |
| 7. 450N : 100K kg/ha | $3030^{d}$ | $6.06^{d}$ | $234.82^{d}$ |
| 8. 450N : 200K kg/ha | $3087^{d}$ | $6.17^{d}$ | $238.63^{d}$ |
| 9. 600N : 100K kg/ha | $3292^{c}$ | $6.58^{c}$ | $252.90^{cd}$ |
| 10. 600N : 200K kg/ha | $3275^{c}$ | $6.55^{c}$ | $249.97^{cd}$ |
| 11. 300N : 100K+CM | $3059^{d}$ | $6.12^{d}$ | $258.34^{bcd}$ |
| 12. 300N : 200K+CM | $3047^{d}$ | $6.10^{d}$ | $253.16^{cd}$ |
| 13. 450N : 100K+CM | $3604^{b}$ | $7.21^{b}$ | $279.53^{ab}$ |
| 14. 450N : 200K+CM | $3615^{ab}$ | $7.23^{b}$ | $274.67^{abc}$ |
| 15. 600N : 100K+CM | $3752^{ab}$ | $7.51^{ab}$ | $291.43^{a}$ |
| 16. 600N : 200K+CM | $3792^{a}$ | $7.59^{a}$ | $290.23^{a}$ |
| Significant level | ** | ** | ** |
| CV (%) | 3.86 | 3.86 | 6.29 |
| Std. Error (±) | 59.19 | 0.12 | 7.63 |

Letters in the same column indicate significant differences of DMRT at probability of 0.05.

K = $K_2O$. CM = Cattle manure at the rate of 40 tonnes/ha.

** = Probability $\leq 0.01$. CV = Coefficient of variations.

Std. Error = Standard error of means.

By the fourth sampling period at 9 weeks after emergence, the results showed that total dry weights/ha for treated plants were double or almost double the control treatments, ranged from 6,372 to 13,732 kg/ha for T1 and T16, respectively (Table 5.8). A similar trend was shown by stem dry weights and leaf dry weights/plant, i.e. chemical fertilisers N and K and fermented cattle manure added to the soil significantly increased stem dry weights and leaf dry weights/plant over the control treatments of the sorghum plants. The differences were large and highly significant. At this sampling period, some amounts of lower dead leaves were apparent; in general, dead leaf dry weights were greater for those treated with chemical N and K fertilisers and cattle manure than the control treatments. There were no clear trends for dead leaf dry weights/plant but the results indicated that those treatments with fermented cattle manure and low rates of both N and K had greater dead leaf dry weights/plant than those with high rates of chemical N and K fertilisers. By this harvest stage the highest N rate with cattle manure (T15 and T16) does not produce significantly higher biomass than T13 and T14.

The results showed that leaf areas/plant were significantly greater for fertiliser and cattle manure treated plants than the control treatments. Leaf areas/plant ranged from 2,637 to 5,898 cm$^2$/plant for T1 and T15, respectively (Table 5.9). A similar trend was found with LAI, i.e. all fertiliser and manure treatments had significantly greater LAI than the control treatments. LAI values were highest in treatments 13-16, i.e. at the highest N fertiliser levels plus fermented cattle manure. LAI values ranged from 5.28 to 12.06 for T1 and T14, respectively. Crop growth rates followed a similar pattern to that of leaf areas and LAI with highest value for 450 kg/ha N plus cattle manure (T13-T14).

By this harvest stage, it seems clear that the best treatment for all parameters is the highest or second highest N level (600 or 450 kg N/ha) plus cattle manure, while increasing K from 100 to 200 kg $K_2O$/ha has little or no effect.

**Table 5.8 Mean values of total dry weights, stem dry weights, leaf dry weights and dead leaf dry weights 9 weeks after emergence as influenced by cattle manure, chemical fertilisers nitrogen and potassium, grown on Yasothon soil series (Oxic Paleustults), and ANOVA (n=16).**

| Treatments | Total dry weights (kg/ha) | Stem dry weights (g/plant) | Leaf dry weights (g/plant) | Dead leaf dry weights (g/plant) |
|---|---|---|---|---|
| 1. Control # 1 | $6372^{i}$ | $19.27^{i}$ | $11.42^{i}$ | $1.12^{cd}$ |
| 2. Control # 2 | $7252^{h}$ | $21.64^{h}$ | $13.40^{h}$ | $1.23^{cd}$ |
| 3. CM 40 t/ha | $8546^{g}$ | $25.70^{g}$ | $15.96^{g}$ | $1.08^{d}$ |
| 4. CM 80 t/ha | $10723^{f}$ | $35.19^{f}$ | $16.59^{g}$ | $1.85^{ab}$ |
| 5. 300N : 100K kg/ha | $11321^{ef}$ | $35.25^{ef}$ | $20.13^{f}$ | $1.23^{cd}$ |
| 6. 300N : 200K kg/ha | $11532^{de}$ | $35.92^{def}$ | $20.47^{ef}$ | $1.28^{cd}$ |
| 7. 450N : 100K kg/ha | $12252^{bcd}$ | $37.25^{cde}$ | $22.23^{cde}$ | $1.79^{ab}$ |
| 8. 450N : 200K kg/ha | $12389^{bc}$ | $37.35^{cd}$ | $22.67^{cd}$ | $1.95^{a}$ |
| 9. 600N : 100K kg/ha | $12696^{b}$ | $38.83^{c}$ | $23.38^{bc}$ | $1.28^{cd}$ |
| 10. 600N : 200K kg/ha | $12712^{b}$ | $38.86^{c}$ | $23.49^{bc}$ | $1.21^{cd}$ |
| 11. 300N : 100K+CM | $11845^{cde}$ | $36.19^{def}$ | $21.05^{def}$ | $2.00^{a}$ |
| 12. 300N : 200K+CM | $11862^{cde}$ | $36.25^{def}$ | $21.22^{def}$ | $1.84^{ab}$ |
| 13. 450N : 100K+CM | $13826^{a}$ | $42.02^{b}$ | $25.22^{ab}$ | $1.90^{a}$ |
| 14. 450N : 200K+CM | $13944^{a}$ | $41.89^{b}$ | $26.11^{a}$ | $1.74^{ab}$ |
| 15. 600N : 100K+CM | $14400^{a}$ | $44.99^{a}$ | $25.53^{a}$ | $1.49^{bc}$ |
| 16. 600N : 200K+CM | $13732^{a}$ | $42.67^{b}$ | $24.67^{ab}$ | $1.33^{cd}$ |
| Significant level | ** | ** | ** | ** |
| CV (%) | 4.17 | 3.60 | 6.16 | 15.82 |
| Std. Error (±) | 241.72 | 0.64 | 0.64 | 0.12 |

Letters in the same column indicate significant differences of DMRT at probability of 0.05.

K = $K_2O$. CM = Cattle manure at the rate of 40 tonnes/ha.

** = Probability ≤ 0.01. CV = Coefficient of variations.

Std. Error = Standard error of means.

Table 5.9 Mean values of leaf areas, leaf area indices and crop growth rate of the sorghum plants at 9 weeks after emergence as influenced by cattle manure, chemical fertilisers nitrogen and potassium, grown on Yasothon soil series (Oxic Paleustults), and ANOVA (n=16).

| Treatments | Leaf areas ($cm^2$/plant) | Leaf area indices | Crop growth rates ($g/m^2$/week) |
|---|---|---|---|
| 1. Control # 1 | $2637^{i}$ | $5.28^{i}$ | $128.51^{e}$ |
| 2. Control # 2 | $3095^{h}$ | $6.19^{h}$ | $170.45^{d}$ |
| 3. CM 40 t/ha | $3686^{g}$ | $7.37^{g}$ | $183.37^{d}$ |
| 4. CM 80 t/ha | $3832^{g}$ | $7.66^{g}$ | $234.76^{c}$ |
| 5. 300N : 100K kg/ha | $4649^{f}$ | $9.30^{g}$ | $240.63^{bc}$ |
| 6. 300N : 200K kg/ha | $4729^{ef}$ | $9.46^{ef}$ | $251.73^{abc}$ |
| 7. 450N : 100K kg/ha | $5134^{cde}$ | $10.27^{cde}$ | $279.65^{abc}$ |
| 8. 450N : 200K kg/ha | $5234^{cd}$ | $10.47^{cd}$ | $280.50^{abc}$ |
| 9. 600N : 100K kg/ha | $5399^{bc}$ | $10.80^{bc}$ | $264.79^{abc}$ |
| 10. 600N : 200K kg/ha | $5426^{bc}$ | $10.85^{bc}$ | $265.90^{abc}$ |
| 11. 300N : 100K+CM | $4862^{def}$ | $9.72^{def}$ | $253.83^{abc}$ |
| 12. 300N : 200K+CM | $4901^{def}$ | $9.80^{def}$ | $256.66^{abc}$ |
| 13. 450N : 100K+CM | $5825^{ab}$ | $11.65^{ab}$ | $290.89^{a}$ |
| 14. 450N : 200K+CM | $6030^{a}$ | $12.06^{a}$ | $294.19^{a}$ |
| 15. 600N : 100K+CM | $5898^{a}$ | $11.80^{a}$ | $284.87^{ab}$ |
| 16. 600N : 200K+CM | $5698^{ab}$ | $11.40^{ab}$ | $248.19^{abc}$ |
| Significant level | ** | ** | ** |
| CV (%) | 6.16 | 6.16 | 11.69 |
| Std. Error (±) | 148.25 | 0.30 | 14.35 |

Letters in the same column indicate significant differences of DMRT at probability of 0.05.

K = $K_2O$. CM = Cattle manure at the rate of 40 tonnes/ha.

** = Probability $\leq 0.01$. CV = Coefficient of variations.

Std. Error = Standard error of means.

At the fifth sampling period at 11 weeks after emergence, the results showed that total dry weights/ha of the sorghum plants treated with chemical fertilisers and cattle manure were significantly greater than the control treatments and the differences were much greater than the control treatments when N and K chemical fertilisers were added together with fermented cattle manure. Total dry weights ranged from 11,773 to 29,149 kg/ha for T1 and T16, respectively (Table 5.10). A similar trend was found with stem dry weights and leaf dry weights/plant, i.e. the differences due to treatments were highly significant. All three parameters achieved their highest values at the highest N level (600 kg/ha) supplemented with cattle manure (T15). Increasing K (T16) had no further significant effect. By this stage of growth, the sorghum plants had produced seed heads (Plate 5.1).

Plate 5.1 Sorghum heads of IS 23585 cultivar, harvested at the age of 11 weeks after emergence, grown on Yasothon soil series at Khon Kaen University Experimental Farm, Khon Kaen, Northeast Thailand.

The results for dead leaf dry weights, head dry weights, and leaf areas/plant, showed that dead leaf dry weights/plant were highest in the control treatments with no consistent pattern elsewhere and a range of 2.43 (T6) to 3.42 (T10) in the fertiliser and manure treatments. Head dry weights in the fertilizer and manure treatments were all significantly greater than the controls. Head dry weights/plant ranged from 4.40 to 20.45 g/plant for T1 and T16, respectively. The highest head dry weights/plant were found in T15 and T16, 600 kg/ha N (plus K) supplemented with cattle manure. An increase in the rate of fermented cattle manure (T4) significantly increased head dry weights/plant. A similar trend to that of head dry weights was found with leaf areas/plant, i.e. in most cases, leaf areas/plant were highest in chemical fertilisers (N and K) plus fermented cattle manure treatments (T11-T16) followed by chemical fertilisers N and K treatments alone (T5-T10). Leaf areas/plant ranged from 1828 to 4887 $cm^2$/plant for T1 and T15, respectively. An increase in the rate of cattle manure (T4) significantly increased leaf areas/plant.

The results showed that LAI values were lowest in the control treatments (T1 and T2) and highest in T15 with values of 3.66, 3.70 and 9.77, respectively. Differences due to fertiliser and manure treatments were large and highly significant (Table 5.12). A similar trend was found with CGR and D, i.e. both parameters were highest in T15/16, (high N plus K plus cattle manure) and lowest in the control treatments.

The results showed that dry seed head yields were lowest with T1 and highest with T16 with values of 2,230 and 9,779 kg/ha, respectively. Seed yields followed a similar trend ranging from 1,940 to 8,507 kg/ha for T1 and T16, respectively. Differences due to treatment were large and highly significant (Table 5.13). An increase in the rate of fermented cattle manure (T4) added to the soil significantly increased dry seed head yields and seed yields/ha of the sorghum plants. The results for 1000-seed weights revealed that higher rates of N (plus K) significantly increased 1000-seed weights e.g. T8-T10. When supplementary cattle manure was applied (T11-T16), increasing the N level had little or no significant effect on 1000-seed weights.

**Table** 5.10 Mean values of total dry weights, stem dry weights and leaf dry weights of the sorghum plants at 11 weeks after emergence as influenced by cattle manure, chemical fertilisers nitrogen and potassium, grown on Yasothon soil series (Oxic Paleustults), and ANOVA (n=16).

| Treatments | Total dry weights (kg/ha) | Stem dry weights (g/plant) | Leaf dry weights (g/plant) |
|---|---|---|---|
| 1. Control # 1 | 11773$^{g}$ | 40.31$^{h}$ | 8.85$^{g}$ |
| 2. Control # 2 | 12039$^{g}$ | 40.91$^{h}$ | 8.95$^{g}$ |
| 3. CM 40 t/ha | 15756$^{f}$ | 54.83$^{g}$ | 12.38$^{f}$ |
| 4. CM 80 t/ha | 17997$^{e}$ | 63.75$^{ef}$ | 15.06$^{g}$ |
| 5. 300N : 100K kg/ha | 17889$^{e}$ | 62.36$^{f}$ | 13.25$^{ef}$ |
| 6. 300N : 200K kg/ha | 18227$^{e}$ | 62.67$^{f}$ | 14.52$^{de}$ |
| 7. 450N : 100K kg/ha | 19828$^{d}$ | 66.75$^{def}$ | 14.95$^{de}$ |
| 8. 450N : 200K kg/ha | 20097$^{d}$ | 66.70$^{def}$ | 15.34$^{d}$ |
| 9. 600N : 100K kg/ha | 23270$^{c}$ | 76.95$^{c}$ | 18.37$^{c}$ |
| 10. 600N : 200K kg/ha | 24247$^{c}$ | 79.97$^{c}$ | 19.57$^{c}$ |
| 11. 300N : 100K+CM | 20704$^{d}$ | 68.88$^{de}$ | 19.28$^{c}$ |
| 12. 300N : 200K+CM | 21101$^{d}$ | 71.29$^{d}$ | 18.65$^{c}$ |
| 13. 450N : 100K+CM | 26282$^{b}$ | 91.11$^{b}$ | 21.78$^{b}$ |
| 14. 450N : 200K+CM | 25673$^{b}$ | 87.42$^{b}$ | 21.71$^{b}$ |
| 15. 600N : 100K+CM | 29072$^{a}$ | 98.67$^{a}$ | 23.66$^{a}$ |
| 16. 600N : 200K+CM | 29149$^{a}$ | 99.29$^{a}$ | 23.05$^{ab}$ |
| Significant level | ** | ** | ** |
| CV (%) | 4.54 | 5.35 | 7.09 |
| Std. Error (±) | 472.60 | 1.89 | 0.60 |

Letters in the same column indicate significant differences of DMRT at probability of 0.05.

K = $K_2O$. CM = Cattle manure at the rate of 40 tonnes/ha.

** = Probability ≤ 0.01. CV = Coefficient of variations.

Std. Error = Standard error of means.

**Table 5.11** Mean values of dead leaf dry weights, head dry weights and leaf areas of the sorghum plants at 11 weeks after emergence as influenced by cattle manure, chemical fertilisers nitrogen and potassium, grown on Yasothon soil series (Oxic Paleustults), and ANOVA (n=16).

| Treatments | Dead leaf dry weights (g/plant) | Head dry weights (g/plant) | Leaf areas ($cm^2$/plant) |
|---|---|---|---|
| 1. Control # 1 | $5.62^{a}$ | $4.40^{i}$ | $1828^{g}$ |
| 2. Control # 2 | $5.31^{a}$ | $4.72^{i}$ | $1850^{g}$ |
| 3. CM 40 t/ha | $4.56^{b}$ | $7.03^{h}$ | $2556^{f}$ |
| 4. CM 80 t/ha | $3.19^{c}$ | $8.01^{g}$ | $3110^{de}$ |
| 5. 300N : 100K kg/ha | $2.46^{ef}$ | $11.38^{f}$ | $2738^{ef}$ |
| 6. 300N : 200K kg/ha | $2.43^{f}$ | $11.52^{f}$ | $3001^{de}$ |
| 7. 450N : 100K kg/ha | $2.73^{def}$ | $14.71^{d}$ | $3088^{de}$ |
| 8. 450N : 200K kg/ha | $2.96^{cdef}$ | $15.50^{c}$ | $3168^{d}$ |
| 9. 600N : 100K kg/ha | $3.19^{cd}$ | $17.86^{b}$ | $3794^{c}$ |
| 10. 600N : 200K kg/ha | $3.42^{c}$ | $18.29^{b}$ | $4042^{c}$ |
| 11. 300N : 100K+CM | $3.04^{cde}$ | $12.32^{e}$ | $3984^{c}$ |
| 12. 300N : 200K+CM | $2.96^{cdef}$ | $12.61^{e}$ | $3853^{c}$ |
| 13. 450N : 100K+CM | $3.11^{cd}$ | $15.40^{cd}$ | $4501^{b}$ |
| 14. 450N : 200K+CM | $3.19^{cd}$ | $16.05^{c}$ | $4486^{b}$ |
| 15. 600N : 100K+CM | $2.81^{cdef}$ | $20.23^{a}$ | $4887^{a}$ |
| 16. 600N : 200K+CM | $2.96^{cdef}$ | $20.45^{a}$ | $4763^{ab}$ |
| Significant level | ** | ** | ** |
| CV (%) | 10.94 | 4.00 | 7.10 |
| Std. Error (±) | 0.18 | 0.26 | 123.47 |

Letters in the same column indicate significant differences of DMRT at probability of 0.05.

K = $K_2O$. CM = Cattle manure at the rate of 40 tonnes/ha.

** = Probability $\leq 0.01$. CV = Coefficient of variations.

Std. Error = Standard error of means.

Table 5.12 Mean values of leaf area indices, crop growth rates, and leaf area duration (D) of the sorghum plants at 11 weeks after emergence as influenced by cattle manure, chemical fertilisers nitrogen and potassium, grown on Yasothon soil series (Oxic Paleustults), and ANOVA (n=16).

| Treatments | Leaf area indices | Crop growth rates ($g/m^2/week$) | D ($m^2.week$) |
|---|---|---|---|
| 1. Control # 1 | $3.66^{g}$ | $270.03^{hi}$ | $1.30^{i}$ |
| 2. Control # 2 | $3.70^{g}$ | $239.30^{i}$ | $1.41^{h}$ |
| 3. CM 40 t/ha | $5.11^{f}$ | $360.46^{fg}$ | $1.67^{g}$ |
| 4. CM 80 t/ha | $6.22^{de}$ | $363.71^{fg}$ | $1.99^{f}$ |
| 5. 300N : 100K kg/ha | $5.48^{ef}$ | $328.45^{gh}$ | $2.13^{e}$ |
| 6. 300N : 200K kg/ha | $6.00^{de}$ | $334.73^{gh}$ | $2.17^{e}$ |
| 7. 450N : 100K kg/ha | $6.18^{de}$ | $378.75^{fg}$ | $2.36^{d}$ |
| 8. 450N : 200K kg/ha | $6.34^{d}$ | $385.39^{efg}$ | $2.41^{d}$ |
| 9. 600N : 100K kg/ha | $7.59^{c}$ | $528.68^{cd}$ | $2.63^{c}$ |
| 10. 600N : 200K kg/ha | $8.09^{c}$ | $576.77^{bc}$ | $2.67^{c}$ |
| 11. 300N : 100K+CM | $7.97^{c}$ | $442.94^{ef}$ | $2.33^{d}$ |
| 12. 300N : 200K+CM | $7.71^{c}$ | $461.95^{de}$ | $2.34^{d}$ |
| 13. 450N : 100K+CM | $9.00^{b}$ | $622.82^{b}$ | $2.81^{b}$ |
| 14. 450N : 200K+CM | $8.98^{b}$ | $586.46^{bc}$ | $2.89^{ab}$ |
| 15. 600N : 100K+CM | $9.77^{a}$ | $733.61^{a}$ | $2.97^{a}$ |
| 16. 600N : 200K+CM | $9.52^{ab}$ | $770.80^{a}$ | $2.94^{a}$ |
| Significant level | ** | ** | ** |
| CV (%) | 7.10 | 11.60 | 3.01 |
| Std. Error (±) | 0.25 | 26.78 | 0.03 |

Letters in the same column indicate significant differences of DMRT at probability of 0.05.

K = $K_2O$. CM = Cattle manure at the rate of 40 tonnes/ha.

** = Probability $\leq 0.01$. CV = Coefficient of variations.

Std. Error = Standard error of means.

Table 5.13 Mean values of dry seed head yields, seed yields and 1000-seed weights of the sorghum plants as influenced by cattle manure, chemical fertilisers nitrogen and potassium, grown on Yasothon soil series (Oxic Paleustults), and ANOVA (n=16).

| Treatments | Dry seed head yields (kg/ha) | Seed yields (kg/ha) | 1000-seed weights (g) |
|---|---|---|---|
| 1. Control # 1 | $2230^{i}$ | $1940^{i}$ | $29.56^{f}$ |
| 2. Control # 2 | $2390^{i}$ | $2080^{i}$ | $30.66^{ef}$ |
| 3. CM 40 t/ha | $3670^{h}$ | $3193^{h}$ | $31.59^{de}$ |
| 4. CM 80 t/ha | $4141^{g}$ | $3603^{g}$ | $32.48^{d}$ |
| 5. 300N : 100K kg/ha | $5429^{f}$ | $4723^{f}$ | $32.71^{d}$ |
| 6. 300N : 200K kg/ha | $5564^{f}$ | $4841^{f}$ | $32.93^{cd}$ |
| 7. 450N : 100K kg/ha | $7134^{d}$ | $6207^{d}$ | $33.15^{bcd}$ |
| 8. 450N : 200K kg/ha | $7503^{cd}$ | $6528^{cd}$ | $34.87^{ab}$ |
| 9. 600N : 100K kg/ha | $8651^{b}$ | $7527^{b}$ | $34.71^{abc}$ |
| 10. 600N : 200K kg/ha | $8774^{b}$ | $7633^{b}$ | $35.23^{a}$ |
| 11. 300N : 100K+CM | $5802^{ef}$ | $5047^{ef}$ | $34.87^{ab}$ |
| 12. 300N : 200K+CM | $6027^{e}$ | $5243^{e}$ | $34.52^{abc}$ |
| 13. 450N : 100K+CM | $7327^{cd}$ | $6374^{cd}$ | $34.56^{abc}$ |
| 14. 450N : 200K+CM | $7585^{c}$ | $6599^{c}$ | $34.94^{ab}$ |
| 15. 600N : 100K+CM | $9676^{a}$ | $8418^{a}$ | $35.94^{a}$ |
| 16. 600N : 200K+CM | $9779^{a}$ | $8507^{a}$ | $35.55^{a}$ |
| Significant level | ** | ** | ** |
| CV (%) | 4.08 | 4.08 | 3.46 |
| Std. Error (±) | 126.63 | 112.78 | 0.58 |

Letters in the same column indicate significant differences of DMRT at probability of 0.05.

K = $K_2O$. CM = Cattle manure at the rate of 40 tonnes/ha.

** = Probability $\leq$ 0.01. CV = Coefficient of variations.

Std. Error = Standard error of means.

### 5.2.4 Relationship Between Leaf Area Duration (D) and Total Dry Weights

The result showed that D was significantly associated with total dry weights. $R^2$ of 0.95 indicated that 95 % of the variation in the mean total dry weight was accounted for by the linear function of the D value (Fig. 5.1).

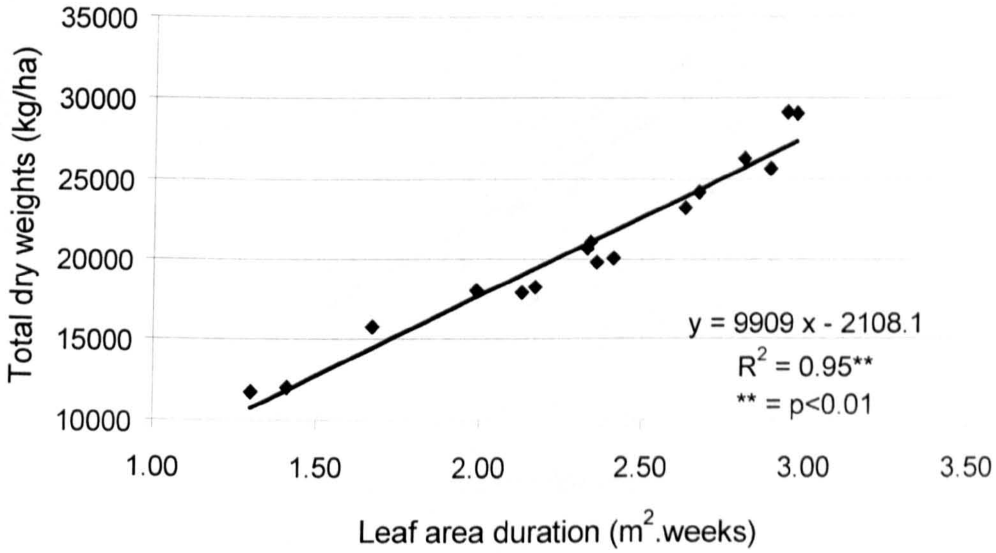

Fig. 5.1 Relationship between leaf area durations and total dry weights of the sorghum plants at 11 weeks after emergence as influenced by the combined effects of nitrogen and potassium chemical fertilisers plus fermented cattle manure, grown on Yasothon soil series (Oxic Paleustults).

### 5.2.5 Relationship Between Leaf Area Duration (D) and Seed Yields

A similar result as that of the relationship between total dry weights and D was found with the relationship between seed yields and D. $R^2$ of 0.91 indicated that 91 % of the variation in the mean seed yield was accounted for by the linear function of the D value (Fig. 5.2).

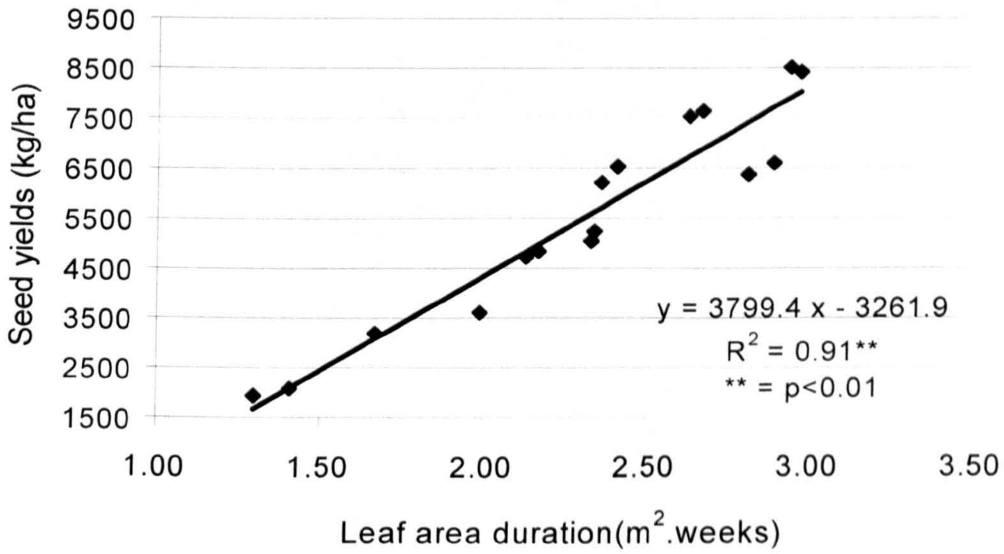

Fig. 5.2 Relationship between leaf area duration and seed yields of the sorghum plants at 11 weeks after emergence as influenced by the combined effects of nitrogen and potassium chemical fertilisers plus fermented cattle manure, grown on Yasothon soil series (Oxic Paleustults).

### 5.2.6 Crude Protein (CP) Contents, Neutral Detergent Fibre (NDF), and Acid Detergent Fibre (ADF) Contents, Dry Matter Degradability (DMD), and Brix Values

The results showed that CP values were lowest in T1 and highest in T16 with values of 3.88 and 7.77, respectively. CP values were significantly increased when fermented cattle manure was added to the soil (T3 and T4). All the fertiliser treatments with and without cattle manure significantly increased CP values compared with the control but increasing rates of N (and K) had no consistent significant effect on CP values. NDF, DMD and brix percentages of the sorghum plants showed no significant differences in any of the treatments compared with the control values. ADF data show a very inconsistent pattern; there are some individual results, which are significantly higher than control values (e.g. T5-T8) but most are similar to the control.

Table 5.14 Mean values of estimated crude protein (CP), neutral detergent fibre (NDF), acid detergent fibre (ADF) contents dry matter degradability (DMD) and brix values of the sorghum plants at 11 weeks after emergence as influenced by cattle manure, chemical fertilisers nitrogen and potassium, grown on Yasothon soil series (Oxic Paleustults), and ANOVA (n=16).

| Treatments | CP (% DM) | NDF (% DM) | ADF (% DM) | DMD (%) | Brix (%) |
|---|---|---|---|---|---|
| 1. Control # 1 | 3.88$^{c}$ | 71.36 | 41.56$^{cd}$ | 50.86 | 13.19 |
| 2. Control # 2 | 3.91$^{c}$ | 70.37 | 40.87$^{d}$ | 50.75 | 13.20 |
| 3. CM 40 t/ha | 6.12$^{b}$ | 71.22 | 43.04$^{abcd}$ | 51.22 | 13.52 |
| 4. CM 80 t/ha | 6.46$^{ab}$ | 71.35 | 41.55$^{cd}$ | 51.28 | 14.21 |
| 5. 300N : 100K kg/ha | 6.77$^{ab}$ | 75.58 | 45.50$^{ab}$ | 52.05 | 12.63 |
| 6. 300N : 200K kg/ha | 6.88$^{ab}$ | 75.10 | 46.27$^{a}$ | 52.96 | 12.00 |
| 7. 450N : 100K kg/ha | 7.42$^{ab}$ | 72.65 | 44.93$^{abc}$ | 53.39 | 14.09 |
| 8. 450N : 200K kg/ha | 7.31$^{ab}$ | 73.29 | 45.51$^{ab}$ | 52.43 | 13.02 |
| 9. 600N : 100K kg/ha | 7.44$^{ab}$ | 74.37 | 44.88$^{abc}$ | 53.76 | 13.20 |
| 10. 600N : 200K kg/ha | 7.55$^{ab}$ | 70.69 | 40.60$^{d}$ | 53.58 | 11.95 |
| 11. 300N : 100K+CM | 6.76$^{ab}$ | 71.30 | 41.88$^{bcd}$ | 51.24 | 13.07 |
| 12. 300N : 200K+CM | 7.72$^{ab}$ | 71.58 | 41.81$^{bcd}$ | 51.50 | 12.35 |
| 13. 450N : 100K+CM | 7.18$^{ab}$ | 73.59 | 42.08$^{bcd}$ | 53.06 | 13.43 |
| 14. 450N : 200K+CM | 7.30$^{ab}$ | 72.87 | 43.04$^{abcd}$ | 53.83 | 12.37 |
| 15. 600N : 100K+CM | 7.74$^{ab}$ | 72.57 | 42.29$^{bcd}$ | 54.44 | 12.06 |
| 16. 600N : 200K+CM | 7.77$^{a}$ | 71.90 | 42.46$^{bcd}$ | 54.72 | 14.52 |
| Significant level | ** | NS | * | NS | NS |
| CV (%) | 14.14 | 3.57 | 5.38 | 3.89 | 10.54 |
| Std. Error (±) | 0.48 | 1.29 | 1.16 | 1.02 | 0.69 |

Letters in the same column indicate significant differences of DMRT at probability of 0.05.

K = $K_2O$. CM = Cattle manure at the rate of 40 tonnes/ha.

** = Probability $\leq 0.01$. * = Probability $\leq 0.05$. NS = Non significance.

CV = Coefficient of variations.

Std. Error = Standard error of means.

## 5.3 Discussion

A decision was taken to use two control treatments in this experiment as a check on the possible variability of the field plots. The results for the two control treatments were not significantly different from each other and, therefore, provide a firm basis of comparison for all treatment data. The initial soil analysis revealed that soil nitrogen, extractable potassium and soil organic matter percentages were relatively low and probably inadequate for good crop yields of sorghum; a relatively higher mean value for available phosphorous was found presumably due to the previous cropping history. Mean soil pH was also relatively low, which could have effects on the release of soil nutrients particularly most macronutrients and at the same time some toxic elements could possibly be released, e.g. $Al^{+++}$ ions, hence toxicity effects and reduced availability of macronutrients could have been possible unless soil amendments such as fermented cattle manure were made (Mengel and Kirkby, 1987; Miller and Donahue, 1990; and West and Beinroth, 2000). Suksri (1999) stated that when soil pH is lower than 5 (1: 2.5 soil: water by volume), then toxic element ($Al^{+++}$) in soil could release and affect growth of crop plants. Soil analysis data at the final sampling period indicated that treatment with the additional amounts of fermented cattle manure had resulted in an increase in soil pH with values ranged from 5.0 to 6.4 (1: 2.5 soil: water by volume). The fermented cattle manure could also have improved other soil parameters such as water holding capacity and microbial activity (Alexander, 1967; Miller and Donahue, 1990; and Bulluck *et al.*, 2002).

The results for total dry weights/ha, stem dry weights, leaf dry weights, and leaf areas/plant showed that the differences due to chemical N and K fertilisers plus the fermented cattle manure were highly significant with the highest (600 kg/ha) N rate plus cattle manure giving the best results. This trend was also found with LAI and CGR. The results indicated that Yasothon soil series requires very large inputs of chemical fertilisers (N and K) and organic material such as fermented cattle manure for optimum growth of the sorghum crop plants

(Chuasavathi and Trelo-ges, 2001). LAI and CGR values at the early growth period were relatively low (3-7 weeks after emergence) because the crop plants were relatively young. The growth of the sorghum plants became more rapid after the initial sampling period and by the second and third sampling periods (5 and 7 weeks after emergence), the trends in growth due to N and K levels and manure were continued, i.e. the high application rates of N plus K significantly increased growth parameters of the sorghum plants. The effects on growth were greater for those treatments with fermented cattle manure. At seven weeks after emergence, the sorghum plants attained highest values of LAI in those treatments with high rates of N plus K fertiliser and fermented cattle manure (T13-T16); CGR values followed a similar trend. CGR values were nearly double the control results with cattle manure plus high N (T15 and T16). The results indicated that for this soil type, to improve early vegetative growth, organic material such as fermented cattle manure is always needed in addition to high fertiliser nitrogen and adequate fertiliser potassium (Faungfupong *et al.*, 1979; Russell, 1988; and Chuasavathi and Trelo-ges, 2001).

At 9 weeks after emergence, the sorghum plants had reached a reproductive stage. At this stage of growth, the trends due to fertiliser and manure treatments were similar to the previous sampling periods. Total dry weights/ha for the treatments with fermented cattle manure and high N (T13-T16) were double the control treatments. This trend on total dry weights/ha was also found with all other measured parameters of the sorghum plants with highest values being attained with high N (> 450 kg/ha) plus K and cattle manure. However, at 9 weeks after emergence, some dead leaf dry weights/plant were apparent. The dead leaves could possibly have been attributed to the re-translocation of nitrogen from aging lower leaves to the younger ones or perhaps to sink demand (grains) as discussed in the previous chapters. It was found that most of the treatments with high rates of nitrogen produced a smaller amount of dead leaves compared with some of the other N treatments, but the values were not lower than the controls. The results suggest that high N rate could have supplied adequate N to prolong life of lower leaves (Suksri, 1992 and 1999). Leaf growth of the sorghum plants was up to maximum at this stage of the development, i.e. LAI values exceeded a value of 10 in those treatments with fermented cattle manure plus high rates of nitrogen (T13-T16) or with high rates of N plus K alone (T7-T10). The results suggest that the sorghum plants have reached maximum LAI where leaf canopies can utilise the maximum amount of radiant energy and the maximum utilisation of land area coinciding with the grain-filling process, a critical growth stage (Suksri, 1992, 1998, and 1999). The results also indicate that Yasothon soil series continues to require a large amount of N and K plus organic materials (cattle manure) to sustain and maximize growth and development at this later growth stage (Faungfupong *et al.*, 1979; and Chuasavathi and Trelo-ges, 2001).

At the final sampling period at 11 weeks after emergence, total dry weights/ha and stem dry weights/plant of all treatments were significantly increased from the previous sampling period whilst leaf dry weights/plant of all treatments slightly decreased. The results suggested that the increase in stem dry weights/plant could have been attributed to the temporary storage of assimilates in stems where stems could have been acted as temporary sinks before moving to permanent sinks, i.e. seeds, hence stem dry weights/plant became relatively high (Evans 1971; and Suksri 1991). The decreases in leaf dry weights and leaf areas/plant could have been partly attributed to leaf age and the moving out of nitrogen to seeds apart from the high environmental temperature. At this stage, dead leaf dry weights of the control treatments were significantly greater than the fertiliser treated plants. This could be attributable to the depletion of soil nutrients where N and K aided the survival of leaves of the sorghum plants. Head dry weights/plant had already developed and the results indicated that chemical fertilisers N and K gave much higher head dry weights/plant than the control treatments, whilst an increase in the fermented cattle manure rates significantly increased head dry weights/plant of the sorghum plants. The significant increases in head dry weights/plant due to N and K fertiliser rates were even greater for those treatments with high rates of N plus K and fermented cattle manure (T15 and T16). The results suggest that in order to attain high amounts of sorghum yields (both forage and seed) large amounts of fermented cattle manure plus high fertiliser N and adequate K must be added to the Yasothon soil series. These results are in agreement with those found for other crops as reported by Suksri *et al.* (1991); Suksri (1992); and Chuasavathi and Trelo-ges, 2001).

Seed yields attained with this experiment were much higher than those reported by Anon (1972); and Turk and Tawaha (2002). Anon (1972) reported that sorghum treated with slake lime at a rate of 3,750 kg/ha and $N+P_2O_5+K_2O$ at a rate of 62.5+62.5+78 kg/ha gave seed yield of 4,906 kg/ha compared with slake lime+compost at a rate of 12.5 tonnes/ha gave seed yield of 4,394 kg/ha. These lower seed yields may be attributable to inadequate nitrogen fertiliser and the unfavorable climatic conditions i.e. heavy rainfall and cloudy. Turk and Tawaha (2002) with Izra 3 sorghum genotype with low application rate of diammonium phosphate (18 %N and 46 $\%P_2O_5$) at a rate of 100 kg/ha under drought conditions (342.6 mm rainfall/10 months) gave seed yield of 3,150 kg/ha. By this final sampling stage, leaf areas/plant and LAI values had decreased in all the treated plants. This could have been partly attributed to the increase in the amount of lower dead leaves but is also indicative of the reproductive phase (Begonia *et al.*, 1987; and Wolfe *et al.*, 1988). CGR values are highest at this sampling date and increase with higher rates of both N and K, and N plus K with fermented cattle manure (Suksri, 1992). CGR of the T16 treatment (The highest overall CGR values) was more than twice the control treatments.

Leaf area duration (D) is positively linked to both fertiliser and manure with the highest value at high N with manure (T15 and T16) (Suksri, 1978 and 1992). The results on the relationship between D and total dry weights/ha revealed that an increase in D significantly increased total dry weights/ha of the sorghum plants. This positive result was also found between seed yields and D, i.e. an increase in D significantly increased seed yields/ha of the sorghum plants (Suksri, 1978 and 1998).

Seed head and seed yields are strongly and positively linked to fertiliser application rates and manure, i.e. the highest yields for both are with high N plus manure (T15 and T16) (Suksri, 1992 and 1996). Anon (1972) reported seed yield of sorghum treated with slake lime+compost and slake lime+N+P+K were not significantly difference, whilst slake lime+N+P+K was significantly higher seed yield than control. Seed sizes were also increased with chemical fertilisers N and K and fermented cattle manure. Treatments with intermediate to high rates of N plus K had higher 1000-seed weights than the control treatments (e.g. T5-T10). Cattle manure plus fertiliser seems to increase 1000-seed weights only at lower N levels (e.g. T11 and T12). Nitrogen fertiliser application rates had little effect on grain size (Kamoshita *et al.*, 1998b). It may be possible that seed size could be influenced by genotype of sorghum cultivar. However, the increase in seed yield may be partly attributable to the fermented cattle manure providing some nutrients to the sorghum plants (Appendix C3) and improving other soil properties (Miller and Donahue, 1990; and Suksri, 1999).

The results showed that CP values significantly increased with the application of fermented cattle manure compared to control values. This could have been attributed partly to nitrogen content in the manure where the highest rate (80 tonnes/ha) contained a considerable amount of nitrogen (Appendix C3). CP values significantly increased with N and K chemical fertilisers (T5-T10) and the application of fermented cattle manure together with N and K produced no further clear increases. The results indicated that to produce high quality sorghum forage, fermented cattle manure must be applied together with N and K chemical fertilisers. Chemical fertilisers N and K had a limited significant effect on ADF compared with CP. Fertiliser and fermented cattle manure treatments had no effect on NDF, DMD and brix % of the sorghum plants. The results confirm the data of Pholsen *et al.* (2001) and the results of the previous experiments.

### 5.4 Conclusions

Yasothon soil series (Oxic Paleustults) contained small amounts of plant nutrients, had low organic matter percentage, and soil pH. This soil series could, therefore be considered as a poor soil in the tropics. An increase in the amount of fermented cattle manure to the soil significantly increased the growth parameters of the sorghum plants. High rates of nitrogen and potassium chemical fertilisers significantly increased the growth parameters of the sorghum plants and the effects due to both N and K were generally much greater when fermented cattle manure at the rate of 40 tonnes/ha was applied. High rates of both N and K significantly increased CP. The application of chemical fertilisers N and K and fermented cattle manure together to the soil had no effect on NDF, DMD and brix % of the sorghum plants.

It was concluded that Yasothon soil series could be considered as a poor soil series in Northeast Thailand for the production of forage sorghum. The effects due to the application of fermented cattle manure, in most cases, did not reach the maximum values on growth parameters of the sorghum plants. With doubling application of cattle manure at 80 tonnes/ha significantly improved availability of Yasothon soil resulting in higher total dry weight and seed yield than 40 tonnes/ha. Hence it could be important to investigate further the effects due to the application of the higher rate of fermented cattle manure (80 tonnes/ha) together with the rates of chemical fertilisers N and K used in present experiment. The results of such on experiment could possibly indicate the correct balance of manure and chemical fertiliser for optimum forage sorghum production on Yasothon soil series.

## Experiment 6

## Effects of a High Application Rate of Cattle Manure and Varying Ratios of Nitrogen and Potassium on Growth, Yields and Chemical Components of IS 23585 Forage Sorghum Cultivar (*Sorghum bicolor* L. Moench) Grown on Yasothon Soil Series (Oxic Paleustults) in Rainy Season Without Irrigation

### 5.5 Introduction

It was suggested following the previous experiment (Experiment 5) that a high rate of fermented cattle manure (80 tonnes/ha) should be used in conjunction with the different ratio of nitrogen and potassium treatments used in Experiment 5. This was to investigate further the effects due to N and K when a higher rate of fermented cattle manure was used on growth parameters and seed yields of the sorghum plants. A higher rate of fermented cattle manure was used because of the low fertility level of Yasothon soil series (Oxic Paleustults). Soil analysis data at the end of Experiment 5 (Table 5.2) showed that the manure treated plots (40 tonnes/ha) were low in organic matter with levels only slightly higher than the control plots. These manure plots (plus chemical fertilisers) did retain higher residual levels of some nutrients compare with other plots but these were still relatively low. This could indicate that 40 tonnes/ha of manure is too low a dressing on Yasothon soil series. This final experiment is designed to test this hypothesis by doubling the manure application rate. This high manure rate (80 tonnes), without chemical fertiliser, did return the highest level of residual organic matter in Experiment 5.

**Materials and methods**: This section was given in chapter 2 on page 61. Treatments were the same as Experiment 5 for ratios of fertilisers N and K apart from 1 control treatment and high basal rate of cattle manure (80 tonnes/ha).

## 5.6 Results

### 5.6.1 Initial Soil Analysis Data of Yasothon Soil Series

The initial soil analysis results showed that mean values of soil pH, organic matter %, total soil nitrogen %, available phosphorous, and extractable potassium were 4.93, 0.82, 0.041, 64.8 ppm, and 51.8 ppm, respectively (Table 5.15).

Table 5.15 Initial soil analysis data of Yasothon soil series (Oxic Paleustults) before the sowing of sorghum seeds at Khon Kaen University Experimental Farm, Northeast Thailand during rainy season 2001.

| Items | Blocks | | | | Averages |
|---|---|---|---|---|---|
| | I | II | III | IV | |
| pH (1:2.5) | 4.7 | 4.8 | 5.1 | 5.1 | 4.93 |
| Organic matter (%) | 0.85 | 0.80 | 0.82 | 0.82 | 0.82 |
| Total soil nitrogen (%) | 0.0423 | 0.0401 | 0.0408 | 0.0408 | 0.0410 |
| Available phosphorus (ppm) | 65 | 50 | 69 | 75 | 64.8 |
| Extractable potassium (ppm) | 54 | 49 | 51 | 53 | 51.8 |

### 5.6.2 Soil Analysis Data at the Final Sampling Period

For soil analysis at the final sampling period of the sorghum plants, the results showed that mean values of soil pH ranged from 5.1 to 6.4 for T1 and T14, respectively (Table 5.16). The fermented cattle manure treatments at the rate of 80 tonnes/ha had a higher soil pH than both the control (T1) and the chemical fertiliser only treatments (T3-T8). Similar results were found with organic matter %, total soil nitrogen %, available phosphorous, and extractable potassium, i.e. all treatments with fermented cattle manure had higher values at the final sampling period.

Table 5.16 Soil analysis data of Yasothon soil series (Oxic Paleustults) at the final harvest for grains of the sorghum plants at Khon Kaen University Experimental Farm, Northeast Thailand during rainy season 2001.

| Treatments | pH (1:2.5) | Organic-matter (%) | Total soil N (%) | Available P (ppm) | Extractable K (ppm) |
|---|---|---|---|---|---|
| 1. Control | 5.1 | 0.70 | 0.0349 | 48 | 39 |
| 2. CM 80 t/ha | 6.3 | 1.73 | 0.0670 | 56 | 60 |
| 3. 300N : 100K kg/ha | 5.2 | 0.77 | 0.0530 | 55 | 45 |
| 4. 300N : 200K kg/ha | 5.1 | 0.79 | 0.0539 | 47 | 50 |
| 5. 450N : 100K kg/ha | 5.0 | 0.79 | 0.0563 | 48 | 43 |
| 6. 450N : 200K kg/ha | 5.2 | 0.76 | 0.0569 | 41 | 53 |
| 7. 600N : 100K kg/ha | 5.3 | 0.75 | 0.0674 | 57 | 49 |
| 8. 600N : 200K kg/ha | 5.1 | 0.80 | 0.0601 | 54 | 51 |
| 9. 300N : 100K+CM | 6.3 | 1.85 | 0.0723 | 57 | 76 |
| 10. 300N : 200K+CM | 6.1 | 1.76 | 0.0781 | 59 | 84 |
| 11. 450N : 100K+CM | 6.3 | 1.72 | 0.0811 | 65 | 78 |
| 12. 450N : 200K+CM | 6.4 | 1.61 | 0.0804 | 61 | 85 |
| 13. 600N : 100K+CM | 6.2 | 1.81 | 0.0853 | 68 | 77 |
| 14. 600N : 200K+CM | 6.4 | 1.83 | 0.0815 | 65 | 83 |

K = $K_2O$. CM = Cattle manure at the rate of 80 tonnes/ha.

### 5.6.3 Total Dry Weights, Stem Dry Weights, Leaf Dry Weights, Dead Leaf Dry Weights, Head Dry Weights, Leaf Areas, Leaf Area Indices (LAI), Crop Growth Rates (CGR) and Leaf Area Duration (D)

At the initial sampling period 3 weeks after emergence, the results showed that total dry weights/ha of the sorghum plants treated with N and K plus cattle manure were significantly greater than the control treatment. N and K fertilisers alone also gave significantly greater total dry weights/ha compared to the control but in most cases similar to that of the cattle manure alone except T7 and T8 (Table 5.17). Total dry weights/ha ranged from 121 to 341 kg for T1 and T14, respectively and the highest values were all in manure plus fertiliser treatments (T11-T14). A similar trend as that of total dry weights/ha was found with stem dry weights, leaf dry weights, leaf areas/plant and also LAI. Stem dry weights/plant ranged from 0.16 to 0.53 g for T1 and T14, respectively, leaf dry weights/plant from 0.44 to 1.20 g for T1 and T14, respectively, leaf areas/plant from 183 to 494 cm$^2$ for T1 and T14, respectively. LAI values were less than 1 for all treated plants, but as with all parameters in Table 5.17, highest values were in manure plus fertiliser treatments T11-T14. The higher K treatment (200 kg $K_2O$/ha) had no significant effects.

By the second sampling period at 5 weeks after emergence, the results showed that fermented cattle manure, chemical fertilisers N and K alone and fertilisers N and K plus fermented cattle manure treatments all had total dry weights/ha very significantly higher than the control treatment (Table 5.18). The treatments with lower N and K rates alone (T3-T6) had total dry weights/ha similar to that of the cattle manure alone. Highest total dry weights were in the high N plus cattle manure treatments (T13-T14). Total dry weights/ha ranged from 427 to 2,615 kg for T1 and T14, respectively. A similar trend as that of total dry weights/ha was found with stem dry weights and leaf dry weights/plant, i.e. chemical fertilisers N and K treatments gave significantly greater dry weights than the control treatment and dry weights of the treatments with fermented cattle manure plus 450 and 600 kg N/ha were significantly greater than the chemical fertilisers N and K alone. Dead leaf dry weights attained at this sampling period were relatively high ranged from 0.69 to 1.58 g/plant for T1 and T9, respectively. All treatments were significantly higher than the control but there was no clear pattern within or between treatments. Leaf areas, LAI and CGR followed a similar pattern to the growth parameters. All treatments were higher than controls, manure alone was similar to low fertiliser N, highest values were at high N plus manure. Leaf areas ranged from 568 to 2977 cm$^2$/plant for T1 and T14, respectively, LAI values from 1.14 to 5.96 for T1 and T14, respectively, whilst CGR ranged from 15.33 to 113.55 g/m$^2$/week for T1 and

T14, respectively (Table 5.19). As in the 1st harvest (3 weeks after emergence) the higher K treatment (200 kg $K_2O$/ha) had no significant effects in most cases.

Table 5.17 Mean values of total dry weights, stem dry weights, leaf dry weights, leaf areas and leaf area indices of the sorghum plants at 3 weeks after emergence as influenced by cattle manure, chemical fertilisers nitrogen and potassium, grown on Yasothon soil series (Oxic Paleustults), and ANOVA (n=14).

| Treatments | Total dry weights (kg/ha) | Stem dry weights (g/plant) | Leaf dry weights (g/plant) | Leaf areas ($cm^2$/plant) | Leaf area indices |
|---|---|---|---|---|---|
| 1. Control | $121^{e}$ | $0.16^{f}$ | $0.44^{e}$ | $183^{e}$ | $0.37^{f}$ |
| 2. CM 80 t/ha | $174^{d}$ | $0.24^{e}$ | $0.63^{de}$ | $259^{de}$ | $0.52^{ef}$ |
| 3. 300N : 100K kg/ha | $173^{d}$ | $0.25^{e}$ | $0.62^{de}$ | $254^{de}$ | $0.51^{ef}$ |
| 4. 300N : 200K kg/ha | $170^{d}$ | $0.26^{e}$ | $0.60^{de}$ | $248^{de}$ | $0.50^{ef}$ |
| 5. 450N : 100K kg/ha | $199^{cd}$ | $0.28^{de}$ | $0.72^{cd}$ | $297^{cd}$ | $0.60^{de}$ |
| 6. 450N : 200K kg/ha | $202^{cd}$ | $0.29^{de}$ | $0.73^{cd}$ | $300^{cd}$ | $0.60^{de}$ |
| 7. 600N : 100K kg/ha | $235^{c}$ | $0.35^{c}$ | $0.83^{c}$ | $342^{c}$ | $0.69^{cd}$ |
| 8. 600N : 200K kg/ha | $241^{c}$ | $0.36^{c}$ | $0.85^{bc}$ | $352^{bc}$ | $0.70^{bcd}$ |
| 9. 300N : 100K+CM | $240^{c}$ | $0.32^{cd}$ | $0.86^{bc}$ | $365^{bc}$ | $0.73^{bcd}$ |
| 10. 300N : 200K+CM | $241^{c}$ | $0.33^{cd}$ | $0.88^{bc}$ | $362^{bc}$ | $0.72^{bcd}$ |
| 11. 450N : 100K+CM | $296^{b}$ | $0.43^{b}$ | $1.05^{ab}$ | $434^{ab}$ | $0.87^{ab}$ |
| 12. 450N : 200K+CM | $295^{b}$ | $0.45^{b}$ | $1.03^{ab}$ | $426^{ab}$ | $0.85^{abc}$ |
| 13. 600N : 100K+CM | $332^{ab}$ | $0.50^{a}$ | $1.16^{a}$ | $479^{a}$ | $0.96^{a}$ |
| 14. 600N : 200K+CM | $341^{a}$ | $0.53^{a}$ | $1.20^{a}$ | $494^{a}$ | $0.99^{a}$ |
| Significant level | ** | ** | ** | ** | ** |
| CV (%) | 12.48 | 11.19 | 15.30 | 15.34 | 15.23 |
| Std. Error (±) | 14.54 | 0.02 | 0.06 | 26.25 | 0.05 |

Letters in the same column indicate significant differences of DMRT at probability of 0.05.

K = $K_2O$. CM = Cattle manure at the rate of 80 tonnes/ha.

** = Probability ≤ 0.01. CV = Coefficient of variations.

Std. Error = Standard error of means.

Table 5.18 Mean values of total dry weights, stem dry weights, leaf dry weights and dead leaf dry weights of the sorghum plants at 5 weeks after emergence as influenced by cattle manure, chemical fertilisers nitrogen and potassium, grown on Yasothon soil series (Oxic Paleustults), and ANOVA (n=14).

| Treatments | Total dry weights (kg/ha) | Stem dry weights (g/plant) | Leaf dry weights (g/plant) | Dead leaf dry weights (g/plant) |
|---|---|---|---|---|
| 1. Control | $427^{f}$ | $0.32^{g}$ | $1.32^{g}$ | $0.69^{c}$ |
| 2. CM 80 t/ha | $1139^{de}$ | $1.92^{f}$ | $2.75^{def}$ | $1.04^{b}$ |
| 3. 300N : 100K kg/ha | $1034^{e}$ | $2.00^{f}$ | $2.25^{f}$ | $0.93^{bc}$ |
| 4. 300N : 200K kg/ha | $1124^{de}$ | $2.04^{f}$ | $2.54^{ef}$ | $1.04^{b}$ |
| 5. 450N : 100K kg/ha | $1274^{de}$ | $2.14^{f}$ | $3.19^{de}$ | $1.04^{b}$ |
| 6. 450N : 200K kg/ha | $1295^{d}$ | $2.18^{f}$ | $3.32^{d}$ | $0.99^{bc}$ |
| 7. 600N : 100K kg/ha | $1954^{c}$ | $4.41^{bc}$ | $4.28^{c}$ | $1.12^{b}$ |
| 8. 600N : 200K kg/ha | $2015^{bc}$ | $4.76^{b}$ | $4.36^{c}$ | $0.96^{bc}$ |
| 9. 300N : 100K+CM | $1786^{c}$ | $3.16^{e}$ | $4.19^{c}$ | $1.58^{a}$ |
| 10. 300N : 200K+CM | $1813^{c}$ | $3.44^{de}$ | $4.61^{bc}$ | $1.03^{b}$ |
| 11. 450N : 100K+CM | $1966^{c}$ | $3.87^{cd}$ | $4.90^{bc}$ | $1.06^{b}$ |
| 12. 450N : 200K+CM | $2216^{b}$ | $4.77^{b}$ | $5.27^{ab}$ | $1.04^{b}$ |
| 13. 600N : 100K+CM | $2452^{a}$ | $5.69^{a}$ | $5.33^{ab}$ | $1.24^{b}$ |
| 14. 600N : 200K+CM | $2615^{a}$ | $6.03^{a}$ | $5.92^{a}$ | $1.13^{b}$ |
| Significant level | ** | ** | ** | ** |
| CV (%) | 9.85 | 11.31 | 12.55 | 19.68 |
| Std. Error (±) | 81.32 | 0.19 | 0.24 | 0.10 |

Letters in the same column indicate significant differences of DMRT at probability of 0.05.

K = $K_2O$. CM = Cattle manure at the rate of 80 tonnes/ha.

** = Probability ≤ 0.01. CV = Coefficient of variations.

Std. Error = Standard error of means.

**Table 5.19** Mean values of leaf areas, leaf area indices and crop growth rate of the sorghum plants at 5 weeks after emergence as influenced by cattle manure, chemical fertilisers nitrogen and potassium, grown on Yasothon soil series (Oxic Paleustults), and ANOVA (n=14).

| Treatments | Leaf areas ($cm^2$/plant) | Leaf area indices | Crop growth rates ($g/m^2$/week) |
|---|---|---|---|
| 1. Control | 568$^{g}$ | 1.14$^{g}$ | 15.33$^{f}$ |
| 2. CM 80 t/ha | 1380$^{def}$ | 2.76$^{def}$ | 48.25$^{e}$ |
| 3. 300N : 100K kg/ha | 1127$^{f}$ | 2.26$^{f}$ | 43.07$^{e}$ |
| 4. 300N : 200K kg/ha | 1276$^{ef}$ | 2.55$^{ef}$ | 47.67$^{e}$ |
| 5. 450N : 100K kg/ha | 1604$^{de}$ | 3.21$^{de}$ | 53.75$^{e}$ |
| 6. 450N : 200K kg/ha | 1666$^{d}$ | 3.33$^{d}$ | 54.67$^{e}$ |
| 7. 600N : 100K kg/ha | 2135$^{c}$ | 4.27$^{c}$ | 85.92$^{cd}$ |
| 8. 600N : 200K kg/ha | 2190$^{c}$ | 4.38$^{c}$ | 88.67$^{cd}$ |
| 9. 300N : 100K+CM | 2105$^{c}$ | 4.21$^{c}$ | 77.28$^{d}$ |
| 10. 300N : 200K+CM | 2314$^{bc}$ | 4.63$^{bc}$ | 78.59$^{d}$ |
| 11. 450N : 100K+CM | 2464$^{bc}$ | 4.93$^{bc}$ | 83.49$^{d}$ |
| 12. 450N : 200K+CM | 2647$^{ab}$ | 5.29$^{ab}$ | 96.02$^{bc}$ |
| 13. 600N : 100K+CM | 2680$^{ab}$ | 5.36$^{ab}$ | 105.98$^{ab}$ |
| 14. 600N : 200K+CM | 2977$^{a}$ | 5.96$^{a}$ | 113.55$^{a}$ |
| Significant level | ** | ** | ** |
| CV (%) | 12.55 | 12.56 | 10.81 |
| Std. Error (±) | 121.64 | 0.24 | 3.83 |

Letters in the same column indicate significant differences of DMRT at probability of 0.05.

K = $K_2O$. CM = Cattle manure at the rate of 80 tonnes/ha.

** = Probability $\leq 0.01$. CV = Coefficient of variations.

Std. Error = Standard error of means.

By third sampling period at 7 weeks after emergence, the results showed that total dry weights/ha of the lowest chemical fertiliser N and K treatments (T3 and T4) were significantly greater than the control but similar to the cattle manure treated plants (T2). Total dry weights/ha significantly increased with an increase in N and K rates particularly with the added fermented cattle manure. The differences due to treatments were greatest for chemical fertilisers N and K plus fermented cattle manure, particularly in those treatments with the higher rates of nitrogen (T11-T14). Total dry weights ranged from 1,234 to 6,463 kg/ha for T1 and T14, respectively (Table 5.20). A similar trend as that of total dry weights/ha was also found with stem dry weights and leaf dry weights/plant of the sorghum plants, i.e. chemical fertilisers N and K and fermented cattle manure gave much greater dry weights/plant than the control treatment. Stem dry weights/plant ranged from 2.24 to 17.33 g for T1 and T14, respectively, leaf dry weights/plant from 6.14 to 13.52 g for T1 and T14, respectively. Dead leaf dry weights were generally greater for manure and chemical fertiliser treatments than in control. Dead leaf dry weights/plant ranged from 0.98 to 1.70 for T1 and T9, respectively, but showed no clear pattern within or between fertiliser and fertiliser plus manure treatments.

Leaf areas/plant for all treatments were greater, increased from the second to the third sampling period. A similar trend to that shown for leaf dry weights/plant was found with both leaf areas and LAI. Leaf areas/plant ranged from 730 to 3,339 $cm^2$ for T1 and T14, respectively, LAI values from 1.46 to 6.68 for T1 and T14, respectively (Table 5.21). All treatment values for both parameters were much higher than controls and the highest values were with N plus cattle manure in treatments 11-14. CGR values significantly increased with fermented cattle manure compared with control. Increased N plus K rates, and particularly N plus K with fermented cattle manure further increased CGR. CGR values ranged from 40.35 to 192.36 $g/m^2$/week for T1 and T14, respectively. As with other parameters, lower levels of chemical fertilisers (T3-T4) gave CGRs similar to the manure only with T2 treatment. The highest CGRs were with medium to high N plus manure (T11-T14).

Table 5.20 Mean values of total dry weights, stem dry weights, leaf dry weights and dead leaf dry weights of the sorghum plants at 7 weeks after emergence as influenced by cattle manure, chemical fertilisers nitrogen and potassium, grown on Yasothon soil series (Oxic Paleustults), and ANOVA (n=14).

| Treatments | Total dry weights (kg/ha) | Stem dry weights (g/plant) | Leaf dry weights (g/plant) | Dead leaf dry weights (g/plant) |
|---|---|---|---|---|
| 1. Control | $1234^{f}$ | $2.24^{h}$ | $6.14^{h}$ | $0.98^{e}$ |
| 2. CM 80 t/ha | $3683^{e}$ | $11.07^{g}$ | $6.15^{h}$ | $1.20^{cde}$ |
| 3. 300N : 100K kg/ha | $3700^{e}$ | $11.16^{g}$ | $6.07^{h}$ | $1.28^{bcde}$ |
| 4. 300N : 200K kg/ha | $3716^{e}$ | $11.26^{g}$ | $6.14^{h}$ | $1.19^{de}$ |
| 5. 450N : 100K kg/ha | $4220^{d}$ | $12.47^{f}$ | $6.98^{gh}$ | $1.65^{ab}$ |
| 6. 450N : 200K kg/ha | $4288^{d}$ | $12.68^{f}$ | $7.29^{fgh}$ | $1.18^{abcd}$ |
| 7. 600N : 100K kg/ha | $4997^{c}$ | $13.53^{e}$ | $8.10^{efg}$ | $1.36^{abcd}$ |
| 8. 600N : 200K kg/ha | $5152^{c}$ | $16.01^{bc}$ | $8.44^{ef}$ | $1.31^{bcde}$ |
| 9. 300N : 100K+CM | $4968^{c}$ | $13.99^{e}$ | $9.14^{de}$ | $1.70^{a}$ |
| 10. 300N : 200K+CM | $5211^{c}$ | $14.32^{de}$ | $10.21^{cd}$ | $1.53^{abcd}$ |
| 11. 450N : 100K+CM | $5639^{b}$ | $15.14^{cd}$ | $11.42^{bc}$ | $1.65^{ab}$ |
| 12. 450N : 200K+CM | $5689^{b}$ | $15.26^{cd}$ | $11.68^{b}$ | $1.50^{abcd}$ |
| 13. 600N : 100K+CM | $6226^{a}$ | $16.60^{ab}$ | $12.96^{a}$ | $1.57^{abc}$ |
| 14. 600N : 200K+CM | $6463^{a}$ | $17.33^{a}$ | $13.52^{a}$ | $1.46^{abcd}$ |
| Significant level | ** | ** | ** | ** |
| CV (%) | 5.56 | 5.40 | 10.12 | 15.79 |
| Std. Error (±) | 129.35 | 0.36 | 0.44 | 0.11 |

Letters in the same column indicate significant differences of DMRT at probability of 0.05.

K = $K_2O$. CM = Cattle manure at the rate of 80 tonnes/ha.

** = Probability $\leq 0.01$. CV = Coefficient of variations.

Std. Error = Standard error of means.

Table 5.21 Mean values of leaf areas, leaf area indices and crop growth rate of the sorghum plants at 7 weeks after emergence as influenced by cattle manure, chemical fertilisers nitrogen and potassium, grown on Yasothon soil series (Oxic Paleustults), and ANOVA (n=14).

| Treatments | Leaf areas ($cm^2$/plant) | Leaf area indices | Crop growth rates ($g/m^2$/week) |
|---|---|---|---|
| 1. Control | $730^{i}$ | $1.46^{i}$ | $40.35^{g}$ |
| 2. CM 80 t/ha | $1519^{h}$ | $3.04^{h}$ | $127.23^{f}$ |
| 3. 300N : 100K kg/ha | $1499^{h}$ | $3.00^{h}$ | $133.29^{ef}$ |
| 4. 300N : 200K kg/ha | $1516^{d}$ | $3.04^{h}$ | $129.60^{f}$ |
| 5. 450N : 100K kg/ha | $1725^{gh}$ | $3.45^{gh}$ | $147.32^{def}$ |
| 6. 450N : 200K kg/ha | $1800^{fgh}$ | $3.60^{fgh}$ | $149.65^{def}$ |
| 7. 600N : 100K kg/ha | $2000^{efg}$ | $4.00^{efg}$ | $152.19^{cde}$ |
| 8. 600N : 200K kg/ha | $2084^{ef}$ | $4.17^{ef}$ | $156.85^{cd}$ |
| 9. 300N : 100K+CM | $2258^{de}$ | $4.52^{de}$ | $159.12^{cd}$ |
| 10. 300N : 200K+CM | $2521^{cd}$ | $5.04^{cd}$ | $169.87^{bcd}$ |
| 11. 450N : 100K+CM | $2820^{bc}$ | $5.64^{bc}$ | $183.67^{ab}$ |
| 12. 450N : 200K+CM | $2884^{b}$ | $5.77^{b}$ | $173.61^{abc}$ |
| 13. 600N : 100K+CM | $3202^{a}$ | $6.40^{a}$ | $188.74^{ab}$ |
| 14. 600N : 200K+CM | $3339^{a}$ | $6.68^{a}$ | $192.36^{a}$ |
| Significant level | ** | ** | ** |
| CV (%) | 10.12 | 10.11 | 9.41 |
| Std. Error (±) | 108.00 | 0.22 | 7.07 |

Letters in the same column indicate significant differences of DMRT at probability of 0.05.

K = $K_2O$. CM = Cattle manure at the rate of 80 tonnes/ha.

** = Probability $\leq 0.01$. CV = Coefficient of variations.

Std. Error = Standard error of means.

By the fourth sampling period at 9 weeks after emergence, the sorghum plants had reached reproductive stage and had formed heads with young grains. Total dry weights/ha due to both cattle manure alone (T2) and chemical fertiliser N-K treated plants (T3-T8) were significantly greater than the control treatment. The total dry weights were much greater in the chemical fertiliser plus fermented cattle manure treatments particularly for those with the highest rates of nitrogen (T13-T14). Total dry weights/ha of the sorghum plants ranged from 3,979 to 14,644 kg for T1 and T14, respectively (Table 5.22). A similar trend due to treatments to that of total dry weights/ha was also found with stem dry weights and leaf dry weights/plant, i.e. stem dry weights and leaf dry weights/plant were increased most by the cattle manure plus high chemical fertiliser treatments. Stem dry weights/plant ranged from 10.92 to 46.84 g for T1 and T14, respectively, leaf dry weights/plant from 5.95 to 16.79 g for T1 and T14, respectively. Dead leaf dry weights were also affected most by fermented cattle manure and chemical fertilisers N and K treatments, i.e. most fertiliser treated plants had greater amounts of dead leaf dry weights than both the control and cattle manure only treatment. The highest value was found with T14 with a value of 3.46 g/plant, whilst that of the control treatment was only 1.45 g/plant.

Head dry weights/plant for the cattle manure only, chemical fertiliser and N plus K with fermented cattle manure treated plants were significantly greater than control treatment with values ranged from 1.58 to 6.14 g/plant for T1 and T14, respectively. The highest head dry weights were with high N plus manure (T13 and T14) (Table 5.23). A similar trend to that of head dry weights/plant was also found with leaf areas/plant, and LAI, i.e. fermented cattle manure plus high N with K (13 and T14) had the greatest positive effects on leaf areas and LAI of the sorghum plants. Leaf areas ranged from 1,288 to 3,635 cm$^2$/plant for T1 and T14, respectively, and LAI values from 2.58 to 7.27 for T1 and T14, respectively. CGR values were much higher than at third sampling period with values ranged from 137.25 to 409.08 g/m$^2$/week for T1 and T14, respectively. The pattern was similar to most other parameters considered at 9 weeks after emergence; all treatments were significantly higher than control with the highest CGRs in the high N plus manure treatments (T13 and T14).

Table 5.22 Mean values of Total dry weights, stem dry weights, leaf dry weights and dead leaf dry weights of the sorghum plants at 9 weeks after emergence as influenced by cattle manure, chemical fertilisers nitrogen and potassium, grown on Yasothon soil series (Oxic Paleustults), and ANOVA (n=14).

| Treatments | Total dry weights (kg/ha) | Stem dry weights (g/plant) | Leaf dry weights (g/plant) | Dead leaf dry weights (g/plant) |
|---|---|---|---|---|
| 1. Control | $3979^{f}$ | $10.92^{g}$ | $5.95^{h}$ | $1.45^{e}$ |
| 2. CM 80 t/ha | $7223^{e}$ | $21.82^{f}$ | $9.83^{g}$ | $1.64^{de}$ |
| 3. 300N : 100K kg/ha | $7347^{de}$ | $22.28^{f}$ | $10.11^{g}$ | $1.74^{de}$ |
| 4. 300N : 200K kg/ha | $7880^{d}$ | $24.73^{e}$ | $10.29^{fg}$ | $1.81^{de}$ |
| 5. 450N : 100K kg/ha | $9946^{c}$ | $32.80^{d}$ | $11.44^{def}$ | $2.09^{cd}$ |
| 6. 450N : 200K kg/ha | $10184^{c}$ | $33.47^{d}$ | $11.86^{de}$ | $2.08^{cd}$ |
| 7. 600N : 100K kg/ha | $12179^{b}$ | $42.12^{bc}$ | $12.31^{cde}$ | $2.10^{cd}$ |
| 8. 600N : 200K kg/ha | $12705^{b}$ | $43.82^{b}$ | $12.49^{cd}$ | $2.74^{b}$ |
| 9. 300N : 100K+CM | $9780^{c}$ | $31.96^{d}$ | $11.07^{efg}$ | $2.60^{bc}$ |
| 10. 300N : 200K+CM | $9916^{c}$ | $32.56^{d}$ | $11.37^{def}$ | $2.46^{bc}$ |
| 11. 450N : 100K+CM | $12110^{b}$ | $40.77^{c}$ | $13.23^{bc}$ | $2.89^{b}$ |
| 12. 450N : 200K+CM | $12452^{b}$ | $41.61^{c}$ | $13.76^{b}$ | $2.89^{b}$ |
| 13. 600N : 100K+CM | $14249^{a}$ | $45.87^{a}$ | $16.57^{a}$ | $3.43^{a}$ |
| 14. 600N : 200K+CM | $14644^{a}$ | $46.84^{a}$ | $16.79^{a}$ | $3.46^{a}$ |
| Significant level | ** | ** | ** | ** |
| CV (%) | 3.74 | 4.15 | 6.81 | 14.37 |
| Std. Error (±) | 193.29 | 0.70 | 0.41 | 0.17 |

Letters in the same column indicate significant differences of DMRT at probability of 0.05.

K = $K_2O$. CM = Cattle manure at the rate of 80 tonnes/ha.

** = Probability ≤ 0.01. CV = Coefficient of variations.

Std. Error = Standard error of means.

Table 5.23 Mean values of head dry weights, leaf areas, leaf area indices and crop growth rates of the sorghum plants at 9 weeks after emergence as influenced by cattle manure, chemical fertilisers nitrogen and potassium, grown on Yasothon soil series (Oxic Paleustults), and ANOVA (n=14).

| Treatments | Head dry weights (g/plant) | Leaf areas (cm$^2$/plant) | Leaf area indices | Crop growth rates (g/m$^2$/week) |
|---|---|---|---|---|
| 1. Control | 1.58$^{h}$ | 1288$^{i}$ | 2.58$^{i}$ | 137.25$^{h}$ |
| 2. CM 80 t/ha | 2.84$^{fg}$ | 2126$^{h}$ | 4.25$^{h}$ | 176.99$^{g}$ |
| 3. 300N : 100K kg/ha | 2.16$^{g}$ | 2188$^{gh}$ | 4.38$^{gh}$ | 182.37$^{g}$ |
| 4. 300N : 200K kg/ha | 2.58$^{g}$ | 2227$^{fgh}$ | 4.46$^{fgh}$ | 208.2$^{fg}$ |
| 5. 450N : 100K kg/ha | 3.41$^{e}$ | 2477$^{def}$ | 4.95$^{def}$ | 286.29$^{e}$ |
| 6. 450N : 200K kg/ha | 3.52$^{de}$ | 2567$^{de}$ | 5.13$^{de}$ | 294.78$^{de}$ |
| 7. 600N : 100K kg/ha | 4.37$^{c}$ | 2665$^{cde}$ | 5.33$^{cde}$ | 359.07$^{bc}$ |
| 8. 600N : 200K kg/ha | 4.48$^{c}$ | 2703$^{cd}$ | 5.41$^{cd}$ | 377.66$^{ab}$ |
| 9. 300N : 100K+CM | 3.27$^{ef}$ | 2397$^{efgh}$ | 4.79$^{efgh}$ | 240.60$^{f}$ |
| 10. 300N : 200K+CM | 3.20$^{ef}$ | 2461$^{defg}$ | 4.92$^{defg}$ | 235.28$^{f}$ |
| 11. 450N : 100K+CM | 3.65$^{de}$ | 2865$^{bc}$ | 5.73$^{bc}$ | 323.57$^{cd}$ |
| 12. 450N : 200K+CM | 4.01$^{cd}$ | 2979$^{b}$ | 5.96$^{b}$ | 338.23$^{c}$ |
| 13. 600N : 100K+CM | 5.39$^{b}$ | 3587$^{a}$ | 7.17$^{a}$ | 401.12$^{a}$ |
| 14. 600N : 200K+CM | 6.14$^{a}$ | 3635$^{a}$ | 7.27$^{a}$ | 409.08$^{a}$ |
| Significant level | ** | ** | ** | ** |
| CV (%) | 9.67 | 6.81 | 6.81 | 8.54 |
| Std. Error (±) | 0.18 | 88.01 | 0.18 | 12.11 |

Letters in the same column indicate significant differences of DMRT at probability of 0.05.

K = $K_2O$. CM = Cattle manure at the rate of 80 tonnes/ha.

** = Probability $\leq$ 0.01. CV = Coefficient of variations.

Std. Error = Standard error of means.

By the fifth sampling period at 11 weeks after emergence, the results showed that total dry weights/ha had increased considerably from the fourth sampling period to the fifth sampling period. At this stage, the sorghum plants had also filled their grains to a considerable extent. Total dry weights/ha ranged from 5,299 to 19,394 kg for T1 and T14, respectively (Table 5.24). The pattern was similar to the previous harvest; all treatments were significantly higher than control, high N fertiliser plus K fertiliser increased total dry weights, and the highest dry weights were with high N plus cattle manure (T13 and T14). A similar trend due to treatments to that of total dry weights/ha was also found with stem dry weights and leaf dry weights/plant of the sorghum plants, i.e. fermented cattle manure and chemical fertilisers N plus K had highly significant effects on dry weight accumulation of stems and leaves of the sorghum plants. Stem dry weights/plant ranged from 16.71 to 57.40 g for T1 and T14, respectively and leaf dry weights/plant from 4.47 to 12.03 g for T1 and T14, respectively.

The results showed that head dry weights were significantly greater for fermented cattle manure, chemical fertilisers N and K, and N and K fertilisers plus fermented cattle manure treatments than control with values ranged from 4.79 to 23.82 g/plant for T1 and T14, respectively (Table 5.25). Head dry weights/plant for chemical fertilisers N and K treatments alone were highest with the highest rate of nitrogen treatments (600 kg N/ha). The highest rate of nitrogen plus cattle manure treatments (T13 and T14) gave significantly greater head dry weights/plant than the highest rate of chemical fertilisers N and K alone (T8 and T8). A similar trend to that of head dry weights/plant was found with leaf areas/plant where fermented cattle manure alone gave significantly greater leaf areas/plant than that of the control treatment. The greatest effects due to treatments were found with those of chemical fertilisers N and K plus fermented cattle manure treatments but only with the highest rate of nitrogen/ha (T13 and T14). Leaf areas were lower in all treatments at 11 weeks after emergence compared with the previous harvest; this is a reflection of the plant now being in the reproductive phase. All treatments had significantly higher dead leaf dry weights/plant than control. Dead leaf dry weights/plant were highest with those treated with N and K plus cattle manure. The amounts of dead leaf dry weights/plant were smaller for cattle manure, and N and K alone. Dead leaf dry weights ranged from 1.54 to 3.73 g/plant for T1 and T14, respectively.

For LAI, a similar trend to that for leaf areas/plant was found. LAI values were significantly greater for those plants treated with fermented cattle manure, chemical fertilisers N and K and also N and K plus cattle manure treatments than the control treatment. LAI values ranged from 1.76 to 6.12 for T1 and T14, respectively (Table 5.26). The highest LAI value was found with the highest rate of N plus cattle manure (T13 and T14). A similar trend to that of LAI was also found with CGR and D, i.e. CGR and D values were significantly greater for the manure and fertiliser treated plants than control. CGR values ranged from 66.00 to 237.50 g/m$^2$/week for T1 and T14, respectively, and D values from 0.62 to 2.34 m$^2$.week. In both cases, the highest values were in the manure plots with medium or high N (T11-T14).

**Table 5.24** Mean values of total dry weights, stem dry weights and leaf dry weights of the sorghum plants at 11 weeks after emergence as influenced by cattle manure, chemical fertilisers nitrogen and potassium, grown on Yasothon soil series (Oxic Paleustults), and ANOVA (n=14).

| Treatments | Total dry weights (kg/ha) | Stem dry weights (g/plant) | Leaf dry weights (g/plant) |
|---|---|---|---|
| 1. Control | $5299^{h}$ | $16.71^{h}$ | $4.47^{f}$ |
| 2. CM 80 t/ha | $11461^{g}$ | $31.01^{g}$ | $6.89^{e}$ |
| 3. 300N : 100K kg/ha | $11795^{g}$ | $38.20^{fg}$ | $6.94^{e}$ |
| 4. 300N : 200K kg/ha | $12178^{fg}$ | $39.13^{efg}$ | $7.08^{e}$ |
| 5. 450N : 100K kg/ha | $12984^{ef}$ | $40.30^{efg}$ | $7.70^{de}$ |
| 6. 450N : 200K kg/ha | $13077^{ef}$ | $41.05^{ef}$ | $7.17^{e}$ |
| 7. 600N : 100K kg/ha | $15633^{c}$ | $45.98^{cd}$ | $8.49^{bcd}$ |
| 8. 600N : 200K kg/ha | $15911^{c}$ | $46.97^{c}$ | $8.50^{bcd}$ |
| 9. 300N : 100K+CM | $13758^{de}$ | $41.50^{ef}$ | $8.37^{cd}$ |
| 10. 300N : 200K+CM | $14128^{d}$ | $42.88^{de}$ | $8.52^{bcd}$ |
| 11. 450N : 100K+CM | $16617^{bc}$ | $52.76^{b}$ | $8.67^{bc}$ |
| 12. 450N : 200K+CM | $17178^{b}$ | $53.96^{ab}$ | $9.34^{b}$ |
| 13. 600N : 100K+CM | $19059^{a}$ | $56.71^{a}$ | $11.85^{a}$ |
| 14. 600N : 200K+CM | $19394^{a}$ | $57.40^{a}$ | $12.03^{a}$ |
| Significant level | ** | ** | ** |
| CV (%) | 4.74 | 5.45 | 7.04 |
| Std. Error (±) | 335.76 | 1.19 | 0.29 |

Letters in the same column indicate significant differences of DMRT at probability of 0.05.

K = $K_2O$. CM = Cattle manure at the rate of 80 tonnes/ha.

** = Probability ≤ 0.01. CV = Coefficient of variations.

Std. Error = Standard error of means.

Table 5.25 Mean values of head dry weights, leaf areas and dead leaf dry weights of the sorghum plants at 11 weeks after emergence as influenced by cattle manure, chemical fertilisers nitrogen and potassium, grown on Yasothon soil series (Oxic Paleustults), and ANOVA (n=14).

| Treatments | Head dry weights (g/plant) | Leaf areas ($cm^2$/plant) | Dead leaf dry weights (g/plant) |
|---|---|---|---|
| 1. Control | $4.79^{h}$ | $882^{f}$ | $1.54^{e}$ |
| 2. CM 80 t/ha | $10.96^{g}$ | $1751^{e}$ | $2.46^{cd}$ |
| 3. 300N : 100K kg/ha | $11.29^{g}$ | $1763^{e}$ | $2.56^{cd}$ |
| 4. 300N : 200K kg/ha | $12.39^{g}$ | $1801^{e}$ | $2.29^{d}$ |
| 5. 450N : 100K kg/ha | $14.16^{f}$ | $1958^{de}$ | $2.77^{bcd}$ |
| 6. 450N : 200K kg/ha | $14.70^{ef}$ | $1823^{e}$ | $2.47^{cd}$ |
| 7. 600N : 100K kg/ha | $20.92^{c}$ | $2159^{bcd}$ | $2.79^{bcd}$ |
| 8. 600N : 200K kg/ha | $21.38^{bc}$ | $2162^{bcd}$ | $2.72^{cd}$ |
| 9. 300N : 100K+CM | $15.71^{ef}$ | $2129^{cd}$ | $3.22^{abc}$ |
| 10. 300N : 200K+CM | $16.16^{e}$ | $2167^{bcd}$ | $3.08^{abcd}$ |
| 11. 450N : 100K+CM | $18.00^{d}$ | $2204^{bc}$ | $3.67^{a}$ |
| 12. 450N : 200K+CM | $19.07^{d}$ | $2376^{b}$ | $3.53^{ab}$ |
| 13. 600N : 100K+CM | $23.02^{ab}$ | $3014^{a}$ | $3.72^{a}$ |
| 14. 600N : 200K+CM | $23.82^{a}$ | $3059^{a}$ | $3.73^{a}$ |
| Significant level | ** | ** | ** |
| CV (%) | 7.28 | 7.05 | 16.74 |
| Std. Error (±) | 0.59 | 73.26 | 0.24 |

Letters in the same column indicate significant differences of DMRT at probability of 0.05.

K = $K_2O$. CM = Cattle manure at the rate of 80 tonnes/ha.

** = Probability $\leq 0.01$. CV = Coefficient of variations.

Std. Error = Standard error of means.

Table 5.26 Mean values of leaf area indices, crop growth rates, and leaf area duration (D) of the sorghum plants at 11 weeks after emergence as influenced by cattle manure, chemical fertilisers nitrogen and potassium, grown on Yasothon soil series (Oxic Paleustults), and ANOVA (n=14).

| Treatments | Leaf area indices | Crop growth rates ($g/m^2/week$) | D ($m^2.week$) |
|---|---|---|---|
| 1. Control | $1.76^{f}$ | $66.00^{f}$ | $0.62^{f}$ |
| 2. CM 80 t/ha | $3.51^{e}$ | $211.89^{abc}$ | $1.21^{e}$ |
| 3. 300N : 100K kg/ha | $3.53^{e}$ | $222.36^{ab}$ | $1.17^{e}$ |
| 4. 300N : 200K kg/ha | $3.61^{e}$ | $214.89^{ab}$ | $1.21^{e}$ |
| 5. 450N : 100K kg/ha | $3.92^{de}$ | $151.90^{de}$ | $1.38^{d}$ |
| 6. 450N : 200K kg/ha | $3.65^{e}$ | $144.64^{e}$ | $1.42^{d}$ |
| 7. 600N : 100K kg/ha | $4.32^{bcd}$ | $172.70^{bcde}$ | $1.61^{c}$ |
| 8. 600N : 200K kg/ha | $4.33^{bcd}$ | $160.30^{cde}$ | $1.65^{c}$ |
| 9. 300N : 100K+CM | $4.26^{cd}$ | $198.91^{abcd}$ | $1.60^{c}$ |
| 10. 300N : 200K+CM | $4.33^{bcd}$ | $210.59^{abc}$ | $1.72^{c}$ |
| 11. 450N : 100K+CM | $4.41^{bc}$ | $225.34^{ab}$ | $1.90^{b}$ |
| 12. 450N : 200K+CM | $4.75^{b}$ | $236.30^{a}$ | $1.98^{b}$ |
| 13. 600N : 100K+CM | $6.03^{a}$ | $240.51^{a}$ | $2.24^{a}$ |
| 14. 600N : 200K+CM | $6.12^{a}$ | $237.50^{a}$ | $2.34^{a}$ |
| Significant level | ** | ** | ** |
| CV (%) | 7.05 | 17.30 | 5.75 |
| Std. Error (±) | 0.15 | 16.64 | 0.04 |

Letters in the same column indicate significant differences of DMRT at probability of 0.05.

K = $K_2O$. CM = Cattle manure at the rate of 80 tonnes/ha.

** = Probability $\leq 0.01$. CV = Coefficient of variations.

Std. Error = Standard error of means.

### 5.6.4 Dry Seed Head Yields, Seed Yields, and 1000-Seed Weights

The results for dry seed head yields revealed that fermented cattle manure applied to the soil (T2) gave significantly greater yields than control; dry seed head yields ranged from 4,582 to 12,423 kg/ha for T1 and T14, respectively (Table 5.27). The greater the amount of N and K alone the higher the amount of dry seed head yields. A similar trend to that of N and K alone was found with N and K plus cattle manure. The highest dry seed head yield was found with T13 and T14 with values of 12,135 and 12,423 kg/ha, respectively. A similar trend to that of dry seed head yield was found with seed yield; T13 and T14 gave the highest seed yields of 9,500 and 9,726 kg/ha, respectively. 1000-seed weights ranged from 25.20 to 35.05 g for T1 and T14, respectively. Cattle manure, chemical fertilisers N and K and N and K plus cattle manure gave significantly greater seed size (1000-seed) than control. The highest 1000-seed weights were found in the high N plus K (T7 and T8) and in the high N plus K with manure (T13 and T14) treatments.

Table 5.27 Mean values of dry seed head yields, seed yields and 1000-seed weights of the sorghum plants as influenced by cattle manure, chemical fertilisers nitrogen and potassium, grown on Yasothon soil series (Oxic Paleustults), and ANOVA (n=14).

| Treatments | Dry seed head yields (kg/ha) | Seed yields (kg/ha) | 1000-seed weights (g) |
|---|---|---|---|
| 1. Control | $4582^{e}$ | $3587^{e}$ | $25.20^{f}$ |
| 2. CM 80 t/ha | $7532^{d}$ | $5897^{d}$ | $31.30^{de}$ |
| 3. 300N : 100K kg/ha | $7903^{d}$ | $6187^{d}$ | $30.80^{e}$ |
| 4. 300N : 200K kg/ha | $7991^{d}$ | $6256^{d}$ | $30.89^{e}$ |
| 5. 450N : 100K kg/ha | $9092^{c}$ | $7118^{c}$ | $33.45^{bc}$ |
| 6. 450N : 200K kg/ha | $9211^{c}$ | $7212^{c}$ | $33.89^{abc}$ |
| 7. 600N : 100K kg/ha | $10653^{b}$ | $8340^{b}$ | $34.04^{abc}$ |
| 8. 600N : 200K kg/ha | $10741^{b}$ | $8409^{b}$ | $34.06^{abc}$ |
| 9. 300N : 100K+CM | $9470^{c}$ | $7414^{c}$ | $32.57^{cd}$ |
| 10. 300N : 200K+CM | $9541^{c}$ | $7470^{c}$ | $33.08^{c}$ |
| 11. 450N : 100K+CM | $10411^{b}$ | $8151^{b}$ | $33.67^{abc}$ |
| 12. 450N : 200K+CM | $10428^{b}$ | $8164^{b}$ | $34.06^{abc}$ |
| 13. 600N : 100K+CM | $12135^{a}$ | $9500^{a}$ | $34.72^{ab}$ |
| 14. 600N : 200K+CM | $12423^{a}$ | $9726^{a}$ | $35.05^{a}$ |
| Significant level | ** | ** | ** |
| CV (%) | 5.59 | 5.59 | 2.89 |
| Std. Error (±) | 263.64 | 206.33 | 0.47 |

Letters in the same column indicate significant differences of DMRT at probability of 0.05.

K = $K_2O$. CM = Cattle manure at the rate of 80 tonnes/ha.

** = Probability $\leq 0.01$. CV = Coefficient of variations.

Std. Error = Standard error of means.

### 5.6.5 Relationship Between Leaf Area Duration (D) and Total Dry Weights

The result showed that D was significantly associated with total dry weights. $R^2$ of 0.95 indicated that 95 % of the variation in the mean total dry weight was accounted for by the linear function of the D value (Fig. 5.3). It is that there was a very strong positive relationship between leaf area duration and total dry weights.

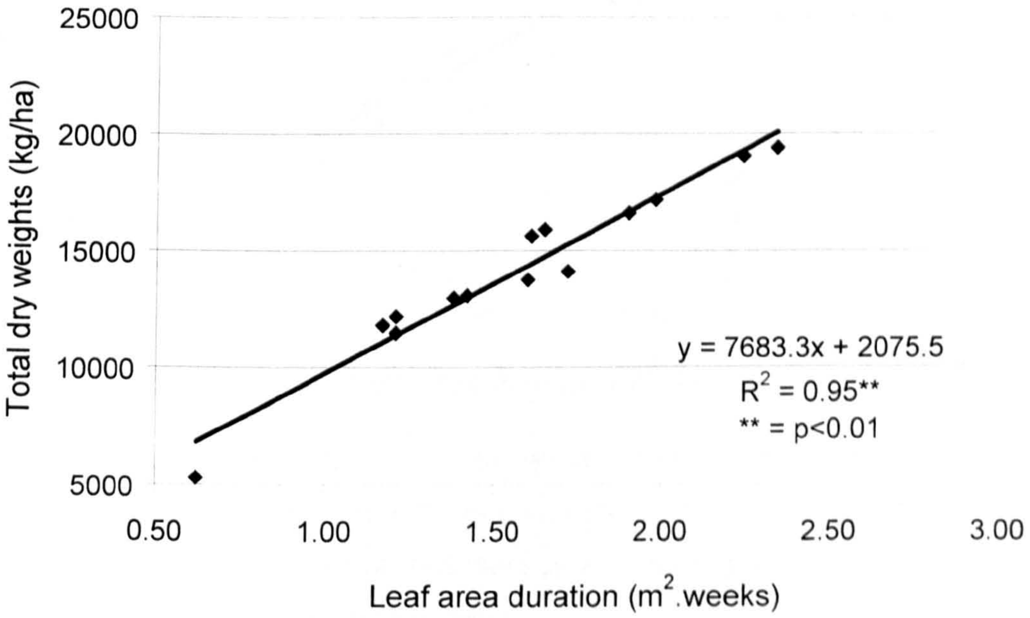

Fig. 5.3 Relationship between leaf area duration and total dry weights of the sorghum plants at 11 weeks after emergence as influenced by the combined effects of nitrogen and potassium chemical fertilisers plus cattle manure, grown on Yasothon soil series (Oxic Paleustults).

### 5.6.6 Relationship Between Leaf Area Duration (D) and Seed Yields

The results showed that D was significantly associated with seed yields. $R^2$ of 0.92 indicated that 92 % of the variation in the mean seed yield was accounted for by the linear function of the D value (Fig. 5.4). This is shown to be a very similar relationship to that between D and total dry weights (Fig. 5.3) and indicates a strong positive relationship between leaf area duration and seed yield.

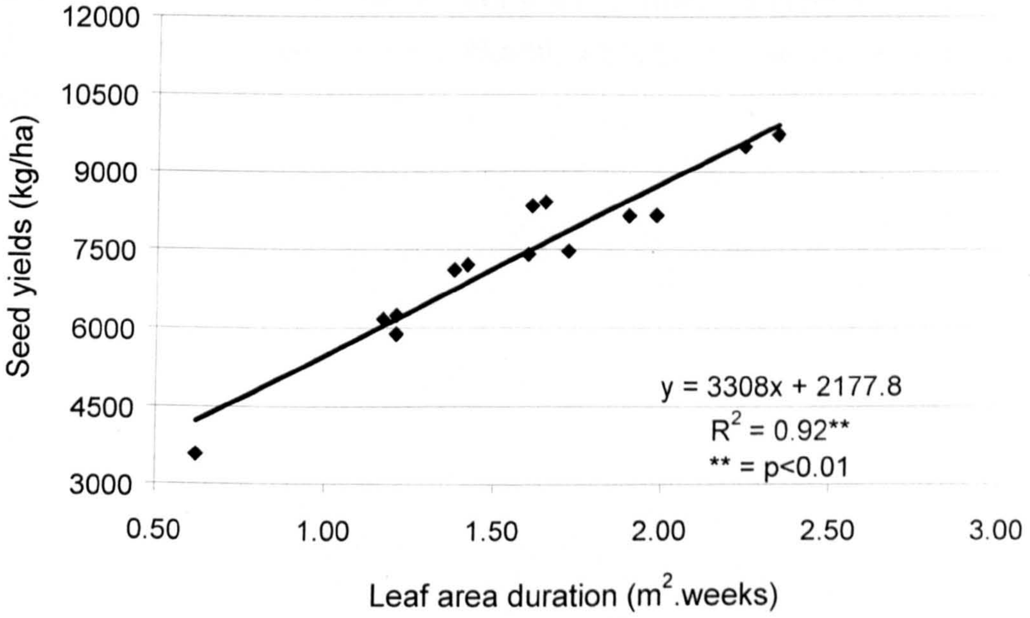

Fig. 5.4 Relationship between leaf area duration and seed yields of the sorghum plants as influenced by the combined effects of nitrogen and potassium chemical fertilisers plus cattle manure, grown on Yasothon soil series (Oxic Paleustults).

### 5.6.7 Crude Protein (CP) Contents, Neutral Detergent Fibre (NDF), and Acid Detergent Fibre (ADF) Contents, Dry Matter Degradability (DMD) and Brix Values

The results show that CP contents of the sorghum plants treated with fermented cattle manure were significantly greater than the control treatment with values of 4.70 and 6.67 for T1 and T2, respectively (Table 5.28). CP values were similar for all treatments with chemical fertilisers N and K, and N and K plus fermented cattle manure, but all of these values were significantly greater than that of the that of the cattle manure treated plants alone. Neutral detergent fibre (NDF) and acid detergent fibre (ADF) results were only significant at the 5 % level. NDF and ADF content of the sorghum plants were significantly reduced by cattle manure alone and by chemical fertiliser N and K treatments compared with control. Data for the fertilisers plus manure treatments (T9-T14) were more variable, but in most cases, were lower than or similar to control. DMD values and brix percentages were not significantly affected by manure and N and K fertiliser treatments.

Table 5.28 Mean values of estimated crude protein (CP), neutral detergent fibre (NDF), acid detergent fibre (ADF) contents dry matter degradability (DMD) and brix values of the sorghum plants at 11 weeks after emergence as influenced by cattle manure, chemical fertilisers nitrogen and potassium, grown on Yasothon soil series (Oxic Paleustults), and ANOVA (n=14).

| Treatments | CP (% DM) | NDF (% DM) | ADF (% DM) | DMD (%) | Brix (%) |
|---|---|---|---|---|---|
| 1. Control | 4.70$^{c}$ | 61.42$^{a}$ | 35.12$^{a}$ | 54.39 | 9.23 |
| 2. CM 80 t/ha | 6.67$^{b}$ | 55.94$^{bc}$ | 31.99$^{b}$ | 55.38 | 10.68 |
| 3. 300N : 100K kg/ha | 8.26$^{a}$ | 57.19$^{bc}$ | 32.11$^{b}$ | 57.83 | 11.34 |
| 4. 300N : 200K kg/ha | 8.11$^{a}$ | 56.67$^{bc}$ | 31.44$^{b}$ | 57.19 | 11.68 |
| 5. 450N : 100K kg/ha | 8.75$^{a}$ | 56.64$^{bc}$ | 32.12$^{b}$ | 56.32 | 10.96 |
| 6. 450N : 200K kg/ha | 8.95$^{a}$ | 55.87$^{bc}$ | 32.06$^{b}$ | 56.21 | 11.13 |
| 7. 600N : 100K kg/ha | 9.16$^{a}$ | 55.49$^{bc}$ | 33.28$^{ab}$ | 56.46 | 11.05 |
| 8. 600N : 200K kg/ha | 9.12$^{a}$ | 54.39$^{c}$ | 32.73$^{b}$ | 56.42 | 11.79 |
| 9. 300N : 100K+CM | 8.47$^{a}$ | 56.14$^{bc}$ | 31.34$^{b}$ | 56.19 | 10.76 |
| 10. 300N : 200K+CM | 8.45$^{a}$ | 55.15$^{bc}$ | 31.53$^{b}$ | 56.15 | 11.17 |
| 11. 450N : 100K+CM | 8.63$^{a}$ | 58.95$^{ab}$ | 32.74$^{b}$ | 55.58 | 10.53 |
| 12. 450N : 200K+CM | 8.57$^{a}$ | 58.81$^{ab}$ | 32.58$^{b}$ | 55.52 | 10.82 |
| 13. 600N : 100K+CM | 9.22$^{a}$ | 57.69$^{abc}$ | 31.83$^{b}$ | 57.18 | 10.84 |
| 14. 600N : 200K+CM | 9.13$^{a}$ | 57.84$^{abc}$ | 31.68$^{b}$ | 58.05 | 11.14 |
| Significant level | ** | * | * | NS | NS |
| CV (%) | 8.47 | 4.34 | 4.04 | 3.22 | 8.77 |
| Std. Error (±) | 0.35 | 1.24 | 0.65 | 0.91 | 0.48 |

Letters within the same column indicate significant differences of DMRT at probability of 0.05.

K = $K_2O$. CM = Cattle manure at the rate of 80 tonnes/ha.

** = Probability ≤ 0.01. * = Probability ≤ 0.0. NS = Non significance.

CV = Coefficient of variations.

Std. Error = Standard error of means.

## 5.7 Combined Analysis Between Experiment 5 and Experiment 6

### 5.7.1 Introduction

In order to try to determine more clearly the effects due to the application of fermented cattle manure alone and chemical fertiliser ratio and rate on growth parameters and seed yields of the sorghum plants, some further calculations on selected data from the fifth and sixth experiments were carried out in an attempt to clarify possible effects due to different sowing seasons of the two experiments.

### 5.7.2 Results

#### 5.7.2.1 Total Dry Weights and Seed Yields of the Experiment 5 and Experiment 6

The results on analysis of variance within the group of selected treatments, i.e. control, fermented cattle manure, and chemical fertilisers N and K alone, showed that the cattle manure and all N and K treatments had significantly greater total dry weights/ha than control (Table 5.29). Nitrogen at 450 kg/ha and above further and progressively increased total dry weights above the level in the cattle manure rate of 80 tonnes/ha treatment (T2). There was no significant effect of the higher (200 kg $K_2O$/ha) K treatment. A similar trend to that of total dry weights/ha was found with seed yields/ha of the sorghum plants, i.e. higher rates of nitrogen significantly and progressively increased seed yields/ha of the sorghum plants and all treatments including the manure alone were higher than control.

Table 5.29 Mean values of total dry weights at 11 weeks after emergence and seed yields/ha of the sorghum plants of the Experiment 5 in dry season 2001 and ANOVA (n=8).

| Treatments | Total dry weights (kg/ha) | Seed yields (kg/ha) |
|---|---|---|
| 1. Control | 12039$^{d}$ | 2080$^{e}$ |
| 2. CM 80 t/ha | 17997$^{c}$ | 3603$^{d}$ |
| 3. 300N : 100K kg/ha | 17889$^{c}$ | 4723$^{c}$ |
| 4. 300N : 200K kg/ha | 18227$^{c}$ | 4841$^{c}$ |
| 5. 450N : 100K kg/ha | 19828$^{b}$ | 6207$^{b}$ |
| 6. 450N : 200K kg/ha | 20097$^{b}$ | 6528$^{b}$ |
| 7. 600N : 100K kg/ha | 23270$^{a}$ | 7527$^{a}$ |
| 8. 600N : 200K kg/ha | 24247$^{a}$ | 7633$^{a}$ |
| Significant level | ** | ** |
| CV (%) | 4.63 | 4.61 |
| Std. Error (±) | 444.18 | 124.34 |

Letters within the same column indicate significant differences of DMRT at probability of 0.05

K = $K_2O$. CM = Cattle manure.

** = Probability $\leq 0.01$. CV = Coefficient of variations.

Std. Error = Standard error of means.

In the sixth experiment, fermented cattle manure treatment and all chemical fertiliser treatments gave significantly greater total dry weights/ha and seed yields/ha than that of control (Table 5.30). The pattern and trends of the results were similar to that of the fifth experiment. However, it should be noted that in Experiment 6 the mean total dry weights are much lower than Experiment 5 for all treatments, while the seed yields are higher.

Table 5.30 Mean values of total dry weights at 11 weeks after emergence and seed yields of the sorghum plants of the Experiment 6 in rainy season 2001 and ANOVA (n=8).

| Treatments | Total dry weights (kg/ha) | Seed yields (kg/ha) |
|---|---|---|
| 1. Control | 5299$^{d}$ | 3587$^{d}$ |
| 2. CM 80 t/ha | 11461$^{c}$ | 5897$^{c}$ |
| 3. 300N : 100K kg/ha | 12178$^{bc}$ | 6187$^{c}$ |
| 4. 300N : 200K kg/ha | 12984$^{b}$ | 6256$^{c}$ |
| 5. 450N : 100K kg/ha | 12984$^{b}$ | 7118$^{b}$ |
| 6. 450N : 200K kg/ha | 13077$^{b}$ | 7212$^{b}$ |
| 7. 600N : 100K kg/ha | 15633$^{a}$ | 8340$^{a}$ |
| 8. 600N : 200K kg/ha | 15911$^{a}$ | 8409$^{a}$ |
| Significant level | ** | ** |
| CV (%) | 5.56 | 5.69 |
| Std. Error (±) | 341.76 | 188.63 |

Letters in the same column indicate significant differences of DMRT at probability of 0.05.

K = $K_2O$. CM = Cattle manure.

** = Probability ≤ 0.01. CV = Coefficient of variations.

Std. Error = Standard error of means.

### 5.7.2.2 Combined Analysis on Total Dry Weights, and Seed Yields Between Experiment 5 and Experiment 6

The results found with the combined analysis of the fifth and sixth experiments show that the effects due to seasons on total dry weights/ha and seed yields/ha were highly significant. Total dry weights/ha significantly increased with the application of fermented cattle manure and nitrogen rates. Similarly, the effects due to treatments on total dry weights/ha and seed yields/ha were also highly significant (Table 5.31). The effects due to season x treatments on total dry weights/ha were not significant, but the effects due to season x treatments on seed yields/ha were highly significant. The best treatment based on total dry weights and seed yields/ha must be the 600N: 100 $K_2O$ kg/ha although the highest total dry weights and seed yields/ha was found with the highest rates of both N and K treatment (600N: 200 $K_2O$ kg/ha) but there was no significant difference found between the two treatments. Total dry weights and seed yields of the best treatment were 19,451 and 7,933 kg/ha, respectively.

Table 5.31 Combined analysis on means of total dry weights at 11 weeks after emergence, and seed yields of the sorghum plants between Experiment 5 and Experiment 6.

| Treatments | Total dry weights (kg/ha) | Seed yields (kg/ha) |
|---|---|---|
| 1. Control | $8669^{d}$ | $2832^{e}$ |
| 2. CM 80 t/ha | $14729^{c}$ | $4750^{d}$ |
| 3. 300N : 100K kg/ha | $14842^{c}$ | $5455^{c}$ |
| 4. 300N : 200K kg/ha | $15202^{c}$ | $5548^{c}$ |
| 5. 450N : 100K kg/ha | $16406^{b}$ | $6663^{b}$ |
| 6. 450N : 200K kg/ha | $16587^{b}$ | $6870^{b}$ |
| 7. 600N : 100K kg/ha | $19451^{a}$ | $7933^{a}$ |
| 8. 600N : 200K kg/ha | $20079^{a}$ | $8021^{a}$ |
| Items | Significant level | Significant level |
| Seasons | ** | ** |
| Treatments | ** | ** |
| Seasons x Treatments | NS | ** |
| CV (%) | 5.03 | 5.32 |
| Std. Error (±) | 396.30 | 159.75 |

Letters in the same column indicate significant differences of DMRT at probability of 0.05.

K = $K_2O$. CM = Cattle manure.

** = Probability $\leq 0.01$. NS = Non significance.

CV = Coefficient of variations.

Std. Error = Standard error of means.

### 5.7.2.3 Crude Protein (CP) Contents, Neutral Detergent Fibre (NDF), and Acid Detergent Fibre (ADF) Contents, Dry Matter Degradability (DMD), and Brix Values

The results of the fifth experiment revealed that CP values of the cattle manure treatment and chemical fertilisers N and K treatments were significantly greater than control (Table 5.32). Cattle manure application alone gave a similar result to that of the chemical fertiliser N and K treatments. A similar result was found with ADF for N and K treatments over the control in most cases, but cattle manure treatment alone was similar to the control treatment. NDF was significantly higher in some of the fertiliser treatments compared with the control treatment, but there was no consistent pattern. NDF in the manure treatment was not significantly different from the control treatment. DMD and brix values showed no significant differences in any of the treatments.

Table 5.32 Mean values of the estimated crude protein (CP), neutral and acid detergent fibres (NDF and ADF), dry matter degradability (DMD), and brix values of the sorghum plants of Experiment 5 in dry season 2001 at 11 weeks after emergence.

| Treatments | CP (%DM) | NDF (%DM) | ADF (%DM) | DMD (%) | Brix (%) |
|---|---|---|---|---|---|
| 1. Control | $3.91^{b}$ | $70.37^{d}$ | $40.87^{b}$ | 50.75 | 13.20 |
| 2. CM 80 t/ha | $6.46^{a}$ | $71.35^{bcd}$ | $41.55^{b}$ | 51.28 | 14.21 |
| 3. 300N : 100K kg/ha | $6.77^{a}$ | $75.58^{a}$ | $45.50^{a}$ | 52.05 | 12.63 |
| 4. 300N : 200K kg/ha | $6.88^{a}$ | $75.10^{ab}$ | $46.27^{a}$ | 52.96 | 12.00 |
| 5. 450N : 100K kg/ha | $7.42^{a}$ | $72.65^{abcd}$ | $44.93^{a}$ | 53.39 | 14.09 |
| 6. 450N : 200K kg/ha | $7.31^{a}$ | $73.29^{abcd}$ | $45.51^{a}$ | 52.43 | 13.02 |
| 7. 600N : 100K kg/ha | $7.44^{a}$ | $74.37^{abc}$ | $44.88^{a}$ | 53.76 | 13.20 |
| 8. 600N : 200K kg/ha | $7.55^{a}$ | $70.69^{cd}$ | $40.60^{b}$ | 53.58 | 11.95 |
| Significant level | ** | * | ** | NS | NS |
| CV (%) | 13.41 | 3.23 | 4.61 | 4.05 | 12.39 |
| Std. Error (±) | 0.45 | 2.36 | 1.01 | 1.06 | 0.81 |

Letters in the same column indicate significant differences of DMRT at probability of 0.05.

K = $K_2O$. CM = Cattle manure.

** = Probability $\leq 0.01$. * = Probability $\leq 0.05$. NS = Non significance.

CV = Coefficient of variations.

Std. Error = Standard error of means.

In experiment 6, the results showed that fermented cattle manure treatment had significantly greater crude protein content than control, whilst all fertiliser treatments were significantly greater than the cattle manure treatment (Table 5.33). A partially similar trend was found with NDF, ADF, and brix values of the sorghum plants, i.e. NDF and brix values were significantly greater for both manure treated plants and N and K treated plants than control. ADF was lower in both manure and fertiliser treatments compared with control. The results showed that DMD values were not significantly affected by manure and chemical fertiliser treatments.

Table 5.33 Mean values of the estimated crude protein (CP), neutral detergent fibre (NDF), acid detergent fibre (ADF), dry matter degradability (DMD), and brix values of the sorghum plants at 11 weeks after emergence of Experiment 6 in rainy season 2001.

| Treatments | CP (%DM) | NDF (%DM) | ADF (%DM) | DMD (%) | Brix (%) |
|---|---|---|---|---|---|
| 1. Control | $4.70^{c}$ | $61.42^{a}$ | $35.12^{a}$ | 54.39 | $9.23^{b}$ |
| 2. CM 80 t/ha | $6.67^{b}$ | $55.94^{bc}$ | $31.99^{b}$ | 55.38 | $10.68^{a}$ |
| 3. 300N : 100K kg/ha | $8.26^{a}$ | $57.19^{b}$ | $32.11^{b}$ | 57.83 | $11.34^{a}$ |
| 4. 300N : 200K kg/ha | $8.11^{a}$ | $56.67^{bc}$ | $31.44^{b}$ | 57.19 | $11.68^{a}$ |
| 5. 450N : 100K kg/ha | $8.75^{a}$ | $56.64^{bc}$ | $32.12^{b}$ | 56.32 | $10.96^{a}$ |
| 6. 450N : 200K kg/ha | $8.95^{a}$ | $55.87^{bc}$ | $32.06^{b}$ | 56.21 | $11.13^{a}$ |
| 7. 600N : 100K kg/ha | $9.61^{a}$ | $55.49^{bc}$ | $33.28^{b}$ | 56.46 | $11.05^{a}$ |
| 8. 600N : 200K kg/ha | $9.12^{a}$ | $54.39^{c}$ | $32.73^{b}$ | 56.42 | $11.79^{a}$ |
| Significant level | ** | ** | ** | NS | ** |
| CV (%) | 8.81 | 2.69 | 3.55 | 3.02 | 7.22 |
| Std. Error (±) | 0.35 | 0.76 | 0.58 | 0.85 | 0.40 |

Letters in the same column indicate significant differences of DMRT at probability of 0.05.

K = $K_2O$. CM = Cattle manure.

** = Probability ≤ 0.01. NS = Non significance.

CV = Coefficient of variations.

Std. Error = Standard error of means.

### 5.7.2.4 Combined Analysis on Crude Protein (CP) Contents, Neutral Detergent Fibre (NDF), and Acid Detergent Fibre (ADF) Contents, Dry Matter Degradability (DMD), and Brix Values Between Experiment 5 and Experiment 6

The combined analysis results between Experiments 5 and Experiment 6 on CP, NDF, ADF, DMD, and brix values, showed that the effects due to season on CP, NDF, ADF, DMD, and brix values were highly significant (Table 5.34). The effects due to treatments were highly significant for CP, NDF, and ADF content but not for DMD and brix values. The effects due to season x treatment were not significant for CP and brix values, but highly significant for NDF and ADF content and significant at the 5% level for DMD.

Table 5.34 Combined analysis of means on estimated crude protein (CP), neutral detergent fibre (NDF), acid detergent fibre (ADF), dry matter degradability (DMD) and brix values of the sorghum plants at 11 weeks after emergence between Experiment 5 and Experiment 6 and ANOVA (n=8).

| Treatments | CP (%DM) | NDF (%DM) | ADF (%DM) | DMD (%) | Brix (%) |
|---|---|---|---|---|---|
| 1. Control | $4.30^{c}$ | $65.89^{ab}$ | $37.99^{ab}$ | 52.57 | 11.21 |
| 2. CM 80 t/ha | $6.56^{b}$ | $63.64^{bc}$ | $36.77^{b}$ | 53.33 | 12.45 |
| 3. 300N : 100K kg/ha | $7.52^{a}$ | $66.39^{a}$ | $38.80^{a}$ | 54.92 | 11.98 |
| 4. 300N : 200K kg/ha | $7.50^{a}$ | $65.89^{ab}$ | $38.85^{a}$ | 55.08 | 11.84 |
| 5. 450N : 100K kg/ha | $8.08^{a}$ | $64.64^{abc}$ | $38.52^{a}$ | 54.85 | 12.52 |
| 6. 450N : 200K kg/ha | $8.13^{a}$ | $64.58^{abc}$ | $38.79^{a}$ | 54.32 | 12.03 |
| 7. 600N : 100K kg/ha | $8.30^{a}$ | $64.93^{ab}$ | $39.08^{a}$ | 55.11 | 12.12 |
| 8. 600N : 200K kg/ha | $8.33^{a}$ | $62.54^{c}$ | $36.66^{b}$ | 55.00 | 11.87 |
| Items | Significant level | | | | |
| Seasons | ** | ** | ** | ** | ** |
| Treatments | ** | ** | ** | NS | NS |
| Seasons x Treatments | NS | ** | ** | * | NS |
| CV (%) | 11.00 | 3.07 | 4.30 | 3.54 | 10.59 |
| Std. Error (±) | 0.40 | 0.99 | 0.32 | 0.96 | 0.64 |

Letters in the same column indicate significant differences of DMRT at probability of 0.05.

K = $K_2O$. CM = Cattle manure.

** = Probability ≤ 0.01. * = Probability ≤ 0.05. NS = Non significance.

CV = Coefficient of variations.

Std. Error = Standard error of means.

## 5.8 Discussion

Yasothon soil series (Oxic Paleustults), a subsoil group of the great soil groups in Northeast Thailand where many annual crops have been cultivated for both overseas and domestic consumption has been found to be a relatively poor soil series of the region (Chuasavathi and Tre-loges, 2001). The results of the sixth experiment showed that a soil fertility improvement programme for this type of soil series should be an urgent task for growers in the region if high crop yields are to be attained annually. The improvement of soil fertility with the use of soil amendment material such as organic composts, manure from animal pens or sheds or crop residues and other organic waste materials could be of significant value (Suksri *et al.*, 1991; and Suksri, 1992 and 1999). However, it has been reported that organic amendments added to this soil series are short-lived, i.e. less than a year (Ratnapradipa, 1996; and Suksri, 1999). In this work (Experiment 6), after adding 80 tonnes/ha of cattle manure (41.02 % OM, Appendix C4) as basal dressing, at the end of the experimental period, the rest of organic percentages found in manure plot are 1.61 to 1.85. Therefore, when growing cash crops in most tropical areas, and particularly in Northeast Thailand, large amounts of plant materials, manure or crop residues must be annually added to the soil to assure high yield of the crops. Organic soil amendment material such as fermented manure when added to the soil could improve soil pH and also avoid the release of some toxic elements (e.g. $Al^{+++}$) as previously discussed in the fifth experiment.

The results attained with this experiment showed similar trends to the fifth experiment but were not the same; biomass yields were lower in Experiment 6 but seed yields were higher. The results confirm that Yasothon soil series could be considered as a poor soil series in Northeast Thailand where a large amount of organic soil amendment material and high rates of chemical fertiliser (especially N) must be applied annually in order to assure better growth and high yield of the many crop plants grown such as cassava, sugarcane, sesame, kenaf, sunflower and other cereal crops (Suksri *et al.*, 1991; Suksri, 1992 and

1999; and Chuasavathi and Tre-loges, 2001). The initial soil analysis results revealed that this Yasothon soil series had a similar fertility level as that of the fifth experiment. Mean values of the initial soil pH and soil nitrogen % were relatively low. Soil extractable potassium values were not adequate for the growth of crop plants, while available phosphorus had a high mean value (64.8 ppm), well above the minimum threshold for sorghum plants. The high values of available soil phosphorus could have been attributed to the previous cropping history. It has been stated by a number of workers that adequate amount of available P in soils should exceed 20 ppm (Shelton *et al.* 1979; Singer and Munns, 1987; Mengel and Kirkby, 1987; and Suksri, 1999). However, after chemical fertilisers N and K and fermented cattle manure had been added to the soil, the values of these soil nutrients were relatively high and this was partly reflected in the soil analysis data at the final sampling period particularly in plots with the high rates of chemical fertilisers N and K together with fermented cattle manure, the rest were slightly greater than the initial values. The results indicated that Yasothon series requires high rates of cattle manure and also a significant amount of chemical fertilisers especially N and also adequate K to be added to the soil annually. Fermented cattle manure must be required for high annual crop yield although considerable amounts of growth and yield of the sorghum plants were attained with high rates of N and K application alone but still lower than that of the high rate of N and K together with the 80 tonnes/ha of the cattle manure. The results suggest that for this soil type, soil amendment material together with the complete chemical fertilisers must be used annually since organic material being added to the soil could be decomposed most rapidly with time and a high leaching rate could also be occurring during the rainy season in most years of crop cultivation (Suksri *et al.*, 1991; Suksri, 1992; Seripong and Suksri, 1990; and Chuasavathi and Tre-loges, 2001). Other workers with maize have also found a significant effect of soil amendment materials, e.g. Parr (1981); Barajas and Dendooven (2001); and Akanbi and Togum (2002).

At the initial sampling period (3 weeks after emergence), the results showed that the growth parameters of the sorghum plants in this experiment were relatively greater than in the fifth experiment. This suggests that the sorghum plants in this experiment could have had better aeration and soil moisture content during the early growth period than that of the fifth experiment. It may be possible that organic manure of the sixth experiment aids better soil properties than the fifth experiment (Miller and Donahue, 1990). However, after the initial sampling period, the growth parameters of the sorghum plants were slightly lower than in the fifth experiment. This persisted throughout the subsequent sampling periods. The results indicated that rain-fed plants in Experiment 6 could have received more water than those in the fifth experiment and perhaps more than needed for optimum soil moisture content (Appendix B5 and B6). Rainfall conditions during Experiment 6 could have provided too much rainwater and waterlogging conditions could have occurred due to high rainfall particularly in the last half of the growth period (Appendix B6). This could have affected the growth rates of the sorghum plants. The results on CGR support this view. CGR values of the fifth experiment were greater than in the sixth experiment. The slight stunted growth of the sorghum plants of the sixth experiment had direct effect on other growth parameters of the sorghum plants such as LAI and D. LAI values were much lower than in the fifth experiment with a highest value of 7.27 (9 weeks after emergence) where the highest value for the fifth experiment was 12.06 (9 weeks after emergence). These results indicated that the sorghum plants in the sixth experiment failed to achieve maximum LAI for optimum growth. Whilst in the fifth experiment the optimum value was much higher (maximum values 8-10 as stated by Suksri, 1992 and 1999). However, LAI values in the sixth experiment were greater than those reported by Rao *et al.* (1999) (at anthesis LAI for CSH-9 sorghum cultivar with irrigation and rain-fed were 6 and 1.58, respectively).

The results also showed that there were significant relationship between D and total dry weights/ha and D on seed yields/ha. The results indicated that an increase in D significantly increased total dry weights/ha and seed yields/ha of the sorghum plants. It was also found that dead leaf dry weights/plant of the sixth experiment occurred at the second sampling period (5 weeks after emergence), whilst in the fifth experiment, dead leaf dry weights first occurred at the fourth sampling period (9 weeks after emergence). A possible explanation for this early senescence of dead leaf could have been due to too much water in the early part of the growing season (Appendix B6.2 and B6.3). As waterlogging caused leaf senescence and perhaps some nitrogen in aging leaves being re-translocated to the upper young leaves. Another possibility could be low light intensity levels and short sunshine duration in the early part of the rainy season (Appendix B6.2) (Begonia *et al.*, 1987; Wolfe *et al.*, 1988; and Tollenaar and Aguilera, 1992).

With respect to chemical components, the results showed that CP, in most cases, was greater than that of the fifth experiment reaching a value of 9.22, whilst that of the fifth experiment was up to 7.77. The results suggested a better CP value for the sixth experiment, although the growth of the sorghum plants in the sixth experiment was less. This could have been attributed partly to nitrogen from the double rate of cattle manure application in Experiment 6 resulted in higher nitrogen content in the sorghum tissues and the lower environmental temperatures in the sixth experiment may favour a higher level of CP. Suksri (1974) reported that radish plants accumulated higher nitrogen content under both low light intensity and temperature than higher light intensity. It was reported that N concentration in grass herbage is usually lower in summer than in spring and autumn (Whitehead, 2000). This could possibly also be a reason for this work. The higher temperature could have affected NDF and ADF in the fifth experiment when NDF and ADF values were higher than in the sixth experiment, resulting in higher values of DMD in Experiment 6. These higher values of DMD could make better qualities of fodder. The high environmental temperature in Experiment 5 could also have affected brix values of the sorghum plants, i.e. brix values in the fifth experiment were much higher than in the sixth experiment reaching a highest value of 14.52 %, whilst that of the sixth experiment was only 11.79 %. These results also indicate that soil moisture content could have affected brix values, i.e. soil moisture content was higher in the sixth experiment than in the fifth experiment (Appendix B5 and B6).

The results obtained from both the fifth and sixth experiments, indicated that Yasothon soil series requires large amount of fermented cattle manure or other organic amendment plus high rate of chemical fertiliser for high amount of growth and seed yield of sorghum plants. The results signified the poor status of soil fertility of Yasothon soil series. Therefore, in each growing session of annual crop cultivation, a large amount of organic material plus high rate of N fertiliser (plus K) must be added to the soil in order to attain high growth and crop yield. These requirements for soil amendment to the Yasothon soil series (Oxic Paleustults) could be considered as essential for growers of crops in the region if high annual crop yields are to be attained. The additional organic soil amendment materials could improve soil properties resulting in better water holding capacity and a high leaching rate could possibly be reduced (Miller and Donahue, 1990; and Suksri, 1992 and 1999).

The differences in the level of growth parameters of the sorghum plants between Experiment 5 and Experiment 6 could have been attributed partly to the differences in total radiant energy where in dry season (Experiment 5) the total energy was much greater than that of the rainy season (Experiment 6) and perhaps also the effects of high amounts of rainwater in the sixth experiment could have resulted in excess water for the sorghum plants during the sixth experiment as discussed earlier. The results of combined analysis of total dry weights/ha and seed yields/ha revealed that season has a highly significant effect on total dry weights/ha and seed yields/ha of the sorghum plants. The best results on total dry weights/ha and seed yields/ha of the sorghum plants were found with 600 kg N/ha plus 100 kg $K_2O$/ha in both experiments. Total dry weights/ha were much higher than the results of Lertprasertrat *et al.* (1998) who recorded 11,875 kg/ha for the same cultivar, whilst the highest total dry weight in this work was 29,149 kg/ha in Experiment 5 (Table 5.10) and 19,394 kg/ha in Experiment 6 (Table 5.24).

For CP, NDF, ADF, DMD and brix values, the results of the combined analysis between Experiment 5 and Experiment 6 show that season has highly significant effects on these parameters. Effects due to treatments were found and were also significant for CP, NDF, and ADF, whilst treatment effects for DMD and brix values were not significant. CP values were much higher than the results of Lertprasertrat *et al.* (1998), whilst brix values were similar. This may be attributable to low rate of chemical fertiliser application (16-20-0, N-$P_2O_5$-$K_2O$) at a rate of 187.5 kg/ha carried out in this literature. Some highly significant effects due to seasons x treatments were also found with NDF and ADF and significantly found with DMD but not with CP and brix values.

# Chapter 6

## General Discussion

### 6.1 Introduction

In order to compare further and analyse the effects of chemical fertilisers nitrogen (N), potassium (K) and also the application of cattle manure to Yasothon soil series (Oxic Paleustults) on above ground biomass yield of IS 23585 forage sorghum cultivar some of the results of the six experiments carried out in rainy and dry seasons have been shown in Table 6. This table provides summary information on how the forage sorghum responded to N, K, cattle manure and environmental conditions in terms of total dry weights at 10 to 11 + weeks after emergence. Information in the literature shows significant effects due to the application of NPK chemical fertilisers, organic amendments, and climatic conditions on growth and fodder yields of sorghum on different soil series, e.g. Meesawat *et al.* (1977); Myers (1978); Seetharama *et al.* (1984); Hammer *et al.* (1989); and Hammer and Broad (2003). The various factors are considered separately in relation to the experiments reported here.

### 6.2 Soil Conditions

Yasothon soil series belongs to a great soil group of Oxic Paleustults, Order Ultisols. Panchaban (1976) analysed this soil type taken at Khon Kaen University Experimental Farm. He found a sandy loam texture, 75 % sand, 18 % silt and 7 % clay. Miura *et al.* (1990) reported that Yasothon soil series in Khon Kaen Province (approximately 10 km away from the experimental site of Khon Kaen University) has a moderate medium granular structure (Ap horizon, 0-25 cm), and a moderate medium subangular with blocky structure for B1 horizon (25-37 cm). Ap horizon contains 75.3 % sand, 17.2 % silt and 7.5 % clay, whilst B1 horizon contains 69.3 % sand, 19.2 % silt and 11.5 % clay. Clay mineralogical compositions of both horizons are kaolinite (> 60 %), illite (0 %), smectite (10-20 %) and quartz (10-20 %) with exchangeable cations (CEC) of 2.53 me/100g for Ap horizon (1.84 $Ca^{2+}$, 0.26 $Mg^{2+}$, 0.06 $K^+$, 0.18 $Na^+$, < 0.01 $Al^{3+}$ and 0.19 $H^+$), and 2.52 me/100g for B1 horizon

(1.78 $Ca^{2+}$, 0.25 $Mg^{2+}$, 0.08 $K^{+}$, 0.17 $Na^{+}$, < 0.10 $Al^{3+}$ and 0.14 $H^{+}$). However, Okabe and Somabhi (1989) also analysed Yasothon soil series at other locations in Northeast Thailand and found that cation exchange capacity (CEC) was only 1.12 me/100g. The differences may be attributable to the differences in sampling sites and/or historical background of crop cultivation. The low value of CEC could be due to the low amount of clay minerals, and low organic matter (average 0.69 % in initial soil analysis on page 63). There is an urgent need to increase CEC in order to increase the amount and availability of soil nutrients in this soil. Chuasavathi and Trelo-ges (2001) also analysed Yasothon soil series, they found that this is an acid soil with low amounts of nutrient contents particularly nitrogen and potassium.

The results of the initial soil analysis data for Experiments 1-6 indicate that mean values of soil pH were similar for Experiments 1-3 (5.4), relatively lower for Experiments 5 and 6 (4.93 and 4.93) and slightly increased in Experiment 4 (6.1). It has been advocated that suitable soil pH for the growth of most crops should range between 6-6.5 (Miller and Donahue, 1990; Suksri, 1999). It was found that only Experiment 4 is fitted to this range of soil pH. The results also revealed that mean values of soil organic matter % (OM) were similar in all experiments, except Experiments 3 and 6 where OM values were relatively higher (0.73 and 0.82 %, respectively). The differences found on soil pH and OM could be attributable to the effect of rotating the sowing of sorghum seeds in the experimental plots which may have been previously used for other crops. Therefore, the relatively small differences found on soil pH and OM among the experimental plots may be attributable to the previous history of crop cultivation. Soil N and K were relatively low ranging from 0.035-0.042 % and 38-60 ppm, respectively, but soil P was relatively high ranging from 21-65 ppm. This may be attributable to the same reason given for soil pH and OM and also the low clay mineral content as discussed earlier. The results of the initial soil analysis for all experiments showed that Yasothon soil series is a poor soil type compared with other soil series in Thailand such as Tha muang (0.088 % N, 10.56 me/100g CEC), and Ratchaburi soil series (0.087 % N, 10.75 me/100g CEC) as reported by Okabe and Somabhi (1989). These initial results justify our experiments to add both significant levels of N and K fertilisers and OM in the form of cattle manure.

Soil analysis data at the final sampling periods of the six experiments showed that mean pH values of Experiments 1-4 ranged from 5.7-6.4 (Tables 3.2, 3.9, 4.2 and 4.13), whilst Experiments 5-6 ranged from 4.9-6.4 (Tables 5.2, and 5.16). The higher values of soil pH of Experiments 1-4, which were slightly higher than the initial sampling periods, must be attributable to the added amounts of dolomite at a rate of 3,750 kg/ha. The low values of soil pH of 4.9-5.3 of Experiment 5 and the low values of 5.0-5.3 of Experiment 6 derived from the control treatments and the chemical fertilisers N and K treatments where no cattle manure was added. For treatments added with cattle manure, mean pH values ranged from 5.9-6.4 for Experiment 5 and 6.1-6.4 for Experiment 6. The higher pH values were in the treatments with cattle manure with higher mean values than the control treatments. The results indicate significant effect of cattle manure on soil pH. The increases in soil pH values must be attributable to the presence of weakly acidic chemical functional groups on soil organic molecules, that can act as conjugate acid/base pairs, making soil OM an effective buffer. Star *et al.* (1996) found a good correlation between acid buffer capacity and OM content for 29 organic and 87 mineral soil horizons. Yan *et al.* (1996) stated that the net effect of adding OM to acidic soils is generally an increase in soil pH. They further stated that the decarboxylation of organic acids has also been shown to increase the pH of acid soils.

At the final sampling, the results showed that OM % of the added cattle manure treatments of the six experiments, in most cases, increased soil OM of Yasothon soil. For total soil N, in most cases, soil N % was also increased. However, soil nitrogen was found to be at a low level relative to requirements for the sorghum plants. This may be due to a high leaching rate in this sandy loam soil as well as N uptake by the sorghum plants. Soil K values were relatively increased as a result of an increase in K application rates. Mean value of soil P was at a high level due to the added amount of phosphorus fertiliser as a basal dressing and perhaps the previous cropping history. Overall soil analyses at the final harvests indicate a continuing requirement for relatively high inputs of N and cattle manure, and to a lesser extent, K.

### 6.3 Climatic conditions

Rainfall patterns and the amount of rainwater largely affected growth of the sorghum plants and obviously erratic rainfall pattern affected the responsiveness of plants to fertiliser application. The total amounts of rainfall in Experiments 1-6 were not the same (Table 6). This may be attributable to the seasonal variation from year to year (1997-2001); total amounts were 404.70, 221.70, 318.90, 692.10, 275.90 and 543.60 mm for Experiments 1-6, respectively. These amounts of rainfall affected growth of the sorghum plants particularly total dry weights of the six experiments but there appears to be an interaction with both OM and N: K ratios because the highest total dry weight values (Table 6) are in the dry season (Experiment 5). The results confirmed the work reported by Seetharama *et al.* (1984), Rao *et al.* (1999), and Ockerby *et al.* (2001). Myers (1978) reported that total above ground biomass of sorghum (15.5 tonnes/ha) occurred in a season of above average rainfall (989 mm from October to April) with the use of nitrogen fertiliser at a rate of 150 kg N/ha. The highest biomass values of this work were much higher (Table 6 Experiment 5) probably reflecting higher N applications and the use of cattle manure, even though rainfall was lower. In a season when rainfall was below average rainfall (667 + 60 mm irrigation), vegetative growth of sorghum was stimulated by N only up to 90 kg/ha during the 56 days of growth. He further stated that a shortage of water during the grain filling stage coincided with an excessive vegetative growth at the high N application and appeared to be the major factor causing the depression of crop yield. Rego *et al.* (1998) found that biomass production of sorghum positively responded to water (irrigated plots) as well as to N application rates. Our data in Table 6 indicate that overall highest biomass yields (Experiment 5) in the dry season with initial irrigation provided that the N: K ratio and OM additions are adequate.

Total solar radiation of the six sorghum experiments was not similar (Table 6) but percent variation is much lower than for rainfall. This must be attributable to the changing of seasons from a certain period to a certain period and it was found that total radiation was higher for dry season experiments (2000-2001) than rainy season experiments (Experiments 4-6) resulting in higher total dry weight of sorghum plants in dry seasons than rainy seasons. This could have been due to cloudy conditions in rainy seasons decreasing the intensity of the incoming solar radiation. Tollennaar (1983) reported that incident solar radiation is a function of solar height, i.e. latitude, day and hour and the attenuation of the radiation by the atmosphere such as clouds. For temperate climate, maximum average daily incident solar radiation is attained in early summer and rapidly declines in late summer. Tollennaar and Dwyer (1998) stated that about 50 % of the incident solar radiance could be used in photosynthesis. Hebert *et al.* (2001) found that maize shoot dry weight was significantly reduced by a shading effect. At silky stage, shoot dry weights attained for sunlight and shade were 102.2 ± 9.3 and 75.6 ± 9.3 g/plant, respectively. Hammer and Broad (2003) carried out four experiments of three hybrid sorghum cultivars. They found that biomass of the first two experiments at anthesis significantly increased with an increase in the sum of intercepted solar radiation until anthesis for quick mature, intermediate mature and medium late mature cultivars, respectively. The results of the last two experiments showed that biomass at anthesis was significantly reduced by both a lower plant population and the consequent lower values of sum intercepted radiation to anthesis. The experiments with the higher values of the sum of intercepted radiation of the same cultivars gave greater biomass and grain yield than the lower values of the sum of intercepted radiation.

## 6.4 Growth of Sorghum as Affected by Nitrogen, Potassium and Cattle Manure

The results on mean values of total dry weights of sorghum plants at 10-11 + weeks after emergence, amounts of rainfall, solar radiation in the six experiments were compared in Table 6. The results on total dry weight in Experiment 1 showed that at 11.7 weeks after emergence, the applied rates of both N and K had no significant effect on total dry weight presumably due to low application rates and also perhaps high leaching rate. However, with Experiment 2 when higher rates of both N and K were applied. At 10 weeks after emergence, the results showed that total dry weight significantly increased with both N and K application but only up to N2 (300 kg/ha) and K2 (200 kg/ha). The results indicate total dry weights, in most cases, higher than Experiment 1 but a statistical comparison is not possible. For Experiment 3 with cattle manure as a basal dressing at 11 weeks after emergence, the results showed that total dry weights, in four cases out of eight, were less than Experiment 2 but percent differences are small and the other four are higher. This may be partly attributable to the slighly longer sampling period of 11 weeks compared with 10 weeks of Experiment 2. At the period of 11 weeks after emergence, the sorghum plants could have filled up their grains more rapidly hence total dry weights of the sorghum plants declined with time due to the re-translocation of a certain amount of assimilates from source to sink (Heathcote, 1973; Evans, 1975; and Grundon *et al.* 1987). Another reason could possibly be attributable to drought conditions in Experiment 3 during 13-26 September and from 27 September to 10 October where the average amounts of rainfall reached only 1.9 and 1.5 mm/day for both periods, respectively.

In Experiment 4 carried out in dry season, the results showed that total dry weights, in *all* cases, were higher than Experiment 3 (Table 6). This could be partly attributable to higher total solar radiation in Experiment 4, which was approximately 10 % greater than Experiment 3. However, amounts of total rainfall were much higher for Experiment 4 than Experiment 3. Supplementary irrigation was given to Experiment 4 after sowing of seeds for three weeks. This higher rainfall is probably the main reason for the higher total dry weights in Experiment 4(although Experiment 4 was carried out in dry season but the rain came early in April 2000; May is the beginning of rainy season). The results confirm the work reported by Myers (1978); Rego *et al.* (1998); and Hammer and Broad (2003).

Experiments 5 and 6 were carried out in different seasons, i.e. Experiment 5 was done during the last half of the dry season (March-June) with the use of irrigation for six weeks from sowing. Experiment 6 was carried out in rainy season without supplementary irrigation. These two experiments are compared due to their similarities in the application rates of both N and K and experimental design but different rates of cattle manure, i.e. 40 tonnes/ha for Experiment 5 and 80 tonnes/ha for Experiment 6. The results showed that cattle manure tremendously improved soil pH, OM, total N, available P and extractable K of Yasothon soil series (Table 5.16). Cattle manure application significantly increased total dry weights of sorghum plants over the control treatment of both Experiments 5 and 6 (Table 6). An increase in cattle manure rate from 40 to 80 tonnes/ha significantly increased total dry weights (Experiment 5). OM clearly has a significant effect on soil properties of Yasothon soil series. It improves soil structure and the release availability of nutrients for crop growth. The findings of a number of workers, e.g. Emerson *et al.* (1986); Chen and Aviad (1990); Churchman and Foster (1994); Foster (1994); Stevenson (1994); Ladd *et al.* (1996); and Brady and Well (2002) support this view.

The application of cattle manure when applied together with different ratios of N and K revealed that total dry weights of the sorghum in both Experiments 5 and 6 significantly increased presumably due to the improvement of soil structure and soil chemical properties particularly soil pH, OM %, and CEC. OM from cattle manure normally improves CEC. Stevenson (1994) showed that OM contributes from 25-90 % in improving CEC of surface layers of mineral soils. The contribution is greatest for soils with low clay content or where the clay fraction is dominated by a mineral with a low charge density (e.g. kaolinite). Oades (1989) found that each increment of OM % in soils contributes approximately 1 $cmol_c/kg$ soil to the CEC of variable charge soils. Likewise, McBride (1994) found an improvement of approximately 3 $cmol_c/kg$ soil to the CEC of neutral permanent charge soils. Measurements (of the effect of soil OM) on CEC have yielded values ranging from 60-300 $cmol_c/kg$ soil (Leinweber *et al.*, 1993; and Stevenson, 1994). Yasothon soil contained > 60 % kaolinite

(Miura *et al.*, 1990), thus OM from cattle manure application should tremendously increase CEC value. An indirect effect of OM on soil conditions and plant growth is the maintenance of the structural stability of a wide range of soil types including Mollisols, Alfisols, Ultisols and Inceptisols. OM associated with each level of soil aggregation varies (Emerson *et al.*, 1986; Churchman and Foster, 1994; Foster, 1994; and Ladd *et al.*, 1996). Stevenson (1994) stated that soil OM can absorb and hold substantial quantities of water up to 20 times its mass. OM in the form of surface residues can also influence water retention directly by reducing evaporation and increasing infiltration of water. The indirect effect of OM on water retention arises from its impact on soil aggregation and pore size distribution, and thus on the plant available water holding capacity. A Farmyard Manure (FYM) trial carried out at Rothamsted, Davies and Payne (1989) reported that crumb stability in arable soils can usually be increased if regular applications of FYM are given, though the amounts required may be very large. An annual application of 35 tonnes/ha being practiced for century have made a measurable increase in the crumb stability of the Rothamsted soil, increasing the proportion of water-stable crumbs over 0.5 mm in size from 28 to 55 % on Broadbank, which is in continuous wheat, and from 54 to 70 % on Barnfield, in continuous root crops. On a very unstable fine sandy loam soil, 75 tonnes/ha FYM application annually did not effect the stability of the structure appreciably, but it gave a very large earthworm population which maintained aeration and drainage due to the number and distribution of their burrows.

In relation to the direct effect of OM on plant growth, Brady and Well (2002) stated that certain organic compounds are absorbed by higher plants. The plants can absorb a very small portion of their nitrogen and phosphorus needs as soluble organic compounds. The various growth promoting compounds, i.e. vitamins, amino acids, auxins and gibberellins are also formed as organic matter decays. These substances also stimulate growth in microorganisms. Chen and Aviad (1990) reported that components of humic substances (humic and fulvic acids) stimulated root initiation and elongation and enhanced growth of plant shoots and roots.

The effect on total dry weights of the sorghum plants at 11 weeks after emergence due to solar radiation in Experiments 5 and 6 revealed that total solar radiation of Experiment 5 (18,565 cal/cm$^2$/day) was much higher than Experiment 6 (15,696 cal/cm$^2$/day). This must partially explain why total dry weights in Experiment 5 were higher than Experiment 6. These differences in solar radiation must be attributable to a clear sky in dry season providing a greater amount of radiation than in rainy season. In rainy season, cloudy skies obviously occur when monsoon comes, thus there is greater radiation in dry season than in rainy season (Tollennaar, 1983; and Hammer and Broad, 2003). It may also be possible that the smaller amount of total dry weights of Experiment 6 than Experiment 5 could have been attributable to waterlogging conditions in Experiment 6 due to a high average amount of rainfall attained during September which could have encouraged a high amount of nutrient leaching. Miller and Donahue (1990) reported that an annual loss of soil nitrogen due to leaching under heavy rainfall conditions could range from 50-80 kg N/ha. Brady and Well (2002) showed that an annual loss of K is usually about 25-50 kg/ha and the greater values are found in acid sandy soils. Liming an acid soil to raise its pH can reduce the loss of K from leaching because of the complementary ion effect ($K^+$ can be easily replaced by $Ca^{2+}$ ions than they could be replaced by $Al^{3+}$ ions).

A combine analysis between Experiments 5 and 6 (Table 5.31) showed that total dry weights were significantly affected ($P < 0.01$) by seasons and treatments but not the interaction of seasons x treatments. The results indicated that both seasons (mainly amounts of rainfall and solar radiation) and treatments (N, K and cattle manure application) had the highest effect on growth of the sorghum. It was also found that total dry weights were independent of the interaction between seasons and treatments.

An overview of the results of the six experiments due to N application on total dry weights showed that N application had no effect on total dry weights of Experiment 1; N2 (300 kg/ha) of Experiment 2 gave the highest value. N2 and N3 levels of Experiment 4 were similar whereas N3 (450 kg N/ha) of Experiment 3 was the highest. From these results, it might be inferred that

N2 (300 kg/ha) should be an appropriate application rate for use by farmers. Total dry weights for N2 (300 kg N/ha) level of Experiments 1 to 4 ranged from 10,932 – 19,431 kg/ha. There were no effects due to K found on total dry weights of Experiments 1 and 4, whilst K1 (100 kg $K_2O$/ha), and K2 (200 kg $K_2O$/ha) of Experiment 2 were similar. K2 and K3 (400 kg $K_2O$/ha) of Experiment 3 were highest but having a similar value whereas K1 was the second. Therefore, in terms of economic value, K1 should be an appropriate level for K fertiliser application. Total dry weights of the sorghum for K1 of Experiments 1-4 ranged from 11,580 – 16,898 kg/ha.

The results on total dry weights of Experiments 5 and 6 (Table 6) showed that the application rate of 40 tonnes/ha of cattle manure plus different N and K ratios of Experiment 5, in all cases, gave higher total dry weights than Experiment 6 (the same N, K rates plus 80 tonnes/ha of cattle manure were used for Experiment 6). With K1 level (100 kg $K_2O$/ha) of Experiment 5 when applied with N rates of 300, 450, 600 kg N/ha plus 40 tonnes/ha cattle manure it gave total dry weights of 20,704; 26,282; and 29,072 kg/ha, respectively whilst Experiment 6 gave only 13,758; 16,617; and 19,059 kg/ha, respectively. The results indicated that N rate at 600 kg N/ha could be considered to be an excessive amount and it is unnecessary although it gave the highest total dry weights for both Experiments 5 and 6. The results also revealed that Experiment 5 (29,072 kg/ha of total dry weight) was much higher than Experiment 6 (19,059 kg/ha). This must be attributable to the effect due to seasons where total dry weight in dry season was much higher than in rainy season. It was also found that N2 and K1 levels plus cattle manure (40 kg/ha) of Experiment 4 carried out in dry season gave the highest total dry weight (19,431 kg/ha). Therefore, N2 plus K1 should be more appropriate levels than the other N rates to be applied. It is generally recognised that most growers in Thailand sow sorghum seeds in rainy season rather than in dry season; only a few large farms may sow seeds in dry season with the use of irrigation water when amount of fodder is inadequately available for their cattle.

Sajipanon *et al.* (1985) showed that urea application rate of 400 kg N/ha plus a basal dressing of 100, 100 and 100 of N, $P_2O_5$, and $K_2O$ kg/ha to Ruzi grass (*Brachiaria ruziziensis*) grown on Korat soil series (Oxic Paleustults) using a 40-day split application gave the highest yield and they recommended this N rate for high fodder quality and maximum yield for this soil type. This Korat soil series is a poor soil type being classified into the same great soil group of Oxic Paleustults as Yasothon soil series. These results indicated that a high rate of N application is needed for maximum biomass yield. In an experiment carried out with Napier and Mauritius grasses on Ratchaburi soil series (a clay soil type) in Chainat Province, Thailand Punyavirocha *et al.* (1991) found that Napier and Mauritius grasses yields significantly increased with an increase in cattle manure application rates. The highest total dry weight was attained from manure rate of 37.50 tonnes/ha of cattle manure. These fertiliser and manure application rates are in a similar range to the median in our experiments with sorghum and close to those we would suggest for farm use.

Yuthavoravit *et al.* (1995) carried out experiments in the Middle Plain area in Thailand and stated that maximum N rate for maximum yield was 400 kg/ha (with basal application of 15-15-15 NPK at a rate of 156.25 kg/ha). They applied this N rate to *Panicum maximum* TD 58 grass cultivar and found that this N rate is most appropriate for maximum fodder yield. However, their soil OM was up to 2.5 %. These results imply that higher N rate is needed for sandy soils such as Yasothon soil when OM content is much lower than many other soil types. Thinnakorn *et al.* (1998) reported an experiment with signal grass (*Brachiaria decumbens* cv. Basilisk) grown on silty clay soil (Pakchong soil series) with initial soil pH, OM, total N, available P and extractable K of 6.64, 2.6 %, 0.13 %, 20.77ppm, 186 ppm, respectively. N rates applied were 0, 125, 250, and 375 kg N/ha/year with a basal dressing of KCl at a rate of 125 kg $K_2O$/ha/year. Total dry weights over a two-year period significantly increased with an increase in N application, whilst P application had no significant effect on total dry weight. The highest rate of N gave the highest total dry weight. The results indicated that even the highest rate of N did not maximise dry weight; thus it is possible that a higher rate is needed for this soil type. They recommended their highest rate of N for growers for a higher income. A value of OM % of 2.6 is considered to be a high level when compared with Yasothon soil series. Therefore, Yasothon soil series may need high N and cattle manure rates to increase OM and CEC levels for high crop yield.

Udchachon *et al.* (1998) carried out forage crop experiments at Khon Kaen Province, Northeast Thailand on Korat soil series (Oxic Paleustults), they used four forage species with a basal dressing of cattle manure at a rate of 92.5 tonnes/ha/year plus chemical fertiliser 15-15-15 (NPK) at a rate of 140.62 kg/ha for each N, $P_2O_5$, and $K_2O$ plus 92.5 kg N/ha from urea. They grew *Panicum maximum* cv. TD 58 (Guinea grass), *Sorghum bicolor* cv. SP1 (sorghum), *Zea mays* cv. Suwan 2 (maize) and Late sorghum x Sudan hybrid (Jumbo grass). The yield of sorghum reached 29,644 kg/ha (3 cutting periods), which was similar to the yield of Guinea grass and maize but significantly lower than Jumbo grass for the first growing period from 26 January to 20 July 1996. For the second planting period from 22 July 1996 to 11 January 1997, SP1 sorghum gave dry matter yield of 26,625 kg/ha (3 cutting periods). This yield was similar to Guinea grass but significantly lower than maize and Jumbo grass. In this experiment, at each growing period (3 cuttings) they added N of 116.6 kg N/ha, $P_2O_5$ and $K_2O$ of 70.3 kg/ha plus cattle manure of 46.25 tonnes/ha. This cattle manure rate is slightly higher than the cattle manure rate of Experiment 5 where dry matter yield was lower. The lower dry matter yield could have been attributable to only a single cutting while theirs had for 3 cuttings from ratoon crops. Of the four crops, they stated that the lowest inputs were with Guinea grass followed by sorghum, Jumbo grass and maize the highest. However, an advantage is found with Guinea grass since it lasted many years while sorghum and Jumbo grass are sown twice a year, maize for six times a year. Comparing these findings with our experiments it might be inferred that a rate of 40 tonnes/ha of cattle manure used in Experiment 5 could be a suitable rate to be practiced by Thai growers.

Chinosaeng *et al.* (2000) carried out experiments on a clay soil (Ratchaburi soil series) in the Middle Plain area at Chainat Province, Thailand with *Setaria sphacelata* CPI 15899 forage grass and found that maximum nitrogen rate for maximum yield was up to 250 kg N/ha plus cattle manure rate at 12.5 tonnes/ha. In another experiment carried out with the use of the same soil series nearby, Nakamanee *et al.* (2000) found that N application at 500 and 750 kg N/ha gave the highest total dry weights of Mauritius grass (*Brachiaria mutica*); the higher rate did not significantly increase dry weight. They also found that cattle manure at a rate of 75 tonnes/ha gave the highest dry weight but this was not significantly different from lower rates of 50 and 62.50 tonnes/ha. Sukkasem *et al.* (2000) did an experiment on a grass grown on a poor sandy soil type (Banthon soil series) in the southern region of Thailand and reported that cattle manure application significantly increased soil pH, OM %, available P, extractable K and Ca. *Brachiaria humidicola* grass yield significantly increased with manure application up to 25 kg/ha. Increased manure application rates gave no significant effect in yield; the grass dry weight was highest with N application only up to 250 kg N/ha. Yuthavoravit *et al.* (2004) applied nitrogen rates of 375 and 500 kg N/ha to dwarf napier grass (*Pennisetum purpureum* cv. Mott). Both N rates gave a similar fodder yield and were the highest yields. Their soil type is a sandy loam soil. Similarly, Chinosaeng *et al.* (2004) carried out experiments with the use of dwarf napier grass. They used the same rates of N fertiliser but with different soil types and found that these two rates of N gave a similar fodder yield. These results suggested that high rate of nitrogen application is required for high fodder yields. Therefore, tropical soils unlike those of the temperate soils, require a high amount of nitrogen for high crop yields. However, in most of these experiments with a range of fodder species N rates giving the highest dry matter yields are similar to the median rate used in our experiments i.e. 300 kg/ha. This further supports the view that this could be a practicable rate for farmers.

## 6.5 Environmental Conservation

The application of chemical fertilisers to crop plants particularly nitrogen obviously creates pollutants to soils and underground water especially in temperate areas. Miller and Gardiner (1998) stated that soils are nature's dispose-all, its sewage treatment plant, its water purifier, and at times, also a pollutant. Soils are valuable cleaners of the Earth's environments. The soil is a *physical filter* (decomposition of organic materials), as well as the receptacle for all things buried and disposed of on the surface. With respect to nutrient pollution, nitrate and phosphorus are the major nutrients of concern. Nitrate is leached into waters by rainfall and irrigation any time water flushes through soil. A large amount of nitrate can be flushed into soil where nitrogen chemical fertilisers have been applied and the crop plants are unable to quickly utilise most of it for growth. Decomposition of organic materials can also build up nitrate reservoirs if they are released faster than utilisation by plants. Pollution problems created by fertiliser application have been emphasized in many countries e.g. in Arizona State of the USA, Munson and Russell (1990) reported that Arizona State granted a law on best management practices (BMPs) for the application of nitrogen fertilisers to crops and for animal feeding operations. In Thailand a regulation on environmental integrity on duck production has been granted by Ministry of Agriculture and Cooperatives. It is known as "Thai agricultural commodity and food standard (TACFS 6900-2003)". The regulations on duck production include the practices on farm components, farm management, animal health management, environmental management and animal welfare management. It is carried out under the Office of TACFS (enacted in the 2003). A similar regulation on chemical fertiliser applications could possibly be granted in the near future.

It could be possible that the rates of 600 kg N/ha and 40 tonnes/ha of cattle manure used in this sorghum experiment (Experiment 5) may be considered too high to be applied to Yasothon soil although together they gave the highest total dry weight of the sorghum. These rates of both chemical fertiliser and cattle manure could possibly produce excessive level of nitrate leaching to form environmental pollutants. Therefore, rates recommended for growers need further consideration.

Based on environmental integrity, current local manuring practices, economic reality and the results on total dry weights of the six experiments, it might be inferred that suitable rates for nitrogen should be at a range of 300-450 kg N/ha, for potassium at a rate of 100 kg $K_2O$ and cattle manure at a rate of 40 tonnes/ha. These rates of N, K and cattle manure/ha should provide adequate nutrients and improve soil properties for optimum total dry weights of the sorghum crop. The highest applied rates of N, K and cattle manure being used in the present work may not appropriate for growers to practice due to higher inputs of expenses on fertilisers, labour and environmental pollution of nitrate. The application of cattle manure annually at a rate of 46.25 tonnes/ha plus chemical fertilisers on Korat soil series (Oxic Paleustults) has proven adequate for high yield of sorghum crop (Udchachon *et al.*, 1998). Therefore, a rate of 40 tonnes/ha for sorghum should be appropriate for Yasothon soil type. However, growers may find complications in applying manure at this level due to transportation and labour inputs. However, should growers not avoid applying organic amendment materials to their farms, these are vital to improve soil conditions for optimum yields.

## 6.6 Conclusions

Yasothon soil series (Oxic Paleustults) is a poor sandy loam soil in Northeast Thailand. The application of cattle manure improves soil structure, organic matter, soil pH, CEC, and indirectly increases the availability of soil nutrients for sorghum plants particularly N and K.

Total dry weights of the sorghum plants were influenced most by seasons, solar radiation and amounts of rainfall and also rainfall plus irrigation in dry season. Solar radiation is greater for dry season than rainy season. Total dry weights of sorghum were greater in dry season with initial irrigation than in rainy season. Cattle manure application significantly increased total dry weights. N and K plus cattle manure also significantly increased total dry weights of sorghum plants over N and K rates alone.

In terms of both economic and environmental concerns, the appropriate rates for nitrogen, potassium and cattle manure for optimum total dry weights should be at the application rates of 300-450 kg N/ha, 100 kg $K_2O$/ha plus 40 tonnes/ha. These application rates, used in this work gave relatively high dry matter yields, are recommended for growers of the IS 23585 forage sorghum cultivar on Yasothon soil series (Oxic Paleustults) in Thailand.

## 6.7 Further Work

Further work should concentrate on: (1) To be able to conclude more precisely the effect due to N, K and cattle manure application rates on growth and fodder yield of sorghum. Experiments on different rates of both N and K at 0-450 kg N/ha and 0-100 kg $K_2O$/ha should be carried out together with different rates of cattle manure range from 0-40 tonnes/ha. (2) Experiments should be carried out in both rainy and dry seasons in order to justify the effects of amounts of rainfall, and solar radiation when the results of both experiments are compared. (3) It was found that N seems to have more effectiveness on fodder yields than K, hence it may be important to carry out an experiment on $N^{15}$ isotope to follow up the utilisation of N in the sorghum plants and also the annual leaching rate of nitrate on Yasothon soil series with a sorghum crop.

Table 6 Means of total dry weights (TTDW, kg/ha) of sorghum at 10-11+ weeks after emergence in six experiments as influenced by treatments, average amounts of rainfall (mm/day) and solar radiation (cal/cm$^2$/day), grown on Yasothon soil series, Northeast Thailand.

| Treatments | | | Expt.1 (low rate of N&K in rainy season) 1997 | | | Expt.2 (high rate of N&K in rainy season) 1999 | | | Expt.3 (high rate of N&K+basal CM in rainy season) 1999 | | | Expt.4 (high rate of N&K+basal CM, dry season+irrigation) 2000 | | | Expt.5 (N-K ratio +40 t/ha CM in dry season+irrigation) 2001 | | | Expt.6 (N-K ratio +80 t/ha CM in rainy season) 2001 | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Number | N | K | TTDW (11.7 WAE) | Rainfall | Solar Radiation | TTDW (10 WAE) | Rainfall | Solar Radiation | TTDW (11 WAE) | Rainfall | Solar Radiation | TTDW (11 WAE) | Rainfall | Solar Radiation | TTDW (11 WAE) | Rainfall | Solar Radiation | TTDW (11 WAE) | Rainfall | Solar Radiation |
| 1 | N0 | | 11462 | 11 | 31 | 6507d | 28 | 10 | 8265d | 23 | 12 | 11686c | 28 | 17 | 11773g | 20 | 9 | 5299h | 30 | 19 |
| | | | | July- | July | | July- | Aug | | Aug- | Sept | | Mar- | Apr | | Mar- | Apr | | July | Aug |
| 2 | N1 | | 11318 | 5.7 | 207 | 12264c | 3.3 | 232 | 11278c | 5.0 | 232 | 17328b | 6.8 | 245 | 12039g | 0.4 | 233 | – | 8.6 | 196 |
| 3 | N2 | | 10932 | 1-14 | Aug | 13942a | 11-24 | Aug | 12705b | 13-26 | Sept | 19431a | 18 | -1 | 15756f | 10-23 | Apr | – | 20 Aug- | 2 Sept |
| | | | | 3.7 | 237 | | 2.0 | 245 | | 1.9 | 215 | | Apr | May | | 0.1 | 274 | | 4.7 | 210 |
| 4 | N3 | | 11574 | | | 13407b | | | 15018a | | | 20550a | 10.3 | 256 | 17997e | | | 11461g | | |
| 5 | | K0 | 11050 | 15 | 28 | 11034c | 25 | 7 | 10911c | 27 | -10 | 16459 | 2 | -15 | 17889e | 24 | 7 | 11795g | 3 | 16 |
| | | | | Aug- | Aug | | Aug- | Sept | | Sept | Oct | | May | May | | Apr- | May | | Sept- | Sept |
| 6 | | K1 | 12212 | 7.8 | 249 | 11639ab | 7.0 | 230 | 11580b | 1.5 | 259 | 16898 | 14.1 | 241 | 18227e | 6.3 | 244 | 12178fg | 8.7 | 195 |
| 7 | | K2 | 11092 | 29 | 11 | 12065a | 8-21 | Sept | 12321a | 11-24 | Oct | 17688 | 16-29 | May | 19828d | 8-21 | May | 12984ef | 17-30 | Sept |
| | | | | Aug | Sept | | 1.7 | 222 | | 4.1 | 228 | | 6.0 | 248 | | 6.8 | 222 | | 9.3 | 212 |
| 8 | | K3 | 10932 | 5.5 | 193 | 11383bc | | | 12454a | | | 17950 | | | 20097d | | | 13077ef | | |
| 9 | | | | 12 | -30 | | 22 | -5 | | 25 | 7 | | 30 | -12 | 23270c | 22 | -4 | 15633c | 1 | 14 |
| | | | | Sept | Sept | | Sept | Oct | | Oct- | Nov | | May | June | | May | June | | Oct- | Oct |
| 10 | | | | 2.5 | 266 | | 1.8 | 252 | | 7.8 | 202 | | 8.8 | 245 | 24247c | 5.9 | 237 | 15911c | 3.3 | 210 |
| 11 | | | | Grand | mean | | Grand | mean | | Grand | mean | | Grand | mean | 20704d | Grand | mean | 13758de | Grand | mean |
| | | | | 11 | 30 | | 28 | 5 | | 23 | 7 | | 28 | 12 | | 20 | 4 | | 30 | 14 |
| 12 | | | | July- | Sept | | July- | Oct | | Aug | Nov | | Mar- | June | 21101d | Mar- | June | 14128d | July- | Oct |
| | | | | 4.94 | 230.3 | | 3.17 | 236.5 | | 4.14 | 227.5 | | 8.99 | 246.8 | | 3.58 | 241.1 | | 7.06 | 203.9 |
| 13 | | | | | | | | | | | | | | | 26282b | | | 16617bc | | |
| 14 | | | | Grand | total | | Grand | total | | Grand | total | | Grand | total | 25673b | Grand | Total | 17178b | Grand | total |
| | | | | 11 | 30 | | 28 | 5 | | 23 | 7 | | 28 | 12 | | 20 | 4 | | 30 | 14 |
| 15 | | | | July- | Sept | | July- | Oct | | Aug- | Nov | | Mar- | June | 29072a | Mar- | June | 19059a | July- | Oct |
| 16 | | | | 404.70 | 18884 | | 221.70 | 16554 | | 318.90 | 17520 | | 692.10 | 19002 | 29149a | 275.90 | 18565 | 19394a | 543.60 | 15696 |

Remarks: For Experiments 1-4, numbers 1-4 and 5-8 are means of TTDW for $N_{0-3}$ and $K_{0-3}$ application rates, respectively. For Experiment 4 and 5, mini-sprinkler irrigation was used until the rain came at the 2nd and 4th week of April 2000 and 2001, respectively. For Experiment 5, number 1-4 are control # 1, 2, cattle manure (CM) 40 and 80 t/ha, respectively. For Experiment 6, number 1 and 4 are control and CM 80 t/ha, respectively. WAE = weeks after emergence. Letters in the same column indicate significant differences at p = 0.05

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# Appendix A

## A1 Sorghum Production

### A1.1 World Sorghum Production

Appendix A1.1.1 Area harvested (1000 ha) of the sorghum plants of some selected countries from the year 1992 to 2001.

| Selected countries | Year | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1992 | 1993 | 1994 | 1995 | 1996 | 1997 | 1998 | 1999 | 2000 | 2001 | Means |
| **World** | **46238** | **42284** | **44113** | **42604** | **47104** | **43846** | **43067** | **40863** | **41526** | **41575** | **43322** |
| **Africa** | **21690** | **20105** | **22748** | **21753** | **23780** | **22690** | **23359** | **21138** | **21397** | **21587** | **22025** |
| Nigeria | 5474 | 5605 | 5738 | 6095 | 6191 | 6589 | 6635 | 6678 | 6885 | 6885 | 6278 |
| Sudan | 6200 | 4684 | 6427 | 5045 | 6553 | 5329 | 6311 | 4530 | 4195 | 4195 | 5345 |
| **North & Central America** | **6724** | **4962** | **5276** | **5124** | **7386** | **6022** | **5498** | **5784** | **5427** | **5863** | **5807** |
| USA | 4877 | 3608 | 3594 | 3340 | 4780 | 3706 | 3125 | 3458 | 3125 | 3552 | 3716 |
| Mexico | 1376 | 878 | 1252 | 1372 | 2185 | 1877 | 1953 | 1913 | 1904 | 1930 | 1664 |
| **South America** | **1487** | **1373** | **1275** | **1132** | **1167** | **1327** | **1448** | **1419** | **1585** | **1440** | **1365** |
| Argentina | 764 | 723 | 613 | 477 | 550 | 678 | 782 | 735 | 724 | 613 | 666 |
| Brazil | 164 | 140 | 166 | 154 | 197 | 275 | 332 | 352 | 524 | 482 | 279 |
| Colombia | 245 | 202 | 219 | 181 | 135 | 103 | 63 | 60 | 68 | 70 | 135 |
| Venezuela | 229 | 210 | 209 | 223 | 202 | 198 | 183 | 155 | 180 | 160 | 194 |
| **Asia** | **15525** | **15214** | **14144** | **13756** | **13838** | **13098** | **12095** | **11768** | **12269** | **11897** | **13361** |
| China | 1324 | 1367 | 1392 | 1238 | 1305 | 1096 | 980 | 986 | 894 | 994 | 1153 |
| India | 13041 | 12710 | 11514 | 11326 | 11400 | 10878 | 9980 | 9794 | 10398 | 9975 | 11102 |
| Pakistan | 403 | 365 | 438 | 418 | 370 | 390 | 383 | 357 | 354 | 350 | 383 |
| Thailand | 173 | 146 | 167 | 129 | 134 | 104 | 97 | 87 | 85 | 91 | 121 |
| Yemen | 433 | 457 | 448 | 448 | 427 | 430 | 458 | 368 | 360 | 360 | 419 |
| **Europe** | **229** | **190** | **161** | **143** | **153** | **155** | **150** | **157** | **220** | **185** | **174** |
| **Oceania** | **570** | **428** | **500** | **687** | **771** | **545** | **508** | **588** | **623** | **597** | **582** |
| Australia | 569 | 427 | 499 | 686 | 770 | 544 | 507 | 587 | 622 | 596 | 581 |

Sources: Adapted from FAO (2002).

Appendix A1.1.2 Total grain production (1000 MT) of the sorghum plants of some selected countries from the year 1992 to 2001.

| | Year | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Selected countries | 1992 | 1993 | 1994 | 1995 | 1996 | 1997 | 1998 | 1999 | 2000 | 2001 | Means |
| **World** | **70573** | **57057** | **60114** | **54581** | **71640** | **59647** | **61808** | **59507** | **57744** | **57357** | **61003** |
| **Africa** | **16794** | **16250** | **17532** | **17833** | **20495** | **18869** | **20705** | **18304** | **18828** | **18775** | **18439** |
| Nigeria | 5909 | 6051 | 6197 | 6997 | 7084 | 7297 | 7516 | 7520 | 7711 | 7711 | 6999 |
| Sudan | 4042 | 2386 | 3648 | 2450 | 4179 | 2922 | 4284 | 2347 | 2488 | 2488 | 3123 |
| **North & Central America** | **28197** | **16737** | **20589** | **16316** | **27577** | **22374** | **20225** | **21296** | **18414** | **20270** | **21200** |
| USA | 22227 | 13569 | 16402 | 11650 | 20201 | 16039 | 13207 | 15118 | 11940 | 13610 | 15402 |
| Mexico | 5353 | 2581 | 3701 | 4170 | 6809 | 5712 | 6475 | 5720 | 6003 | 6200 | 5272 |
| **South America** | **4525** | **4538** | **3703** | **3258** | **3595** | **4024** | **5226** | **465** | **4968** | **4720** | **4321** |
| Argentina | 2767 | 2860 | 2148 | 1649 | 2132 | 2499 | 3762 | 3222 | 3351 | 2905 | 2729 |
| Brazil | 282 | 282 | 316 | 277 | 356 | 543 | 590 | 554 | 780 | 895 | 487 |
| Colombia | 752 | 633 | 649 | 554 | 445 | 330 | 189 | 199 | 218 | 220 | 419 |
| Venezuela | 511 | 473 | 446 | 504 | 436 | 421 | 449 | 402 | 460 | 390 | 449 |
| **Asia** | **18705** | **18130** | **16548** | **15320** | **17718** | **12197** | **13913** | **12686** | **12464** | **11419** | **14910** |
| China | 4779 | 5622 | 6438 | 4854 | 5742 | 3695 | 4130 | 3275 | 2608 | 2960 | 4410 |
| India | 12806 | 11415 | 8965 | 9327 | 10934 | 7528 | 8713 | 8415 | 8863 | 7417 | 9438 |
| Pakistan | 238 | 212 | 263 | 254 | 219 | 231 | 228 | 220 | 229 | 225 | 232 |
| Thailand | 250 | 208 | 228 | 194 | 225 | 156 | 146 | 142 | 148 | 200 | 190 |
| Yemen | 459 | 474 | 444 | 464 | 365 | 358 | 474 | 399 | 375 | 375 | 419 |
| **Europe** | **884** | **833** | **641** | **563** | **646** | **739** | **735** | **651** | **630** | **730** | **725** |
| **Oceania** | **1449** | **550** | **1086** | **1275** | **1595** | **1428** | **1084** | **1895** | **2119** | **1427** | **1391** |
| Australia | 1447 | 548 | 1084 | 1273 | 1592 | 1425 | 1081 | 1891 | 2116 | 1423 | 1388 |

Sources: Adapted from FAO (2002).

Appendix A1.1.3 Average grain yield production (kg/ha) of the sorghum plants of some selected countries from the year 1990 to 2001.

| Selected countries | Year | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1992 | 1993 | 1994 | 1995 | 1996 | 1997 | 1998 | 1999 | 2000 | 2001 | Means |
| **World** | **1526** | **1349** | **1363** | **1281** | **1521** | **1360** | **1435** | **1456** | **1391** | **1380** | **1406** |
| **Africa** | **774** | **808** | **771** | **820** | **862** | **832** | **886** | **866** | **880** | **870** | **837** |
| Nigeria | 1080 | 1080 | 1080 | 1148 | 1144 | 1108 | 1133 | 1126 | 1120 | 1120 | 1114 |
| Sudan | 652 | 509 | 568 | 486 | 638 | 548 | 679 | 518 | 593 | 593 | 578 |
| **North & Central America** | **4194** | **3373** | **3902** | **3184** | **3734** | **3716** | **3679** | **3682** | **3393** | **3458** | **3631** |
| USA | 4558 | 3761 | 4564 | 3488 | 4226 | 4342 | 4226 | 4372 | 3820 | 3832 | 4119 |
| Mexico | 3891 | 2941 | 2957 | 3089 | 3117 | 3042 | 3315 | 2990 | 3153 | 3212 | 3166 |
| **South America** | **3044** | **3306** | **2906** | **2879** | **3082** | **3033** | **3610** | **3280** | **3134** | **3277** | **3155** |
| Argentina | 3622 | 3953 | 3507 | 3459 | 3876 | 3685 | 4811 | 4385 | 4630 | 4739 | 4067 |
| Brazil | 1719 | 2017 | 1906 | 1798 | 1812 | 1976 | 1777 | 1571 | 1488 | 1857 | 1792 |
| Colombia | 3068 | 3139 | 2961 | 3064 | 3299 | 3213 | 3023 | 3295 | 3180 | 3147 | 3139 |
| Venezuela | 2231 | 2251 | 2134 | 2265 | 2164 | 2270 | 2456 | 2600 | 2556 | 2438 | 2336 |
| **Asia** | **1205** | **1192** | **1170** | **1114** | **1280** | **931** | **1150** | **1078** | **1016** | **960** | **1110** |
| China | 3610 | 4111 | 4622 | 3921 | 4399 | 3370 | 4214 | 3322 | 2917 | 3136 | 3762 |
| India | 982 | 898 | 779 | 824 | 959 | 692 | 873 | 859 | 852 | 744 | 846 |
| Pakistan | 591 | 582 | 601 | 610 | 593 | 593 | 595 | 617 | 646 | 643 | 607 |
| Thailand | 1444 | 1424 | 1364 | 1504 | 1673 | 1498 | 1504 | 1631 | 1730 | 2210 | 1598 |
| Yemen | 1060 | 1037 | 991 | 1036 | 857 | 832 | 1034 | 1086 | 1043 | 1043 | 1002 |
| **Europe** | **3859** | **4392** | **3990** | **3950** | **4214** | **4752** | **4235** | **4137** | **4223** | **3952** | **4170** |
| **Oceania** | **2543** | **1285** | **2170** | **1856** | **2069** | **2620** | **2134** | **3221** | **3400** | **2389** | **2369** |
| Australia | 2543 | 1283 | 2170 | 1856 | 2068 | 2620 | 2132 | 3222 | 3400 | 2388 | 2368 |

Sources: Adapted from FAO (2002).

## A1.2 Sorghum Cultivation in Thailand

Appendix A1.2.1 Harvested area, total grain production and average yield of the sorghum plants in Thailand during 1991 to 2000.

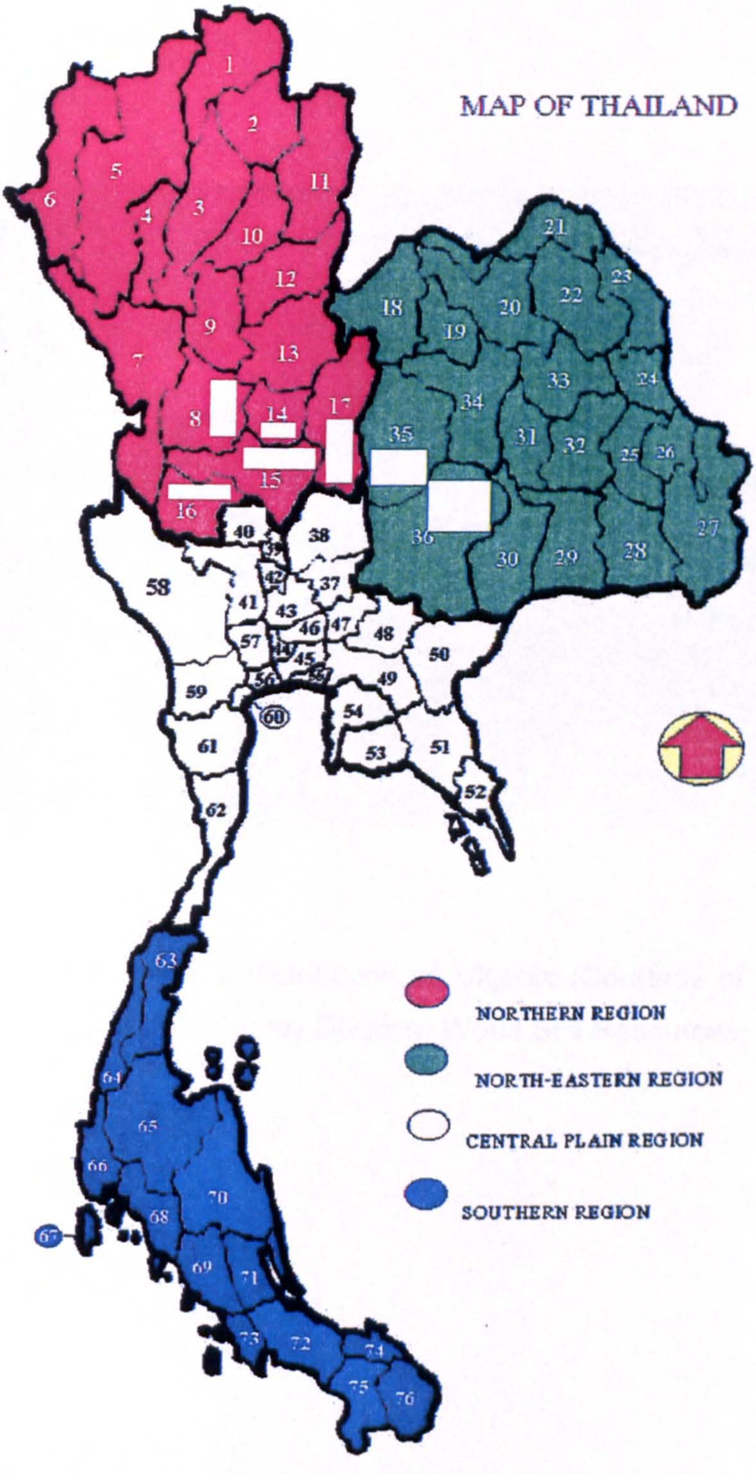
| Year | Harvested area (1000ha) | Production (MT) | Yield (kg/ha) |
|---|---|---|---|
| 1991 | 192 | 250 | 1300 |
| 1992 | 173 | 250 | 1444 |
| 1993 | 146 | 208 | 1425 |
| 1994 | 167 | 228 | 1363 |
| 1995 | 129 | 194 | 1506 |
| 1996 | 134 | 225 | 1675 |
| 1997 | 104 | 156 | 1500 |
| 1998 | 97 | 146 | 1506 |
| 1999 | 87 | 142 | 1631 |
| 2000 | 85 | 148 | 1731 |

Sources: Adapted from Agricultural Statistics of Thailand (1999 and 2000).

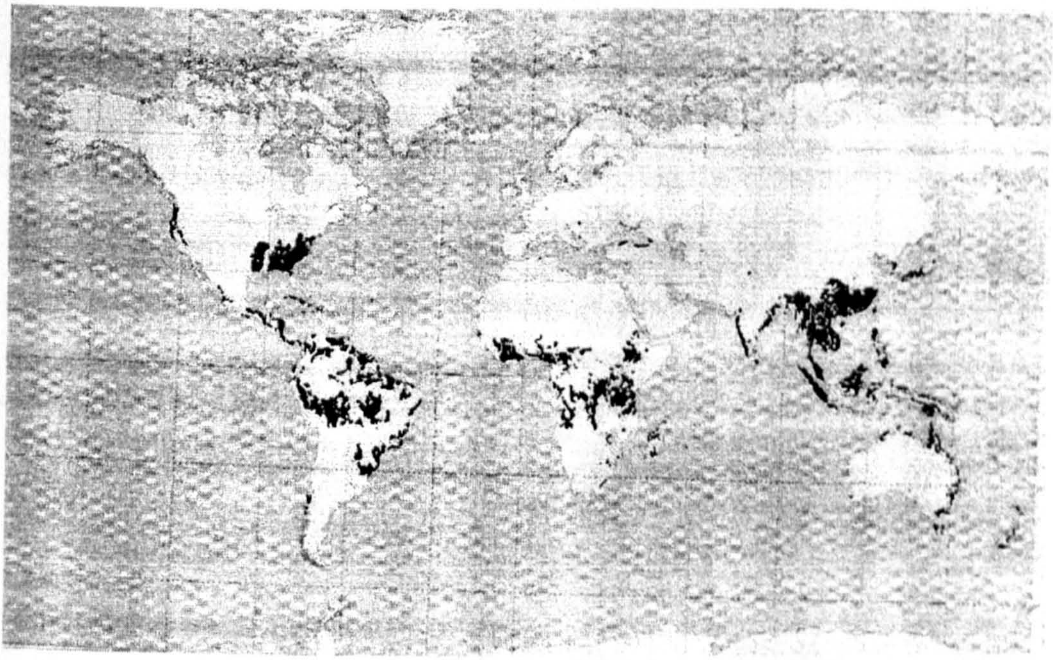
Appendix A1.2.2 Harvested area, production and yield of the sorghum plants in Thailand during 1996-2000.

| Provinces | Production (MT) | | | | | Yield (kg/ha) | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| (No. on map) | 96 | 97 | 98 | 99 | 00 | 96 | 97 | 98 | 99 | 00 |
| Total | 225 | 156 | 146 | 142 | 148 | 1675 | 1500 | 1500 | 1638 | 1731 |
| Chaiyaphum (35) | 0.3 | 0.3 | 0.3 | 0.2 | - | 1506 | 1438 | 1381 | 1475 | - |
| Nakhonratchasima (36) | 4.0 | 4.5 | 3.4 | 3.0 | 0.8 | 1531 | 1813 | 1669 | 1706 | 1856 |
| Nakhon Sawan (15) | 101.2 | 47.1 | 43.2 | 32.9 | 38.9 | 1625 | 1475 | 1550 | 1625 | 1775 |
| Phetchabun (17) | 21.9 | 20.1 | 21.2 | 24.6 | 25.3 | 1431 | 1313 | 1231 | 1413 | 1538 |
| Uthai Thani (16) | 0.5 | 0.4 | 0.4 | 0.1 | 0.2 | 1569 | 1281 | 1263 | 1438 | 1613 |
| Kamphaeng Phet (8) | 0.07 | - | 0.06 | - | - | 1719 | - | 1481 | - | - |
| Phichit (14) | 0.05 | - | 0.02 | - | - | 1106 | - | 1150 | - | - |
| Lop Buri (38) | 79.1 | 70.6 | 65.5 | 70.5 | 71.4 | 1831 | 1519 | 1531 | 1706 | 1781 |
| Saraburi (37) | 7.8 | 5.1 | 5.6 | 5.4 | 5.9 | 1675 | 1706 | 1888 | 1956 | 1888 |
| Chai Nat (40) | 1.1 | 0.8 | 0.9 | 0.6 | 0.5 | 1725 | 1550 | 1544 | 1544 | 1556 |
| Suphan Buri (41) | 1.8 | 1.7 | 1.4 | 1.7 | 1.5 | 1550 | 1450 | 1400 | 1494 | 1481 |
| Kanchana Buri (58) | 3.4 | 2.9 | 1.7 | 1.6 | 1.2 | 1663 | 1919 | 1663 | 1675 | 1631 |
| Sa Kaeo (50) | 3.3 | 2.8 | 2.8 | 1.7 | 1.9 | 1938 | 2088 | 2169 | 2063 | 1800 |

Sources: Adapted from Agricultural Statistics of Thailand (1999 and 2000).



Appendix A1.2.3 Map of Thailand showing numbers of sorghum belt provinces where sorghum cultivars have been cultivated at number 8, 14, 15, 16, 17, 35, 36, 37, 38, 40, 41, 50 and 58 (Agricultural Statistics of Thailand, 2000).



Appendix A1.2.4 Global distribution of Ultisols (Courtesy of USSA-NRCS, Soil Survey Division, World Soil Resources, 1998).

# Appendix B

## Climatic data

### B1. Experiment 1

Appendix B1.1 Daily amount of rainfall, maximum temperature, minimum temperature, average temperature, solar radiation and sunshine duration in July 1997 at meteorological station Khon Kaen University Experimental Farm, Northeast Thailand.

| Date | Rainfall (mm) | Max. temp. (°C) | Min. temp. (°C) | Ave. temp. (°C) | Solar radiation (cal/cm$^2$/day) | Sunshine duration (hours/day) |
|---|---|---|---|---|---|---|
| | | | July 1997 | | | |
| 1 | 0.0 | 32.5 | 25.0 | 28.8 | 225.03 | 1.6 |
| 2 | 8.6 | 34.2 | 25.2 | 29.7 | 291.65 | 7.5 |
| 3 | 2.3 | 33.0 | 22.5 | 27.8 | 248.83 | 4.8 |
| 4 | 0.2 | 32.3 | 23.2 | 27.8 | 210.49 | 2.4 |
| 5 | 3.9 | 34.0 | 23.8 | 28.9 | 258.23 | 8.2 |
| 6[a] | 13.4 | 34.6 | 25.4 | 30.0 | 241.74 | 5.0 |
| 7 | 0.2 | 33.7 | 25.0 | 29.4 | 291.65 | 5.7 |
| 8 | 0.0 | 33.4 | 24.5 | 29.0 | 241.74 | 1.8 |
| 9 | 1.0 | 31.1 | 25.1 | 28.1 | 153.36 | 0.0 |
| 10 | 1.5 | 31.3 | 24.0 | 27.7 | 207.36 | 0.5 |
| 11[b] | 1.0 | 31.8 | 24.0 | 27.9 | 69.76 | 0.0 |
| 12 | 0.8 | 32.6 | 23.5 | 28.1 | 219.89 | 3.8 |
| 13 | 0.0 | 32.6 | 24.5 | 28.6 | 225.03 | 2.8 |
| 14 | 0.0 | 32.5 | 24.4 | 28.5 | 208.32 | 3.3 |
| 15 | 13.3 | 33.2 | 24.1 | 28.7 | 254.11 | 5.0 |
| 16 | 0.0 | 32.4 | 24.1 | 28.3 | 261.36 | 4.5 |
| 17 | 39.7 | 33.1 | 24.8 | 29.0 | 298.51 | 6.9 |
| 18 | 8.7 | 30.9 | 22.6 | 26.8 | 189.85 | 2.1 |
| 19 | 0.0 | 32.5 | 23.2 | 27.9 | 215.57 | 1.6 |
| 20 | 1.7 | 31.1 | 24.3 | 27.7 | 157.68 | 0.0 |
| 21 | 29.8 | 30.7 | 23.3 | 27.0 | 178.42 | 0.1 |
| 22 | 10.4 | 28.3 | 22.7 | 25.5 | 156.22 | 0.6 |
| 23 | 2.6 | 27.6 | 23.5 | 25.6 | 160.29 | 0.0 |
| 24 | 0.0 | 30.6 | 23.4 | 27.0 | 239.51 | 2.2 |
| 25 | 0.0 | 32.3 | 24.0 | 28.2 | 174.10 | 7.7 |
| 26 | 0.0 | 33.0 | 24.1 | 28.6 | 295.77 | 8.5 |
| 27 | 0.0 | 31.0 | 25.0 | 28.0 | 186.62 | 1.2 |
| 28 | 3.1 | 32.3 | 25.3 | 28.8 | 254.86 | 3.4 |
| 29 | 5.2 | 32.5 | 25.0 | 28.8 | 228.10 | 2.2 |
| 30 | 3.1 | 30.6 | 23.8 | 27.2 | 169.21 | 1.7 |
| 31 | 0.0 | 31.0 | 23.4 | 27.2 | 194.83 | 2.1 |
| Total | 150.5 | 992.7 | 746.7 | 870.6 | 6699.10 | 97.2 |
| Average | 4.9 | 32.0 | 24.1 | 28.09 | 216.10 | 3.1 |

Remarks: a = Planting date of the sorghum plants. b = Seeds emergence.

Appendix B1.2 Daily amount of rainfall, maximum temperature, minimum temperature, average temperature, solar radiation and sunshine duration in August 1997 at meteorological station Khon Kaen University Experimental Farm, Northeast Thailand.

| Date | Rainfall (mm) | Max. temp. (°C) | Min. temp. (°C) | Ave. temp. (°C) | Solar radiation (cal/cm²/day) | Sunshine duration (hours/day) |
|---|---|---|---|---|---|---|
| | | | August 1997 | | | |
| 1 | 2.9 | 33.1 | 24.1 | 28.6 | 174.90 | 1.1 |
| 2 | 1.8 | 28.9 | 23.2 | 26.1 | 132.01 | 0.2 |
| 3 | 0.0 | 31.8 | 23.9 | 27.9 | 257.04 | 4.3 |
| 4 | 0.0 | 33.0 | 24.5 | 28.8 | 244.73 | 4.0 |
| 5 | 0.0 | 33.0 | 25.0 | 29.0 | 258.23 | 4.6 |
| 6 | 39.8 | 33.8 | 24.5 | 29.2 | 223.99 | 6.4 |
| 7 | 0.0 | 33.6 | 23.0 | 28.3 | 316.60 | 10.9 |
| 8 | 0.0 | 33.2 | 24.2 | 28.7 | 325.07 | 9.8 |
| 9 | 0.0 | 31.4 | 24.2 | 27.8 | 257.04 | 2.4 |
| 10 | 0.0 | 33.5 | 24.7 | 29.1 | 282.10 | 5.3 |
| 11 | 0.0 | 33.1 | 25.2 | 29.2 | 258.23 | 4.3 |
| 12 | 7.8 | 33.3 | 25.0 | 29.2 | 225.03 | 3.1 |
| 13 | 0.0 | 32.7 | 24.5 | 28.6 | 195.73 | 1.2 |
| 14 | 0.0 | 31.9 | 25.0 | 28.5 | 165.89 | 1.1 |
| 15 | 29.7 | 33.7 | 25.5 | 29.6 | 210.49 | 3.2 |
| 16 | 5.2 | 33.2 | 20.8 | 27.0 | 287.53 | 6.9 |
| 17 | 0.7 | 32.4 | 23.4 | 27.9 | 223.99 | 1.4 |
| 18 | 1.8 | 29.7 | 24.2 | 27.0 | 169.21 | 0.7 |
| 19 | 0.6 | 34.8 | 23.7 | 29.3 | 304.23 | 8.0 |
| 20 | 0.0 | 34.5 | 25.0 | 29.8 | 325.07 | 9.5 |
| 21 | 1.4 | 34.4 | 23.8 | 29.1 | 304.23 | 7.1 |
| 22 | 1.2 | 34.9 | 22.1 | 28.5 | 277.78 | 7.5 |
| 23 | 0.0 | 31.5 | 23.0 | 27.3 | 182.52 | 1.3 |
| 24 | 7.7 | 32.6 | 24.7 | 28.7 | 215.57 | 2.9 |
| 25 | 22.5 | 31.1 | 24.0 | 27.6 | 184.90 | 1.8 |
| 26 | 0.0 | 31.5 | 22.7 | 27.1 | 302.83 | 6.6 |
| 27 | 0.0 | 33.4 | 24.0 | 28.7 | 298.51 | 7.8 |
| 28 | 38.7 | 33.1 | 24.5 | 28.8 | 199.15 | 1.7 |
| 29 | 9.1 | 26.5 | 22.4 | 24.5 | 74.04 | 0.0 |
| 30 | 4.4 | 30.5 | 23.3 | 26.9 | 181.68 | 0.1 |
| 31 | 0.0 | 32.5 | 23.5 | 28.0 | 257.04 | 6.2 |
| Total | 173.5 | 1006.6 | 741.6 | 874.8 | 7315.40 | 131.40 |
| Average | 5.7 | 32.5 | 23.9 | 28.22 | 235.98 | 4.24 |

Appendix B1.3 Daily amount of rainfall, maximum temperature, minimum temperature, average temperature, solar radiation and sunshine duration in September 1997 at meteorological station Khon Kaen University Experimental Farm, Northeast Thailand.

| Date | Rainfall (mm) | Max. temp. (°C) | Min. temp. (°C) | Ave. temp. (°C) | Solar radiation (cal/cm$^{2}$/day) | Sunshine duration (hours/day) |
|---|---|---|---|---|---|---|
| | | | September 1997 | | | |
| 1$^{c}$ | 0.0 | 32.7 | 23.6 | 28.2 | 282.10 | 5.1 |
| 2 | 0.0 | 29.5 | 23.8 | 26.7 | 152.65 | 0.0 |
| 3 | 0.0 | 32.7 | 23.1 | 27.9 | 252.94 | 3.3 |
| 4 | 0.0 | 32.0 | 23.0 | 27.5 | 244.73 | 1.9 |
| 5 | 0.0 | 32.5 | 23.5 | 28.0 | 223.99 | 3.6 |
| 6 | 1.2 | 33.3 | 24.0 | 28.7 | 277.78 | 7.0 |
| 7 | 48.2 | 30.8 | 23.1 | 27.0 | 143.81 | 0.3 |
| 8 | 0.9 | 28.5 | 21.4 | 25.0 | 131.40 | 1.4 |
| 9 | 1.2 | 31.8 | 21.9 | 26.9 | 214.57 | 5.4 |
| 10 | 8.4 | 31.5 | 23.3 | 27.4 | 152.65 | 3.2 |
| 11 | 3.2 | 28.8 | 23.2 | 26.0 | 106.79 | 1.6 |
| 12 | 0.0 | 32.5 | 22.6 | 27.6 | 269.57 | 8.2 |
| 13 | 0.0 | 34.0 | 23.0 | 28.5 | 312.48 | 10.7 |
| 14 | 0.0 | 35.0 | 24.5 | 29.8 | 233.28 | 9.6 |
| 15 | 0.0 | 34.2 | 24.9 | 29.6 | 312.48 | 9.9 |
| 16 | 0.0 | 32.6 | 24.3 | 28.5 | 311.04 | 10.0 |
| 17 | 22.8 | 32.5 | 23.3 | 27.9 | 312.48 | 9.3 |
| 18 | 0.0 | 32.7 | 23.0 | 27.9 | 306.94 | 9.7 |
| 19 | 0.0 | 32.5 | 23.8 | 28.2 | 315.14 | 9.8 |
| 20 | 0.0 | 31.9 | 25.3 | 28.6 | 252.94 | 5.9 |
| 21 | 0.0 | 31.2 | 23.5 | 27.4 | 326.16 | 9.4 |
| 22 | 0.0 | 30.0 | 21.7 | 25.9 | 268.32 | 6.1 |
| 23 | 0.0 | 31.4 | 22.3 | 26.9 | 286.20 | 7.9 |
| 24 | 0.0 | 32.5 | 23.2 | 27.9 | 252.94 | 6.5 |
| 25 | 18.9 | 33.5 | 24.8 | 29.2 | 282.10 | 7.8 |
| 26 | 4.5 | 31.1 | 23.5 | 27.3 | 169.21 | 1.3 |
| 27 | 0.5 | 25.6 | 22.2 | 23.9 | 159.54 | 0.1 |
| 28 | 0.0 | 27.7 | 20.7 | 24.2 | 147.87 | 0.3 |
| 29 | 0.2 | 31.5 | 21.1 | 26.3 | 227.04 | 7.0 |
| 30 | 0.0 | 33.3 | 23.0 | 28.2 | 301.43 | 7.4 |
| Total | 110.0 | 949.8 | 694.6 | 823.1 | 7230.60 | 169.7 |
| Average | 3.7 | 31.7 | 23.2 | 27.44 | 241.02 | 5.7 |

Remarks: c = 1$^{st}$ harvest of the sorghum plants at 52 days after emergence.

Appendix B1.4 Daily amount of rainfall, maximum temperature, minimum temperature, average temperature, solar radiation and sunshine duration in October 1997 at meteorological station Khon Kaen University Experimental Farm, Northeast Thailand.

| Date | Rainfall (mm) | Max. temp. (°C) | Min. temp. (°C) | Ave. temp. (°C) | Solar radiation (cal/$cm^2$/day) | Sunshine duration (hours/day) |
|---|---|---|---|---|---|---|
| | | | October 1997 | | | |
| 1[d] | 0.0 | 34.0 | 23.8 | 28.9 | 294.41 | 7.7 |
| 2 | 0.0 | 29.5 | 24.6 | 27.1 | 107.29 | 1.6 |
| 3 | 56.2 | 32.5 | 23.1 | 27.8 | 298.51 | 6.8 |
| 4 | 17.8 | 30.0 | 22.1 | 26.1 | 188.96 | 1.3 |
| 5 | 12.1 | 29.5 | 22.7 | 26.1 | 214.57 | 4.6 |
| 6 | 0.4 | 31.0 | 23.0 | 27.0 | 243.60 | 7.4 |
| 7 | 0.3 | 32.5 | 23.5 | 28.0 | 294.41 | 9.3 |
| 8 | 0.0 | 32.5 | 23.7 | 28.1 | 302.83 | 10.0 |
| 9 | 0.2 | 32.5 | 23.8 | 28.2 | 302.83 | 10.6 |
| 10 | 0.0 | 32.5 | 24.7 | 28.6 | 219.89 | 6.0 |
| 11 | 0.0 | 32.9 | 23.9 | 28.4 | 248.83 | 6.4 |
| 12[e] | 0.0 | 32.5 | 23.0 | 27.8 | 206.40 | 4.4 |
| 13 | 52.3 | 31.3 | 23.8 | 27.6 | 130.78 | 3.9 |
| 14 | 0.0 | 31.5 | 22.0 | 26.8 | 240.62 | 10.1 |
| 15 | 40.0 | 32.3 | 22.6 | 27.5 | 189.85 | 4.7 |
| 16 | 0.0 | 32.1 | 21.7 | 26.9 | 268.32 | 8.5 |
| 17 | 45.5 | 31.5 | 23.5 | 27.5 | 198.23 | 4.3 |
| 18 | 0.0 | 31.2 | 21.4 | 26.3 | 305.52 | 10.6 |
| 19 | 0.0 | 32.5 | 22.8 | 27.7 | 298.51 | 6.1 |
| 20 | 0.0 | 33.5 | 23.8 | 28.7 | 265.46 | 9.0 |
| 21 | 0.0 | 33.7 | 23.7 | 28.7 | 277.78 | 10.1 |
| 22 | 0.0 | 35.0 | 24.1 | 29.6 | 270.82 | 9.7 |
| 23 | 0.0 | 35.1 | 24.2 | 29.7 | 262.57 | 9.2 |
| 24 | 0.4 | 35.9 | 24.4 | 30.2 | 270.82 | 8.6 |
| 25 | 0.0 | 32.8 | 24.0 | 28.4 | 294.41 | 9.8 |
| 26 | 0.0 | 32.1 | 23.1 | 27.6 | 286.20 | 9.5 |
| 27 | 1.8 | 31.5 | 22.6 | 27.1 | 293.05 | 10.1 |
| 28 | 0.0 | 30.4 | 24.8 | 27.6 | 287.62 | 9.7 |
| 29 | 0.0 | 31.0 | 20.0 | 25.5 | 260.15 | 8.5 |
| 30 | 0.0 | 30.5 | 20.5 | 25.5 | 279.48 | 9.1 |
| 31 | 0.0 | 28.8 | 23.5 | 26.2 | 265.82 | 9.2 |
| Total | 227.0 | 994.6 | 718.4 | 857.2 | 7868.50 | 236.8 |
| Average | 7.3 | 32.1 | 23.17 | 27.7 | 253.82 | 7.6 |

Remarks: d = 2nd harvest of the sorghum plants at 82 days after emergence. e = Harvested of seeds at 93 days after emergence.

## B2. Experiment 2

Appendix B2.1 Daily amount of rainfall, maximum temperature, minimum temperature, average temperature, solar radiation and sunshine duration in July 1999 at meteorological station Khon Kaen University Experimental Farm, Northeast Thailand.

| Date | Rainfall (mm) | Max. temp. (°C) | Min. temp. (°C) | Ave. temp. (°C) | Solar radiation (cal/cm²/day) | Sunshine duration (hours/day) |
|---|---|---|---|---|---|---|
| | | | July 1999 | | | |
| 1 | 22.4 | 33.7 | 23.9 | 28.8 | 279.48 | 9.3 |
| 2 | 35.3 | 33.8 | 24.1 | 29.0 | 271.14 | 6.8 |
| 3 | 33.2 | 32.0 | 22.5 | 27.3 | 220.88 | 5.2 |
| 4 | 0.3 | 31.1 | 23.1 | 27.1 | 245.38 | 3.1 |
| 5 | 15.4 | 32.0 | 23.0 | 27.5 | 269.87 | 5.8 |
| 6 | 0.4 | 29.5 | 23.0 | 26.3 | 196.39 | 3.2 |
| 7 | 0.0 | 33.2 | 24.0 | 28.6 | 338.41 | 11.3 |
| 8 | 0.0 | 33.5 | 25.0 | 29.3 | 322.07 | 8.9 |
| 9 | 0.0 | 33.4 | 25.5 | 29.5 | 317.77 | 9.8 |
| 10 | 14.4 | 33.5 | 24.6 | 29.1 | 308.16 | 9.2 |
| 11 | 0.0 | 32.2 | 25.0 | 28.6 | 275.20 | 8.3 |
| 12 | 0.0 | 31.5 | 25.0 | 28.3 | 230.05 | 0.3 |
| 13 | 0.0 | 32.0 | 25.1 | 28.6 | 279.48 | 5.7 |
| 14[a] | 0.0 | 33.6 | 24.3 | 29.0 | 305.52 | 9.2 |
| 15 | 0.0 | 34.0 | 25.4 | 29.7 | 260.15 | 8.2 |
| 16 | 0.0 | 34.0 | 25.7 | 29.9 | 260.15 | 5.5 |
| 17 | 0.0 | 34.2 | 25.6 | 29.9 | 297.13 | 9.1 |
| 18 | 0.0 | 32.2 | 24.3 | 28.3 | 260.15 | 5.0 |
| 19 | 0.0 | 34.2 | 25.4 | 29.8 | 272.41 | 7.3 |
| 20 | 0.0 | 34.4 | 25.5 | 30.0 | 288.96 | 9.2 |
| 21 | 0.0 | 33.5 | 25.1 | 29.3 | 290.50 | 8.6 |
| 22 | 0.0 | 33.5 | 25.6 | 29.6 | 268.32 | 7.7 |
| 23 | 17.5 | 32.8 | 25.0 | 28.9 | 184.03 | 4.3 |
| 24 | 1.2 | 29.8 | 24.5 | 27.0 | 147.18 | 0.2 |
| 25 | 6.4 | 26.7 | 25.1 | 25.9 | 97.13 | 0.0 |
| 26 | 0.1 | 29.6 | 24.6 | 27.1 | 155.49 | 0.1 |
| 27 | 0.0 | 31.6 | 24.0 | 27.8 | 225.98 | 3.0 |
| 28[b] | 0.6 | 32.2 | 25.3 | 28.8 | 197.31 | 3.1 |
| 29 | 9.3 | 33.5 | 25.2 | 27.4 | 279.48 | 5.8 |
| 30 | 9.7 | 30.7 | 25.2 | 28.0 | 281.37 | 2.1 |
| 31 | 6.3 | 30.5 | 25.3 | 27.9 | 151.23 | 1.1 |
| Total | 172.7 | 1002.1 | 764.9 | 884.3 | 7699.92 | 176.4 |
| Average | 5.6 | 32.3 | 24.7 | 28.5 | 243.39 | 5.7 |

Remarks: a = Planting date of the sorghum plants. b = Seed emergence.

Appendix B2.2 Daily amount of rainfall, maximum temperature, minimum temperature, average temperature, solar radiation and sunshine duration in August 1999 at meteorological station Khon Kaen University Experimental Farm, Northeast Thailand.

| Date | Rainfall (mm) | Max. temp. (°C) | Min. temp. (°C) | Ave. temp. (°C) | Solar radiation (cal/cm$^2$/day) | Sunshine duration (hours/day) |
|---|---|---|---|---|---|---|
| | | | August 1999 | | | |
| 1 | 1.4 | 30.1 | 23.5 | 26.8 | 188.08 | 0.6 |
| 2 | 0.6 | 29.2 | 23.8 | 26.5 | 188.08 | 0.4 |
| 3 | 0.0 | 32.4 | 24.1 | 28.3 | 267.07 | 3.7 |
| 4 | 0.0 | 32.4 | 24.8 | 28.6 | 200.43 | 0.5 |
| 5 | 0.0 | 30.7 | 24.3 | 27.5 | 208.53 | 1.4 |
| 6 | 0.9 | 32.3 | 24.1 | 28.2 | 220.88 | 3.0 |
| 7 | 0.0 | 32.5 | 24.4 | 28.5 | 205.44 | 3.8 |
| 8 | 0.0 | 33.5 | 25.2 | 29.4 | 332.82 | 8.8 |
| 9 | 0.0 | 34.0 | 25.0 | 29.5 | 288.96 | 6.0 |
| 10 | 17.5 | 34.7 | 25.5 | 30.1 | 246.53 | 5.1 |
| $11^{c}$ | 0.0 | 31.6 | 24.0 | 27.8 | 267.07 | 1.8 |
| 12 | 1.1 | 29.6 | 24.9 | 27.3 | 189.93 | 0.6 |
| 13 | 0.0 | 31.8 | 23.6 | 27.7 | 300.03 | 3.3 |
| 14 | 0.0 | 30.6 | 23.6 | 27.1 | 213.57 | 0.3 |
| 15 | 3.6 | 33.5 | 24.0 | 28.8 | 237.28 | 3.0 |
| 16 | 0.0 | 34.0 | 23.5 | 28.8 | 320.57 | 8.4 |
| 17 | 6.9 | 32.5 | 24.8 | 28.7 | 220.88 | 2.4 |
| 18 | 2.3 | 31.7 | 23.0 | 27.4 | 175.11 | 3.7 |
| 19 | 9.6 | 32.2 | 23.7 | 28.0 | 234.12 | 5.7 |
| 20 | 0.0 | 32.6 | 23.5 | 28.1 | 237.28 | 8.2 |
| 21 | 0.0 | 35.7 | 24.0 | 29.9 | 263.01 | 8.0 |
| 22 | 0.0 | 36.1 | 25.5 | 30.8 | 264.24 | 6.6 |
| 23 | 0.0 | 33.5 | 26.1 | 29.8 | 250.59 | 6.4 |
| 24 | 4.9 | 33.6 | 25.1 | 29.4 | 263.01 | 6.9 |
| $25^{d}$ | 0.0 | 32.8 | 24.5 | 28.7 | 258.94 | 5.4 |
| 26 | 0.7 | 32.6 | 25.1 | 28.9 | 267.07 | 7.0 |
| 27 | 0.0 | 31.0 | 24.6 | 27.8 | 171.68 | 2.3 |
| 28 | 0.6 | 32.2 | 24.2 | 28.2 | 249.42 | 3.9 |
| 29 | 0.0 | 31.6 | 24.3 | 28.0 | 179.99 | 1.6 |
| 30 | 31.9 | 32.2 | 23.5 | 27.9 | 171.68 | 3.7 |
| 31 | 0.0 | 30.6 | 23.0 | 26.8 | 188.96 | 0.6 |
| Total | 84.7 | 1003.8 | 753.2 | 879.3 | 7271.25 | 123.1 |
| Average | 2.7 | 32.4 | 24.3 | 28.4 | 234.56 | 4.0 |

Remarks: c = 1st sampling. d = 2nd sampling of the sorghum plants.

Appendix B2.3 Daily amount of rainfall, maximum temperature, minimum temperature, average temperature, solar radiation and sunshine duration in September1999 at meteorological station Khon Kaen University Experimental Farm, Northeast Thailand.

| Date | Rainfall (mm) | Max. temp. (°C) | Min. temp. (°C) | Ave. temp. (°C) | Solar radiation (cal/cm²/day) | Sunshine duration (hours/day) |
|---|---|---|---|---|---|---|
| | | | September 1999 | | | |
| 1 | 0.0 | 33.0 | 24.7 | 28.9 | 258.94 | 7.2 |
| 2 | 0.0 | 32.2 | 24.5 | 28.4 | 167.63 | 2.6 |
| 3 | 4.0 | 34.3 | 24.1 | 29.2 | 284.88 | 8.8 |
| 4 | 2.9 | 32.7 | 24.0 | 28.4 | 221.92 | 4.2 |
| 5 | 2.5 | 33.4 | 24.0 | 28.7 | 296.68 | 7.5 |
| 6 | 9.6 | 32.8 | 24.0 | 28.4 | 271.14 | 7.0 |
| 7 | 45.7 | 31.1 | 23.6 | 27.4 | 237.28 | 2.5 |
| 8[e] | 0.5 | 31.5 | 22.3 | 26.9 | 294.37 | 6.4 |
| 9 | 0.0 | 31.5 | 23.7 | 27.6 | 188.08 | 3.2 |
| 10 | 0.5 | 30.0 | 24.0 | 27.0 | 170.87 | 2.0 |
| 11 | 0.0 | 31.3 | 24.0 | 27.7 | 224.93 | 4.1 |
| 12 | 0.6 | 31.7 | 22.8 | 27.3 | 257.73 | 5.4 |
| 13 | 6.0 | 31.4 | 23.5 | 27.5 | 200.43 | 7.1 |
| 14 | 0.0 | 32.8 | 23.9 | 28.4 | 246.53 | 5.9 |
| 15 | 3.3 | 32.3 | 25.0 | 28.7 | 230.05 | 5.0 |
| 16 | 1.2 | 32.0 | 24.0 | 28.0 | 204.48 | 3.9 |
| 17 | 0.0 | 31.3 | 24.6 | 28.0 | 241.33 | 4.5 |
| 18 | 0.0 | 32.0 | 24.5 | 28.3 | 233.02 | 5.9 |
| 19 | 3.8 | 34.1 | 24.5 | 29.3 | 250.59 | 6.2 |
| 20 | 7.4 | 28.7 | 25.2 | 27.0 | 147.18 | 0.3 |
| 21 | 0.0 | 30.2 | 23.0 | 26.6 | 220.88 | 2.7 |
| 22[f] | 0.0 | 32.0 | 23.8 | 27.9 | 221.92 | 6.0 |
| 23 | 4.3 | 28.7 | 24.8 | 26.8 | 118.08 | 0.3 |
| 24 | 0.0 | 30.3 | 23.0 | 26.7 | 171.68 | 2.2 |
| 25 | 0.0 | 32.0 | 23.4 | 27.7 | 269.87 | 8.5 |
| 26 | 0.0 | 32.6 | 24.5 | 28.6 | 253.47 | 8.8 |
| 27 | 1.4 | 32.9 | 24.1 | 28.5 | 246.53 | 8.1 |
| 28 | 7.9 | 32.8 | 22.7 | 27.8 | 267.07 | 7.7 |
| 29 | 0.0 | 32.4 | 22.4 | 27.4 | 298.63 | 9.7 |
| 30 | 0.4 | 32.5 | 23.3 | 27.9 | 286.27 | 8.6 |
| Total | 102.0 | 956.5 | 715.9 | 836.9 | 6977.46 | 162.3 |
| Average | 3.4 | 31.9 | 23.9 | 27.9 | 232.58 | 5.4 |

Remarks: e = 3rd sampling. f = 4th sampling of the sorghum plants.

Appendix B2.4 Daily amount of rainfall, maximum temperature, minimum temperature, average temperature, solar radiation and sunshine duration in October 1999 at meteorological station Khon Kaen University Experimental Farm, Northeast Thailand.

| Date | Rainfall (mm) | Max. temp. (°C) | Min. temp. (°C) | Ave. temp. (°C) | Solar radiation (cal/cm$^2$/day) | Sunshine duration (hours/day) |
|---|---|---|---|---|---|---|
| | | | October 1999 | | | |
| 1 | 9.1 | 32.3 | 24.4 | 28.4 | 282.23 | 9.4 |
| 2 | 1.0 | 32.0 | 23.0 | 27.5 | 278.18 | 6.2 |
| 3 | 1.7 | 31.1 | 22.7 | 27.0 | 253.47 | 5.9 |
| 4 | 0.0 | 31.7 | 22.1 | 26.9 | 269.23 | 8.2 |
| 5 | 0.0 | 33.5 | 22.7 | 28.1 | 308.16 | 11.0 |
| 6[g] | 0.0 | 33.8 | 24.3 | 29.1 | 263.01 | 10.0 |
| 7 | 0.0 | 34.0 | 24.8 | 29.4 | 293.05 | 10.0 |
| 8 | 0.0 | 33.4 | 25.2 | 29.3 | 166.84 | 3.6 |
| 9 | 0.0 | 31.6 | 22.8 | 27.2 | 203.52 | 5.1 |
| 10 | 0.0 | 31.3 | 24.2 | 27.8 | 204.48 | 4.5 |
| 11 | 0.5 | 33.1 | 23.7 | 28.4 | 263.01 | 8.5 |
| 12 | 0.0 | 33.3 | 23.9 | 28.6 | 246.53 | 7.9 |
| 13 | 0.0 | 33.7 | 24.4 | 29.1 | 271.14 | 9.7 |
| 14 | 6.7 | 33.1 | 24.5 | 28.8 | 263.01 | 6.2 |
| 15 | 0.0 | 32.0 | 23.2 | 27.6 | 250.59 | 8.1 |
| 16 | 35.3 | 30.5 | 23.7 | 27.1 | 135.68 | 2.4 |
| 17 | 0.0 | 30.6 | 22.7 | 26.7 | 291.68 | 4.6 |
| 18 | 0.0 | 29.5 | 21.5 | 25.5 | 268.60 | 8.0 |
| 19 | 9.2 | 30.0 | 19.2 | 24.6 | 267.34 | 5.5 |
| 20[h] | 5.7 | 22.5 | 18.7 | 20.6 | 100.32 | 0.0 |
| 21 | 0.0 | 27.1 | 19.2 | 23.2 | 166.06 | 1.0 |
| 22 | 0.0 | 30.7 | 21.3 | 26.0 | 256.52 | 6.9 |
| 23 | 0.1 | 31.7 | 22.3 | 27.0 | 228.98 | 5.7 |
| 24 | 0.3 | 30.2 | 22.6 | 26.4 | 179.14 | 1.1 |
| 25 | 3.4 | 30.1 | 22.7 | 26.4 | 179.14 | 0.7 |
| 26 | 0.9 | 32.2 | 23.5 | 27.9 | 261.78 | 8.8 |
| 27 | 40.5 | 31.7 | 23.4 | 27.6 | 224.93 | 7.0 |
| 28 | 0.0 | 31.3 | 22.7 | 27.0 | 245.38 | 7.8 |
| 29 | 0.0 | 31.0 | 23.1 | 27.1 | 253.47 | 8.6 |
| 30 | 56.4 | 32.5 | 23.7 | 28.1 | 265.82 | 7.7 |
| 31 | 3.5 | 30.7 | 23.1 | 26.9 | 179.99 | 3.5 |
| Total | 183.3 | 972.2 | 709.5 | 841.3 | 7321.28 | 193.6 |
| Average | 5.9 | 31.4 | 22.9 | 27.1 | 236.17 | 6.3 |

Remarks: g = 5th sampling. h = 6th sampling. 4th November = Harvested of grains.

## B3. Experiment 3

Appendix B3.1 Daily amount of rainfall, maximum temperature, minimum temperature, average temperature, solar radiation and sunshine duration in November 1999 at Meteorological station Khon Kaen University Experimental Farm, Northeast Thailand.

| Date | Rainfall (mm) | Max. temp. (°C) | Min. temp. (°C) | Ave. temp. (°C) | Solar radiation (cal/cm$^2$/day) | Sunshine duration (hours/day) |
|---|---|---|---|---|---|---|
| | | | November1999 | | | |
| 1 | 0.4 | 31.4 | 23.5 | 27.5 | 253.47 | 6.5 |
| 2 | 0.2 | 25.4 | 22.1 | 23.8 | 141.12 | 0.0 |
| 3 | 0.0 | 25.5 | 20.0 | 22.8 | 153.30 | 0.1 |
| 4 | 0.0 | 27.7 | 19.7 | 23.7 | 233.94 | 4.6 |
| 5 | 0.0 | 26.7 | 20.3 | 23.5 | 128.94 | 0.0 |
| 6 | 3.7 | 29.1 | 21.2 | 25.2 | 162.05 | 0.1 |
| 7 | 0.2 | 27.0 | 21.5 | 24.3 | 141.79 | 1.0 |
| 8[g] | 0.0 | 30.0 | 21.0 | 25.5 | 158.79 | 2.0 |
| 9 | 0.0 | 30.7 | 23.7 | 27.2 | 184.03 | 1.8 |
| 10 | 0.0 | 32.0 | 23.5 | 27.8 | 241.33 | 9.4 |
| 11 | 0.2 | 33.4 | 23.3 | 28.4 | 230.05 | 8.6 |
| 12 | 0.0 | 34.0 | 23.9 | 29.0 | 287.62 | 9.9 |
| 13 | 0.0 | 29.7 | 24.7 | 27.2 | 199.49 | 3.7 |
| 14 | 0.0 | 32.6 | 23.5 | 28.1 | 261.78 | 9.7 |
| 15 | 0.0 | 32.3 | 22.2 | 27.3 | 253.47 | 10.4 |
| 16 | 0.0 | 31.3 | 20.1 | 25.7 | 264.58 | 10.2 |
| 17 | 0.0 | 30.2 | 19.2 | 24.7 | 268.60 | 10.0 |
| 18 | 0.0 | 29.6 | 18.0 | 23.8 | 263.33 | 9.9 |
| 19 | 0.0 | 28.9 | 17.1 | 23.0 | 274.26 | 9.8 |
| 20 | 0.0 | 29.0 | 16.5 | 22.8 | 245.91 | 9.6 |
| 21 | 0.0 | 29.4 | 16.6 | 23.0 | 262.08 | 10.0 |
| 22[h] | 0.0 | 30.8 | 17.3 | 24.1 | 243.07 | 8.4 |
| 23 | 0.0 | 31.0 | 18.7 | 24.9 | 107.20 | 5.0 |
| 24 | 0.0 | 33.3 | 21.2 | 27.3 | 253.47 | 10.2 |
| 25 | 0.0 | 33.2 | 21.7 | 27.5 | 257.73 | 10.3 |
| 26 | 0.0 | 33.5 | 20.3 | 26.9 | 228.98 | 9.3 |
| 27 | 0.0 | 33.2 | 26.1 | 29.7 | 228.98 | 9.4 |
| 28 | 0.0 | 32.6 | 20.4 | 26.5 | 212.57 | 7.6 |
| 29 | 0.0 | 29.5 | 21.3 | 25.4 | 206.57 | 7.7 |
| 30 | 0.0 | 28.7 | 17.0 | 22.9 | 236.80 | 7.5 |
| Total | 4.7 | 911.7 | 625.6 | 769.5 | 6579.30 | 202.7 |
| Average | 0.2 | 30.4 | 20.9 | 25.7 | 219.31 | 6.8 |

Remarks: Planting date of the sorghum plants = 13 August. seed emergence = 23 August, 1st sampling = 13 September, 2nd sampling = 27th September. 3rd sampling = 11 October. 4th sampling = 25 October. 5th sampling = 8 November (g). 22 November = Harvested of seeds (h).

## B4. Experiment 4

Appendix B4.1 Daily amount of rainfall, maximum temperature, minimum temperature, average temperature, solar radiation and sunshine duration in March 2000 at meteorological station Khon Kaen University Experimental Farm, Northeast Thailand.

| Date | Rainfall (mm) | Max. temp. (°C) | Min. temp. (°C) | Ave. temp. (°C) | Solar radiation (cal/cm$^2$/day) | Sunshine duration (hours/day) |
|---|---|---|---|---|---|---|
| | | | March 2000 | | | |
| 1 | 1.9 | 19.8 | 17.1 | 18.5 | 106.71 | 0.1 |
| 2 | 0.0 | 22.1 | 16.1 | 19.1 | 107.23 | 0.0 |
| 3 | 0.0 | 31.2 | 16.2 | 23.7 | 210.58 | 5.7 |
| 4 | 0.0 | 35.2 | 19.3 | 27.3 | 265.82 | 9.4 |
| 5 | 0.0 | 36.8 | 21.7 | 29.3 | 282.23 | 10.2 |
| 6 | 0.0 | 36.0 | 21.6 | 28.8 | 241.33 | 8.7 |
| 7 | 0.0 | 36.7 | 22.1 | 29.4 | 254.81 | 10.0 |
| 8 | 0.0 | 38.1 | 21.7 | 29.9 | 271.14 | 10.2 |
| 9 | 0.0 | 36.5 | 22.3 | 29.4 | 260.15 | 9.8 |
| 10 | 0.0 | 35.2 | 23.6 | 29.4 | 234.12 | 6.5 |
| 11 | 0.0 | 37.5 | 24.2 | 30.9 | 247.68 | 9.8 |
| 12 | 0.0 | 37.5 | 20.8 | 29.2 | 268.32 | 10.2 |
| 13 | 0.0 | 37.4 | 19.7 | 28.6 | 275.20 | 10.3 |
| 14 | 0.0 | 37.1 | 20.4 | 28.8 | 267.07 | 9.7 |
| 15 | 0.0 | 37.7 | 22.4 | 30.1 | 276.49 | 10.2 |
| 16 | 0.0 | 38.8 | 22.5 | 30.7 | 264.24 | 10.4 |
| 17 | 0.0 | 38.6 | 23.0 | 30.8 | 276.49 | 9.8 |
| 18 | 0.0 | 37.6 | 23.6 | 30.6 | 265.46 | 9.8 |
| 19 | 0.0 | 38.1 | 25.1 | 31.6 | 244.73 | 8.1 |
| 20 | 0.0 | 37.7 | 25.5 | 31.6 | 206.40 | 8.2 |
| 21 | 0.0 | 37.6 | 25.9 | 31.8 | 228.10 | 7.2 |
| 22[a] | 0.0 | 37.8 | 25.2 | 31.5 | 206.40 | 9.8 |
| 23 | 0.0 | 37.9 | 24.0 | 31.0 | 265.46 | 6.3 |
| 24 | 0.0 | 33.2 | 25.2 | 29.2 | 246.53 | 7.0 |
| 25 | 0.0 | 33.7 | 22.0 | 27.9 | 261.48 | 8.7 |
| 26 | 0.0 | 32.7 | 22.0 | 27.4 | 265.82 | 7.9 |
| 27 | 0.0 | 32.5 | 20.1 | 26.3 | 276.87 | 8.6 |
| 28[b] | 0.0 | 35.0 | 21.4 | 28.2 | 295.75 | 9.8 |
| 29 | 0.0 | 33.7 | 20.0 | 26.9 | 273.92 | 7.7 |
| 30 | 0.0 | 35.3 | 21.3 | 28.3 | 291.68 | 9.8 |
| 31 | 23.3 | 35.7 | 22.2 | 29.0 | 230.05 | 6.2 |
| Total | 25.2 | 1090.7 | 678.2 | 885.2 | 8093.14 | 256.1 |
| Average | 0.8 | 35.2 | 21.9 | 28.6 | 261.06 | 8.3 |

Remarks: a = Planting date of the sorghum plants. b = Seed emergence.

Appendix B4.2 Daily amount of rainfall, maximum temperature, minimum temperature, average temperature, solar radiation and sunshine duration in April 2000 at meteorological station Khon Kaen University Experimental Farm, Northeast Thailand.

| Date | Rainfall (mm) | Max. temp. (°C) | Min. temp. (°C) | Ave. temp. (°C) | Solar radiation (cal/cm$^2$/day) | Sunshine duration (hours/day) |
|---|---|---|---|---|---|---|
| | | | April 2000 | | | |
| 1 | 0.0 | 36.6 | 22.6 | 29.6 | 264.24 | 8.2 |
| 2 | 0.0 | 38.0 | 25.7 | 31.9 | 254.11 | 9.9 |
| 3 | 0.0 | 39.1 | 26.8 | 33.0 | 249.98 | 10.2 |
| 4 | 0.0 | 39.0 | 26.7 | 32.9 | 283.40 | 8.9 |
| 5 | 0.0 | 39.4 | 27.6 | 33.5 | 282.10 | 9.7 |
| 6 | 0.0 | 34.7 | 25.1 | 29.9 | 305.52 | 9.8 |
| 7 | 8.8 | 37.1 | 26.6 | 31.9 | 243.60 | 7.2 |
| 8 | 0.0 | 36.2 | 24.5 | 30.4 | 268.32 | 9.7 |
| 9 | 0.0 | 37.4 | 26.3 | 31.9 | 297.13 | 9.3 |
| 10 | 36.2 | 35.5 | 26.8 | 31.2 | 204.48 | 3.2 |
| 11 | 0.0 | 30.5 | 22.2 | 26.4 | 195.46 | 1.4 |
| 12 | 4.2 | 32.6 | 22.6 | 27.6 | 253.47 | 5.0 |
| 13 | 14.1 | 30.0 | 23.2 | 26.6 | 178.30 | 2.1 |
| 14 | 5.0 | 31.0 | 23.3 | 27.2 | 227.90 | 3.5 |
| 15 | 50.3 | 30.1 | 24.0 | 27.1 | 154.03 | 0.7 |
| 16 | 1.2 | 25.0 | 20.5 | 22.8 | 124.36 | 0.0 |
| 17 | 0.0 | 30.2 | 20.5 | 25.4 | 260.55 | 5.7 |
| 18[c] | 0.0 | 33.6 | 23.0 | 28.3 | 295.75 | 8.7 |
| 19 | 20.7 | 34.4 | 24.6 | 29.5 | 300.03 | 9.9 |
| 20 | 2.4 | 34.0 | 22.2 | 28.1 | 223.87 | 4.8 |
| 21 | 1.4 | 33.3 | 24.6 | 29.0 | 254.66 | 5.3 |
| 22 | 57.3 | 28.1 | 24.2 | 26.2 | 28.41 | 0.0 |
| 23 | 0.0 | 31.6 | 22.0 | 26.8 | 290.32 | 9.2 |
| 24 | 0.0 | 33.8 | 23.0 | 28.4 | 249.42 | 6.0 |
| 25 | 3.2 | 34.5 | 26.0 | 30.3 | 309.60 | 9.1 |
| 26 | 6.3 | 33.8 | 23.9 | 28.9 | 287.62 | 6.3 |
| 27 | 40.7 | 32.5 | 23.2 | 27.9 | 233.02 | 5.5 |
| 28 | 0.0 | 33.6 | 22.7 | 28.2 | 279.48 | 7.1 |
| 29 | 12.0 | 34.2 | 25.1 | 29.7 | 275.20 | 7.3 |
| 30 | 0.0 | 32.0 | 23.5 | 27.8 | 233.02 | 3.3 |
| Total | 263.8 | 1011.8 | 723.0 | 868.4 | 7307.35 | 187.0 |
| Average | 8.8 | 33.7 | 24.1 | 28.9 | 243.51 | 6.2 |

Remarks: c = 1st sampling of the sorghum plants.

Appendix B4.3 Daily amount of rainfall, maximum temperature, minimum temperature, average temperature, solar radiation and sunshine duration in May 2000 at meteorological station Khon Kaen University Experimental Farm, Northeast Thailand.

| Date | Rainfall (mm) | Max. temp. (°C) | Min. temp. (°C) | Ave. temp. (°C) | Solar radiation (cal/cm²/day) | Sunshine duration (hours/day) |
|---|---|---|---|---|---|---|
| | | | May 2000 | | | |
| 1 | 0.0 | 33.3 | 24.2 | 28.8 | 326.74 | 10.2 |
| 2[d] | 0.0 | 34.0 | 24.3 | 29.2 | 295.75 | 9.2 |
| 3 | 66.9 | 34.6 | 26.0 | 30.3 | 241.33 | 6.8 |
| 4 | 37.0 | 31.6 | 22.4 | 27.0 | 257.73 | 6.6 |
| 5 | 0.0 | 31.5 | 22.0 | 26.8 | 223.87 | 4.7 |
| 6 | 21.5 | 33.5 | 22.6 | 28.1 | 206.61 | 7.6 |
| 7 | 0.0 | 32.8 | 22.8 | 27.8 | 245.38 | 6.1 |
| 8 | 0.0 | 33.5 | 25.2 | 29.4 | 246.53 | 7.8 |
| 9 | 0.0 | 35.2 | 25.2 | 30.2 | 313.69 | 9.0 |
| 10 | 36.6 | 34.3 | 26.0 | 30.2 | 235.21 | 5.5 |
| 11 | 3.5 | 30.0 | 22.3 | 26.2 | 154.76 | 1.6 |
| 12 | 2.7 | 33.1 | 22.6 | 27.9 | 287.62 | 8.5 |
| 13 | 4.5 | 29.5 | 23.7 | 26.6 | 170.87 | 2.0 |
| 14 | 20.9 | 32.6 | 25.0 | 28.8 | 258.94 | 7.0 |
| 15 | 4.4 | 32.1 | 23.3 | 27.7 | 237.28 | 4.2 |
| 16[e] | 0.4 | 32.6 | 25.0 | 28.8 | 269.87 | 6.6 |
| 17 | 0.0 | 33.1 | 25.5 | 29.3 | 295.75 | 7.7 |
| 18 | 5.9 | 33.5 | 26.0 | 29.8 | 261.78 | 7.2 |
| 19 | 39.7 | 31.6 | 24.5 | 28.1 | 167.63 | 2.4 |
| 20 | 37.3 | 26.7 | 21.5 | 24.1 | 120.96 | 0.3 |
| 21 | 0.8 | 24.5 | 20.7 | 22.6 | 68.13 | 0.0 |
| 22 | 0.0 | 28.2 | 21.5 | 24.9 | 190.32 | 3.1 |
| 23 | 0.0 | 33.4 | 23.0 | 28.2 | 308.16 | 8.8 |
| 24 | 0.0 | 33.3 | 25.3 | 29.3 | 301.43 | 7.7 |
| 25 | 0.0 | 34.0 | 26.1 | 30.1 | 260.15 | 7.4 |
| 26 | 0.0 | 34.2 | 25.7 | 30.0 | 315.84 | 9.3 |
| 27 | 0.0 | 34.9 | 25.6 | 30.3 | 317.77 | 10.9 |
| 28 | 0.0 | 34.7 | 26.5 | 30.6 | 322.07 | 10.6 |
| 29 | 0.2 | 35.0 | 26.7 | 30.9 | 272.41 | 8.6 |
| 30[f] | 0.0 | 32.2 | 25.5 | 28.9 | 159.54 | 3.6 |
| 31 | 0.0 | 32.9 | 24.8 | 28.9 | 205.44 | 1.3 |
| Total | 282.1 | 1006.4 | 751.5 | 879.8 | 7539.56 | 192.3 |
| Average | 9.1 | 32.5 | 24.2 | 28.4 | 243.21 | 6.2 |

Remarks: d = 2nd sampling. e = 3rd sampling. f = 4th sampling period.

Appendix B4.4 Daily amount of rainfall, maximum temperature, minimum temperature, average temperature, solar radiation and sunshine duration in June 2000 at meteorological station Khon Kaen University Experimental Farm, Northeast Thailand.

| Date | Rainfall (mm) | Max. temp. (°C) | Min. temp. (°C) | Ave. temp. (°C) | Solar radiation (cal/cm$^2$/day) | Sunshine duration (hours/day) |
|---|---|---|---|---|---|---|
| | | | June 2000 | | | |
| 1 | 68.7 | 32.8 | 25.3 | 29.1 | 184.03 | 1.6 |
| 2 | 0.8 | 29.1 | 22.9 | 26.0 | 178.30 | 1.2 |
| 3 | 3.5 | 30.9 | 24.0 | 27.5 | 237.28 | 4.2 |
| 4 | 0.0 | 32.0 | 24.5 | 28.3 | 286.27 | 9.4 |
| 5 | 0.0 | 32.6 | 24.2 | 28.4 | 238.40 | 9.9 |
| 6 | 0.0 | 32.6 | 25.5 | 29.1 | 245.38 | 5.5 |
| 7 | 0.0 | 34.3 | 25.4 | 29.9 | 300.03 | 7.6 |
| 8 | 44.1 | 33.6 | 26.4 | 30.0 | 215.82 | 3.8 |
| 9 | 0.0 | 32.5 | 23.3 | 27.9 | 312.23 | 9.4 |
| 10 | 0.0 | 32.5 | 25.1 | 28.8 | 300.03 | 4.8 |
| 11 | 0.0 | 32.2 | 25.0 | 28.6 | 283.55 | 5.0 |
| 12 | 5.6 | 32.8 | 26.0 | 29.4 | 282.23 | 8.8 |
| 13[g] | 0.0 | 31.3 | 24.7 | 28.0 | 196.39 | 1.1 |
| 14 | 0.0 | 33.4 | 25.5 | 29.5 | 275.20 | 3.7 |
| 15 | 10.6 | 32.5 | 25.5 | 29.0 | 217.85 | 5.5 |
| 16 | 19.7 | 31.6 | 24.2 | 27.9 | 195.46 | 2.0 |
| 17 | 29.8 | 31.6 | 23.0 | 27.3 | 163.58 | 3.2 |
| 18 | 0.4 | 28.2 | 22.0 | 25.1 | 122.11 | 0.7 |
| 19 | 31.2 | 31.5 | 23.7 | 27.6 | 162.82 | 3.3 |
| 20 | 0.0 | 31.5 | 23.4 | 27.5 | 241.39 | 4.8 |
| 21 | 0.0 | 32.5 | 25.1 | 28.8 | 287.62 | 6.0 |
| 22 | 0.0 | 32.0 | 25.0 | 28.5 | 155.49 | 0.0 |
| 23 | 41.5 | 31.7 | 25.3 | 28.5 | 212.57 | 3.2 |
| 24 | 26.9 | 31.5 | 22.5 | 27.0 | 203.52 | 2.7 |
| 25 | 0.0 | 31.2 | 22.2 | 26.7 | 196.39 | 2.4 |
| 26 | 0.0 | 28.3 | 24.0 | 26.2 | 142.46 | 0.0 |
| 27[h] | 0.0 | 33.4 | 24.5 | 29.0 | 308.16 | 9.0 |
| 28 | 0.0 | 33.5 | 24.7 | 29.1 | 263.01 | 4.7 |
| 29[i] | 0.0 | 33.8 | 25.0 | 29.4 | 254.66 | 7.5 |
| 30 | 63.8 | 34.3 | 26.0 | 30.2 | 219.84 | 6.6 |
| Total | 346.6 | 961.7 | 733.9 | 848.3 | 6882.07 | 137.6 |
| Average | 11.6 | 32.1 | 24.5 | 28.3 | 229.40 | 4.6 |

Remarks: g = 5th sampling. h = 6th sampling. i = Harvested of seeds.

## B5. Experiment 5

Appendix B5.1 Daily amount of rainfall, maximum temperature, minimum temperature, average temperature, solar radiation and sunshine duration in March 2001 at meteorological station Khon Kaen University Experimental Farm, Northeast Thailand.

| Date | Rainfall (mm) | Max. temp. (°C) | Min. temp. (°C) | Ave. temp. (°C) | Solar radiation (cal/cm²/day) | Sunshine duration (hours/day) |
|---|---|---|---|---|---|---|
| | | | March 2001 | | | |
| 1 | 0.0 | 32.0 | 21.3 | 26.7 | 244.2 | 10.0 |
| 2 | 0.0 | 34.0 | 20.1 | 27.1 | 248.3 | 10.0 |
| 3 | 0.0 | 36.4 | 20.5 | 28.5 | 217.6 | 9.5 |
| 4 | 0.0 | 32.0 | 22.1 | 27.1 | 248.3 | 9.5 |
| 5 | 0.0 | 31.8 | 20.1 | 25.9 | 240.2 | 9.1 |
| 6 | 0.0 | 36.3 | 20.2 | 28.3 | 219.8 | 10.0 |
| 7 | 0.0 | 37.7 | 22.5 | 30.1 | 193.0 | 8.0 |
| 8 | 10.4 | 34.0 | 24.5 | 29.3 | 191.2 | 5.7 |
| 9 | 0.2 | 24.8 | 22.2 | 23.5 | 112.4 | 0.2 |
| 10 | 13.9 | 22.0 | 20.0 | 21.0 | 55.68 | 0.0 |
| 11 | 0.0 | 29.0 | 18.5 | 23.8 | 148.4 | 0.3 |
| 12 | 0.0 | 24.1 | 20.7 | 22.4 | 56.22 | 0.0 |
| 13 | 0.0 | 25.6 | 18.7 | 22.2 | 147.0 | 1.4 |
| 14[a] | 0.0 | 32.3 | 19.0 | 25.7 | 236.2 | 0.8 |
| 15 | 0.0 | 34.8 | 21.2 | 28.0 | 233.0 | 9.0 |
| 16 | 0.0 | 36.2 | 23.5 | 29.9 | 327.8 | 10.3 |
| 17 | 0.0 | 38.1 | 25.0 | 31.6 | 251.8 | 9.0 |
| 18 | 0.0 | 34.8 | 26.0 | 30.4 | 184.9 | 3.1 |
| 19 | 0.0 | 31.7 | 25.0 | 28.4 | 175.1 | 2.2 |
| 20[b] | 0.0 | 33.1 | 23.6 | 28.4 | 175.9 | 2.1 |
| 21 | 0.0 | 27.1 | 24.3 | 25.7 | 101.3 | 1.0 |
| 22 | 8.4 | 32.8 | 22.2 | 27.4 | 216.8 | 5.2 |
| 23 | 0.0 | 35.7 | 23.0 | 29.4 | 275.2 | 9.2 |
| 24 | 0.0 | 36.2 | 25.1 | 30.7 | 202.1 | 5.5 |
| 25 | 0.0 | 36.7 | 25.3 | 31.0 | 218.9 | 7.5 |
| 26 | 0.8 | 34.0 | 24.5 | 29.3 | 159.5 | 3.0 |
| 27 | 0.0 | 34.5 | 23.7 | 29.1 | 216.8 | 8.2 |
| 28 | 0.0 | 35.7 | 24.1 | 29.9 | 200.4 | 8.2 |
| 29 | 0.0 | 31.6 | 24.8 | 28.2 | 204.5 | 6.5 |
| 30 | 0.0 | 33.7 | 22.1 | 27.9 | 298.6 | 10.6 |
| 31 | 0.0 | 36.0 | 22.5 | 29.3 | 254.7 | 10.7 |
| Total | 33.7 | 1015.0 | 696.0 | 856.0 | 6256.0 | 185.8 |
| Average | 1.1 | 32.7 | 22.5 | 27.6 | 202.0 | 5.99 |

Remarks: a = Planting date of the sorghum plants. b = Seed emergence.

Appendix B5.2 Daily rainfall, maximum temperature, minimum temperature, average temperature, solar radiation and sunshine duration in April 2001 at meteorological station Khon Kaen University Experimental Farm, Northeast Thailand.

| Date | Rainfall (mm) | Max. temp. (°C) | Min. temp. (°C) | Ave. temp. (°C) | Solar radiation (cal/cm$^2$/day) | Sunshine duration (hours/day) |
|---|---|---|---|---|---|---|
| | | | April 2001 | | | |
| 1 | 0.0 | 35.4 | 24.3 | 29.9 | 278.2 | 10.0 |
| 2 | 0.0 | 35.5 | 25.5 | 30.5 | 224.9 | 9.1 |
| 3 | 0.0 | 38.5 | 26.0 | 32.3 | 265.5 | 8.3 |
| 4 | 0.0 | 39.3 | 26.8 | 33.1 | 232.2 | 8.7 |
| 5 | 0.0 | 38.5 | 27.8 | 33.0 | 248.8 | 7.1 |
| 6 | 0.0 | 39.6 | 28.0 | 28.8 | 287.5 | 10.2 |
| 7 | 0.0 | 39.5 | 27.7 | 33.6 | 266.7 | 10.5 |
| 8 | 0.0 | 41.0 | 28.0 | 34.5 | 305.5 | 11.2 |
| 9 | 0.0 | 40.2 | 27.6 | 33.9 | 250.0 | 10.8 |
| 10[c] | 0.0 | 41.6 | 27.5 | 34.5 | 274.9 | 10.5 |
| 11 | 1.5 | 42.0 | 28.2 | 35.1 | 224.0 | 9.3 |
| 12 | 0.0 | 33.1 | 23.0 | 28.1 | 298.6 | 9.4 |
| 13 | 0.0 | 36.5 | 23.3 | 29.9 | 276.5 | 10.0 |
| 14 | 0.0 | 38.0 | 25.6 | 31.8 | 243.6 | 8.1 |
| 15 | 0.2 | 36.9 | 26.7 | 31.8 | 267.1 | 8.6 |
| 16 | 0.0 | 38.6 | 24.0 | 31.3 | 265.5 | 10.1 |
| 17 | 0.0 | 40.0 | 25.7 | 32.9 | 277.8 | 9.0 |
| 18 | 0.0 | 40.3 | 26.8 | 33.6 | 287.5 | 10.5 |
| 19 | 0.0 | 39.8 | 26.7 | 33.3 | 291.7 | 11.1 |
| 20 | 0.0 | 40.2 | 27.0 | 33.6 | 279.4 | 11.7 |
| 21 | 0.0 | 41.5 | 27.0 | 34.3 | 311.1 | 11.3 |
| 22 | 0.0 | 40.7 | 25.5 | 33.1 | 266.7 | 11.5 |
| 23 | 0.0 | 40.9 | 28.2 | 34.6 | 276.2 | 10.5 |
| 24[d] | 3.3 | 38.6 | 28.7 | 33.7 | 167.6 | 5.6 |
| 25 | 0.0 | 35.6 | 25.0 | 30.3 | 246.5 | 6.5 |
| 26 | 0.0 | 36.0 | 25.5 | 30.8 | * | 6.8 |
| 27 | 23.6 | 36.4 | 26.2 | 31.3 | * | 3.3 |
| 28 | 1.6 | 37.1 | 26.8 | 31.9 | 251.8 | 9.5 |
| 29 | 0.0 | 35.6 | 26.3 | 30.9 | 255.9 | 7.2 |
| 30 | 7.8 | 34.0 | 27.0 | 30.5 | * | 5.0 |
| Total | 38.0 | 1151.0 | 792.0 | 967.0 | 7117.0 | 271.0 |
| Average | 1.3 | 38.4 | 26.4 | 32.2 | 264.0 | 9.1 |

Remarks: c = 1st sampling. d = 2nd sampling. * = Not recorded.

Appendix B5.3 Daily amount of rainfall, maximum temperature, minimum temperature, average temperature, solar radiation and sunshine duration in May 2001 at meteorological station Khon Kaen University Experimental Farm, Northeast Thailand.

| Date | Rainfall (mm) | Max. temp. (°C) | Min. temp. (°C) | Ave. temp. (°C) | Solar radiation ($cal/cm^2/day$) | Sunshine duration (hours/day) |
|---|---|---|---|---|---|---|
| | | | May 2001 | | | |
| 1 | 3.2 | 35.0 | 24.2 | 29.6 | 251.1 | 9.2 |
| 2 | 27.7 | 32.2 | 23.5 | 27.9 | 231.9 | 6.8 |
| 3 | 1.8 | 30.5 | 22.0 | 26.3 | 193.6 | 2.2 |
| 4 | 16.9 | 33.4 | 23.5 | 28.5 | 216.8 | 5.3 |
| 5 | 2.1 | 34.5 | 23.5 | 29.0 | 308.2 | 11.0 |
| 6 | 0.0 | 35.2 | 25.2 | 30.2 | 283.6 | 11.8 |
| 7 | 0.0 | 36.1 | 26.5 | 31.3 | 277.8 | 9.5 |
| $8^e$ | 0.0 | 35.9 | 26.1 | 31.0 | 242.5 | 7.7 |
| 9 | 0.0 | 35.0 | 25.3 | 30.2 | 309.6 | 11.0 |
| 10 | 31.2 | 30.7 | 25.3 | 28.0 | 141.8 | 1.5 |
| 11 | 0.7 | 28.8 | 23.1 | 26.2 | 166.1 | 3.0 |
| 12 | 0.0 | 31.6 | 22.3 | 26.9 | 260.6 | 7.0 |
| 13 | 0.0 | 33.3 | 24.5 | 28.9 | 257.5 | 8.5 |
| 14 | 0.0 | 33.2 | 25.0 | 29.1 | 216.8 | 6.0 |
| 15 | 30.2 | 32.5 | 25.3 | 28.9 | 174.3 | 4.0 |
| 16 | 3.2 | 30.2 | 22.9 | 26.6 | 162.1 | 0.7 |
| 17 | 26.5 | 31.0 | 24.4 | 27.7 | 162.8 | 3.4 |
| 18 | 2.7 | 32.0 | 23.0 | 27.5 | 245.4 | 7.0 |
| 19 | 0.0 | 32.2 | 24.5 | 28.4 | 223.9 | 8.0 |
| 20 | 0.0 | 33.2 | 25.0 | 29.1 | 291.7 | 10.8 |
| 21 | 0.0 | 33.3 | 25.3 | 29.3 | 246.5 | 11.0 |
| $22^f$ | 0.0 | 35.1 | 25.7 | 30.4 | 268.3 | 10.7 |
| 23 | 0.2 | 33.5 | 26.2 | 29.9 | 217.9 | 6.8 |
| 24 | 0.0 | 34.6 | 25.6 | 30.1 | 213.6 | 7.0 |
| 25 | 0.0 | 34.6 | 26.0 | 30.3 | 290.3 | 10.8 |
| 26 | 4.4 | 33.5 | 26.1 | 29.8 | 217.9 | 7.1 |
| 27 | 7.7 | 32.6 | 24.0 | 28.3 | 234.1 | 8.5 |
| 28 | 24.2 | 31.8 | 25.0 | 28.4 | 208.5 | 4.0 |
| 29 | 5.5 | 31.2 | 23.9 | 27.6 | 207.6 | 2.5 |
| 30 | 0.0 | 33.0 | 24.1 | 28.6 | 233.0 | 6.0 |
| 31 | 0.0 | 32.5 | 25.3 | 28.9 | * | 7.0 |
| Total | 188.0 | 1022.0 | 762.0 | 893.0 | 6956.0 | 216.0 |
| Average | 6.07 | 33.0 | 24.6 | 28.8 | 232 | 7.0 |

Remarks: e = 3rd sampling. f = 4th sampling. * = Not recorded.

Appendix B5.4 Daily amount of rainfall, maximum temperature, minimum temperature, average temperature, solar radiation and sunshine duration in June 2001 at meteorological station Khon Kaen University Experimental Farm, Northeast Thailand.

| Date | Rainfall (mm) | Max. temp. (°C) | Min. temp. (°C) | Ave. temp. (°C) | Solar radiation (cal/cm$^2$/day) | Sunshine duration (hours/day) |
|---|---|---|---|---|---|---|
| | | | June 2001 | | | |
| 1 | 0.5 | 34.6 | 25.6 | 30.1 | * | 10.8 |
| 2 | 40.0 | 32.2 | 25.2 | 28.7 | * | 5.5 |
| 3 | 0.0 | 32.4 | 23.1 | 27.8 | 269.9 | 8.0 |
| 4 | 0.0 | 34.0 | 24.1 | 29.1 | 246.5 | 8.0 |
| 5[g] | 0.0 | 32.5 | 25.2 | 28.9 | 175.9 | 2.0 |
| 6 | 9.3 | 33.5 | 25.8 | 29.7 | 167.6 | 3.1 |
| 7 | 0.0 | 32.0 | 24.6 | 28.3 | 175.9 | 3.0 |
| 8 | 2.1 | 33.3 | 25.0 | 29.2 | 253.5 | 6.0 |
| 9 | 0.4 | 34.0 | 24.6 | 29.3 | 189.0 | 4.2 |
| 10 | 6.0 | 32.0 | 24.3 | 28.2 | * | 6.8 |
| 11 | 7.9 | 31.5 | 24.0 | 27.8 | 174.1 | 5.8 |
| 12 | 0.0 | 31.5 | 23.6 | 27.6 | * | 4.1 |
| 13 | 19.2 | 30.8 | 23.6 | 27.2 | * | 1.5 |
| 14 | 2.8 | 33.0 | 23.7 | 28.4 | 183.2 | 5.2 |
| 15 | 0.0 | 33.3 | 24.5 | 28.9 | * | 7.3 |
| 16 | 36.8 | 33.9 | 24.8 | 29.4 | 269.9 | 10.5 |
| 17 | 0.0 | 35.0 | 24.0 | 29.5 | * | 11.0 |
| 18 | 0.0 | 34.6 | 25.4 | 30.0 | 263.0 | 11.0 |
| 19 | 0.0 | 35.7 | 25.8 | 30.8 | 359.1 | 11.0 |
| 20 | 0.0 | 34.7 | 25.3 | 30.0 | 271.1 | 8.7 |
| 21 | 0.0 | 35.1 | 25.3 | 30.2 | 287.6 | 10.2 |
| 22 | 17.2 | 30.9 | 26.0 | 28.5 | * | 4.0 |
| 23 | 7.5 | 32.1 | 23.2 | 27.7 | * | 5.0 |
| 24 | 23.6 | 28.5 | 24.2 | 26.4 | 121.5 | 8.7 |
| 25 | 1.2 | 32.3 | 24.0 | 28.2 | 184.0 | 2.5 |
| 26 | 0.1 | 30.7 | 24.6 | 27.7 | 158.8 | 0.5 |
| 27 | 2.6 | 31.3 | 24.2 | 27.8 | 207.6 | 3.2 |
| 28 | 0.0 | 30.7 | 24.5 | 27.6 | 227.9 | 1.5 |
| 29 | 1.9 | 30.4 | 25.0 | 27.7 | 162.8 | 0.2 |
| 30[h] | 0.0 | 30.5 | 25.5 | 27.9 | 166.1 | 1.3 |
| Total | 179.0 | 977.0 | 739.0 | 859.0 | 4515.0 | 171.0 |
| Average | 6.0 | 32.6 | 24.6 | 28.6 | 215.0 | 5.7 |

Remarks: g = 5th sampling. h = Seed harvest. * = Not recorded.

## B6. Experiment 6

Appendix B6.1 Daily amount of rainfall, maximum temperature, minimum temperature, average temperature, solar radiation and sunshine duration in July 2001 at meteorological station Khon Kaen University Experimental Farm, Northeast Thailand.

| Date | Rainfall (mm) | Max. temp. (°C) | Min. temp. (°C) | Ave. temp. (°C) | Solar radiation (cal/cm$^2$/day) | Sunshine duration (hours/day) |
|---|---|---|---|---|---|---|
| | | | July 2001 | | | |
| 1 | 0.0 | 33.7 | 24.6 | 29.2 | 237.3 | 3.6 |
| 2 | 18.5 | 34.0 | 25.2 | 29.6 | 180.6 | 5.1 |
| 3 | 0.0 | 32.0 | 23.6 | 27.8 | 252.3 | 7.7 |
| 4 | 0.0 | 32.0 | 25.6 | 28.8 | 206.1 | 7.0 |
| 5 | 0.0 | 33.3 | 25.6 | 29.5 | * | 7.0 |
| 6 | 0.0 | 33.0 | 26.0 | 29.5 | 220.9 | 6.0 |
| 7 | 1.0 | 32.7 | 26.0 | 29.4 | 142.5 | 0.8 |
| 8 | 15.0 | 31.5 | 25.3 | 28.4 | 175.1 | 0.7 |
| 9 | 2.1 | 30.7 | 23.6 | 27.2 | 219.8 | 3.3 |
| 10 | 0.2 | 32.6 | 23.3 | 27.9 | 259.3 | 8.6 |
| 11 | 0.0 | 33.2 | 23.7 | 28.5 | 265.8 | 10.0 |
| 12 | 0.0 | 33.8 | 24.7 | 29.3 | 234.1 | 9.0 |
| 13 | 0.0 | 33.7 | 25.2 | 29.5 | 216.8 | 8.0 |
| 14 | 0.0 | 32.0 | 25.6 | 28.8 | 192.1 | 8.3 |
| 15 | 2.3 | 34.1 | 25.7 | 29.9 | 283.6 | 9.0 |
| 16 | 0.7 | 33.0 | 25.7 | 29.4 | 224.9 | 3.3 |
| 17 | 0.0 | 33.3 | 24.6 | 28.9 | 237.3 | 5.3 |
| 18 | 0.0 | 33.0 | 25.1 | 29.1 | * | 4.5 |
| 19 | 1.4 | 35.1 | 25.2 | 30.2 | 265.8 | 8.3 |
| 20 | 2.0 | 31.4 | 26.3 | 28.9 | 175.1 | 0.0 |
| 21 | 9.8 | 30.7 | 24.9 | 27.8 | 179.1 | 0.3 |
| 22 | 2.4 | 27.5 | 22.7 | 25.1 | * | 0.0 |
| 23 | 6.2 | 32.1 | 23.0 | 27.6 | * | 10.0 |
| 24[a] | 0.9 | 34.6 | 23.6 | 29.1 | * | 9.3 |
| 25 | 0.0 | 33.2 | 25.1 | 29.2 | * | 5.0 |
| 26 | 4.2 | 33.8 | 25.6 | 29.7 | * | 6.0 |
| 27 | 20.7 | 32.7 | 24.2 | 28.5 | * | 3.8 |
| 28 | 19.5 | 32.2 | 22.5 | 27.4 | * | 4.8 |
| 29 | 0.0 | 33.5 | 23.4 | 28.5 | * | 8.0 |
| 30[b] | 3.0 | 33.5 | 24.7 | 29.1 | 229.0 | 9.0 |
| 31 | 0.8 | 34.8 | 25.3 | 30.1 | 233.0 | 10.1 |
| Total | 111.0 | 1017.0 | 766.0 | 892.0 | 4631.0 | 182.0 |
| Average | 3.6 | 32.8 | 24.7 | 28.8 | 201.0 | 5.9 |

Remarks: a = Planting date of the sorghum plants. b = Seed emergence. * = Not recorded.

Appendix B6.2 Daily amount of rainfall, maximum temperature, minimum temperature, average temperature, solar radiation and sunshine duration in August 2001 at meteorological station Khon Kaen University Experimental Farm, Northeast Thailand.

| Date | Rainfall (mm) | Max. temp. (°C) | Min. temp. (°C) | Ave. temp. (°C) | Solar radiation (cal/cm$^2$/day) | Sunshine duration (hours/day) |
|---|---|---|---|---|---|---|
| | | | August 2001 | | | |
| 1 | 0.0 | 33.5 | 25.2 | 29.4 | 278.2 | 8.7 |
| 2 | 0.0 | 32.5 | 25.5 | 29.0 | 269.9 | 9.0 |
| 3 | 0.0 | 30.1 | 24.2 | 27.2 | 170.9 | 1.5 |
| 4 | 0.0 | 33.0 | 25.0 | 29.0 | 229.0 | 9.4 |
| 5 | 21.2 | 33.6 | 25.7 | 29.7 | 249.4 | 8.2 |
| 6 | 36.6 | 31.1 | 23.5 | 27.3 | 231.9 | 8.1 |
| 7 | 18.1 | 31.2 | 23.2 | 27.2 | 186.3 | 3.6 |
| 8 | 0.7 | 30.2 | 23.5 | 26.9 | 170.1 | 3.5 |
| 9 | 19.1 | 28.1 | 24.3 | 26.2 | 68.79 | 0.1 |
| 10 | 29.7 | 31.9 | 23.6 | 27.8 | 223.9 | 4.0 |
| 11 | 21.8 | 26.0 | 23.7 | 24.9 | 64.16 | 1.2 |
| 12 | 0.0 | 30.5 | 23.6 | 27.1 | 236.2 | 6.3 |
| 13 | 13.1 | 31.9 | 24.7 | 28.3 | 215.8 | 4.5 |
| 14 | 0.0 | 31.5 | 23.8 | 27.7 | 195.5 | 3.5 |
| 15 | 1.3 | 31.8 | 24.0 | 27.9 | 158.8 | 5.2 |
| 16 | 11.5 | 31.6 | 25.1 | 28.4 | 174.3 | 2.5 |
| 17 | 1.9 | 29.0 | 24.1 | 26.6 | 149.8 | 2.3 |
| 18 | 2.0 | 32.5 | 24.1 | 28.3 | 175.1 | 6.3 |
| 19 | 0.0 | 32.8 | 25.1 | 28.9 | 203.9 | 9.0 |
| 20[c] | 10.8 | 31.0 | 25.2 | 28.1 | 146.5 | 3.0 |
| 21 | 0.0 | 33.2 | 25.6 | 29.4 | 261.8 | 10.3 |
| 22 | 1.1 | 34.0 | 25.4 | 29.7 | 278.4 | 8.5 |
| 23 | 1.4 | 34.2 | 25.8 | 30.0 | 240.2 | 7.1 |
| 24 | 0.0 | 34.7 | 25.8 | 30.3 | 295.8 | 10.5 |
| 25 | 0.0 | 34.3 | 26.0 | 30.2 | 291.7 | 7.2 |
| 26 | 7.3 | 31.1 | 26.3 | 28.7 | 129.6 | 0.0 |
| 27 | 22.2 | 26.3 | 24.6 | 25.5 | 56.49 | 0.0 |
| 28 | 0.7 | 30.0 | 24.1 | 27.1 | 158.8 | 2.2 |
| 29 | 10.2 | 31.5 | 24.6 | 28.1 | 154.6 | 3.2 |
| 30 | 0.0 | 31.3 | 24.7 | 28.0 | 200.4 | 7.1 |
| 31 | 0.0 | 32.0 | 24.5 | 28.3 | 233.0 | 7.2 |
| Total | 231.0 | 976.0 | 765.0 | 871.0 | 6099.0 | 163.0 |
| Average | 7.4 | 31.5 | 24.7 | 28.1 | 197.0 | 5.3 |

Remarks: c = 1st sampling.

Appendix B6.3 Daily rainfall, maximum temperature, minimum temperature, average temperature, solar radiation and sunshine duration in September 2001 at meteorological station Khon Kaen University Experimental Farm, Northeast Thailand.

| Date | Rainfall (mm) | Max. temp. (°C) | Min. temp. (°C) | Ave. temp. (°C) | Solar radiation (cal/cm²/day) | Sunshine duration (hours/day) |
|---|---|---|---|---|---|---|
| | | | September 2001 | | | |
| 1 | 0.0 | 32.9 | 25.1 | 29.0 | 236.2 | 6.2 |
| 2 | 11.6 | 32.4 | 25.2 | 28.8 | 261.8 | 7.2 |
| 3[d] | 6.6 | 31.1 | 24.6 | 27.9 | 125.5 | 1.7 |
| 4 | 20.5 | 29.0 | 23.5 | 26.3 | 81.4 | 0.0 |
| 5 | 0.0 | 30.6 | 22.5 | 26.6 | 248.3 | 6.2 |
| 6 | 0.0 | 32.5 | 23.5 | 28.0 | 202.6 | 4.1 |
| 7 | 1.2 | 33.7 | 25.2 | 29.5 | 269.9 | 10.2 |
| 8 | 27.9 | 33.4 | 25.5 | 29.5 | 224.9 | 4.5 |
| 9 | 6.7 | 27.6 | 22.2 | 24.9 | 105.3 | 1.0 |
| 10 | 12.2 | 29.7 | 22.7 | 26.2 | 162.1 | 2.2 |
| 11 | 0.5 | 30.5 | 23.6 | 27.1 | 154.6 | 0.5 |
| 12 | 0.9 | 30.5 | 24.5 | 27.5 | 141.8 | 2.7 |
| 13 | 2.4 | 31.5 | 25.5 | 28.5 | 206.6 | 5.1 |
| 14 | 0.0 | 32.5 | 23.0 | 27.8 | 301.3 | 10.1 |
| 15 | 0.0 | 33.3 | 24.0 | 28.7 | 284.9 | 10.7 |
| 16 | 42.1 | 33.7 | 26.0 | 29.9 | 222.8 | 8.2 |
| 17[e] | 4.1 | 31.1 | 21.8 | 26.5 | 170.1 | 4.8 |
| 18 | 0.0 | 33.1 | 22.0 | 27.6 | 253.5 | 10.0 |
| 19 | 44.2 | 34.3 | 24.3 | 29.3 | 272.6 | 9.3 |
| 20 | 3.4 | 32.4 | 20.7 | 26.6 | 153.8 | 5.2 |
| 21 | 55.5 | 30.9 | 24.7 | 27.8 | 162.1 | 4.0 |
| 22 | 3.4 | 29.6 | 22.2 | 25.9 | 153.8 | 3.4 |
| 23 | 19.5 | 31.2 | 23.0 | 27.1 | 191.2 | 4.8 |
| 24 | 0.0 | 31.8 | 23.4 | 27.6 | 248.3 | 9.4 |
| 25 | 0.0 | 31.5 | 24.4 | 27.9 | 211.6 | 5.1 |
| 26 | 0.0 | 32.8 | 22.8 | 27.8 | 200.4 | 9.8 |
| 27 | 0.0 | 32.7 | 24.2 | 28.7 | 229.0 | 0.0 |
| 28 | 0.0 | 32.4 | 25.0 | 28.7 | 233.0 | 10.0 |
| 29 | 0.0 | 32.4 | 24.9 | 28.7 | 231.9 | 9.2 |
| 30 | 0.0 | 33.0 | 25.8 | 29.4 | 253.5 | 9.7 |
| Total | 263.0 | 954.0 | 716.0 | 836.0 | 6194.0 | 175.0 |
| Average | 8.8 | 31.8 | 23.9 | 27.9 | 206.0 | 5.8 |

Remarks: d = 2nd sampling. e = 3rd sampling.

Appendix B6.4 Daily amount of rainfall, maximum temperature, minimum temperature, average temperature, solar radiation and sunshine duration in October 2001 at meteorological station Khon Kaen University Experimental Farm, Northeast Thailand.

| Date | Rainfall (mm) | Max. temp. (°C) | Min. temp. (°C) | Ave. temp. (°C) | Solar radiation (cal/cm²/day) | Sunshine duration (hours/day) |
|---|---|---|---|---|---|---|
| | | | October 2001 | | | |
| 1[f] | 0.0 | 33.0 | 25.1 | 29.1 | 224.9 | 10.1 |
| 2 | 5.3 | 32.9 | 25.1 | 29.0 | 229.0 | 9.8 |
| 3 | 0.2 | 32.1 | 23.5 | 27.8 | 219.8 | 7.2 |
| 4 | 1.0 | 32.2 | 23.8 | 28.0 | 223.9 | 8.2 |
| 5 | 0.0 | 32.3 | 24.5 | 28.4 | 208.5 | 9.3 |
| 6 | 0.0 | 32.5 | 24.5 | 28.5 | 187.2 | 7.9 |
| 7 | 0.0 | 33.5 | 25.0 | 29.3 | 241.3 | 9.1 |
| 8 | 0.9 | 31.5 | 25.0 | 28.3 | 135.0 | 5.2 |
| 9 | 36.0 | 28.7 | 24.7 | 26.7 | 113.0 | 1.5 |
| 10 | 0.0 | 31.8 | 22.5 | 27.2 | 231.9 | 9.2 |
| 11 | 0.0 | 32.7 | 24.0 | 28.4 | 231.9 | 10.3 |
| 12 | 0.0 | 32.7 | 24.2 | 28.5 | 233.0 | 10.4 |
| 13 | 3.0 | 32.7 | 24.7 | 28.7 | 227.9 | 9.5 |
| 14 | 0.0 | 33.2 | 24.8 | 29.0 | 233.0 | 10.5 |
| 15[g] | 0.0 | 33.1 | 25.1 | 29.1 | 224.9 | 9.7 |
| 16 | 0.0 | 33.0 | 24.8 | 28.9 | 257.5 | 10.0 |
| 17 | 0.0 | 32.5 | 23.0 | 27.8 | 231.9 | 10.0 |
| 18 | 0.0 | 32.0 | 23.3 | 27.7 | 207.6 | 8.0 |
| 19 | 0.0 | 32.0 | 23.0 | 27.5 | 219.8 | 9.8 |
| 20 | 0.0 | 32.5 | 22.9 | 27.7 | 215.8 | 7.5 |
| 21 | 0.0 | 32.2 | 24.0 | 28.1 | 215.8 | 7.2 |
| 22 | 29.4 | 30.5 | 22.4 | 26.5 | 108.8 | 0.7 |
| 23 | 82.1 | 29.7 | 21.2 | 25.5 | 152.6 | 2.3 |
| 24 | 11.3 | 29.2 | 21.7 | 25.5 | 162.1 | 4.3 |
| 25 | 0.0 | 31.0 | 22.8 | 26.9 | 162.1 | 6.6 |
| 26 | 0.0 | 32.0 | 23.0 | 27.5 | 203.5 | 9.6 |
| 27 | 1.9 | 33.0 | 24.1 | 28.6 | 215.8 | 9.6 |
| 28 | 0.0 | 30.9 | 23.3 | 27.1 | 194.5 | 7.2 |
| 29 | 0.0 | 31.7 | 22.7 | 27.2 | 198.6 | 8.8 |
| 30[h] | 0.0 | 31.6 | 21.1 | 26.4 | 214.8 | 9.0 |
| 31 | 0.0 | 31.7 | 22.0 | 26.9 | 215.8 | 9.2 |
| Total | 171.0 | 990.0 | 732.0 | 862.0 | 6342.0 | 248.0 |
| Average | 5.5 | 30.9 | 23.6 | 27.8 | 205 | 8.0 |

Remarks: f = 4th sampling. g = 5th sampling. h = Harvested of seeds.

# Appendix C

## Fermented Cattle Manure Analysis Data

Appendix C1. Fermented cattle manure analysis data before being applied to the sorghum plots of Yasothon soil series (Oxic Paleustults) for the Experiment 3 at Khon Kaen University Experimental Farm, Northeast Thailand in rainy season 1999.

| Items | Replications | | | | Averages |
|---|---|---|---|---|---|
| | I | II | III | IV | |
| PH (1:10) | 6.95 | 6.82 | 7.25 | 7.28 | 7.08 |
| Organic matter (%) | 41.25 | 39.15 | 39.32 | 40.75 | 40.12 |
| Total nitrogen (%) | 1.152 | 1.132 | 1.112 | 1.145 | 1.14 |
| Total phosphorus (%) | 0.212 | 0.192 | 0.232 | 0.228 | 0.22 |
| Total potassium (%) | 1.85 | 1.67 | 1.78 | 1.62 | 1.73 |

Appendix C2. Fermented cattle manure analysis data before being applied to the sorghum plots of Yasothon soil series (Oxic Paleustults) for the Experiment 4 at Khon Kaen University Experimental Farm, Northeast Thailand in dry season 2000.

| Items | Replications | | | | Averages |
|---|---|---|---|---|---|
| | I | II | III | IV | |
| PH (1:10) | 8.15 | 7.20 | 7.35 | 7.28 | 7.58 |
| Organic matter (%) | 39.15 | 37.65 | 38.45 | 40.75 | 38.42 |
| Total nitrogen (%) | 0.943 | 0.893 | 0.947 | 1.145 | 0.942 |
| Total phosphorus (%) | 0.192 | 0.186 | 0.191 | 0.228 | 0.189 |
| Total potassium (%) | 1.79 | 1.63 | 1.85 | 1.62 | 1.80 |

Appendix C3 Fermented cattle manure analysis data before being applied to the sorghum plots of Yasothon soil series (Oxic Paleustults) for the Experiment 5 at Khon Kaen University Experimental Farm, Northeast Thailand in dry season 2001.

| Items | Replications | | | | Averages |
|---|---|---|---|---|---|
| | I | II | III | IV | |
| PH (1:10) | 8.55 | 8.55 | 8.55 | 8.55 | 8.55 |
| Organic matter (%) | 35.29 | 33.44 | 38.28 | 40.84 | 36.96 |
| Total nitrogen (%) | 0.852 | 0.868 | 0.919 | 0.950 | 0.897 |
| Total phosphorus (%) | 0.194 | 0.192 | 0.208 | 0.200 | 0.199 |
| Total potassium (%) | 1.79 | 1.65 | 2.00 | 1.93 | 1.84 |

Appendix C4. Fermented cattle manure analysis data before being applied to the sorghum plots of Yasothon soil series (Oxic Paleustults) for the Experiment 6 at Khon Kaen University Experimental Farm, Northeast Thailand in rainy season 2001.

| Items | Replications | | | | Averages |
|---|---|---|---|---|---|
| | I | II | III | IV | |
| PH (1:10) | 7.65 | 7.95 | 8.05 | 8.25 | 7.98 |
| Organic matter (%) | 35.29 | 45.82 | 39.99 | 42.98 | 41.02 |
| Total nitrogen (%) | 1.127 | 0.940 | 0.971 | 1.120 | 1.040 |
| Total phosphorus (%) | 0.191 | 0.188 | 0.231 | 0.223 | 0.211 |
| Total potassium (%) | 1.51 | 1.79 | 1.61 | 1.61 | 1.63 |

# Appendix D

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## Determinations of Chemical Components and Biological Analysis of Dry matter Degradability

### D.1 Chemical components determinations

### D.1.1 Crude protein determination by Kjeldahl method

### D.1.2 Materials

Dry ground sorghum samples passed through 1 mm screen grinder, which dry matter percentages were determined.

### D.1.3 Reagents

1. Concentrated sulfuric acid.
2. 30% hydrogen peroxide.
3. Catalyst (10 g of potassium sulfate and 0.5 g of copper sulfate).
4. Standard solution of 0.1N $H_2SO_4$.
5. 4 % boric acid indicator solution (40 g of boric acid in 400 ml of distilled water, add 400 ml of ethanol and 40 ml of mixed indicator solution of 0.66 g of bromocresol green and 0.33 g of methyl red in 1,000 ml of ethanol).
6. 40 % sodium hydroxide.
7. Distilled water.

### D.1.4 Equipment

1. Digestion tubes.
2. Digester.
3. Kjeldahl distillation process equipment (KJELTECH SYSTEM 1026 Distilling Unit, Sweden).
4. Automatic titer of Burette Digital *III*, Germany.

### D.1.5 Procedure

1. Weigh 0.2-0.5 g of sorghum sample and fill into digestion tube.
2. Add 2 g of catalyst into each digestion tube.
3. Add 15 ml of sulfuric acid and mix carefully by swirling the tube.
4. Add 1 ml of hydrogen peroxide and temperature becomes very high.
5. Place the digestion tube on the digester.
6. Digest for 2-3 hours at 385-400° C until solution becomes transparency.
7. Place each of digester tube in Kjeldahl distillation process.
8. Place receiving flask, which contained 30 ml of boric acid and indicator solution under the condenser to collect the distillate of ammonia.
9. Add 40 ml of distilled water and 20 ml of 40 % sodium hydroxide into the digestion tube and start steam distillation.
10. Stop distillation after the volume of ammonia distillate in the receiving flask reaches to 150 ml.
11. Titrate the distillate against the standard sulfuric acid (0.1N) using automatic titer. The end point occurs when the colour of indicator changes from green to purple colour.
12. Record both of the volume of standard sulfuric acid used in sample and blank titers.
13. Calculate total nitrogen percentage and estimated protein percentage.

### D.1.6 Calculations by:

$$\text{Total N \%} = \frac{n \times (t - t') \times 100}{W}$$

Where:

**n** = Nitrogen level corresponding to 1 ml of 0.1 N $H_2SO_4$ (1 ml of 0.1 N $H_2SO_4$ corresponds to 0.0014 g of nitrogen).

**t** = 0.1 N sulfuric acid in sample titer (ml).

**t'** = 0.1 N sulfuric acid in blank titer (ml).

**W** = Sample weight (g).

**Protein % = Total N % x 6.25**

6.25 = an assumption of average N content of feedstuff is 16 g per 100 g of protein.

## D.2 Detergent analysis

### D.2.1 Method of Goering and Van Soest (1970) in ADF determination

#### D.2.1.1 Materials

Dry ground sorghum samples passed through 1 mm screen grinder, which dry matter percentages were determined.

#### D.2.1.2 Reagents

**1. Acid detergent solution preparation**

To make 10 litres of acid detergent solution, weight 200 g of cetyltrimethyl-ammonium bromide (CTAB, technical grade) into 2-litre glass beaker then add 1.5 litres of distilled water and stir with magnetic stirrer. To another 2-litre glass beaker add 1725 ml of distilled water, place in the fume cupboard, slowly add 275 ml of 98% sulfuric acid and stir with a glass rod to ensure thoroughly mixing. Add 6.5 litres of distilled water to the dispensing bottle then add the CTAB solution followed by the sulfuric acid solution and mix thoroughly.

**2. Acetone, technical grade.**

#### D.2.1.3 Equipment

1. Refluxing apparatus.
2. Sintered glass crucible, coarse porosity no. 1.
3. Vacuum flask.

### D.2.1.4 Procedure

1. Weigh 0.5-1.0 g ($W_o$) of sorghum ground sample into round-bottomed Quickfit flasks for refluxing.
2. Add 100 ml of ADF solution into each flask.
3. Heat the flasks to boiling in 5-10 minutes. To avoid foaming, reduce heat just before boiling begins, to achieve gentle refluxing.
4. Reflux for 120 minutes from the onset of boiling and then adjust boiling to slow even level.
5. Allow flask to cool down for 5-10 minutes.
6. Weight crucible ($W_1$). Weighted crucible must be oven and then cool down in desiccator to make sure of an exactly weight of each crucible.
7. Filter the cool down of boiled sample through crucibles by light suction.
8. Wash residue (ADF) in crucible thoroughly with hot water and rinse twice with acetone
9. Dry ADF crucible over night in 50° C oven.
10. Cool down in desiccator and weight ADF crucible ($W_2$).

### D.2.1.5 Calculations by:

$$\text{ADF \%} = \frac{(W_2 - W_1) \times 100}{W_o}$$

### D.3 Method of Goering and Van Soest (1970) in NDF determination

### D.3.1 Reagents

1. Neutral detergent solution preparation

To make 10 litres of neutral detergent solution, the solution is made up in three different beakers. The two-figure balance should be placed in the fume- cupped board to weight out the reagent. This will avoid breathing in the dust of detergents and etc.

a. Weight 186.1 g EDTA (disodium ethylene diamine tetra acetate) and 68.1 g BORAX into a beaker. Add 1.5 litres of distilled water and stir on magnetic stirrer.

b. Weight 45.6 g of $Na_2HPO_4$ into a beaker and dissolve in 1 litre of distilled water.
c. Weight 300 g of sodium lauryl sulphate into a 2-litre beaker and dissolve in 1.5 litre of distilled water. When fully dissolve then add 100 ml of 2-ethoxyethanal.
d. Add 6 litre of distilled water to the dispensing bottle. Then add the sodium lauryl sulphate solution, followed by the EDTA-BORAX solution. Add the $Na_2HPO_4$ solution last. Ensure that the solutions are well mixed. Check pH of solution ranging between 6.9 and 7.1.

1. Acetone, technical grade.
2. If the sample is expected to be high in starch, prepare a 2% α-amylase solution using Sigma Chemicals A-3403 to add into boiled NDF solution.

### D.3.2 Procedure

1. Weigh 0.5-1.0 g ($Y_o$) of sorghum ground sample into rounded bottomed Quickfit flasks for refluxing.
2. Add 100 ml of NDF solution into each flask.
3. Heat the flasks to boiling in 5-10 minutes. To avoid foaming, reduce heat just before boiling begins. Note that the NDF solution is more prone to frothing than ADF solution.
4. Reflux for 60 minutes from the onset of boiling, adjusting boiling to a slow even level. Then cool down flasks for 5-10 minutes.
5. Weight crucible ($Y_1$). Weighted crucible must be oven and then cool down in desiccator to make sure of an exactly weight of each crucible.
6. Filter the cool down of boiled sample through crucibles by light suction.
7. If the sample is expected to be high in starch allow the flasks to cool down to about 50° C. Add 1 ml of 2% α-amylase solution per 100 ml of NDF solution then allow to stand for 30 minutes and filter.
8. Wash NDF crucible thoroughly with hot water and rinse twice with acetone.

9. Dry NDF crucible over night in an oven at 100° C.
10. Cool down the sample in desiccator and weigh out the NDF crucible ($Y_2$).

### D.3.3 Calculations

$$\text{NDF \%} = \frac{(Y_2 - Y_1) \times 100}{Y_o}$$

## D.4 Biological feed analysis

### D.4.1 Dry matter degradability (DMD) determination by nylon bag technique of Oskov *et al.* (1970)

### D.4.2 Procedure

1. Dry nylon bags (size 6x12 cm, pore size 54 micron) at 60° C in a drying oven for 48 hours, allow cool in desiccator and weigh (**B** g).
2. Determine the dry matter content (**DM %**) ground sorghum samples at 135° C for 2 hours.
3. Weigh 2-3 g of ground sorghum sample into a nylon bag (three bags for each sample) and weigh (**S** g).
4. Close nylon bags with nylon thread and attach on a plastic rod connected with 50 cm length of vinyl tube string for suspension in the rumen.
5. Insert suspension nylon bags into the rumen through the cannula of three fistulated Brahman cattle and allow remaining to digest for 48 hours.
6. After 48 hours incubation all the bags were taken off and washed under running tap water until the washed water becomes clear.
7. Dry nylon bags with digested samples at 60° C for 48 hours and weigh (**D** g).

### D.4.3 Calculations on dry matter degradability at 48 hours in the rumen by:

$$\text{DMD }\% = \frac{(D - B)}{S} \times (\text{DM }\%) \times 100$$

# Appendix E

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## Analysis of Variance of Means

### E1. Experiment 1

Appendix E1.1 Analysis of variance of means (n=16) of stem dry weights, leaf dry weights and leaf areas of the sorghum plants at 52 days after emergence as influenced by nitrogen and potassium levels grown on Yasothon soil series (Oxic Paleustults), in rainy season 1997.

| Items | Significant levels | | | CV | Std |
|---|---|---|---|---|---|
| | Nitrogen (N) | Potassium (K) | N x K | (%) | Error(±) |
| Stem dry weights | NS | NS | NS | 23.45 | 2.14 |
| Leaf dry weights | * | NS | NS | 16.20 | 0.78 |
| Leaf areas | * | NS | NS | 17.72 | 138.50 |

Remarks: NS = Non significant. * = Probability ≤ 0.05,

CV = Coefficient of variations. Std. Error = Standard error of means.

Appendix E1.2 Analysis of variance of means (n=16) of total dry weights, stem dry weights, leaf dry weights, head dry weights and leaf area of the sorghum plants at 82 days after emergence as influenced by nitrogen and potassium levels grown on Yasothon soil series (Oxic Paleustults) in rainy season 1997.

| Items | Significant levels | | | CV | Std |
|---|---|---|---|---|---|
| | Nitrogen (N) | Potassium (K) | N x K | (%) | Error(±) |
| Total dry weights | NS | NS | NS | 19.99 | 5.66 |
| Stem dry weights | NS | NS | NS | 20.06 | 3.59 |
| Leaf dry weights | NS | NS | NS | 24.00 | 0.83 |
| Head dry weights | NS | NS | NS | 25.62 | 1.78 |
| Leave areas | NS | NS | NS | 24.00 | 179.03 |

Remarks: NS = Non significant.

CV = Coefficient of variations. Std. Error = Standard error of means.

Appendix E1.3 Analysis of variance of means (n=16) of seed head dry weights, seed yields and 1000-seed weights of the sorghum plants at 93 days after emergence as influenced by nitrogen and potassium levels grown on Yasothon soil series (Oxic Paleustults) in rainy season 1997.

| Items | Significant levels | | | CV | Std |
|---|---|---|---|---|---|
| | Nitrogen (N) | Potassium (K) | N x K | (%) | Error(±) |
| Seed head dry weights | NS | NS | NS | 13.12 | 1.80 |
| Seed yields | NS | NS | NS | 13.34 | 276.68 |
| 1000-seed weights | NS | NS | NS | 4.27 | 0.67 |

Remarks: NS = Non significant.

CV = Coefficient of variations. Std. Error = Standard error of means.

Appendix E1.4 Analysis of variance of means (n=16) of crude protein, neutral detergent fibre (NDF), acid detergent fibre (ADF) contents, dry matter degradability (DMD) at 24 and 48 hours and brix values of the sorghum plants at 82 days after emergence as influenced by nitrogen and potassium levels grown on Yasothon soil series (Oxic Paleustults) in rainy season 1997.

| Items | Significant levels | | | CV | Std |
|---|---|---|---|---|---|
| | Nitrogen (N) | Potassium (K) | N x K | (%) | Error(±) |
| Crude protein | * | NS | NS | 12.86 | 0.31 |
| NDF | NS | NS | NS | 7.43 | 1.90 |
| ADF | NS | NS | NS | 7.89 | 1.18 |
| DMD at 24 hrs. | NS | NS | NS | 8.16 | 2.26 |
| DMD at 48 hrs. | NS | NS | NS | 5.48 | 1.86 |
| Brix values | * | * | NS | 16.64 | 0.83 |

Remarks: NS = Non significant. * = Probability ≤ 0.05.

CV = Coefficient of variations. Std. Error = Standard error of means.

## E2. Experiment 2

Appendix E2.1 Analysis of variance of means (n=16) of total dry weights, stem dry weights, leaf dry weights, leaf areas and leaf area indices (LAI) of the sorghum plants at 2 weeks after emergence as influenced by nitrogen and potassium levels grown on Yasothon soil series (Oxic Paleustults) in rainy season 1999.

| Items | Significant levels | | | CV | Std |
|---|---|---|---|---|---|
| | Nitrogen (N) | Potassium (K) | N x K | (%) | Error(±) |
| Total dry weights | ** | * | NS | 12.04 | 8.04 |
| Stem dry weights | ** | NS | * | 11.65 | 0.01 |
| Leaf dry weights | ** | * | NS | 13.30 | 0.03 |
| Leaf areas | ** | * | NS | 13.30 | 10.75 |
| Leaf area indices | ** | * | NS | 13.29 | 0.02 |

Remarks: NS = Non significant. ** = Probability ≤ 0.01. * = Probability ≤ 0.05.

CV = Coefficient of variations. Std. Error = Standard error of means.

Appendix E2.2 Analysis of variance of means (n=16) of total dry weights, stem dry weights, leaf dry weights, leaf areas, leaf area indices and crop growth rates of the sorghum plants at 4 weeks after emergence as influenced by nitrogen and potassium levels grown on Yasothon soil series (Oxic Paleustults) in rainy season 1999.

| Items | Significant levels | | | CV | Std |
|---|---|---|---|---|---|
| | Nitrogen (N) | Potassium (K) | N x K | (%) | Error(±) |
| Total dry weights | ** | NS | NS | 12.77 | 93.52 |
| Stem dry weights | ** | NS | NS | 14.61 | 0.19 |
| Leaf dry weights | ** | NS | NS | 12.75 | 0.30 |
| Leave areas | ** | NS | NS | 12.75 | 79.19 |
| Leaf area indices | ** | NS | NS | 12.75 | 0.16 |
| Crop growth rates #1 | ** | NS | NS | 14.44 | 4.80 |

Remarks: NS = Non significant. ** = Probability ≤ 0.01.

CV = Coefficient of variations. Std. Error = Standard error of means.

Appendix E2.3 Analysis of variance of means (n=16) of total dry weights, stem dry weights, leaf dry weights, leaf areas, leaf area indices and crop growth rates of the sorghum plants at 6 weeks after emergence as influenced by nitrogen and potassium levels grown on Yasothon soil series (Oxic Paleustults) *in rainy season* 1999.

| Items | Significant levels | | | CV | Std |
|---|---|---|---|---|---|
| | Nitrogen (N) | Potassium (K) | N x K | (%) | Error(±) |
| Total dry weights | ** | NS | NS | 11.16 | 310.42 |
| Stem dry weights | ** | NS | NS | 14.74 | 0.98 |
| Leaf dry weights | ** | NS | NS | 11.32 | 0.82 |
| Leaf areas | ** | NS | NS | 11.32 | 209.42 |
| Leaf area indices | ** | NS | NS | 11.32 | 0.42 |
| Crop growth rates # 2 | ** | NS | NS | 14.94 | 15.31 |

Remarks: NS = Non significant. ** = Probability ≤ 0.01.

CV = Coefficient of variations. Std. Error = Standard error of means.

Appendix E2.4 Analysis of variance of means (n=16) of total dry weights, stem dry weights, leaf dry weights, leaf areas, leaf area indices and crop growth rates of the sorghum plants at 8 weeks after emergence as influenced by nitrogen and potassium levels grown on Yasothon soil series (Oxic Paleustults) *in rainy season* 1999.

| Items | Significant levels | | | CV | Std |
|---|---|---|---|---|---|
| | Nitrogen (N) | Potassium (K) | N x K | (%) | Error(±) |
| Total dry weights | ** | NS | NS | 6.79 | 308.52 |
| Stem dry weights | ** | NS | ** | 8.71 | 1.27 |
| Leaf dry weights | ** | ** | NS | 6.21 | 0.51 |
| Leaf areas | ** | ** | NS | 6.21 | 118.47 |
| Leaf area indices | ** | ** | NS | 6.21 | 0.24 |
| Crop growth rates # 3 | * | NS | ** | 22.04 | 19.41 |

Remarks: NS = Non significant. ** = Probability ≤ 0.01. * = Probability ≤ 0.05.

CV = Coefficient of variations. Std. Error = Standard error of means.

Appendix E2.5 Analysis of variance of means (n=16) of total dry weights, stem dry weights, leaf dry weights, dead leaf dry weights, head dry weights, leaf areas, leaf area indices, crop growth rates, leaf area duration and brix values of the sorghum plants at 10 weeks after emergence as influenced by nitrogen and potassium levels grown on Yasothon soil series (Oxic Paleustults) in rainy season 1999.

| Items | Significant levels | | | CV | Std |
|---|---|---|---|---|---|
| | Nitrogen (N) | Potassium (K) | N x K | (%) | Error(±) |
| Total dry weights | ** | ** | NS | 6.19 | 357.11 |
| Stem dry weights | ** | ** | NS | 7.24 | 1.36 |
| Leaf dry weights | ** | NS | NS | 9.46 | 0.49 |
| Dead leaf dry weights | ** | NS | NS | 12.56 | 0.20 |
| Head dry weights | ** | ** | ** | 10.67 | 0.35 |
| Leaf areas | ** | NS | NS | 9.45 | 95.11 |
| Leaf area indices | ** | NS | NS | 9.46 | 0.19 |
| Crop growth rates # 4 | ** | ** | ** | 27.25 | 16.66 |
| Leaf area duration | ** | NS | NS | 6.21 | 0.06 |
| Brix values | ** | ** | NS | 6.40 | 0.34 |

Remarks: NS = Non significant. ** = Probability ≤ 0.01.

CV = Coefficient of variations. Std. Error = Standard error of means.

Appendix E2.6 Analysis of variance of means (n=16) of total dry weights, stem dry weights, leaf dry weights, dead leaf dry weights, head dry weights, leaf areas, leaf area, crop growth rates, brix values, leaf area duration, dry seed head yields, seed yields and 1000-seed weights of the sorghum plants at 12 weeks after emergence as influenced by nitrogen and potassium levels grown on Yasothon soil series (Oxic Paleustults) in rainy season 1999.

| Items | Significant levels | | | CV | Std |
|---|---|---|---|---|---|
| | Nitrogen (N) | Potassium (K) | N x K | (%) | Error(±) |
| Total dry weights | ** | ** | NS | 6.35 | 425.02 |
| Stem dry weights | ** | ** | NS | 8.44 | 1.41 |
| Leaf dry weights | ** | ** | NS | 9.53 | 0.35 |
| Dead leaf dry weights | ** | * | NS | 12.67 | 0.40 |
| Head dry weights | ** | ** | NS | 5.87 | 0.58 |
| Leaf areas | ** | ** | NS | 9.52 | 79.29 |
| Leaf area indices | ** | ** | NS | 9.52 | 0.16 |
| Crop growth rates # 5 | ** | NS | * | 24.28 | 11.31 |
| Brix values | ** | ** | NS | 10.03 | 0.30 |
| Leaf area duration | ** | NS | NS | 5.95 | 0.07 |
| Dry seed head yields | ** | ** | NS | 9.23 | 208.11 |
| Seed yields | ** | ** | NS | 9.54 | 196.28 |
| 1000-seed weights | ** | NS | NS | 6.12 | 0.89 |

Remarks: NS = Non significant. ** = Probability ≤ 0.01. * = Probability ≤ 0.05.
CV = Coefficient of variations. Std. Error = Standard error of means.

Appendix E2.7 Analysis of variance of means (n=16) of crude protein, neutral detergent fibre (NDF), acid detergent fibre (ADF) contents and dry matter degradability of the sorghum plants at 10 weeks after emergence as influenced by nitrogen and potassium levels grown on Yasothon soil series (Oxic Paleustults) in rainy season 1999.

| Items | Significant levels | | | CV | Std |
|---|---|---|---|---|---|
| | Nitrogen (N) | Potassium (K) | N x K | (%) | Error(±) |
| Crude protein | ** | NS | NS | 13.30 | 0.49 |
| NDF | NS | NS | NS | 3.55 | 1.09 |
| ADF | NS | NS | NS | 4.96 | 0.88 |
| DMD | NS | NS | NS | 3.88 | 1.34 |

Remarks: NS = Non significant. ** = Probability ≤ 0.01.

CV = Coefficient of variations. Std. Error = Standard error of means.

## E3. Experiment 3

Appendix E3.1 Analysis of variance of means (n=16) of total dry weights, stem dry weights, leaf dry weights, leaf areas and leaf area indices of the sorghum plants at 3 weeks after emergence as influenced by nitrogen and potassium levels grown on Yasothon soil series (Oxic Paleustults) in rainy season 1999.

| Items | Significant levels | | | CV | Std |
|---|---|---|---|---|---|
| | Nitrogen (N) | Potassium (K) | N x K | (%) | Error(±) |
| Total dry weights | ** | ** | NS | 11.04 | 60.17 |
| Stem dry weights | ** | ** | * | 11.04 | 0.08 |
| Leaf dry weights | ** | ** | NS | 11.61 | 0.23 |
| Leaf areas | ** | ** | NS | 11.61 | 63.53 |
| Leaf area indices | ** | ** | NS | 11.60 | 0.13 |

Remarks: NS = Non significant. ** = Probability ≤ 0.01. * = Probability ≤ 0.05.

CV = Coefficient of variations. Std. Error = Standard error of means.

Appendix E3.2 Analysis of variance of means (n=16) total dry weights, stem dry weights, leaf dry weights, leaf areas, leaf area indices and crop growth rates of the sorghum plants at 5 weeks after emergence as influenced by nitrogen and potassium levels grown on Yasothon soil series (Oxic Paleustults) in rainy season 1999.

| Items | Significant levels | | | CV | Std |
|---|---|---|---|---|---|
| | Nitrogen (N) | Potassium (K) | N x K | (%) | Error(±) |
| Total dry weights | ** | * | NS | 8.07 | 137.02 |
| Stem dry weights | ** | ** | NS | 7.23 | 0.28 |
| Leaf dry weights | ** | NS | NS | 9.55 | 0.44 |
| Leaf areas | ** | NS | NS | 9.55 | 105.75 |
| Leaf area indices | ** | NS | NS | 9.55 | 0.21 |
| Crop growth rates # 1 | * | NS | NS | 11.68 | 6.73 |

Remarks: NS = Non significant. ** = Probability ≤ 0.01. * = Probability ≤ 0.05.

CV = Coefficient of variations. Std. Error = Standard error of means.

Appendix E3.3 Analysis of variance of means (n=16) of total dry weights, stem dry weights, leaf dry weights, leaf areas, leaf area indices and crop growth rates of the sorghum plants at 7 weeks after emergence as influenced by nitrogen and potassium levels grown on Yasothon soil series (Oxic Paleustults) in rainy season 1999.

| Items | Significant levels | | | CV | Std |
|---|---|---|---|---|---|
| | Nitrogen (N) | Potassium (K) | N x K | (%) | Error(±) |
| Total dry weights | ** | ** | NS | 6.52 | 212.07 |
| Stem dry weights | ** | ** | NS | 8.91 | 0.86 |
| Leaf dry weights | ** | NS | NS | 6.75 | 0.45 |
| Leaf areas | ** | NS | NS | 6.76 | 100.65 |
| Leaf area indices | ** | NS | NS | 6.76 | 0.20 |
| Crop growth rates #2 | * | NS | NS | 15.85 | 12.31 |

Remarks: NS = Non significant. ** = Probability ≤ 0.01. * = Probability ≤ 0.05.

CV = Coefficient of variations. Std. Error = Standard error of means.

Appendix E3.4 Analysis of variance of means (n=16) of total dry weights, stem dry weights, leaf dry weights, dead leaf dry weights, head dry weights, leaf areas, leaf area indices, crop growth rates and brix values of the sorghum plants at 9 weeks after emergence as influenced by nitrogen and potassium levels grown on Yasothon soil series (Oxic Paleustults) in rainy season 1999.

| Items | Significant levels | | | CV | Std |
|---|---|---|---|---|---|
| | Nitrogen (N) | Potassium (K) | N x K | (%) | Error(±) |
| Total dry weights | ** | ** | NS | 6.16 | 291.78 |
| Stem dry weights | ** | ** | NS | 6.78 | 1.05 |
| Leaf dry weights | ** | ** | NS | 7.29 | 0.33 |
| Dead leaf dry weights | ** | * | NS | 13.66 | 0.20 |
| Head dry weights | ** | * | NS | 14.02 | 0.31 |
| Leaf areas | ** | ** | NS | 7.29 | 70.72 |
| Leaf area indices | ** | ** | NS | 7.30 | 0.14 |
| Crop growth rates # 3 | * | NS | NS | 22.59 | 16.82 |
| Brix values | ** | NS | NS | 4.93 | 0.32 |

Remarks: NS = Non significant. ** = Probability ≤ 0.01. * = Probability ≤ 0.05.

CV = Coefficient of variations. Std. Error = Standard error of means.

Appendix E3.5 Analysis of variance of means (n=16) of total dry weights, stem dry weights, leaf dry weights, dead leaf dry weights, head dry weights, leaf areas, leaf area indices, crop growth rates, leaf area duration, brix values, dry seed head yields at 11 weeks after emergence, seed yields and 1000-seed weights of the sorghum plants as influenced by nitrogen and potassium levels grown on Yasothon soil series (Oxic Paleustults) in rainy season 1999.

| Items | Significant levels | | | CV | Std |
|---|---|---|---|---|---|
| | Nitrogen (N) | Potassium (K) | N x K | (%) | Error(±) |
| Total dry weights | ** | ** | NS | 4.75 | 280.52 |
| Stem dry weights | ** | ** | NS | 5.70 | 0.88 |
| Leaf dry weights | ** | * | NS | 9.38 | 0.39 |
| Dead leaf dry weights. | ** | ** | NS | 11.61 | 0.17 |
| Head dry weights | ** | ** | NS | 9.24 | 0.78 |
| Leaf areas | ** | ** | NS | 9.38 | 85.89 |
| Leaf area indices | ** | ** | NS | 9.37 | 0.17 |
| Crop growth rates # 4 | ** | ** | NS | 22.66 | 13.23 |
| Leaf area duration | ** | ** | NS | 4.78 | 0.04 |
| Brix values | * | * | ** | 8.00 | 0.48 |
| Dry seed head yields | ** | NS | NS | 16.70 | 455.62 |
| Seed yields | ** | NS | NS | 16.69 | 369.49 |
| 1000-seed weights | ** | NS | NS | 4.40 | 0.74 |

Remarks: NS = Non significant. ** = Probability ≤ 0.01. * = Probability ≤ 0.05.

CV = Coefficient of variations. Std. Error = Standard error of means.

Appendix E3.6 Analysis of variance of means (n=16) of crude protein, neutral detergent fibre (NDF), acid detergent fibre (ADF) contents and dry matter degradability (DMD) of the sorghum plants at 10 weeks after emergence as influenced by nitrogen and potassium levels grown on Yasothon soil series (Oxic Paleustults) in rainy season 1999.

| Items | Significant levels | | | CV | Std |
|---|---|---|---|---|---|
| | Nitrogen (N) | Potassium (K) | N x K | (%) | Error(±) |
| Crude protein | ** | NS | NS | 13.24 | 0.49 |
| NDF | NS | NS | NS | 3.07 | 0.95 |
| ADF | NS | NS | NS | 4.21 | 0.75 |
| DMD | NS | NS | NS | 2.87 | 1.00 |

Remarks: NS = Non significant. ** = Probability ≤ 0.01.

CV = Coefficient of variations. Std. Error = Standard error of means.

## E4. Experiment 4

Appendix E4.1 Analysis of variance of means (n=16) of total dry weights, stem dry weights, leaf dry weights, leaf areas and leaf area indices of the sorghum plants at 3 weeks after emergence as influenced by nitrogen and potassium levels grown on Yasothon soil series (Oxic Paleustults) in dry season 2000.

| Items | Significant levels | | | CV | Std |
|---|---|---|---|---|---|
| | Nitrogen (N) | Potassium (K) | N x K | (%) | Error(±) |
| Total dry weights | ** | NS | NS | 9.34 | 23.20 |
| Stem dry weights | ** | NS | NS | 10.10 | 0.03 |
| Leaf dry weights | ** | NS | NS | 9.48 | 0.09 |
| Leaf areas | ** | NS | NS | 9.46 | 30.76 |
| Leaf area indices | ** | NS | NS | 9.46 | 0.06 |

Remarks: NS = Non significant. ** = Probability ≤ 0.01.

CV = Coefficient of variations. Std. Error = Standard error of means.

Appendix E4.2 Analysis of variance of means (n=16) of total dry weights, stem dry weights, leaf dry weights, dead leaf dry weights, leaf areas, leaf area indices and crop growth rates of the sorghum plants at 5 weeks after emergence as influenced by nitrogen and potassium levels grown on Yasothon soil series (Oxic Paleustults) in dry season 2000.

| | Significant levels | | | CV | Std |
|---|---|---|---|---|---|
| | Nitrogen (N) | Potassium (K) | N x K | (%) | Error(±) |
| Total dry weights | ** | NS | NS | 7.69 | 111.24 |
| Stem dry weights | ** | NS | NS | 8.94 | 0.33 |
| Leaf dry weights | ** | * | NS | 7.65 | 0.26 |
| Dead leaf dry weights | ** | ** | NS | 19.56 | 0.05 |
| Leaf areas | ** | * | NS | 7.65 | 78.40 |
| Leaf area indices | ** | * | NS | 7.66 | 0.16 |
| Crop growth rates # 1 | * | NS | NS | 9.29 | 5.57 |

Remarks: NS = Non significant. ** = Probability ≤ 0.01. * = Probability ≤ 0.05.

CV = Coefficient of variations. Std. Error = Standard error of means.

Appendix E4.3 Analysis of variance of means (n=16) of total dry weights, stem dry weights, leaf dry weights, dead leaf dry weights, leaf areas, leaf area indices and crop growth rates of the sorghum plants at 7 weeks after emergence as influenced by nitrogen and potassium levels grown on Yasothon soil series (Oxic Paleustults) in dry season 2000.

| Items | Significant levels | | | CV | Std |
|---|---|---|---|---|---|
| | Nitrogen (N) | Potassium (K) | N x K | (%) | Error(±) |
| Total dry weights | ** | NS | NS | 8.63 | 299.48 |
| Stem dry weights | ** | NS | NS | 8.86 | 1.00 |
| Leaf dry weights | ** | NS | NS | 9.69 | 0.54 |
| Dead leaf dry weights | ** | NS | * | 11.88 | 0.05 |
| Leaf areas | ** | NS | NS | 9.69 | 135.04 |
| Leaf area indices | ** | NS | NS | 9.69 | 0.27 |
| Crop growth rates # 2 | ** | NS | NS | 17.06 | 17.28 |

Remarks: NS = Non significant. ** = Probability ≤ 0.01. * = Probability ≤ 0.05.

CV = Coefficient of variations. Std. Error = Standard error of means.

Appendix E4.4 Analysis of variance of means (n=16) of total dry weights, stem dry weights, leaf dry weights, dead leaf dry weights, head dry weights, leaf areas, leaf area indices, crop growth rates and brix values of the sorghum plants at 9 weeks after emergence as influenced by nitrogen and potassium levels grown on Yasothon soil series (Oxic Paleustults) in dry season 2000.

| Items | Significant levels | | | CV | Std |
|---|---|---|---|---|---|
| | Nitrogen (N) | Potassium (K) | N x K | (%) | Error(±) |
| Total dry weights | ** | * | NS | 6.43 | 384.56 |
| Stem dry weights | ** | NS | NS | 6.89 | 1.35 |
| Leaf dry weights | ** | ** | NS | 7.28 | 0.49 |
| Dead leaf dry weights | ** | NS | NS | 12.54 | 0.28 |
| Head dry weights | ** | NS | NS | 11.05 | 0.16 |
| Leaf areas | ** | ** | NS | 7.28 | 99.09 |
| Leaf area indices | ** | ** | NS | 7.27 | 0.20 |
| Crop growth rates # 3 | ** | NS | NS | 19.30 | 24.22 |
| Brix values | ** | ** | NS | 7.62 | 0.29 |

Remarks: NS = Non significant. ** = Probability ≤ 0.01. * = Probability ≤ 0.05.

CV = Coefficient of variations. Std. Error = Standard error of means.

Appendix E4.5 Analysis of variance of means (n=16) of total dry weights, stem dry weights, leaf dry weights, dead leaf dry weights, head dry weights, leaf areas, leaf area indices, crop growth rates, leaf area duration and brix values of the sorghum plants at 11 weeks after emergence as influenced by nitrogen and potassium levels grown on Yasothon soil series (Oxic Paleustults) in dry season 2000.

| Items | Significant levels | | | CV | Std |
|---|---|---|---|---|---|
| | Nitrogen (N) | Potassium (K) | N x K | (%) | Error(±) |
| Total dry weights | ** | NS | NS | 10.76 | 928.01 |
| Stem dry weights | ** | NS | NS | 11.26 | 3.25 |
| Leaf dry weights | ** | NS | NS | 17.98 | 1.04 |
| Dead leaf dry weights | ** | ** | ** | 17.27 | 0.36 |
| Head dry weights | ** | * | NS | 12.49 | 0.79 |
| Leaf areas | ** | NS | NS | 17.99 | 181.26 |
| Leaf area indices | ** | NS | NS | 17.99 | 0.36 |
| Crop growth rates # 4 | ** | NS | NS | 32.75 | 43.28 |
| Leaf area duration | ** | ** | NS | 4.73 | 0.04 |
| Brix values | ** | ** | NS | 5.54 | 0.33 |

Remarks: NS = Non significant. ** = Probability ≤ 0.01. * = Probability ≤ 0.05.

CV = Coefficient of variations. Std. Error = Standard error of means.

Appendix E4.6 Analysis of variance of means (n=16) of total dry weights, stem dry weights, leaf dry weights, dead leaf dry weights, head dry weights, leaf areas, leaf area indices, crop growth rates, leaf area duration, dry seed head yields, seed yields and 1000-seed weights at 13 weeks after emergence of the sorghum plants as influenced by nitrogen and potassium levels grown on Yasothon soil series (Oxic Paleustults) in dry season 2000.

| Items | Significant levels 1/ | | | CV | Std |
|---|---|---|---|---|---|
| | Nitrogen (N) | Potassium (K) | N x K | (%) | Error(±) |
| Total dry weights | ** | * | NS | 8.17 | 818.30 |
| Stem dry weights | ** | NS | NS | 9.83 | 2.98 |
| Leaf dry weights | ** | NS | NS | 9.59 | 0.53 |
| Dead leaf dry weights | ** | NS | NS | 16.63 | 0.47 |
| Head dry weights | ** | ** | ** | 8.51 | 0.97 |
| Leaf areas | ** | NS | NS | 9.59 | 100.08 |
| Leaf area indices | ** | NS | NS | 9.58 | 0.20 |
| Crop growth rates # 5 | ** | NS | NS | 19.19 | 13.40 |
| Leaf area duration | ** | ** | NS | 5.44 | 0.06 |
| Dry seed head yields | ** | * | NS | 9.08 | 313.24 |
| Seed yields | ** | * | NS | 9.08 | 264.02 |
| 1000-seed weights | ** | NS | NS | 7.07 | 0.94 |

Remarks: NS = Non significant. ** = Probability ≤ 0.01. * = Probability ≤ 0.05.

CV = Coefficient of variations. Std. Error = Standard error of means.

Appendix E4.7 Analysis of variance of means (n=16) of crude protein, neutral detergent fibre (NDF), acid detergent fibre (ADF) contents and dry matter degradability (DMD) of the sorghum plants at 10 weeks after emergence as influenced by nitrogen and potassium levels grown on Yasothon soil series (Oxic Paleustults) in dry season 2000.

| Items | Significant levels | | | CV | Std |
|---|---|---|---|---|---|
| | Nitrogen (N) | Potassium (K) | N x K | (%) | Error(±) |
| Crude protein | ** | NS | * | 5.81 | 0.23 |
| NDF | NS | NS | NS | 3.41 | 1.26 |
| ADF | NS | NS | NS | 5.74 | 1.24 |
| DMD | NS | NS | NS | 7.12 | 1.80 |

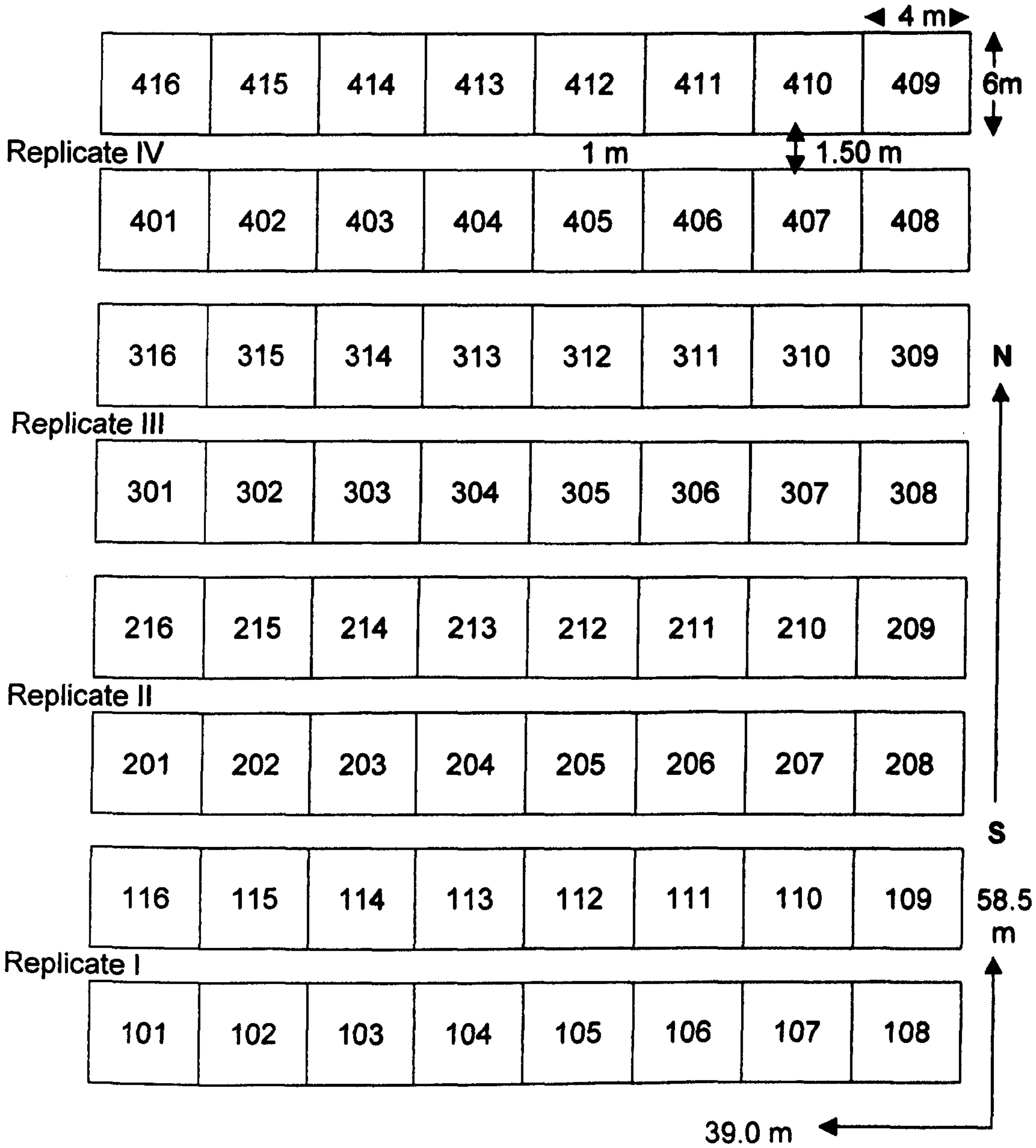
Remarks: NS = Non significant. ** = Probability ≤ 0.01. * = Probability ≤ 0.05.

CV = Coefficient of variations. Std. Error = Standard error of means.

# Appendix F

## Layout of the experiment

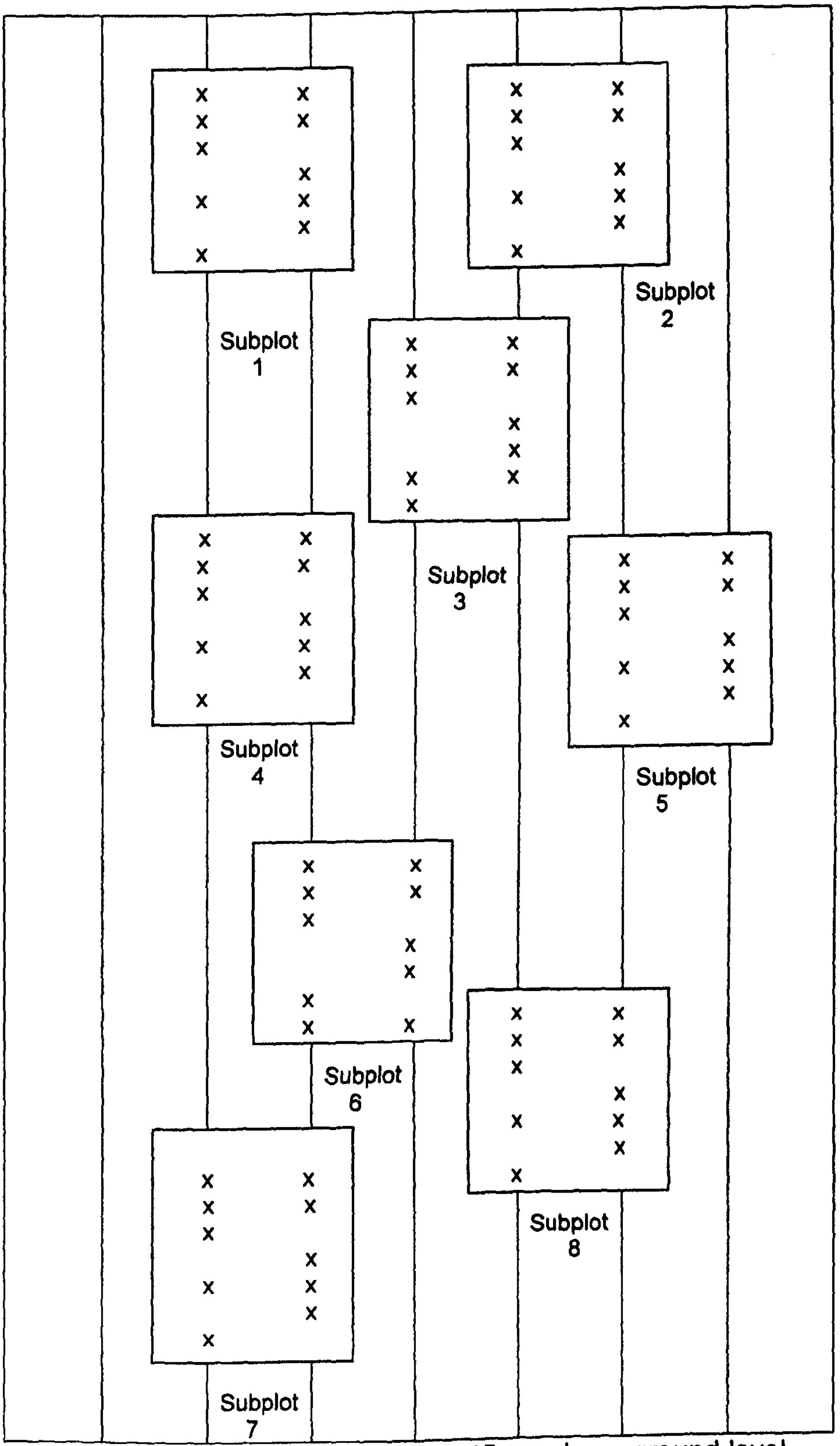
Experiments1 to 4 were laid out in 4x4 factorial arranged in a randomised complete block design (RCBD). Each experiment consisted of 16 treatment combinations with 4 replications and 64 plots (from plot no.101 to 416) as shown below. This layout was also used for Experiment 5 (16 treatments in RCBD) and reduced to 14 treatments for Experiment 6. Each experiment was replicated in a different area of the experimental farm site but on the same soil type.



## Randomisation

Sixteen treatment combinations of N and K levels were applied at random into 16 plots of each replication. Each plot (4 x 6 metre) was divided into 8 subplots (0.75 x 1 metre) for the harvests of plant samples. Ten plant samples were cut at random from each subplot for determinations of fresh and dry weights at 2-week intervals until the final harvest. A plot contained 8 subplots as shown on the next page.

One plot contained 8 subplots as shown below:



X = 1 plant sample cut at random at 15 cm above ground level, with 10 plants/plot.