Relating sorghum yield to growing seasonal weather conditions for Chobe and Barolong agricultural district, Botswana

Master of Science (MSc) in Agricultural Engineering (Soil and Water)

By
Jeomba Mavis Tjitemisa

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University of Botswana

Botswana College of Agriculture

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A dissertation submitted to the Department of Agricultural Engineering and Land Planning in partial fulfilment of the requirement for the degree of Master of Science (MSc) in Agricultural Engineering (Soil and Water)

By

Jeomba Mavis Tjitemisa (ID No: 200500059)

June 2013

Main Supervisor:

Prof N. Batisani

Co-Supervisors:

Dr G. Gaboutloloe

Dr. U. Batlang

Department of Agricultural Engineering and Land Planning

University of Botswana

CERTIFICATION

Nnyaladzi Batisani [signature] 23-07-13

Main Supervisor's Name and Signature   Date

Gilbert Kagelo Gaboutloeloe [signature] 23-07-13

Co-Supervisor's Name and Signature   Date

Utlwang Batlang [signature] 23-07-13

Co-Supervisor's Name and Signature   Date

Khumoetsile Mmolawa [signature] 23-07-13

Head of Department's Name and Signature   Date

APPROVAL

Nnyaladzi Batisani Batisani 23-07-13

Main Supervisor's Name and Signature — Date

GILBERT KABELO GABOUTLOELOE 23-07-13

Co-Supervisor's Name and Signature — Date

UTLWANANG BATLANG 23-07-13

Co-Supervisor's Name and Signature — Date

Kethumetsele Mmolawa 23-07-13

Head of Department's Name and Signature — Date

E B KHONGA 23/07/2013

Dean of Faculty's Name and Signature — Date

STATEMENT OF ORIGINALITY

The work contained in this dissertation was compiled by the author at the University of Botswana, Botswana College of Agriculture between January 2012 and August 2012. It is original except where references are made and it will be not submitted for the award of any other degree or diploma of any other University.

[illegible] 23/07/13

Author's Name and Signature Date

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I would like to take this opportunity to thank my supervisors, being Prof N. Batisani, Dr. G. Gaboutloeloe and Dr U. Batlang who supervised me from the bottom of their hearts, guidance and motivation, cooperation and support they gave me from the beginning to the end of the research work. I owe gratitude to T.I Makoi, from the Department of Agricultural Engineering and B. Sebolai, a Biometrician from the Department of Basic Science at Botswana College of Agriculture. The study was self-funded as part of my MSc Research.

Dedication

I dedicate myself to this piece of work, and to my mother and sister we will always be together.

To my family I am devoted and adhere to them.

Abstract

Growing season rainfall is the most important factor in rain-fed arable agriculture in semi-arid climates. Knowledge of rainfall distribution is needed to make farmers aware of possible crop yield obtainable during and at the end of growing season and also help governments with information for the attainable of food security. The goal of this study was to examine the relationship between crop yield and growing season rainfall distribution in an attempt to contribute to food security early warning system. Specifically, the study determined the relationship between total seasonal rainfall, total number of rainy days, average maximum temperature and sorghum yield. The established relationship was then used to determine the most sensitive growth stage (s) for yield loss. The study explored the relationship between seasonal rainfall distribution and total seasonal rainfall with crop yield for Chobe agricultural district and Barolong agricultural sub-district. In general, seasonal rainfall showed a negative slope while sorghum yield had a positive gradient for Chobe agricultural district. For Barolong agricultural sub-district, a positive trend was observed in both seasonal rainfall and sorghum yield. Number of rainy days and sorghum yield indicated a positive slope for Chobe agricultural district while for Barolong agricultural sub-district, a negative slope in rainy days was observed while sorghum yield had a positive gradient. Exploratory results show that sorghum yield fluctuated with rainfall. Over the years, rainfall and sorghum yield fluctuated for both districts. Average maximum temperature at flowering stage had high correlation with sorghum yield (0.62) for Chobe agricultural district. For Barolong agricultural sub-district, the following showed high correlation with sorghum yield; total rainfall amount at maturity (0.85), total number of rainy days at pre-sowing stage (0.79) and total number of rainy days at maturity stage (0.72). There were no differences in sorghum yield for both districts because both confidence limits at 95%

include the mean of sorghum yield for the respective study periods. Temperature at flowering stage was the only significant ($P < 0.02$) explanatory variable for yield for Chobe. For each degree Celsius increase in average maximum temperature at flowering stage, sorghum yield increased by 0.223 kg/ha for Chobe agricultural district. If there was no influence of average maximum temperature at flowering stage, yield would be less 5.483 kg/ha. For Barolong, rainy days at pre-sowing stage ($P < 0.02$), rainy days at maturity stage ($P < 0.002$), and rainfall amount at maturity stage ($P < 0.02$) were significant. For each increase in number of rainy days at pre-sowing stage, yield decreased by 0.829 kg/ha while at maturity stage, an increase in a number of rainy days, decreased sorghum yield by 3.376 kg/ha. An increase in rainfall at maturity stage increased sorghum yield by 0.912 kg/ha. The most sensitive stage (s) for sorghum grain yield loss due to high rainfall experienced in Chobe agricultural district was the flowering stage, with maximum temperature being the limiting factor while for Barolong agricultural sub-district were the pre-sowing (rainfall distribution more than enough) and maturity stages (total rainfall amount limiting and rainfall distribution more than enough).

Key words: Botswana, food security, growing season, sorghum, warning system, weather conditions, yield

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CHAPTER ONE

1.0 INTRODUCTION

Dryland-arable agriculture will continue to be the base and main source of staple food production for the majority of the rural poor in sub-Saharan Africa. Global rain-fed agriculture currently provides 60% of the world's food (Cooper et al., 2008). Nevertheless, output from rain-fed agriculture is largely determined by climate especially rainfall (Weare, 1971).Therefore, production confidence related to rainfall variability remains an essential limitation to many investors who often over-estimate the negative impacts of climate induced uncertainty (Cooper et al., 2008). Thus the need to examine the relationship between weather and crop production is increasingly becoming important especially with a growing global population and a changing climate (Sakurai et al., 2011).

Chipanshi et al., (2003) noted that shortfall in locally produced grain in Botswana is due to lack of rain. Therefore, subsistence farming households that primarily depend on the arable sector are most vulnerable as production is low and highly variable. Mwamba (2007) concurred and highlighted that most agro-ecosystems in semi-arid countries are characterized by drought both within and between seasons leading to food insecurity and rural poverty. Hence, an improvement in the understanding of the influence of climate on agricultural production is needed to cope with expected climate change related to weather (Rowhani et al., 2011). This understanding is crucial for the development of proactive approaches to deal with rainfall variability on rain-fed agriculture if the Millennium Development Goal of eradicating extreme poverty and hunger is to be achieved (Mwamba, 2007). One way of doing this, is to make farmers aware of the possible quantity of crop yield that will be obtained at the end of the growing season and during the season based on the amount of rainfall at different crop growing stages.

Vossen (1990) noted that a characteristic of the semi-arid regions is not a lack of rainfall alone, but also the unpredictability of its precise distribution within a season. Therefore, rainfall variability has a direct and often adverse effect on the quantity and quality of agricultural production (Mollah and Cook, 1996). In arid regions, the total length of dry spells within a season exceeds that of the period that crop growth without water stress would have been possible in most years, leading to severe yield reduction (Vossen, 1990). As a result the growing season is confined to few periods when there is adequate soil moisture. Therefore, the seasonal nature of the rainfall and the possibility of drought condition arising at the start and during rainy season are the most factors influencing rain-fed arable agriculture (Victor et al., 1994). Rosenzweig et al., (2001) noted that the degree of crop damage due to weather elements depends on the exposure to stress and crop developmental stage. Thus, crop yields are most likely to suffer if unfavourable weather conditions, especially high temperature and excess or deficit precipitation, occur during critical developmental stages (Eze, 2001).

1.1 Justification of the study

Although many studies have evaluated the effects of climate change on crop yields (Lobell and Asner., 2003; Fischer et al., 2005; Parry et al., 2005; Porter and Semenov 2005; Mall et al., 2006; Lobell and Field 2007; Lobell et al., 2008; Schlenker and Roberts 2009; Sakurai et al., 2011), few studies have considered the temporal variability in the relationship between rainfall and crop yield (Eze, 2001; Qian et al., 2009a; Qian et al., 2009b; Ibrahim et al., 2011). Thompson et al., (2010) highlighted the research gap between rain deficit and crop productivity in Sub Saharan Africa.

1.2 Statement of the problem

Out of the total arable land area (4074 km^2) in Botswana, less than 1% is under cultivation (SADC, 2008) probably due to low and variable rainfall, which makes farmers' strategic and tactical decision making difficult (Chipanshi et al., (2003). Mwiturubani and Wyk (2010) highlighted the relationship between rainfall and area planted at various lag years in Botswana. As the country is semi-arid, rainfall is unpredictable therefore, a limiting factor to dryland crop production. Most of the rainfall is generally made up of considerable small amounts of high intensity downpour resulting in reduced infiltration. Rainfall in the country is marked by fluctuations in both monthly distribution and total seasonal rainfall amount (Weare, 1971). Parida and Moalafhi, (2008); Batisani and Yarnal (2010) observed a trend towards decreased rainfall throughout the country, associated with decreases in the number of rainy days. This trend has an effect on quantity of harvest that is obtained at the end of the growing season (Vossen, 1990).

1.3 Objectives

The overall objective of this study was to examine the relationship between crop yield and growing season rainfall distribution in order to contribute to food security early warning system. Specifically, the study

1 Explored the relationship between total seasonal rainfall and crop yield for two sorghum growing agricultural districts in the country.

2 Determined the relationship between total seasonal rainfall, total number of rainy days (total rainfall distribution), average maximum temperature and sorghum yield.

3 Used the established relationship to determine the most sensitive growth stage(s) for yield loss

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Rain-fed farming system

Rain-fed farming systems are the dominant form of agriculture among subsistence farmers in Africa and the technique is considered cheaper than irrigation due to low technology requirement, however it suffers the risks of heavy reliance upon rainfall for water resources (Thompson et al., 2010). Subsistence agricultural systems are thus particularly sensitive to increased instability of rainfall, resulting in impact on food crop yields (Cooper et al., 2008).

Performance of agriculture plays a major role in the progress of the economy in achieving the developmental goal of promoting food security. Food security is a component of a number of variables such as technological input, government policies and environmental factors at which the farmers' level should understand to take the nation to food security level (Adeniyi et al., 2009). Agriculture being constraint by lack of rainfall, the productivity remains the most crucial factor based on which the country's food security goal can be attained if there is sustainable agriculture. Hence, the association between rainfall and yields should be investigated regionally to assess the importance of the water regime in determining yields (Hess et al., 1995; Stephens and Lyons, 1998).

Despite the fact that the contribution of arable agriculture to economy of semi-arid countries is minimal, it plays a role in the livelihoods of many rural households, especially female headed households (UN, 2007). Large-parts of some semi arid countries are devoted to livestock production as opposed to arable agriculture. The area under crops varies from year to year because countries are prone to drought on a regular basis, due to the number of rainy days which is decreasing (Batisani and Yarnal, 2010).Thus, there is a disparity between areas planted and areas harvested in most years, since the harvest depends on rainfall during the growing season. Mary and Majule (2009); Hess et al., (1995) have noted that as well and the changes have affected crops in a number of ways, resulting in reduced productivity. Mwang'ombe et al., (2011) found that successful rainwater harvesting is the most important technique in improving access of the farmers in reducing the problem of crop failures due to rainfall variability.

2.2 Crop yield and seasonal weather conditions

Rainfall is a reasonable measure of dryland crop production because dryland cropping has been found to be sensitive to rainfall but not average maximum temperature variability (Chikozho, 2010; Jerie and Ndabaningi, 2011; Wimalasuriya et al., 2008; Sowunmi and Akintola, 2010). However, the degree of sensitivity to rainfall variability may differ significantly between regions. Other factors being equal, farm inputs, for example, fertilizers and chemicals appear to be less important than rainfall (Wimalasuriya et al., 2008).

Rainfall varies both in space and time (Graef and Haigis, 2001; Ayanlade and Odekunle, 2009; Mwamba, 2007; Batisani and Yarnal, 2010). Ayanlade and Odekunle (2009) discovered that the anomalies (such as decline in annual rainfall, change in the peak and retreat of rainfall and false start of rainfall) are detrimental to crop germination and yield, resulting in little or no harvest at the end of the season. Changes of precipitation coupled with characteristic high rates of evaporation exhibited by semi-arid areas may lead to increased water shortages and affect soil moisture content on which crops depend on.

Victor et al., (1994) revealed that the tremendous variability in rainfall from season to season makes difficult for people to plan for the coming season. They currently have little or no ability to predict the date of the onset of rains or their amount, distribution, or duration. Hence, this calls for better and timely seasonal crop yield forecasts model to enable decisions at farm level. Current estimation of crop yield from the amount of rainfall that has been received for the previous years of the growing season is very important. Mollah and Cook (1996); Graef and Haigis (2001); Gadgil et al., (2002) noted that the records provide evidence of considerable rainfall variability and enhance better conditions for agriculture in the region. Vagueness about rainfall is pointed out when information is available concerning the possible variability and frequencies of historical occurrences of rainfall and its impact on crop yields, thus, the intention of the study to look at.

Adaptation to negative changes brought about by climate can result in positive outcomes (Cooper et al., 2008). People have developed mechanisms to survive long periods of water shortage and during dry periods when food is scarce. They have traditionally adapted their cropping pattern, farming systems, and management of water resources to cope with a dry environment (Ekaya, 2007). Also, with appropriate investment in their farming practice, rural communities can do much to protect their agricultural productivity in the face of climate changes. Based on a proper understanding of the temporal implications of rainfall variability for rain-fed agriculture, the same can be true for Sub Saharan Africa (Cooper et al., 2008).

Forecasting of rainfall based on its historical occurrences during the rainy season is important. This would enable agro-farmers to adequately prepare and take advantage of anticipated moisture surplus or avert production shortfalls if moisture deficits are predicted (Mogotsi et al., 2011). Thus, easily understood rainfall variability would enable better accuracy of predictions on crop yields and allow farmers to buffer their livelihoods against the adverse effects of rainfall variability and ensure sustainable rural development.

Weather data linked to changes in crop yields can also be instrumental in expanding crop insurance schemes to farmers in risk-prone environments (Wimalasuriya et al., 2008) because crops principally respond to daily or sequences of daily rainfall, and thus daily rainfall becomes the key parameter in rain-fed agriculture. The use of such records allows the determination of the probability of occurrence of a wide range of parameters of importance to agriculture and hence the risk associated (Cooper et al., 2008). Victor et al., (1994) found that analysis of available weather record primarily rainfall and evapotranspiration coupled with crop yield data permits evaluation of the suitability of a given crop for production at the planting site and the earliest and latest acceptable dates of the onset of the rains for growing the study crop. The method can also be used to predict the likely yields of the crops two months before harvest and holds great promise for use on an operational basis in dry farming areas Victor et al., (1994).

2.3 Agronomy of Sorghum

Sorghum plant (Sorghum bicolor) falls under the categories of cereal crops. The crop can be able to withstand period of drought better than most cereals and tolerates a wide range of soils (Armah-Agyeman et al., 2002). It can be grown in a rainfall as low as 250 mm and temperature of up to 33 °C (DAR, 1999). However, it performs better under more favourable conditions of moisture, temperature and relative humidity (Eze, 2001). Sorghum is grown on a wide variety of soils ranging in pH from 5.2 to 7.5 (DAR, 1999;Armah-Agyeman et al., 2002).

The time of planting for sorghum depend on the region, variety and season. Planting dates are important particularly for late maturity cultivars that are likely to be damaged by frost if planted late. The risk of crop failure increases with the delay in planting (Eze, 2001; Armah-Agyeman et al., 2002). Late November to early December is considered a good planting period for sorghum in Botswana (DAR, 1999). Double ploughing is recommended for heavy soils to enhance water infiltration and in other soils where persistent weeds are a problem. High yield of sorghum crops requires adequate nutrition, where phosphate and nitrogen fertilization can be significantly increase yield (DAR, 1999).

Row planting is recommended for sorghum to ensure good plant population and facilitate mechanization of field operations such as weeding and harvesting. The recommended inter-row spacing is 75 cm and intra-row spacing depends on the required population (DAR, 1999). Planting depth of 5-10 cm is recommended on sandy soils as they dry out faster and 3-5 cm for heavier soils. Sorghum should be weeded at least once at the early vegetative growth stage as seedlings initially are unable to compete with weeds for water and nutrients (Armah-Agyeman et al., 2002).

The major insect pests of sorghum are stem borer and African bollworm. Quelea birds are also a major problem especially in isolated fields. Sorghum is susceptible to a range of leaf and panicle diseases (DAR, 1999). The major ones are late blight, downey mildew, charcoal rot, sugarcane mosaic virus and long smut (Armah-Agyeman et al., 2002). Crop rotation is a good management practice for maintenance of soil fertility and pest control. Sorghum should be harvested at physiological maturity when no assimilates are going into seed or dry matter is being accumulated into the seed (DAR, 1999). At this stage, a black brownish layer forms at the bottom of the seed.

Sorghum plant develops into different stages with each having distinctive characteristics. The time required to each stage depends on varieties, planting patterns and environment in which it is growing (Mutava, 2009). Other factors such as soil fertility, insect or disease damage, moisture stress, plant population and weed competition may also affect both timing of the various stages of development and condition of plants at each stage of development. The major stages are vegetative, flowering and maturity (Table 1). Vegetative stage occurs approximately 30 days after emergence and is about one-third of the time from planting to physiological maturity (DAR, 1999). Stresses from weed competition, nutrients, water or insects can dramatically reduce yields if not corrected. During flowering stage, half of the total dry weight of the plants has been attained (Mutava, 2009). This stage usually represents two-thirds of the time between planting and physiological maturity. Severe moisture stress can results in poor head filling. Maximum total dry weight of the plant occurs at physiological maturity. Thus nutrient uptake at this point is essentially complete.

Table 1: Duration of sorghum growth stages

Sorghum growth stages	Duration (Days after sowing-DAS)
Vegetative stage	30-40
Flowering stage (50% flowering)	60-65
Maturity stage	125

Source: Department of Agricultural Research (DAR) (1999)

CHAPTER THREE

3.0 METHODOLOGY

3.1 Description of study area

Botswana is a land-locked country located in Southern Africa (Figure 1). It is bordered by South Africa to the east and south, Namibia to the west and north, Zambia to the north and Zimbabwe to the north-east. It lies between approximately 20° to 30°E and 17° to 27°S. Mean altitude above sea level is approximately 1000 m. The country covers approximately 582,000 square kilometers with an estimated population of 1,849,681 (Republic of Botswana, 2011). Much of the country is flat, with gentle undulations and occasional outcrops. About two thirds of Botswana's land area is covered with thick sand layer of the Kalahari Desert (Chanda et al., 2001).

Botswana is close to the sub-tropical high pressure belt of the southern hemisphere and is driven by two distinct climate zones with the majority falling under the Zaire Air Boundary climate zone to the north. This system brings the summer (November to April) thunderstorms and heavy downpours of rain. Most of the rains are due to convection process and are therefore highly variable in incidence in both space and time and tend to occur in the afternoons. As the country's position at the center of the Southern African plateau, average height of 1,000 m, with high evaporation rates of over 54,178 mm per annum, makes its climate to be continental and semi-arid (Weare, 1971). Hence the effect of low and unreliable rainfall makes rain-fed arable farming a risk activity to undertake (Chipanshi et al., (2003). Inter-annual variability of rainfall is high, combined with high evapotranspiration rates, results in shortage of water in the country where drought is a recurring hazard and raising of crops a gamble in the rainy season (Ramothwa and Minja, 2001).

For agricultural administration purposes, the country is divided into ten agricultural regions and 27 agricultural sub-districts (Figure 1).The most productive agricultural sub-districts include Barolong, Bamalete/Tlokweng, Tutume, Ngwaketse South, Tonota, Tati, Kgatleng, Mahalapye and Machaneng. These most productive sub-districts are feasible in terms of crop yield potential, spatial distribution of cultivated lands and agricultural development, hence, given first priority for consideration of development of rain-fed agriculture in the country. The second priority agricultural districts are Serowe, Ngwaketse Central, West and North, Bobonong, Selibe-Phikwe and Palapye while Kweneng North, Kweneng South and Kweneng West are given the third priority. Rain-fed crop production is not viable in the greater part of Ngamiland East and West, Okavango, Ghanzi, Letlhakane, Tsabong and Hukuntsi agricultural sub-districts because of low soil fertility (MoA, 2000).

For this study, Barolong agricultural sub-district and Chobe agricultural district were evaluated (Figure 1). Chobe agricultural district is located between latitudes 18°25'S to 18°40'S and longitudes 025°05'E to 025°47'E while Barolong is at 25°30'S to 25°45'S and 025°00'E to 025°45'E. These two sites have been chosen because they have a long history of arable agriculture productivity and output. The soils are predominantly luvisols for Barolong agricultural sub-district and vertisols for Chobe agricultural district. The vertisols in Chobe agricultural district have water holding capacity of 51.1% while luvisols of Barolong agricultural sub-district have only 43.8% (Ngole and Ekosse, 2008). The annual variation of the sun's declination causes the main pressure systems (tropical high pressure systems) to shift latitudinal (Ramothwa and Minja 2001). This results in the annual north/south oscillation of the Intertropical Convergence Zone (ITCZ). When the ITCZ is active it brings heavy showers to the northern parts of the country, hence, results in the type of rainfall experienced in Chobe agricultural district which is as high as 600 mm in total annually with maximum temperatures ranging between 26°C to 34°C and minimum temperatures ranging between 11°Cto 20°C. But when other conditions, such as temperature in summer are favourable the ITCZ position over the southwest Indian is a source of tropical lows and unstable easterly waves which trigger the formation of tropical storms and tropical cyclones. Cold frost which traverse the Atlantic and Indian Ocean from west to east occasionally give rise to some rainfall which tend to intrude further north into the subcontinent. Such rainfall mainly affects the southern parts of the country, hence, influences rainfall in Barolong agricultural sub-district which receives total annual rainfall of about 500 mm with maximum temperatures generally reaching highs of around 44°C while the minimum temperatures are around -6°C.

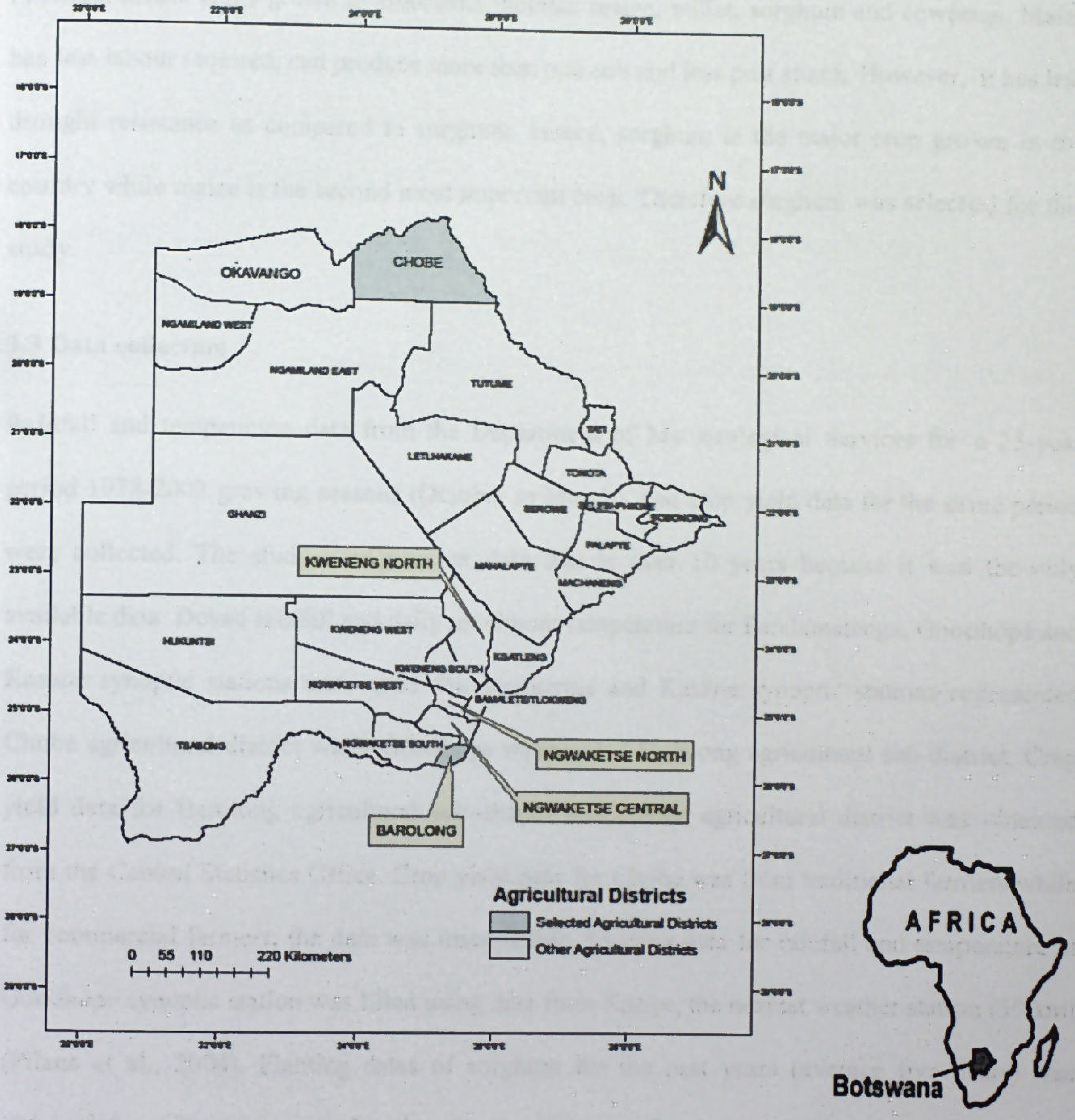

Figure 1: Study sites and agricultural districts

3.2 Selection of study crop

Principal arable crops grown in Botswana include; maize, millet, sorghum and cowpeas. Maize has less labour required, can produce more than one cob and less pest attack. However, it has less drought resistance as compared to sorghum. Hence, sorghum is the major crop grown in the country while maize is the second most important crop. Therefore sorghum was selected for this study.

3.3 Data collection

Rainfall and temperature data from the Department of Meteorological Services for a 25-year period 1978-2003 growing seasons (October to March), and crop yield data for the same period were collected. The study used weather data that is over 10 years because it was the only available data. Dekad rainfall and daily maximum temperature for Pandamatenga, Goodhope and Kasane synoptic stations were used. Pandamatenga and Kasane synoptic stations represented Chobe agricultural district while Goodhope represented Barolong agricultural sub-district. Crop yield data for Barolong agricultural sub-district and Chobe agricultural district was obtained from the Central Statistics Office. Crop yield data for Chobe was from traditional farmers while for commercial farmers, the data was inaccessible. Missing data for rainfall and temperature at Goodhope synoptic station was filled using data from Kanye, the nearest weather station (59 km) (Pilane et al., 2004). Planting dates of sorghum for the past years (average five years) was obtained from Southern agricultural regional office (for Barolong agricultural sub-district) and Chobe district agricultural office and were used to establish sorghum growth stages. Crop growth stages are distinct morphological landmarks of the crop at a specified point in its life cycle

(Pujaret al., 2006). The growth cycle of sorghum were described in terms of the following development phases (Ibrahim et al., 2011):

(1) Vegetative phase (from sowing to head initiation)

(2) Flowering or panicle development phase (from panicle initiation to anthesis)

(3) Grain filling or physiological maturity (from heading to the end of grain filling)

The pre-sowing period (for rainfall only) and total growing season was considered in the study analysis together with these phases (Ibrahim, et al., 2011). The pre-sowing period was included in the study analysis because agro-climatic conditions before the growing season might have some influence on yield, although such influence could be indirect, that is through connections between pre-season and growing season climate (Qian et al., 2009b). The data set also included the number of 10 rainy days for the growing season, which was defined as wet days with effective dekad rainfall amount ≥10 mm (Araya and Stroosnijder, 2011) or else considered as dry days. Effective rainfall was the amount of rainfall infiltrated into the soil and was calculated based on the following relationship:

$$D_{eff} = D_{rain} \times (1 - 0.25) \quad (1.0)$$

Where; D_{eff} is the dekadal effective rainfall (mm), D_{rain} is the dekadal rainfall and the factor 0.25 accounts for the estimated average runoff of 25% (Araya and Stroosnijder, 2010). Temperature was introduced in the study as a confounding factor.

3.4 Methods of data analysis

Exploratory relationship between crop yield and rainfall was carried out and graphs were constructed to study the relationship between total seasonal rainfall, rainy days and crop yield. Time-series analysis was also used to reveal trends and seasonal variations in rainfall and crop yield. Descriptive statistics were calculated to determine the relationship between crop yield and rainfall. These included; correlation coefficient, coefficient of determination (R^2) and Root Mean Square Error (RMSE). Confidence limits were used to evaluate the differences in sorghum yield within Chobe agricultural district and Barolong agricultural sub-district. The total study periods were divided into three periods and the average of sorghum yield for those years was computed.

Correlation analysis between rainfall, temperature and final sorghum yield at various crop growth stages was undertaken to determine the relationship between the variables and to compare sorghum yield with the total seasonal rainfall, number of rainy days, and average maximum temperature at various crop development phases over time for the growing season.

The relationship established between rainfall, temperature and final sorghum yield at various crop growth stages was used to determine the most sensitive stage (s). This analysis was carried out through a multi-linear regression model (equation 2) (Lobell and Field, 2007; Omonona and Akintola, 2009; Ibrahim et al, 2011).

$$Y = \beta_0 + \beta_1\chi_{1i} + \beta_2\chi_{1j} + \beta_3\chi_{1k} + \beta_4\chi_{1m} + \beta_5\chi_{1n} + \beta_6\chi_{2i} + \beta_7\chi_{2j} + \beta_8\chi_{2k} + \beta_9\chi_{2m} + \beta_{10}\chi_{2n} + \beta_{11}\chi_{3j} + \beta_{12}\chi_{3k} + \beta_{13}\chi_{3m} + \beta_{14}\chi_{3n} + \epsilon \qquad (2.0)$$

Y = sorghum yield, β_0= y- intercept (constant), χ_1= total rainfall amount, χ_2= total number of rainy days, χ_3 = average maximum temperature, i, j, k, m, n = pre-sowing stage, vegetative stage, flowering stage, maturity stage and total growing season stage respectively, $\beta_1, \beta_2, \beta_3, \beta_4, \beta_5$= coefficient of total rainfall amount at pre-sowing stage, vegetative stage, flowering stage, maturity stage and total growing season stage respectively, $\beta_6, \beta_7, \beta_8, \beta_9, \beta_{10}$ = coefficient of total number of rainy days at pre-sowing stage, vegetative stage, flowering stage, maturity stage and total growing season stage respectively, $\beta_{11}, \beta_{12}, \beta_{13}, \beta_{14}$ = coefficient of average maximum temperature vegetative stage, flowering stage, maturity stage and total growing season stage respectively, and ϵ = error component

To cater for the variability brought about by management practice, the difference between the final yield at each growing season and mean long-term yield for all growing seasons was computed. These differences were used as input data for yield in all analyses.

The regression model was developed using Statistical Analysis Software (SAS). Rainfall and yield data input into the software for correlation and regression analyses were log transformed to correct skewed distributions. Stepwise regression was employed for the selection of the predictors in multi-linear regression model used for estimating sorghum yield from pre-sowing stage through harvest (total growing season). Thus, the model was used to establish the most sensitive growth stage (s) for yield loss. The goodness of fit of the model was judged by the coefficient of determination (adjusted-R^2) statistic (Sawa and Ibrahim, 2011; Ibrahim et al., 2011), which measured how much of the total variability in yield was accounted for by regressing yield on rainfall and temperature. The accuracy of the model was examined by the Root Mean Square Error (RMSE) (Qian et al., 2009b).

CHAPTER FOUR

4.0 RESULTS

4.1 Time-series for rainfall and sorghum yield

Rainfall fluctuated with sorghum yield at Chobe agricultural district except in 1984/85, 1987/88, 1989/90, 1996/97, 1998/99 and 2002/03 seasons where a negative relationship was observed (Figure 2). Thus, a rainfall increased, yield increased and vice versa while during some years an increase in rainfall resulted in a decrease in yield. For some years, rainfall remained constant whereas yield fluctuated and vice versa. In general, seasonal rainfall showed a slight negative slope ($Y = -0.338x + 363.3$) and did not explain any variation 0.0%. Sorghum yield indicated a positive slope ($Y = 3.510x + 107.2$) with a variation of 11. 2%.

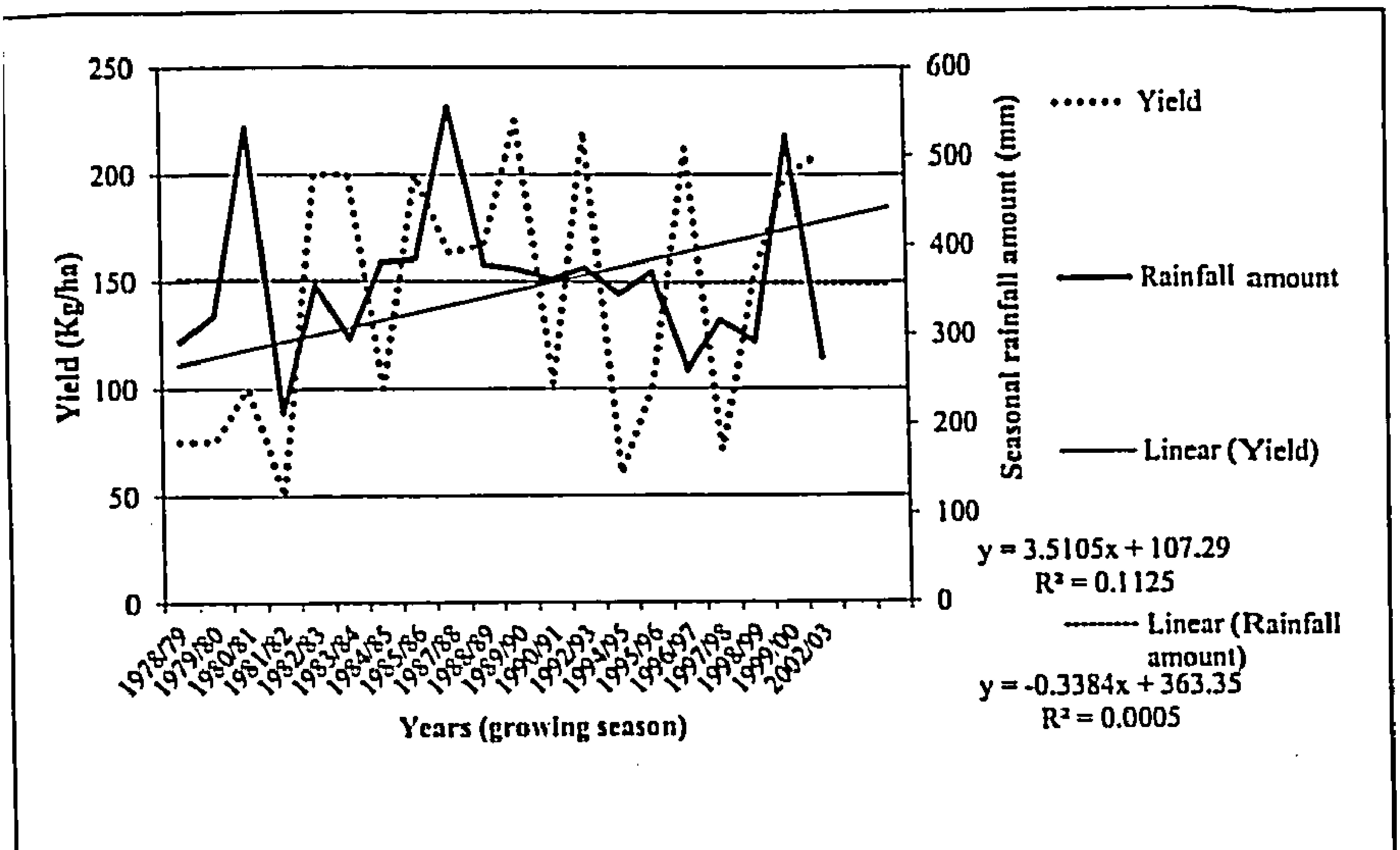

Figure 2: Relationship between total seasonal rainfall and sorghum yield (Chobe agricultural district)

For Barolong agricultural sub-district rainfall fluctuated with sorghum yield except in 1984/85, 1989/90, 1994/95 to 1997/98 and 1999/00 to 2001/02 growing seasons where rainfall increased while sorghum yield decreased and vice versa (Figure 3). During 1982/83, 1983/84, 1985/86 and 1986/87 growing seasons rainfall remained constant while yield fluctuated. A positive trend was observed in both seasonal rainfall and sorghum yield (Y= 1.257x + 272.9 and Y= 24.16x + 181 respectively.) with differences of 0. 5% and 7.3% respectively.

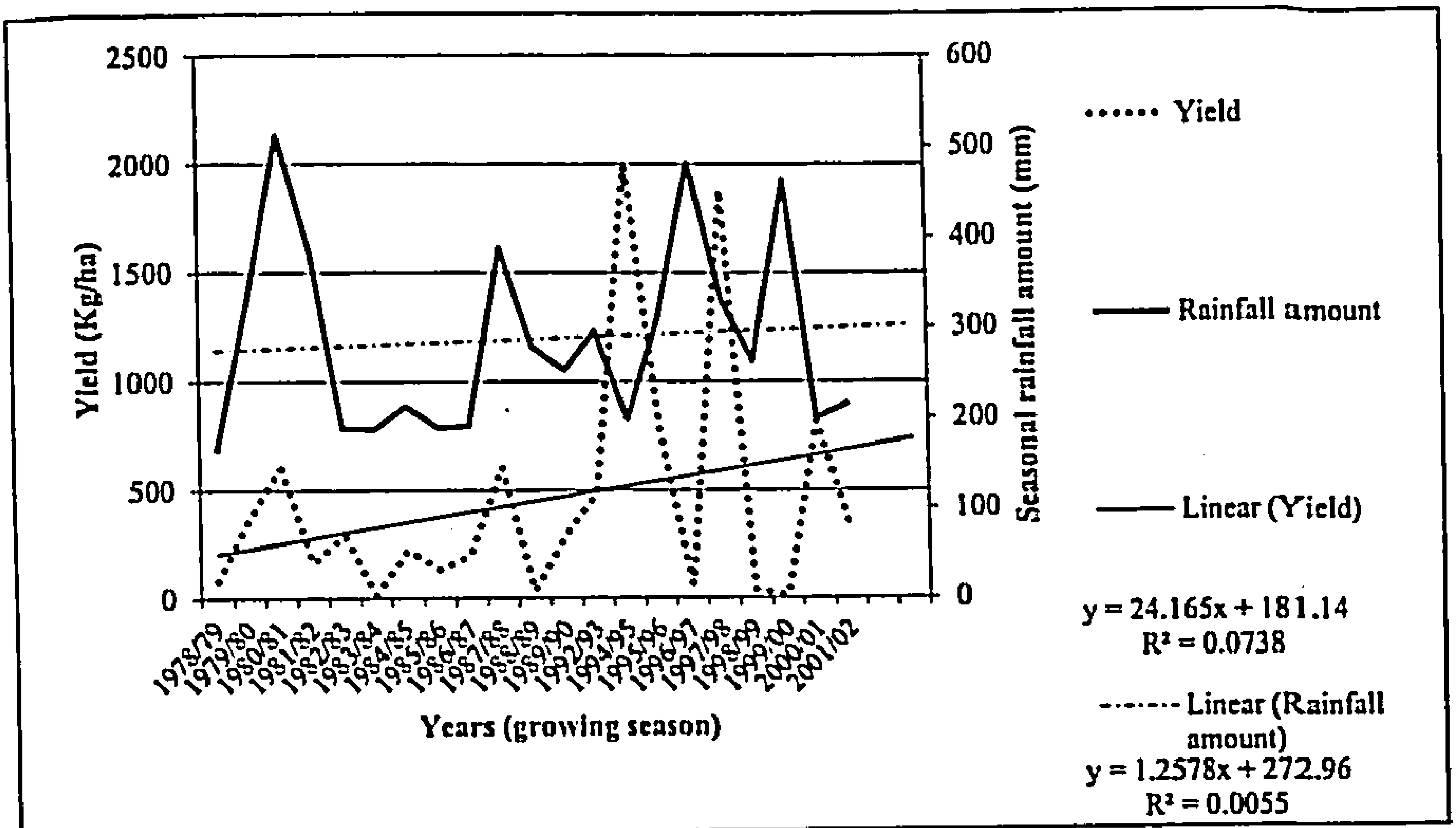

Figure 3: Relationship between total seasonal rainfall and sorghum yield (Barolong agricultural sub-district)

Comparatively, total seasonal rainfall showed similar trends with sorghum yield response at Chobe and Barolong district (Figure 2 and 3). For 1978/79 to 1981/82, positive fluctuations of rainfall with yield were observed for both agricultural districts. A negative relationship between total seasonal rainfall and final sorghum yield was observed for 1984/85, 1989/90 and 1997/98 seasons.

Number of rainy days and sorghum yield fluctuated with sorghum yield for Chobe agricultural district except in 1984/85, 1992/93 to1997/98 and 2002/03 periods where a negative relationship had been observed (Figure 4). For 1982/83 to 1983/84 and 1988/89 to 1989/99 seasons, the number of rainy days remained constant while yield fluctuated. Number of rainy days and sorghum yield showed a positive gradient (Y= 0.047x + 8.252 and Y= 3.510x + 107.2 respectively) with variations of 3.2% and 11.2% respectively.

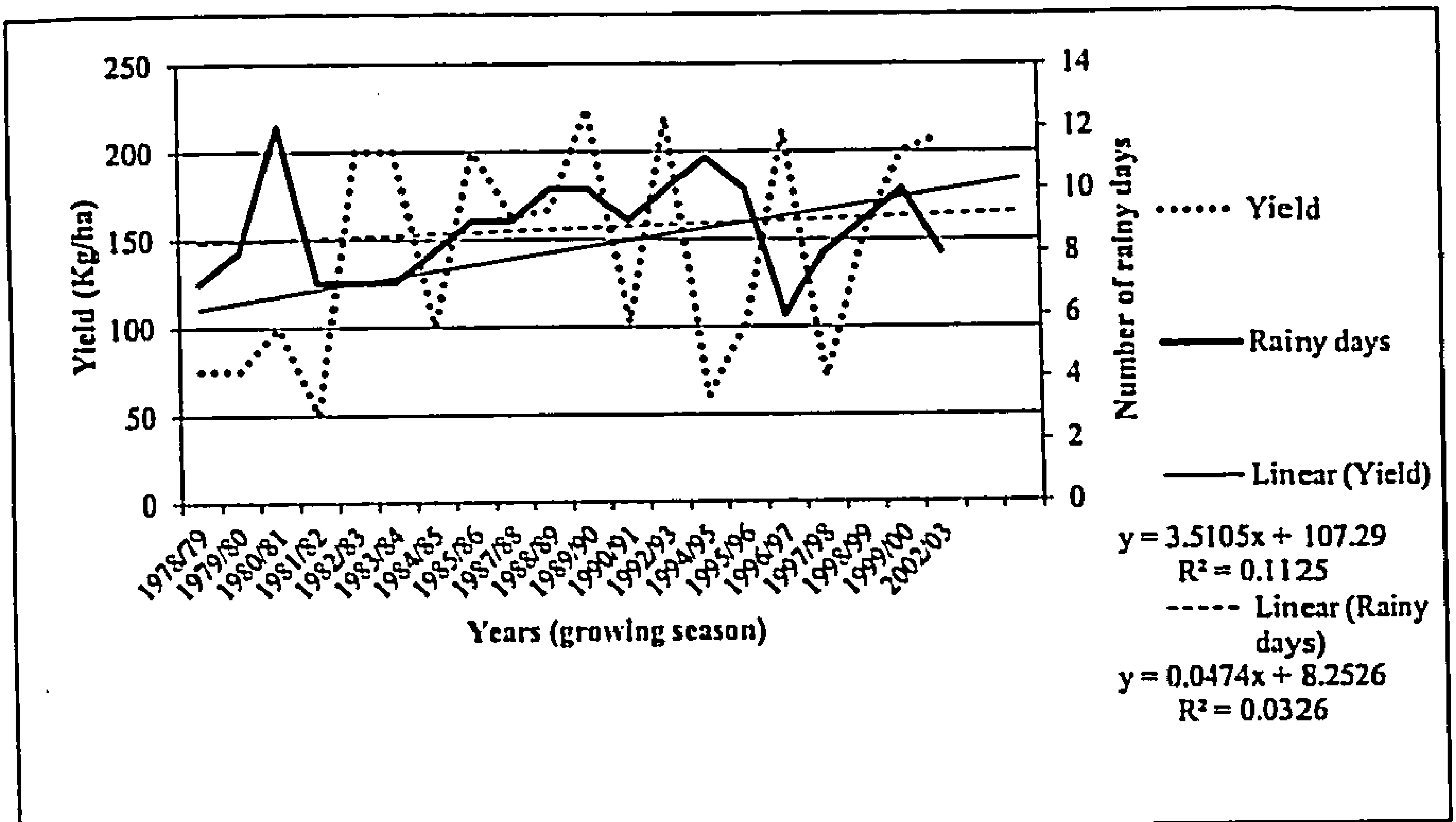

Figure 4: Relationship between rainy days and sorghum yield (Chobe agricultural district)

For Barolong agricultural sub-district the number of rainy days fluctuated with sorghum yield except in 1982/83, 1985/86, 1992/93 to 1997/98 and 2000/01 to 2001/02 (Figure 5). During 1980/81, 1981/82 and 1997/98 to 1999/00 seasons, the number of rainy days remained constant while yield fluctuated. Generally, a negative slope in rainy days (Y= -0.003x + 7.757) was observed while sorghum yield had a positive gradient (Y= 24.16x + 181.1). The variations in rainy days and sorghum yield were 0.0% and 7.3% respectively.

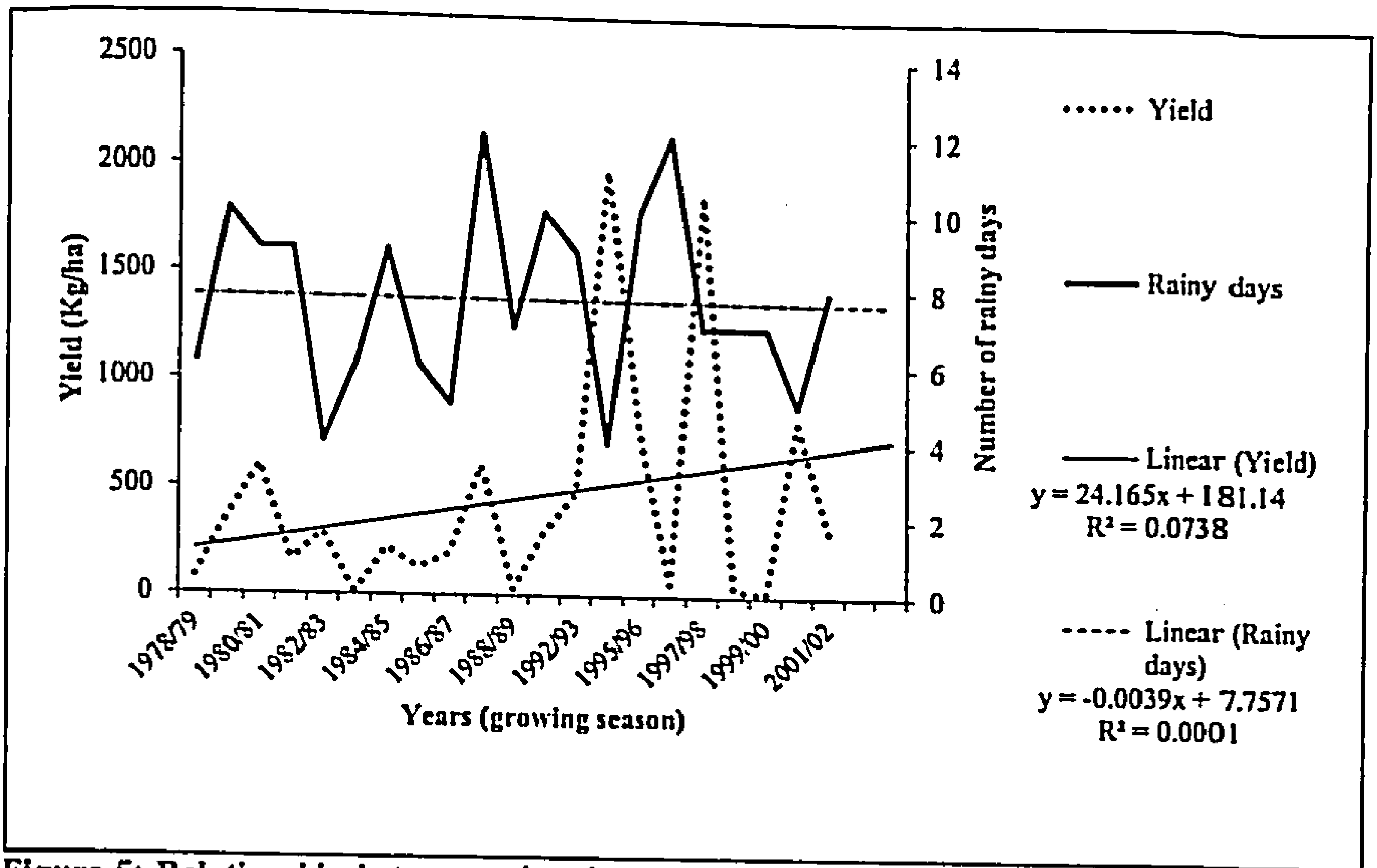

Figure 5: Relationship between rainy days and sorghum yield (Barolong agricultural sub-district)

Relatively, Chobe and Barolong districts showed similar trends for the relationship between the number of rainy days and sorghum yield for 1978/79 to 1979/80 seasons (Figure 4 and 5). During this period, the number of rainy days fluctuated positively with yield. For 1992/93 to 1997/98 seasons, a negative relationship between the number of rainy days and sorghum yield was observed.

Total seasonal rainfall and number of rainy days showed similar trends with sorghum yield response at Chobe agricultural district (Figure 2 and 4). For the 1978/79 to 1981/82, 1990/91 and 1999/00 seasons, a direct positive fluctuations for total rainfall, number of rainy days and sorghum yield was observed. As total seasonal rainfall and number of rainy days increased, yield responded in the same manner and vice versa. Nevertheless, total seasonal rainfall and number of rainy days had negative relationships with sorghum yield in 1984/85. As total seasonal rainfall and number of rainy days increased, grain yield decreased. During 1996/97 and 2002/03 seasons total rainfall and number of rainy days decreased while yield increased.

For Barolong agricultural sub-district rainfall had a positive relationship with yield for 1978/79, 1979/80, 1985/86, 1987/88 and 1988/89 seasons. Total seasonal rainfall and number of rainy days showed similar response with sorghum yield during those periods (Figure 3 and 5). An increase in rainfall was accompanied by an increase in yield whereas a decrease in rainfall was related to low yield. A negative relationship between total seasonal rainfall, number of rainy days and sorghum yield was observed for 1994/95 to 1997/98 and 2000/01 to 2001/02 growing seasons.

Over the years, seasonal rainfall (five-year averages) increased and then decreased while sorghum yield fluctuated, at Chobe agricultural district (Figure 6). At Barolong agricultural sub-district, seasonal rainfall decreased and then increased while yield fluctuated (Figure 7).

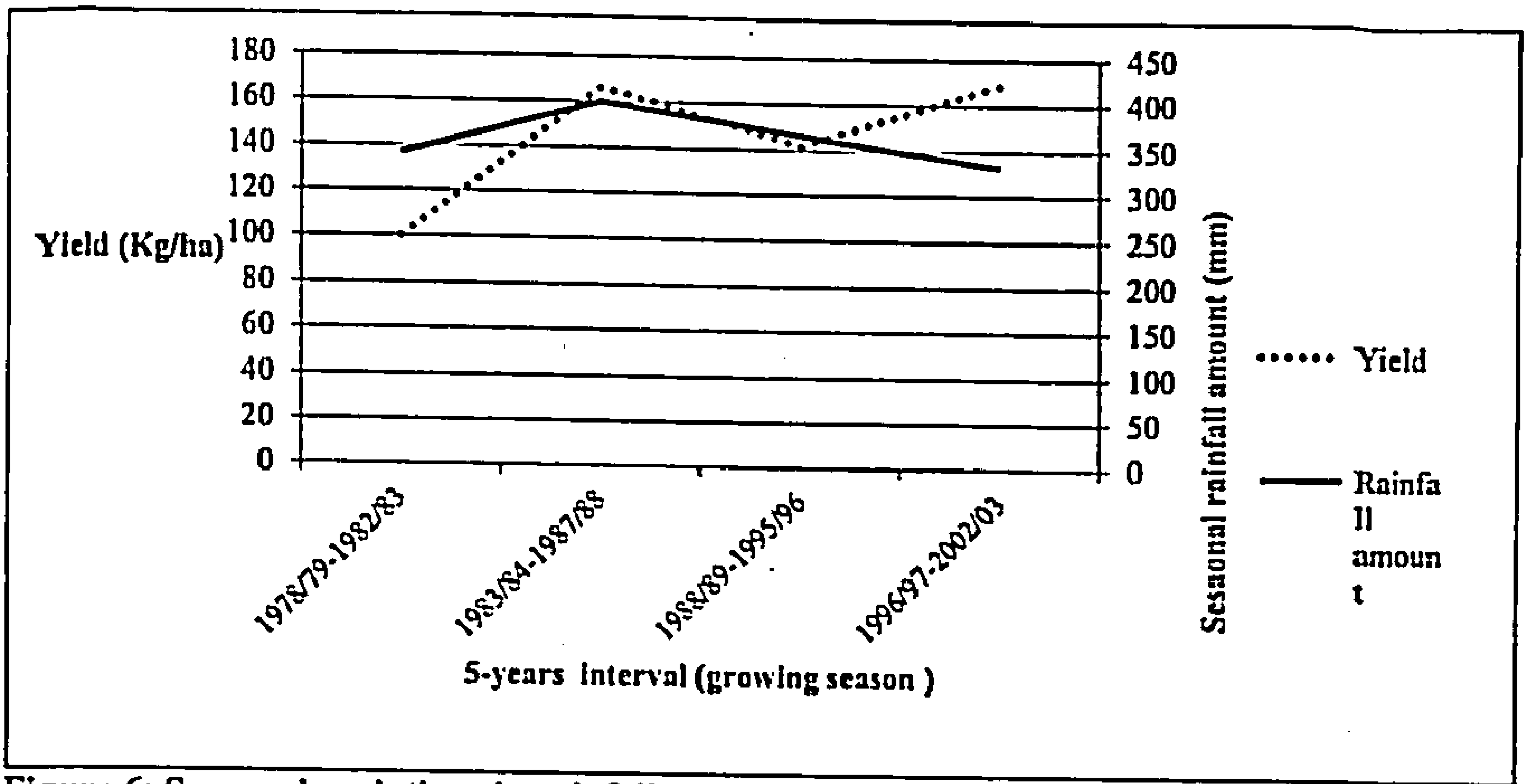

Figure 6: Seasonal variations in rainfall amount and sorghum yield (Chobe agricultural district)

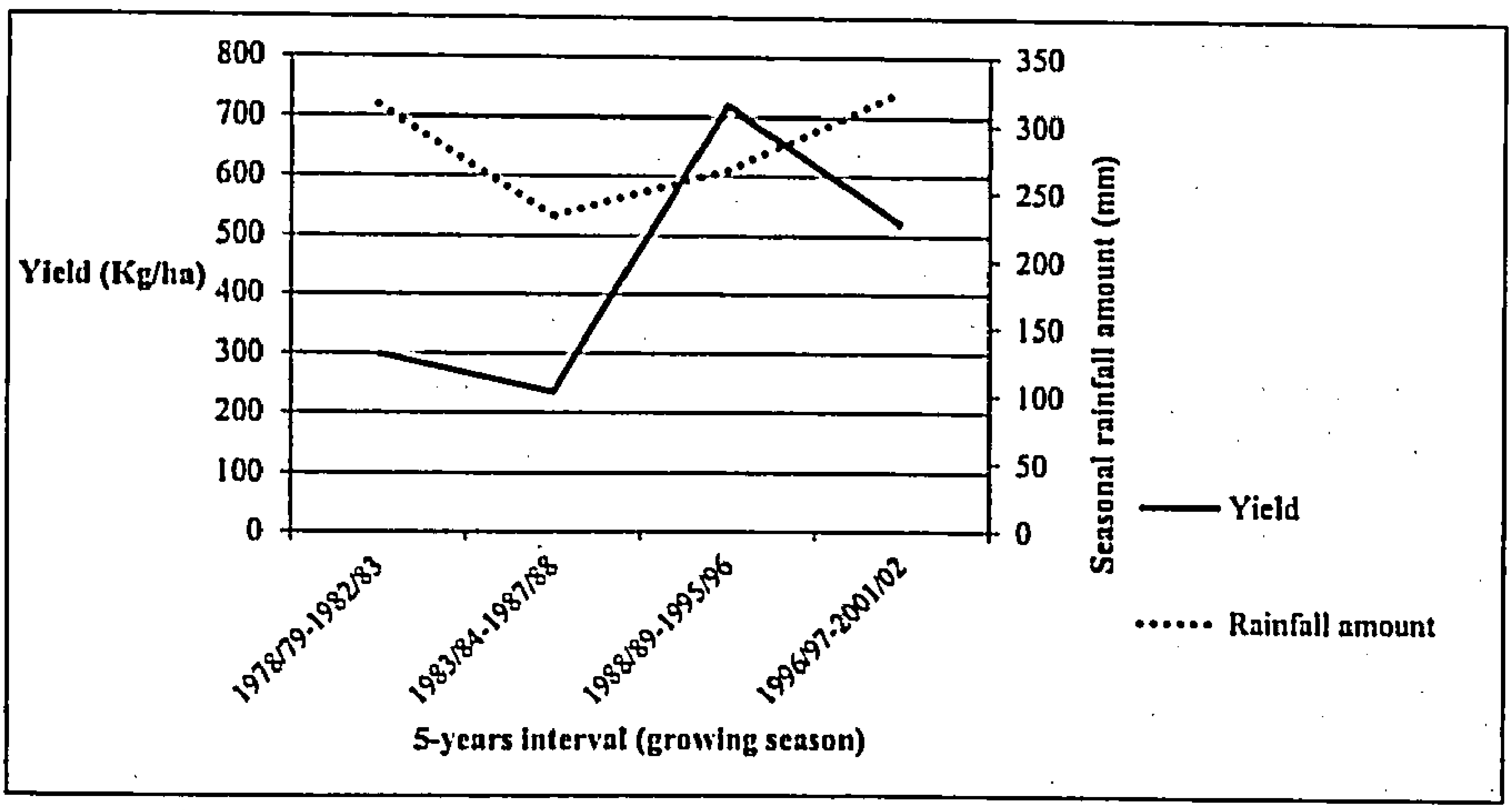

Figure 7: Seasonal variations in rainfall amount and sorghum yield (Barolong agricultural sub-district)

At Chobe agricultural district, rainy days increased and then decreased while sorghum yield fluctuated over the years (Figure 8). Rainy days and sorghum yield fluctuated together at Barolong agricultural sub-district (Figure 9).

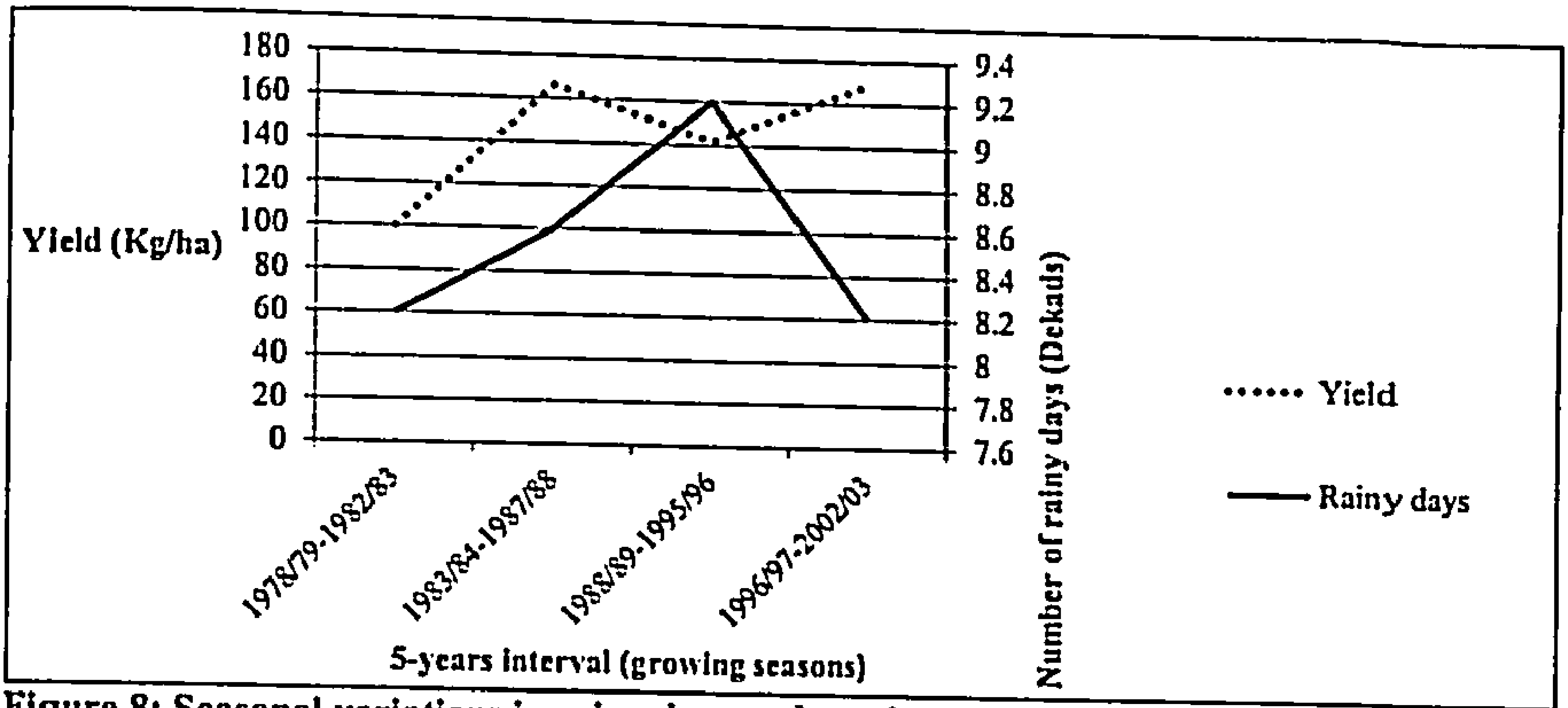

Figure 8: Seasonal variations in rainy days and sorghum yield (Chobe agricultural district)

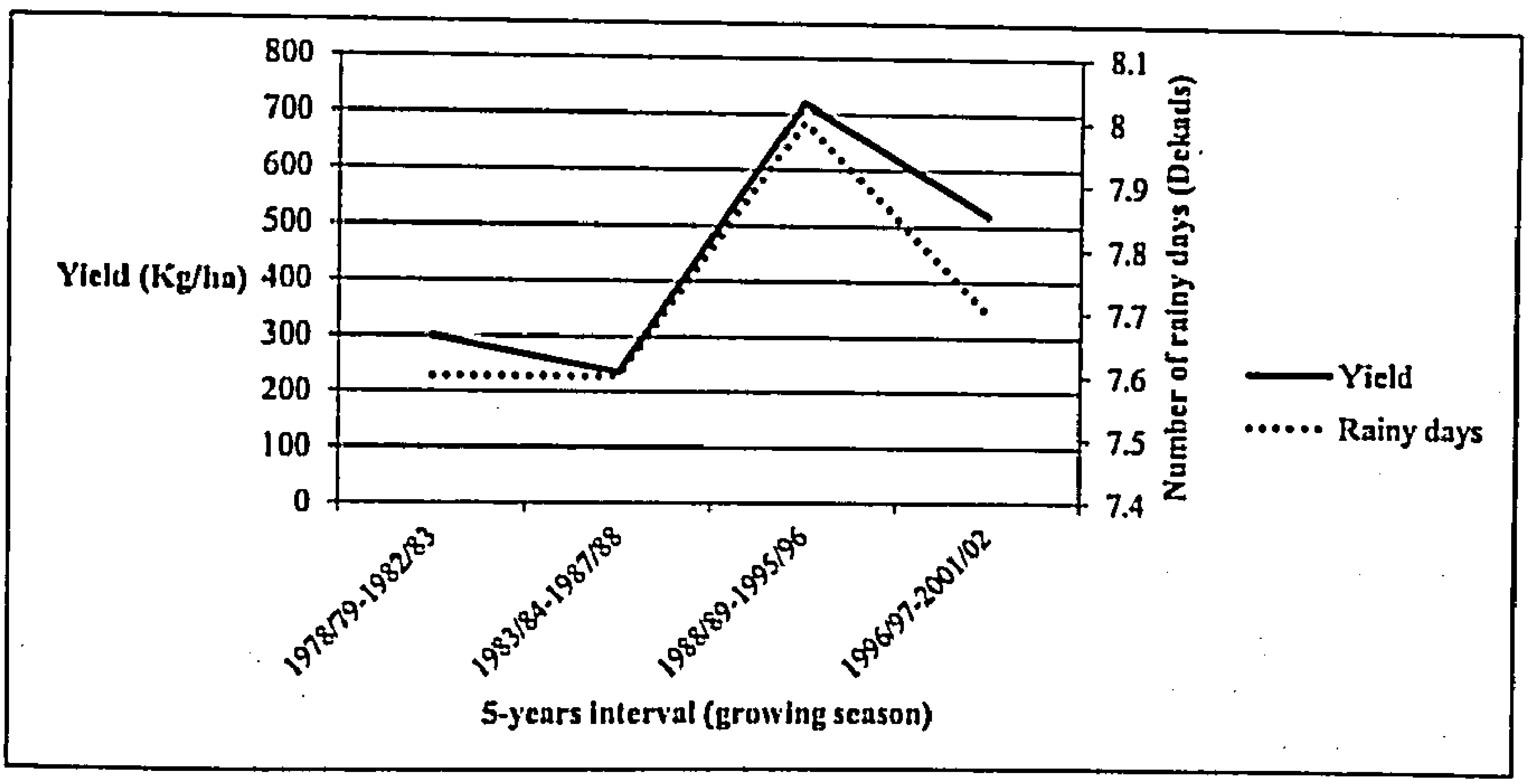

Figure 9: Seasonal variations in rainy days and sorghum yield (Barolong agricultural sub-district)

Table 2 shows correlation of rainfall and temperature at different development phases (pre sowing, vegetative, flowering, maturity and growing season) with final sorghum yield for Chobe district. A positive correlation implies that for increase in the value of one of the variables, the other variable also increases in the value while a negative correlation indicates that an increase in value of one of the variables is accompanied by a decrease in value of the other variable. A correlation of ≥0.5 was considered as high and included in the analysis and model (Ibrahim et al., 2011).

For the pre-sowing period, rainfall had a weak positive and insignificant correlation with the final yield while for the vegetative stage, no climatic elements correlated well with the final yield although rainfall had a weak positive correlation but insignificant. Average maximum temperature had a negative relationship with final yield and insignificant at vegetative stage. Nevertheless, average maximum temperature was found to be significantly ($P < 0.01$) and positively highly correlated with the final yield of sorghum during the flowering stage. There was a negative relationship between rainfall and sorghum yield at flowering stage. Also, rainfall was insignificant at this stage.

No climatic variable correlated significantly with final grain yield for the maturity stage for Chobe agricultural district (Table 2). Total rainfall amount had a weak positive correlation with yield while number of rainy days and average maximum temperature each had negative correlations with sorghum yield. Rainfall had a negative correlation with the sorghum yield for total growing season while average maximum temperature had an insignificant weak positive correlation with the final yield.

Table 2: Correlation between climatic variables and sorghum yield at different growth stages (Chobe agricultural district)

Climatic element	Sorghum yield
Total rainfall amount at pre-sowing stage	0.20
Total rainfall amount at vegetative stage	0.07
Total rainfall amount at flowering stage	-0.26
Total rainfall amount at maturity stage	0.08
Total rainfall amount at total growing season	-0.18
Total number of rainy days at pre-sowing	0.28
Total number of rainy days at vegetative stage	0.08
Total number of rainy days at flowering stage	-0.26
Total number of rainy days at maturity stage	-0.03
Total number of rainy days at total growing season	-0.24
Average maximum temperature at vegetative stage	-0.25
Average maximum temperature at flowering stage	0.62**
Average maximum temperature at maturity stage	-0.14
Average maximum temperature at total growing season	0.23

*** = significant at 1%

** = significant at 5%

For Barolong agricultural sub-district, total rainfall amount was insignificant and had a negative correlation with the sorghum yield for the pre-sowing stage (Table 3). Total number of rainy days was significant ($P < 0.02$) and highly correlated with final yield at pre-sowing stage. For vegetative stage, no climatic variable correlated well with sorghum yield, rainfall had a negative relationship with the final yield at this stage while average maximum temperature, had an insignificant weak positive correlation with the final yield

Even though rainfall had a weak positive correlation with sorghum yield at flowering stage, it was found to be insignificant (Table 3). Average maximum temperature was insignificant and negatively correlated with the final yield at flowering stage. During the maturity stage, total rainfall amount and total number of rainy days were significant ($P < 0.02$ and $P < 0.002$ respectively) and highly correlated with sorghum yield at Barolong agricultural sub-district. Average maximum temperature was insignificant during this stage though had a weak positive correlation with final yield. For total growing season, rainfall was negatively correlated with sorghum yield and insignificant while average maximum temperature, though was insignificant, had a weak positive correlation with the final yield.

Table 3: Correlation between climatic variables and sorghum yield at different growth stages (Barolong agricultural sub-district)

Climatic element	Sorghum yield
Total rainfall amount at pre-sowing stage	-0.32
Total rainfall amount at vegetative stage	-0.50
Total rainfall amount at flowering stage	0.36
Total rainfall amount at maturity stage	0.85**
Total rainfall amount at total growing season	-0.12
Total number of rainy days at pre-sowing stage	0.79**
Total number of rainy days at vegetative stage	-0.63
Total number of rainy days at flowering stage	0.24
Total number of rainy days at maturity stage	0.71***
Total number of rainy days at total growing season	-0.56
Average maximum temperature at vegetative stage	0.06
Average maximum temperature at flowering stage	-0.08
Average maximum temperature at maturity stage	0.34
Average maximum temperature at total growing season	0.14

*** = significant at 1%

** = significant at 5%

4.2 Within-district sorghum yield variations

There were no differences in sorghum yield for both districts because both confidence limits at 95% include the mean of sorghum yield for the respective study periods (Table 4). Nevertheless, rainfall in semi-arid areas such as Botswana display great spatio-temporal variability (Batisani and Yarnal, 2010).

Table 4: Within-district yield variations for Chobe agricultural district and Barolong agricultural sub-district

	Variable	Period	N	Mean	Lower 95% CL for Mean	Upper 95% CL for Mean
Chobe	Yield	1	15	38.10	14.08	62.12
		2	15	57.10	17.78	96.42
		3	15	48.10	12.04	84.16
Barolong	Yield	1	15	320.00	131.08	508.92
		2	15	494.00	-203.41	1191.41
		3	15	573.00	10.39	1135.61

4.3 Determinants of sorghum yield

An analysis of the relationship between total rainfall amounts, number of rainy days, average maximum temperature and sorghum grain yield through regression are presented in Tables 5 and 6. For Chobe agricultural district, each Degree Celsius increase in average maximum temperature at flowering stage increased sorghum yield by 0.223 kg/ha and it was statistically significant at 95% level ($P < 0.04$) (Table 5). Yield decreased by 5.483kg/ha if there was no influence of average maximum temperature at flowering stage for Chobe agricultural district (significant at 95% level, $P < 0.02$).

Table 5: Determinants of sorghum yield (Chobe agricultural district)

Climatic variable	Co-efficient	Pr>|t|
Constant	-5.483	0.04
Average maximum Temperature at flowering stage	0.223	0.02

$F = 8.03$, Adjusted $R^2 = 0.33$ and RMSE = 0.33

The regression equation for sorghum yield estimation for Chobe agricultural district is:

$$Y = 0.223X_{3k} - 5.483 \quad (3.0)$$

Where Y is sorghum yield, X_3 the average maximum temperature, k the flowering stage, 0.223 the coefficient of average maximum temperature at flowering stage and − 5.483 the y-intercept (constant).

For Barolong agricultural sub-district, for each increase in rainy days at pre-sowing stage, sorghum yield decreased by 0.829 kg/ha and was statistically significant at 95% level ($P < 0.02$) while for maturity stage an increase in a number of rainy days decreased sorghum yield by 3.376 kg/ha and was significant at 99% level ($P < 0.002$) (Table 6). An increase in mm of rainfall at maturity stage increased sorghum yield by 0.912 kg/ha and was significant at 95% level ($P < 0.02$). Sorghum yield was 2.798 kg/ha and significant at 99% level ($P < 0.0001$) if there was no influence of total rainfall amount at maturity stage, and total number of rainy days at pre-sowing and maturity stages

Table 6: Determinants of sorghum yield (Barolong agricultural sub-district

Climatic variable	**Co-efficient**	Pr>|t|
Constant	2.798	0.0001
Total rainfall amount at maturity stage	0.912	0.02
Total number of rainy days at pre-sowing stage	-0.829	0.02
Total number of rainy days at maturity stage	-3.376	0.002

$F = 7.95$, Adjusted $R^2 = 0.62$ and RMSE = 0.25

The regression equation for sorghum yield estimation for Barolong agricultural sub-district is:

$$Y = 2.798 + 0.912X_{1m} - 0.829X_{2l} - 3.376X_{2m} \quad (4.0)$$

Where Y is sorghum yield, 2.798 the y-intercept (constant), X_1 the total rainfall amount, m the maturity stage, 0.912 the coefficient of total rainfall amount at maturity stage, X_2 the total number of rainy days, $_i$ the pre-sowing stage, – 0.829 the coefficient of total number of rainy days at pre-sowing stage and – 3.376 the coefficient of total number of rainy days at maturity stage.

CHAPTER 5

5.0 DISCUSSION

Rainfall pattern corresponded with yield for Chobe agricultural district and also for Barolong agricultural sub-district as total seasonal rainfall resulted in increased soil moisture content hence increased sorghum yield while decreased total seasonal rainfall reduced yield due to reduced soil moisture. Water is one of the limiting factors which influences the physiological and biochemical processes affecting crop productivity (Farah et al., 1997). Water provides turgidity to the cell while water stress causes dehydration, reducing the enlargement and expansion of the cell, resulting in reduction in yield. Increased number of rainy days also resulted in an increase in sorghum yield while a decrease in number of rainy days reduced yield. Thus, lengthening of rainfall distribution over the growing seasons allowed the soil to acquire less variable distribution of soil moisture status during the growing season, hence, increase in the final yield. At the same time, confined temporal rainfall distribution or poor temporal distribution of rainfall reduced moisture within the soil to a level which was detrimental to crop growth during some periods within the growing season, therefore reduced the final yield (Turk et al., 2002).

Nevertheless, increased total seasonal rainfall during some years resulted in a decrease in yield probably due to waterlogged soil. This situation is in agreement with Farah et al., (1997) who observed that additional water resulted in non-significant increase in sorghum yield and also reduced grain yield of the crop. Other factors such as damage from wildlife and pest infestations (quelea birds) may also result in a decrease in sorghum yield especially at Chobe agricultural district (MOA, 2009). At the same time reduced total seasonal rainfall resulted in an increase in sorghum yield because sorghum has a strong and effective root system which penetrates the soil more effectively and utilizes stored soil moisture on heavy clay soil more efficiently (Armah-Agyemanet al., 2002), hence a decrease in soil moisture content still resulted in an increase in the final yield.

Also, increased number of rainy days reduced grain yield during some growing seasons. This implies that extending temporal distribution of rainfall over the growing seasons led to a reduction in yield and for yield to increase, rainfall could have been far apart temporally so as to allow drying up of the soils. Continuous rains within growing seasons might have resulted in an increase in the potential for flooding, thereby creating conditions favouring fungal infestations of leaf and root, such as ergot disease, which affected sorghum yield (Rosenzweig et al., 2001; TNAU, 2008).Gebrekidah, (2003) also revealed high sorghum yield in season with low or poorly distributed rains. Reduction in the number of rainy days produced high yield because the residual soil moisture from the previous season continued to support the growth of the crop as vertic soils have high water holding capacity.

Rainfall remained constant while yield increased and then decreased because vertisols and luvisols have higher soil moisture holding capacity which might have permitted crop growth to continue on residual moisture, hence, high yield was experienced. A reduction in sorghum yield was observed probably because the rate of water redistribution through the soil decreased with time and often became so slow that little change in water content was detected after sometimes, consequently, affecting the crop (Spackman, et al., 2001). Also, may be other production factors such as fertility could be limiting (Munodawafa, 2012).

The same scenario above was noticed with the number of rainy days where it remained constant while yield increased then declined, this indicates that soil moisture received by the crop was sufficient for the increase of the final yield and then dropped below optimum amount of sorghum water requirement, hence less yield. This situation was as result of soil moisture which was reduced with time as there was no increase in water recharge, thus corresponded to the increase in water suction at the root zone, hence, affected the productivity of the crop (Spackman, et al., 2001). Also, the number of rainy days remained constant while yield fluctuated and then remained constant. This condition was experienced probably because soil moisture reservoir was less than sorghum water requirement hence less yield was experienced previously and with time an increase in yield was noticed and may be was a result of sorghum adaptive mechanism of the leaves which roll along the midrib to keep the crop from losing water and wilting, hence enabled crops to balance sorghum water requirement with available soil moisture (Armah-Agyeman et al., 2002). In other cases the number of rainy days remained constant while yield decreased .This state was due to uniform rainfall distribution which provided soil moisture reservoir which could be easily depleted by crops thereby reduced yield.

There were significant differences in growing seasons for Chobe agricultural district and Barolong agricultural sub-district. These variations could have led to fluctuations in the yield of sorghum at Chobe agricultural district and Barolong agricultural sub-district. This condition is in line with Mehta et al., (2002); Gebrekidah, (2003); Ekpoh, (2010) who noted that uneven distribution of rainfall during the growing season are the principal factors affecting yield.

The positive fluctuations and negative relationship between total seasonal rainfalls, number of rainy days and sorghum yield implies that rainfall varies within the growing season and this might have an influence on yield even though there were no differences in means of sorghum yield for both districts. Rowhani et al., (2011) also revealed that rainfall during the growing season affect sorghum yield. Therefore, rainfall is an essential determinant of yield for Chobe and Barolong districts.

Average maximum temperature at flowering stage of sorghum in Chobe agricultural district was very essential as opposed to rainfall and can translate to high yield. This means that average maximum temperature was vital to dry up the soils so as to promote good environment for sorghum metabolic processes to take place for better grain yield. Blair, (2010) revealed that drying temperature affects the results of soil water content particularly for the high clay soils and also loosens soil particles, whereby high aggregate stability in soils is maintained, hence, essential for the preservation of agricultural production through the provision of conditions that are favourable for plant growth and soil microbial activity. Also, sorghum is a warm-weather crop that requires high temperatures for good growth (du Plessis, 2008). Hence, favourable temperature conditions at flowering stage affected heading, and increased the number of grains, consequently resulting in high yield (du Plessis, 2008; Craufurd and Wheeler, 2009).Average maximum temperature at flowering stage accounted for 33.4% of the variation in the yield of sorghum at Chobe agricultural district.

For Barolong agricultural sub-district, sorghum yield showed strong relationship with rainfall as opposed to average maximum temperature. Nevertheless, high yield could still be obtained even if there was no influence of rainfall distribution because increased number of rainy days at maturity stage reduced yield dramatically while for pre sowing stage increased number of rainy days has less decrease in the final yield. All the same, increased rainfall amount at maturity stage increased final sorghum yield. For pre sowing stage, rainfall should be at least moderately spread prior to sowing stage to allow adequate soil moisture for crop germination, hence, the moisture status of the soil at planting is more important for good germination or sustained growth of seedlings (Ibrahim et al., 2011). At maturity stage, increased rainfall amount was essential for the development of the crop as opposed to rainfall distribution. Hence, rainfall amount determined the soil moisture availability that might have resulted in full grain fill and therefore high grain weight, thereby, increased the manufacturing of carbohydrates and ultimately increased yield (TNAU, 2008). Mwiturubani and Wyk (2010) also noticed high correlation of land cultivation to total rainfall in Botswana. Total number of rainy days at pre-sowing stage, total number of rainy days at maturity stage and total rainfall amount at maturity stage accounted for 61.6% of the variation in the yield of sorghum at Barolong agricultural sub-district. The model was found to be accurate because the computed RMSE was low (24.6%), hence, fits well in the prediction of sorghum yield at Barolong agricultural sub-district.

The most sensitive stage for sorghum grain yield loss for Chobe agricultural district was the flowering stage while for Barolong agricultural sub-district included the pre-sowing and maturity stages. The results from this study confirm findings of other studies that sorghum yield potential is high with fairly high temperature at flowering stage (Eze, 2001). Maman et al., (2003) also, noticed high sorghum yield with an increase in rainfall amount at maturity stage. However, the study noticed a decrease in sorghum yield when there is lengthening of rainfall distribution at pre-sowing while Eze (2001) revealed an increase in rainfall amount at pre-sowing stage which led to better sorghum establishment thereby improved performance of vegetative and flowering stages, hence, increased yield. Total seasonal rainfall amount was found to be adequately estimate sorghum yield (Abunyewal et al., 2011; Munodawafa, 2012) while in this case is the opposite.

CHAPTER SIX

6.0 CONCLUSION AND RECOMMENDATIONS

6.1 Conclusion

Temperature and rainfall are important determinants for sorghum grain yield. Maximum temperature at flowering stage had positive effects on sorghum yield for Chobe agricultural district. For Barolong agricultural sub-district, total number of rainy days at pre-sowing and maturity stages had negative effects on yield whereas total rainfall amount at maturity stage have positive effects on sorghum grain yield. From the study it has been found that contributions of temperature and rainfall during various growth stages of sorghum, accounted for variations of sorghum yield in Chobe agricultural district and Barolong agricultural sub-district. As the two districts have soils which have high clay content, different water holding capacities and do not experience equal rainfall, sorghum crop responded differently to weather elements. Rainfall in Chobe district is high, hence water is not a limiting factor to sorghum as it is intolerant to water stress. That is for Barolong, total rainfall distributions at pre-sowing stage estimate 0.829 kg/ha decrease in yield while for Chobe, average maximum temperatures at flowering stage estimates 0.223 kg/ha increase in yield as an early warning. Hence, this can contribute to food security. With time at maturity stage, total rainfall amounts predict 0.912 kg/ha increase in sorghum grain yield while total rainfall distributions predict 3.376 kg/ha decrease in yield for Barolong agricultural sub-district. Sorghum yield had high correlation with total rainfall amount at maturity stage (0.85), total rainfall distribution at maturity stage (0.79) and total rainfall distribution at pre-sowing stage (0.71) for Barolong agricultural sub-district. For Chobe district, only average maximum temperature at flowering stage had high correlation (0.62) with sorghum yield. Therefore, average maximum temperature was needed to dry up the soils so as to reduce the potential for flooding which can lead to ergot diseases.

Crops react differently to climatic parameters at various stages of development and these responses are usually manifested in the final yield of the crop, hence, not only reliable climatological data for the growing season is needed but it is also essential to know the temporal distribution of a climatological variable at each growth stage, as an early warning system for the final crop yield that will be obtained at the end of the growing season. Thus earlier information of climatic variables on crop yield influences the economic prosperity of the country, hence, a necessity in policy making. That is, optimum environmental conditions should be provided at these stages to increase sorghum grain yield at both agricultural districts in order to attain food security in Botswana.

6.2 Recommendations

Considering the results of this study, maximum temperature has positive effect on sorghum yield at flowering stage for Chobe agricultural district, hence sorghum should be planted in such that flowering stage concedes with months of high temperatures for high sorghum yield. While for Barolong agricultural sub-district, sorghum should start to be planted early during first rains so as for seeds not to be in the middle of the rainy season, thus they should experience required rainfall distribution, hence good establishment therefore high yield. Also, for Barolong sorghum should be planted during periods where maturity stage concedes with months of high rainfall amount provided the rains are fairly distributed. Findings of this study are specifically to Chobe agricultural district and Barolong agricultural sub-district and the agricultural settings of Chobe and Barolong may differ from the other areas in Botswana. It is therefore proposed that similar studies be done in other environments different from that of Chobe agricultural district and Barolong agricultural sub-district to relate growing season rainfall to crop yield as an early warning system to food security in Botswana. Also other arable crops such as maize, millet and cowpeas should be studied.

REFERENCES

Abunyewal, A.A, Ferguson, R.B, Wortmann, C.S and Lyon, D.J (2011) Grain sorghum water use with skip-row configuration in the Central Great Plains of the United States of America. *African Journal of Agricultural Research* 6: 5328-5338

Adeniyi, M.O, Ogunsola, O.E, Nyamphas, E.F and Oladiran, E.O (2009) Food security measures during uncertain climate conditions in Nigeria. *African Journal of Food* 9: 652-672

Armah-Agyeman, G., Lolland, J., Karow, R., Payne, W.A, Trostle, C. and Bean, B. (2002) Grain Sorghum, Extension Service, Oregon State University

Araya, A. and Stroosnijder, L. (2010) Effects of tied ridges and mulch on barley (*Hordeum vulgare*) rainwater use efficiency and production in Northern Ethiopia. *Agricultural Water Management* 97: 841-847

Araya, A. and Stroosnijder, L. (2011) Assessing drought risk and irrigation need in northern Ethiopia*Agricultural and Forest Meteorology* 151:425-436

Ayanlade, A. and Odekunle, T.O (2009) GIS Approach in Assessing Seasonal Rainfall Variability in Guinea Savanna Part of Nigeria, Nigeria

Batisani, N. and Yarnal, B. (2010) Rainfall variability and trends in semi-arid Botswana: Implications for climate change adaptation policy. *Applied Geography* 30: 483-489

Blair, N. (2010) The impact of soil water content and water temperature on wet aggregate stability, 19th World Congress of Soil Science, Soil Solutions for a changing world, Brisbane, Australia

Chanda, R., Ayaonde, J. and Gwebu, T. (2001) Botswana National Atlas: Geography of Botswana, First edition, Department of Surveys and Mapping, Gaborone, Botswana

Chikohzo, C. (2010) Adaptation to climate change and rainfall variability in the rain-fed agricultural sector of Zimbabwe, Pretoria, South Africa. *Physics and Chemistry of the Earth* 35:780-790

Chipanshi, C., Chanda, R. and Totolo, O. (2003) Vulnerability Assessment of the Maize and Sorghum crops to climate change in Botswana, University, Gaborone, Botswana

Cooper, P.J.M, Dimes, J., Rao, K.P.C, Shapiro, B., Shiferaw, B. and Twomlow, S. (2008)Coping better with current climate variability in the rain-fed farming systems of Sub-Saharan Africa: An essential first step in adapting to future climate change? *Agriculture, Ecosystems and Environment* 126: 24-35

Craufurd, P.Q and Wheeler, T.R (2009) Climate change and the flowering time of annual crops. *Journal of Experimental Botany* 60: 2529-2539

Department of Agricultural Research, (DAR), (1999) Field Crops Reference Handbook in Botswana, Division of Arable Research, Ministry of Agriculture, Gaborone, Botswana duPlessis, J. (2008) Sorghum production, Department of Agriculture, Pretoria, South Africa

Ekaya, W.N, (2007) Strategies for Developing Dryland Agriculture: Role of Knowledge, Department of Land Resources Management and Agricultural Technology, College of Agricultural and Veterinary Services, University of Nairobi, Nairobi, Kenya

Ekpoh, I.J, (2010) Adaptations to the Impact of Climatic Variation of Agriculture by Rural Farmers in North –Western Nigeria. *Journal of Sustainable Development* 3

Eze, O.J (2001) Effect of late planting on the performance and yield of sorghum intercropped with maize, A project submitted in partial fulfilment of the requirement for the Agrometeorology and Water Resource Management, University of Agriculture, Abeokuta, Nigeria

Farah, S.M, Salih, A.A, Taha, A.M, Ali, Z.I and Ali, I.A (1997) Grain sorghum response to supplementary irrigations under post-rainy season conditions. *Agricultural Water Management* 33: 31-41

Fischer, G., Shah, M., Tubiello, F.N, and van Velhuizen H. (2005) Socio-economic and climate change impacts on agriculture: an integrated assessment, 1990–2080. *Philos Trans R SocLond B* 360: 2067–2083

Gadgil, S., Rao, S.P.R and Rao, N.K (2002) Use of climate information for farm level decision making: Rain-fed groundnut in southern India. *Agricultural Systems* 74, 431-457

Gebrekidan, H. (2003) Grain Yield Response of Sorghum (Sorghum bicolor) to Tied Ridges and Planting Methods of Entisols and Vertisols of Alemaya Area, Eastern Ethiopian Highlands. *Journal of Agriculture and Rural Development in the Tropics and Sub-tropics* 104: 113-128

Graef,F.and Halgis, S. (2001) Spatial and temporal rainfall variability in the Sahel and its effect on farmers' management strategies. *Journal of Arid Environments* 48: 221-231

Hess, T.M, Stephens, W. and Maryah, U.M (1995) Rainfall trends in the North East Arid Zone of Nigeria 1961-1990*Agricultural and Forest Meteorology* 74: 87-97

Ibrahim, A. A, Ati, F.O and Adebayo, A.A (2011) Effect of climate on the Growth and Yield of Sorghum (Sorghum bicolor) in Wailo, Gaujwa Local Government Area, Bauchi State. *Research Journal of Environmental and Earth Sciences* 3: 4469-472

Jerie, S. and Ndabaningi, T, (2011) The Impact of Rainfall Variability on Rain-fed Tobacco in Manicaland province of Zimbabwe. *Journal of Sustainable Development in Africa* 13

Lobell, D.B andAsner, G.P (2003) Climate and management contributions to recent trends in U.S. agricultural yields. *Science* 299: 1032

Lobell, D.B and Field, C.B (2007) Global Scale Climate- Crop yield relationships and the impacts of recent warming, Eviron, Res Lett, 2

Lobell, D.B, Burke, M.B, Tebaldi, C, Mastrandrea, M.D, Falcon, W.P and Naylor, R.L (2008) Prioritizing climate change adaptation needs for food security in 2030. *Science* 319: 607–610

Mall, R.K, Singh, R, Gupta,A, Srinivasan, G, Rathore, L.S (2006) Impact of climate challenges on Indian agriculture: a review. *Clim Change* 78: 445–478

Maman, N, Lyon, D.J, Mason, S.C, Galusha, T.D and Higgins, R. (2003) Pearl, millet and grain sorghum yield response to water supply in Nebraska. *Agron. J.* 95: 1618-1624

Mary, A.L and Majule, A.E (2009) Impacts of climate change, variability and adaptation strategies on agriculture in semi-arid areas of Tanzania: The case of Manyoni District in Singida Region. *African Journal of Environmental Science and Technology* 3: 206-218

Mehta, D.R, Kalola, A.D, Saradava, D.A and Yusufzai, A.S (2002) Rainfall variability analysis and its impact on crop productivity- A case study. *Indian J. Agric Res* 36: 29-33

Ministry of Agriculture, (MoA) (2000) National Master Plan for Arable Agricultural Development, Final report Vol. 1, Main Report, Tahal Consulting Engineers Ltd

Ministry of Agriculture, (MoA) (2009) Arable agriculture statistics, Plant production, Gaborone, Botswana

Mollah, W.S and Cook, I.M (1996) Rainfall variability and agriculture in the semi-arid tropics- the Northern Territory, Australia. *Agricultural and Forest Meteorology* 79, 39-60

Mogotsi, K., Moroka, A.B, Sitang, O. and Chibua, R. (2011) Seasonal precipitation forecast: Agro-ecological Knowledge among rural Kalahari communities. *African Journal of Agricultural Research* 6:916-922

Munodawafa, A. (2012) The effect of rainfall characteristics and tillage on sheet erosion and maize grain yield in Semi-arid conditions and granitic sandy soils, Department of Land and Water Resources Management, Midlands State University, Gweru, Zimbabwe

Mutava R.N (2009) Characterization of grain sorghum for physiological and yield traits associated with drought tolerance, A Thesis submitted in partial fulfillment of the requirement for the degree Masters of Science, Department of Agronomy, Kansas State University, Manhattan, Kansas

Mwamba, B.C (2007) Effect of rainfall variability on crop yield under semi-arid conditions at sub-catchment level, Master Thesis, University of Zimbabwe, Zimbabwe

Mwang'ombe, A.W, Ekaya, W.N, Muiru, W.M, Wasonga, V.O, Mnene, W.M, Mongare, P.N and Chege, S.W (2011) Livelihoods under climate variability and change: Analysis of the Adaptive Capacity of Rural Poor to water scarcity in Kenya' Drylands. *Journal of Environmental Science and Technology* 4:403-410

Mwiturubani, D.A and Wyk, J. (2010) Climate change and natural resources conflicts in Africa, Institute for security studies, South Africa, Pretoria

Ngole, V.M and Ekosse, G.E (2008) Physico-chemistry and mineralogy related to productivity of arenosol, luvisol and vertisol. *Iranian Journal of Science and Technology* Transaction A

Omonona, B.T and Akintola, O.K (2009) Rainfall effects on water use and yield of cocoa in Nigeria.*Continental J. Agricultural Economics* 3: 52-60

Parida, B.P and Moalafhi, D.B (2008) Regional rainfall frequency analysis for Botswana. *Physics and Chemistry of the Earth* 33, 614-620

Parry, M., Rosenzweig, C.and Livermore, M. (2005) Climate change, global food supply and risk of hunger.*Philos Trans R SocLond B* 360: 2125–2138

Pilane S., Phirie, S. and Moleta, S. (2004) Social studies Atlas for Botswana. New edition, Macmillan Botswana Publishing Company (Pty) Ltd. Gaborone, Botswana

Porter,J.RandSemenov, M.A (2005) Crop responses to climatic variation. *Philos Trans R SocLond B* 360: 2021–2035

Pujar, A., Jaiswal, P., Kellogg, E.A, Ilic, K., Vincent, L., Avraham, S., Stevens, P., Zapata, F., Reiser, L., Rhee, S., Sachs, M.M, Sachaeffer, M., Stein, L., Ware, D. and McCouch, S. (2006) Whole-plant growth stage ontology for angiosperms and its application in plant biology. *Plant Physiology* 142: 414-428

Qian, B., De Jong, R., and Gameda, S. (2009a) Multivariate analysis of water-related agroclimatic factors limiting spring wheat yields on the Canadian prairies. *European Journal of Agronomy* 30: 140-150

Qian, B., De Jong, R., Warren, R., Shipanshi, A. and Hill, H. (2009b) Statistical spring Wheat Yield forecasting for the Canadian Prairie provinces. *Agricultural and Forest Meteorology* 149: 1022-1031

Ramothwa, G. and Minja, W. (2001) Botswana National Atlas: Weather and Climate, First edition, Department of Surveys and Mapping, Gaborone, Botswana

Republic of Botswana, (2011) Population and Housing Census, Central Statistical Office, Ministry of Finance and Development Planning, Gaborone

Rowhani, P, Lobell, D.B, Linderman, M. and Ramankutty, N. (2011) Climate variability and crop production in Tanzania. *Agricultural Forest Meteorology* 151:449-460

Rosenzweign, C., Iglesius, A., Yang, X.B, Epstein, P. R and Chivian, E. (2001) Climate change and extreme weather events- Implications for food production, plant diseases and pests. NASA Publications, Paper 24, University of Nebraska, Lincoln

Sakurai, G., Iizumi, T. and Yokozawa, M. (2011)Varying temporal and spatial effects of climate on maize and soybean affect yield prediction. *Climate Research* 49: 143-154

Sawa, B.A and Ibrahim, A.A (2011) Forecast Models for the Yield of Millet and Sorghum in the Semi-arid Region of Northern Nigeria using Dry Spell Parameters. *Asian Journal of Agricultural Sciences* 3: 187-191

Schlenker, W. and Roberts, M.J (2009) Non-linear temperature effects indicate severe damages to U.S. crop yields under climate change. *Proc Natl. Acad. Sci. USA* 106: 15594–15598

Southern African Development Community, (SADC) (2008) Implementation and Coordination of Agricultural Research and Training (Botswana), Botswana College of Agriculture consults, Final Report, Gaborone, Botswana

Sowunmi, F.A and Akintola, J.O (2010) Effect of Climate Variability on Maize Production in Nigeria.*Research Journal of Environmental Sciences* 2: 19-30

Spackman, G.B, McCosker, K.J, Farquharson, A.J and Conway, M.J (2001) Innovative management of grain sorghum in Central-Queensland, Australian Agronomy Conference, Emerald, Queensland

Stephens, D.J and Lyons, T.J (1998) Rainfall-Yield Relationships across the Australian Wheatbelt.*Aust. J. Agri. Res.* 49, 211-223

Tamil Nadu Agricultural University (TNAU) (2008) Seed certification, Coimbatore

Thompson, H.E, Ford, L.B and Ford, J.D (2010) Climate change and Food security in Sub-Saharan Africa: A systematic Literature Review. *Sustainability* 2, 2719-2733

Turk, M.A, Rahman, A. and Tawaha, M. (2002) Response of sorghum genotypes to weed management under Mediterranean conditions. *Journal of Agronomy* 1: 31-33

United Nations, (UN) (2007) Second Common Country Assessment for Botswana, Final Report

Victor, U.S, Srivastava, N.N and Kumar, P.V (1994) Drought Vulnerability of Rain-fed crops in Semi-Arid Tropics in India: New Methods of Determining Rainfall variability, University of Nebraska, Lincoln, Drought Network News, paper 90

Vossen, P. (1990) Rainfall and Agricultural production in Botswana, *Afrika Focus*, 6: 141-155

Weare, P. (1971) The influence of environmental factors on Arable Agriculture in Botswana, Botswana Notes and Records 3, 165-168

Wimalasuriya, R., Arthur, H., Tsafack, E. and Larson, K. (2008) Rainfall Variability and its Impact on Dryland Cropping in Victoria, Department of Primary Industries, Victoria, Australia

APPENDICES

Appendix 1

SAS input data for differences in means of sorghum yield (Chobe agricultural district)

```
options formdlim = '_';
data crop;
input amountseas yield dayseas period @@ ;
cards;
355.35 42.5 7 1
 295.5 42.5 7 1
 381.3 57.5 8 1
 385.5 42.5 9 1
 555.225 5.5 9 1
 378.9 9.5 11 2
 373.8 67.5 10 2
 362.25 55.5 8 2
 345.575 97.5 11 2
 370.65 55.5 10 2
 260.325 54.5 6 3
 316.275 86.5 8 3
 291.15 5.5 9 3
 522.6 42.5 10 3
 271.275 51.5 8 3
 ;
proc print;
run;
proc means mean std stderr clm;
var yield;
class period;
run;
proc means mean std stderr clm data=crop;
var yield;
run;
```

;AS output data for differences in means of sorghum yield (Chobe agricultural district)

The MEANS Procedure

Analysis Variable : yield

period	N Obs	Mean	Std Dev	Std Error
1	5	38.1000000	19.3468344	8.6521674
2	5	57.1000000	31.6670175	14.1619208
3	5	48.1000000	29.0396281	12.9869165

Analysis Variable : yield

period	N Obs	Lower 95% CL for Mean	Upper 95% CL for Mean
1	5	14.0777323	62.1222677
2	5	17.7802044	96.4197956
3	5	12.0425393	84.1574607

SAS input data for differences in means of sorghum yield (Barolong agricultural sub-district)

```
options formdlim = '_';
data crop;
input amountseas yield dayseas period @@ ;
cards;
355.35 42.5 7 1
 295.5 42.5 7 1
 381.3 57.5 8 1
 385.5 42.5 9 1
 555.225 5.5 9 1
 378.9 9.5 11 2
 373.8 67.5 10 2
 362.25 55.5 8 2
 345.575 97.5 11 2
 370.65 55.5 10 2
 260.325 54.5 6 3
 316.275 86.5 8 3
 291.15 5.5 9 3
 522.6 42.5 10 3
 271.275 51.5 8 3
 ;
proc print;
run;
proc means mean std stderr clm;
var yield;
class period;
run;
proc means mean std stderr clm data=crop;
var yield;
run;
```

SAS output data for differences in means of sorghum yield (Barolong agricultural sub-district)

The MEANS Procedure

Analysis Variable : yield

period	N Obs	Mean	Std Dev	Std Error
1	5	320.0000000	152.1528836	68.0448382
2	5	494.0000000	561.6702769	251.1865840
3	5	573.0000000	453.1098101	202.6368673

Analysis Variable : yield

period	N Obs	Lower 95% CL for Mean	Upper 95% CL for Mean
1	5	131.0772422	508.9227578
2	5	-203.4057617	1191.41
3	5	10.3898616	1135.61

Appendix 2

(Chobe agricultural district)

```
optionsformdlim = '_';
title'Multiple Linear Regression using PROC REG Procedure';
data crop;
input year amountpre amountveg amountflo amountmat amountseas yield daypre dayveg dayflow daymat
dayseas tempveg tempflo tempmatu tempseas;
cards;
83 0 1.993 2.167 2.053 2.552 1.63 0 0.301 0.602 0.602 0.903 31.9 33.3 30.2 32.0
84 0 1.500 2.233 1.982 2.472 1.63 0 0.301 0.699 0.477 0.903 33.5 30.0 31.9 31.3
85 0.775 1.911 1.825 2.373 2.582 1.76 0 0.602 0.602 0.477 0.954 32.9 31.7 30.0 31.9
86 0 1.605 2.451 1.817 2.87 1.63 0 0.301 0.778 0.602 1.000 33.9 30.8 29.7 31.5
88 0 1.552 2.249 2.538 2.745 0.74 0 0.301 0.778 0.602 1.000 36.3 30.6 31.4 32.7
89 0.641 1.431 2.229 2.193 2.580 0.98 0 0.477 0.699 0.699 1.079 34.0 30.2 31.1 31.0
90 0 1.777 1.992 2.340 2.574 1.83 0 0.477 0.699 0.699 1.041 33.5 33.2 29.4 32.3
91 1.440 1.124 2.374 2.065 2.560 1.74 0.301 0 0.778 0.602 0.954 36.3 32.5 29.4 33.5
95 0 1.778 2.139 2.178 2.539 1.99 0 0.602 0.778 0.602 1.079 34.6 32.8 31.1 32.9
96 0.061 1.804 2.046 2.298 2.570 1.74 0 0.477 0.778 0.602 1.041 35.1 31.4 28.7 31.8
97 0 1.960 1.604 2.120 2.417 1.74 0 0.477 0.477 0.477 0.845 35.7 31.1 28.7 31.9
98 1.323 1.953 1.796 2.223 2.501 1.94 0.301 0.699 0.477 0.477 0.903 33.5 32.5 32.1 32.7
99 0.114 2.116 2.040 1.730 2.467 0.74 0 0.602 0.699 0.477 1.000 34.4 30.6 30.1 32.1
00 0 1.630 2.324 2.435 2.719 1.63 0 0.477 0.778 0.602 1.041 34.4 31.1 29.9 31.8
03 1.397 1.827 2.008 2.022 2.433 1.71 0 0.477 0.477 0.699 0.903 34.2 32.7 32.2 33.0
;
procprint;
run;
procreg;
model yield=amountpre amountveg amountflo amountmat amountseas daypre dayveg dayflow daymat
dayseas tempveg tempflo tempmatu tempseas /ss1ss2corrb
selection=stepwise details=summary;
run;
proccorr;
var yield amountpre amountveg amountflo amountmat amountseas daypre dayveg dayflow daymat dayseas
tempveg tempflo tempmatu tempseas;
run;
```

SAS output data of correlation analysis (Chobe agricultural district)

The CORR Procedure

Pearson Correlation Coefficients, N = 15
Prob> |r| under H0: Rho=0

	yield
amountpre	0.20482 0.4640
amountveg	0.07122 0.8009
amountflo	-0.26063 0.3481
amountmat	0.08094 0.7743

amountseas	-0.18436
	0.5107
daypre	0.28075
	0.3108
dayveg	0.08494
	0.7634
dayflow	-0.26303
	0.3436
daymat	-0.03404
	0.9042
dayseas	-0.24311
	0.3826
tempveg	-0.25226
	0.3644
tempflo	0.61782
	0.0141
tempmatu	0.13632
	0.6281
tempseas	0.23328
	0.4027

SAS output data of the regression analysis (Chobe agricultural district)

The REG Procedure

Model: MODEL1
Dependent Variable: yield

Summary of Stepwise Selection

Step	Variable Entered	Variable Removed	Number Vars In	Partial R-Square	Model R-Square	C(p)	F Value	Pr > F
1	tempflo		1	0.3817	0.3817	.	8.03	0.0141

Multiple Linear Regression using PROC REG Procedure

The REG Procedure
Model: MODEL1
Dependent Variable: yield

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Value	Pr> F
Model	1	0.86364	0.86364	8.03	0.0141
Error	13	1.39900	0.10762		
Corrected Total	14	2.26264			

Root MSE	0.32805	R-Square	0.3817
Dependent Mean	1.56200	Adj R-Sq	0.3341
CoeffVar	21.00177		

Parameter Estimates

Variable	DF	Parameter Estimate	Standard Error	t Value	Pr> |t|	Type I SS	Type II SS
Intercept	1	-5.48284	2.48824	-2.20	0.0462	36.59766	0.52252
tempflo	1	0.22270	0.07861	2.83	0.0141	0.86364	0.86364

SAS input data of the correlation and regression analysis (Barolong agricultural sub-district)

```
optionsformdlim = '_';
title'Multiple Linear Regression using PROC REG Procedure';
data crop;
input year amountpre amountveg amountflo amountmat amountseas yield daypre dayveg
dayflow daymat dayseas tempveg tempflo tempmatu tempseas;
cards;
86 1.322 1.865 1.921 1.503 2.275 2.616 0.301 0.477 0.602 0.301 0.845 33.1 32.9 33.3 33.1
87 1.760 1.667 1.900 1.547 2.280 2.542 0.602 0.301 0.602 0.301 0.778 30.7 33.9 35.2 33.3
88 1.954 1.856 2.104 2.243 2.588 1.792 0.699 0.602 0.778 0.699 1.114 32.9 33.0 30.5 32.3
89 1.916 1.519 2.182 1.944 2.446 2.711 0.477 0 0.778 0.477 0.903 29.4 31.3 29.1 30.1
90 0.999 2.039 1.772 1.925 2.403 2.401 0 0.699 0.477 0.699 1.041 30.6 32.5 30.3 31.3
93 1.391 2.295 1.534 1.699 2.470 1.785 0.301 0.778 0.301 0.602 1.000 31.2 33.2 31.0 31.9
95 0.958 1.483 1.923 1.337 2.299 3.159 0 0 0.602 0.301 0.699 32.7 34.4 32.8 33.4
96 1.708 1.985 2.199 1.691 2.491 2.398 0.477 0.602 0.778 0.477 1.041 31.7 30.0 28.7 30.2
97 1.455 2.098 2.149 2.252 2.682 2.685 0 0.477 0.778 0.602 1.114 30.4 30.7 31.6 30.9
98 1.507 1.745 2.105 2.031 2.519 3.124 0.477 0.477 0.602 0.477 0.903 32.2 32.2 33.8 32.7
99 1.756 2.173 1.901 1.288 2.420 2.708 0.301 0.602 0.602 0.301 0.903 30.1 32.0 33.5 31.8
00 1.525 2.109 2.436 1.525 2.664 2.728 0.477 0.477 0.699 0.301 0.903 32.0 28.8 28.2 29.6
01 1.659 1.917 1.463 1.866 2.298 2.435 0.301 0.477 0.301 0.477 0.778 31.2 32.5 30.3 31.8
02 1.897 2.107 1.758 1.033 2.335 2.375 0.602 0.699 0.602 0.302 0.954 28.0 31.3 29.8 29.8
;
procreg;
model yield=amountpre amountveg amountflo amountmat amountseas daypre dayveg dayflow
daymat dayseas tempveg tempflo tempmatu tempseas /sslss2corrb
selection=stepwise details=summary;
run;
proccorr;
var yield amountpre amountveg amountflo amountmat amountseas daypre dayveg dayflow
daymat dayseastempveg tempflo tempmatu tempseas;
run;
```

SAS output data of correlation analysis (Barolong agricultural sub-district)

The CORR Procedure

Pearson Correlation Coefficients, N = 14
Prob> |r| under H0: Rho=0

	Yield
amountpre	-0.32411 0.2583
amountveg	-0.50156 0.0677
amountflo	0.35924 0.2071
amountmat	-0.19859 0.4961
amountseas	-0.11584 0.6933

daypre	-0.32644 0.2547
dayveg	-0.62646 0.0165
dayflow	0.23591 0.4168
daymat	-0.54566 0.0436
dayseas	-0.55675 0.0386
tempveg	0.06264 0.8315
tempflo	-0.07731 0.7928
tempmatu	0.33573 0.2406
tempseas	0.13887 0.6359

SAS output data of the regression analysis (Barolong agricultural sub-district)

The REG Procedure

Model: MODEL1
Dependent Variable: yield

Summary of Stepwise Selection

Variable Step	Variable Entered	Number Removed	Partial VarsIn	Model R-Square	R-Square	C (p)	F Value	Pr> F
1	dayveg	1		0.3924	0.3924	.	7.75	0.0165
2	daymat	2		0.1183	0.5108	.	2.66	0.1311
3	daypre	3		0.1196	0.6304	.	3.24	0.1022
4	amountma	4		0.0940	0.7243	.	3.07	0.1138
5	dayveg	3		0.0198	0.7045	.	0.65	0.4417

The REG Procedure
Model: MODEL1
Dependent Variable: yield

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Value	Pr> F
Model	3	1.44448	0.48149	7.95	0.0053
Error	10	0.60589	0.06059		
Corrected Total	13	2.05037			

Root MSE 0.24615 R-Square 0.7045
Dependent Mean 2.53279 Adj R-Sq0.6158
Coeff Var 9.71846

Parameter Estimates

Variable	DF	Parameter Estimate	Standard Error	t Value	Pr> |t|	Type I SS	Type II SS
Intercept	1	2.79766	0.36690	7.63	<.0001	89.81005	3.52271
amountmat	1	0.91181	0.33071	2.76	0.0202	0.08086	0.46057
daypre	1	-0.82943	0.30241	-2.74	0.0207	0.24334	0.45579
daymat	1	-3.37601	0.78512	-4.30	0.0016	1.12028	1.12028

Where:

amountpre is the amount of total rainfall at pre-sowing stage

amountveg is the amount of total rainfall at vegetative stage

amountflo is the amount of total rainfall at flowering stage

amountmat is the amount of total rainfall at maturity stage

amountseas is the amount of total seasonal rainfall

daypre is the total number of rainy days at pre-sowing stage

dayveg is the total number of rainy days at vegetative stage

dayflow is the total number of rainy days at flowering stage

daymat is the total number of rainy days at maturity stage

dayseas is the total number of rainy days for the growing season tempveg is the average maximum temperature at vegetative stage

tempflo is the average maximum temperature at flowering stage

tempmatu is the average maximum temperature at maturity stage

tempseas is the average maximum temperature for the total growing season