EFFECTS OF PLANT POPULATION ON GROWTH, DEVELOPMENT AND OIL YEILD OF SAFFLOWER (Carthamus tinctorious L.)

MASTER OF SCIENCE CROP SCIENCE (HORTICULTURE)

BY

BOIPUSO KEDIKANETSWE

SEPTEMBER 2012

UNIVERSITY OF BOTSWANA

BOTSWANA COLLEGE OF AGRICULTURE

EFFECTS OF PLANT POPULATION ON GROWTH, DEVELOPMENT AND OIL YIELD OF SAFFLOWER (*Carthamus tinctorius* L.)

A Dissertation Presented to the Department of Crop Science and Production in Partial Fulfillment of the Requirements for the Degree of Masters of Science (MSc) in Crop Science (Horticulture) Botswana College of Agriculture/ University of Botswana

By

BOIPUSO KEDIKANETSWE ID NO. 200010005

SEPTEMBER 2012

Main Supervisor
Prof. V. Emongor
Department of Crop Science and Production
Botswana College of Agriculture

Co-Supervisor
Dr. O. Oagile
Department of Crop Science and Production
Botswana College of Agriculture

CERTIFICATION

PROF. VALLANTINO EMONGOR

Main Supervisor's Name and Signature

10TH SEPTEMBER 2012

Date

DR OTSOSENG OAGILE

Co-Supervisor's Name and Signature

10th September 2012

Date

DR. SAMODIMO NGWAKO

Head of Department's Name and Signature

10th September 2012

Date

APPROVAL

PROF. VALLANTINO EMONGOR

Main Supervisor's Name and Signature

10TH SEPTEMBER 2012

Date

DR ORSOSENG OAGILE

Co-Supervisor's Name and Signature

10th September 2012

Date

DR SAMODIMO NGWAKO

Head of Department's Name and Signature

10th SEPTEMBER 2012

Date

PROF E B KHONGA

Dean of Faculty's Name and Signature

10/09/2012

Date

<u>STATEMENT OF ORIGINALITY</u>

The work contained in this dissertation was compiled by the author at the University of Botswana, Botswana College of Agriculture between January 2009 and July 2012. It is original except where references are made and it will not be submitted for the award of any other degree or diploma of any other university.

BOIPUSO KEDIKANETSWE [signature] 10/09/12

Author's Name and Signature Date

ACKNOWLEDGEMENT

I wish to express my appreciation and gratitude to main supervisor Professor V. Emongor and co-supervisor Dr. O. Oagile. I could have not successfully finished writing this dissertation without their constant supervision. I thank them for the time they spared for me in order for this work to be completed.

I also extend my gratitude to the writers of the scripts referenced to in writing this dissertation. The supplier of oil expressing machine (T&T Geomatics PTY LTD) is also thanked for the training the company rendered after delivering the machine. Botswana College of Agriculture also deserves to be thanked for offering the scholarship and providing all the equipments and resources used in preparation of this dissertation. I would like to thank the casual workers who helped during plot preparation, planting, weeding, fertilizer application and harvesting of the crop. However, special thanks go to my wife Annastacia, son Setso and daughters Goata and Melodi for giving me moral support during this work.

ABSTRACT

Two field trials were done in the winter of 2010 and summer of 2010/2011 to evaluate the effects of plant density on the growth, development and yield of safflower. The results showed that plant density and season of growth had significant ($P < 0.05$) effects on growth, development, yield components, seed yield and seed oil content of safflower. Increasing safflower plant density from 100,000 to 250,000 plants/ha significantly ($P < 0.05$) reduced plant height (13.2-21.3%), branch number/plant (37-54.7%), leaf number/plant (39-39.2%), leaf area (19.5-53%), plant spread (39.6-54.4%), root length (28.1-54.4%), plant biomass (17-50%), capitula size (12-12.7%), capitula number/plant (39.5-50.5%), seed number/capitula (39-45%), capitula weight (3.3-3.6%), seed yield (67.9-69.8%) and seed oil content (14.7-20.8%) depending on season of growth. The reduction in vegetative growth, yield components, seed yield and seed oil content of safflower due to increased plant density was attributed to mutual competition (inter and intra-plant competition) for light, nutrients and water necessary for growth and development. Winter prolonged the maturation period of safflower by 22 days compared summer. Winter grown safflower was better in quality in all the variables measured than summer grown safflower. The differences between winter and summer grown safflower was attributed to DIF and the average daily temperature which were optimum for safflower growth in winter. Based on the results of the study, it was concluded that plant density and season have a significant effect on the growth, development, yield components, yield and seed oil content of safflower. Under Botswana conditions, safflower should be planted at 50 cm x 20 cm or wider in order to maximize yield and oil content and allow the plants to express their maximum genetic potential.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF ABBREVIATIONS

ANOVA	Analysis of Variance
BIDPA	Botswana Institute for Development Policy Analysis
DAE	Days After Emergence
FAO	Food and Agricultural Organization
GDP	Gross Domestic Product
LAD	Leaf Area Duration
LAI	Leaf Area Index
MoA	Ministry of Agriculture
NAR	Net Assimilation Rate
NDP	National Development Policy
SACU	Southern African Customs Union
SADC	Southern African Development Community
SAS	Statistical Analysis System
WAE	Weeks After Emergence

CHAPTER 1

INTRODUCTION

1.1 General Introduction of Safflower

Safflower (*Carthamus tinctorius* L.) is a herbaceous annual oilseed crop (Knowles and Ashri, 1995) which belongs to the Compositae or Asteraceae family. It is a multipurpose crop commercially grown in Western North Dakota and Eastern Montana (Gonzalez, *et al.*, 1994) mainly for its high quality edible oil and bird seeds. Initially safflower oil was used as source of oil for paint industry and now its edible oil is used for making margarine, salad oil and for cooking. Safflower is also grown for its flowers (which are used as dyes in the textile industry), making herbal tea, vegetable, livestock feeds and for medicinal purposes (Emongor, 2010).

Safflower has been one of the humanity's oldest crops grown in the world. Its seeds have been found in Egyptian tombs over 4,000 years ago (Weiss, 1983). It is commonly known as kusum in India and Pakistan and honghua in China (Chavan, 1961). Its common name varies with country, region, language and use (Chavan, 1961; Smith, 1996). In 1989, the world seed production of safflower was estimated at 908 000 tons (Rowland, 1993). India, Mexico and USA are the major producers of safflower (Rowland, 1993). In the whole world, India is the largest producer of safflower that it accounts for one third of the world's production and uses it mainly in oil production (Rowland, 1993). Mexico also produces large quantities of safflower oil for domestic consumption and export (Bassil and Kaffka *et al.*, 2001) and according to FAO (2010), safflower is produced in large areas in India (350 000 ha), Mexico (85 000 ha), Ethiopia (72 000 ha) and

USA (54 000 ha). Other producing countries in decreasing order are Australia (35 000 ha), Argentina (30 000 ha), Uzbeistan (13 000 ha) and China (12 000 ha). In Africa, Ethiopia produces safflower in (72 000 ha) and is the leading producer with production estimated at 34 000 tons of seed per annum (Rowland, 1993). Amount of land under safflower production varies widely from country to country. Seed yields increased considerably from the 1950s until the 1970s, but have remained relatively constant since that time (Bassil and Kaffka *et al.*, 2001).

1.2 Uses of Safflower

1.2.1 Medicinal uses

Traditionally, safflower was grown for its seeds, and was used for colouring and flavouring foods, in medicines, and making red and yellow dyes, especially before cheaper aniline dyes became available (Mohler *et al.*, 1967). Safflower is regarded as a multipurpose oilseed crop that is mainly grown for high quality oil. The uses of safflower have been recorded in China approximately 2,200 years ago (Dajue and Mündel, 1996). In traditional Chinese medicine, safflower petals are regarded as a stimulant for blood circulation and phlegm reduction, healing of fractures, contusions, and strains, and for various female maladies (Dajue and Mündel, 1996). In Europe and the Middle East, petals are sometimes used as an adulterant for saffron. In Pakistan, the seed decoctions are used to produce heat and dryness in the body. When sugar is added it acts as a laxative (Knowles, 1965). The seeds can also be boiled and taken as a remedy for problem in menses to increase blood flow. Ground safflower seeds mixed with mustard oil reduce rheumatic pain (Knowles, 1965). In Kashmir, a decoction of whole or ground seeds is used to flush out the urinary tract, improve the liver and reduce hives (Knowles, 1965). Knowles (1965) and Wang and Yili (1985) reported that safflower seed is used for the treatment of urinary calculi. It has been realized that a nasal drop of safflower and other herbs speed blood flow in the medial cranial artery (Zhenshun *et al.*, 1992). It is also used to treat cerebral thrombosis and it has been reported to lower blood pressure in over 90% of the patients (Dajue and Mündel, 1996).

According to Liu (1985) it can be used to induce labour and is more effective than western medicine. When boiled in wine along with other flower decoctions it is recommended to encounter retained afterbirth and retained stillbirth (Wang and Yili, 1985). Women in Afghanistan and India use a tea made from safflower foliage to prevent abortion and infertility (Weiss, 1983). Herbalists in these countries sell all parts of safflower to cure various ailments and for aphrodisiac purposes (Knowles, 1965).

In April 2007, it was reported that genetically modified safflower has been bred to create insulin (SemBioSys, 2009). A pharmaceutical company called SemBioSys Genetics is currently using transgenic safflower plants to produce human insulin because the global demand for the hormone has grown so high (SemBioSys, 2009). Safflower-derived human insulin is currently in the PI/II trials on human test subjects. Insulin (SBS-1000) that was extracted from safflower plants, and was created by Sembiosys, has been injected into people for the first time. The hope is that plants will provide a cheaper source of insulin for people with diabetes (SemBioSys, 2009).

High oleic safflower oil is lower in saturates and higher in monounsaturated than olive oil. High oleic oil is a beneficial agent in the prevention of coronary artery disease (Mohler *et al.*, 1967).

1.2.2 Livestock feeds

Safflower can be taken as a nutritional supplement. Safflower meal contains about 24 % crude protein and is considerably high in fiber (Landau *et al.*, 2004). Therefore, it is used as a protein supplement in livestock and poultry feeds. Safflower silage has the potential for widespread adoption as a feed in Mediterranean countries. Special characteristics such as protein degradability which it has are taken into account to optimize its inclusion in total mixed ration (TMR) (Landau *et al.*, 2004). It can be grazed or stored as hay or silage and makes palatable forage. Its feed value and yields are similar to or better than oats or alfalfa (Smith, 1996). Safflower also makes an acceptable livestock forage if cut at or just after bloom stage (Bergland *et al.*, 2007).

Another use of safflower seeds is as birdseed especially for members of the parrot family and pigeons (Dajue and Mündel, 1996). Safflower seed is also used quite commonly as an alternative to sunflower in bird feeds, as squirrels do not like the taste of it (Blackshaw, 1993). The bird feed industry prefers to use the white hull or normal hull type of safflower even though striped and partial hull types usually are higher in oil and protein content. The birdseed market does not have a preference for a fatty acid type.

1.2.3 Food uses

Food producers and industries use safflower oil in various ways. Safflower oil is often considered a healthier option than using sunflower oil (Mohler *et al.*, 1967). The oil consists of two types: that which is high in monounsaturated fatty acid (oleic acid) and that which is high in polyunsaturated fatty acid (linoleic acid). At the moment the predominant oil market is for the varieties that produce seeds higher in oleic acid and very low in saturated fatty acids (Mohler *et al.*, 1967).

For the last fifty years or so, the plant has been cultivated mainly for the vegetable oil that is extracted from its seeds. Experimental trials in India have shown that seed production from ratoon crop is possible. Safflower oil is also used as a heat-stable cooking oil to fry such food items as French fries (chips) and other snack items. Safflower oil is also used in cosmetics, food coatings and infant food formulations. Safflower produces flavourless and colourless oil that is nutritionally similar to sunflower oil (Emongor, 2010). Safflower oil is mainly used for cooking, salad dressing and for the production of margarine (Emongor, 2010). The flowers are occasionally used in cooking as a cheaper substitute for saffron (Bergland *et al.*, 2007). In India, Pakistan and Burma young leaves and thinned seedlings are eaten as a vegetable side dish with curry or with rice (Weiss, 1983).

1.2.4 Other uses of safflower

Before 1960 in the United State of America, safflower oil was used mainly as a base for superior quality paints. It is used as a drying agent in paints and varnishes because of its non-yellowing characteristic (Bergland *et al.*, 2007). In textiles, dried flowers are used as natural dyes. Natural dyes from plants are getting more important because of their naturality and fashion trends. The colourful matter in safflower is carthamin which is benzoquinone – based (Garcia, 2009). Hydrophilic fibres like cotton, wool and others can be dyed with safflower dye because it is a direct dye. In Western Europe, Japan and Latin America spineless varieties have been grown as cut flowers (Dajue and Mündel, 1996).

Safflower straws have similar use as straws of cereals. Two or three rows of safflower around a cereal field can help keeping free ranging cattle out of the grain field (Chavan, 1961).

1.3 Justification

At Independence in 1966, Botswana was dependent mainly on agriculture for livelihood. Beef production was the mainstay of the economy in terms of output and export earnings. In 1966, the contribution of agriculture to the Gross Domestic Product (GDP) was 42% and in 2001, its contribution to GDP had declined to 2.6% (NDP, 2003). Currently, mineral revenues account for over 50% of all the government revenues. Other significant contribution to government revenues is from Southern African Customs Union (SACU), income from investment of Foreign exchange reserves and non mineral income tax (NDP, 2003).

If the market for the few products that Botswana is exporting gets affected it will have a serious problem of getting foreign exchange like it has just happened with minerals sales with global economic recession. Botswana has a robust economic growth but remains too dependent on mining diamonds and beef (MoA, 2009). Barnett (1999) reported that diamonds make 80% of Botswana's exports and warned Botswana on the consequences of over dependence on diamonds. It is projected that diamond production is set to decline in 2015 (Blandy, 2009) and this should be a wake up call for Botswana to diversify its economy. Botswana Institute for Development Policy Analysis report that the three engines of growth such as manufacturing, tourism and financial services if they grow, they won't make much economic growth to the country's Gross Domestic Product (GDP), hence the need for diversification of the economy (BIDPA, 2005).

It is of paramount importance for Botswana to diversify its economy in agriculture. This could be achieved by commercial production of crops such as safflower. Commercial production of safflower will enhance Botswana's national input to the international trade. As Botswana is a semi - arid country with unreliable rainfall and hot weather, safflower with a long tap root that can grow to a depth of 2-3 m, has potential to survive these harsh climatic conditions (Emongor, 2010). The hot weather of Botswana will not adversely affect safflower because it is a heat tolerant crop when established (Emongor, 2010). Safflower tolerates a wide range of temperatures from -7 to 40°C, provided during the elongation and flowering stages of growth and development there is no frost (Emongor, 2010). During the rosette stage, safflower plant can withstand a temperature of -7°C (Mündel, *et al.*, 1992).

There is less rainfall in winter in Botswana. Crops which can thrive with little rainfall like safflower are needed. Winter climate does not support most of the crops grown in Botswana, but safflower which can withstand a temperature of – 7 ° C can be an alternative crop. Commercial production of safflower will enhance the supply of deficient products like vegetable oil. This will also reduce expenditure on imports of vegetable oils.

Commercial production of multipurpose oil seed crop that can be used for oil extraction (for cooking and paint industry), making margarine and salad oil, used as a cut flower, vegetable, colouring and flavouring foods, making dyes for textile industry, livestock forages, making herbal teas and medicinal purposes will improve food security, poverty alleviation, create employment and earn the country foreign exchange.

Though the crop is grown in Thamaga extension area in Botswana, it is not clear what it is grown for. Research in safflower plant density has not been done in SADC or in Botswana. There is a variation in plant density given by different authors in literature. Rowland (1993), Kwarteng and Towler (1994), Dajue and Mündel (1996) and Blackshaw (1993) all reported different plant density in safflower production. Plant density in safflower varies from country to country and from region to region because of different climatic conditions. Therefore, it is important to generate information on the proper plant population for optimum production in order to design a management system which allows maximum expression of genetic potential of safflower under Botswana climatic conditions. Plant population also plays an important economic role, as seed price is an important part of the total production cost.

1.4 Objectives

The objective of the study was to evaluate the effects of plant density on the growth, development and oil yield of safflower in Botswana.

1.5 Hypothesis

H_o: Plant population has no effect on the growth, development and oil yield of safflower.

H_a: Plant population has an effect on the growth, development and oil yield of safflower.

CHAPTER 2

LITERATURE REVIEW

2.1 Effects of plant density on plant growth, development and yield

The aim in plant density is to obtain the correct plant population per hectare or per unit area in order to maximize yield by fully exploiting the environment. Establishing correct plant population ensures that the crop produced is of acceptable quality with regards to size, oil content and yield (Ngugi *et al.*, 1990). Desirable plant density and ultimate best plant density depends on factors such as type and growth habit of the crop, soil fertility, rainfall, purpose for which the crop is grown and accessibility (Ngugi *et al.*, 1990). As plant population increases per unit area, a point is reached at which each plant begins to compete for certain essential growth factors such as nutrients, sunlight and water. The effect of increasing competition is similar to decreasing the concentration of a growth factor. Yield should be interpreted in both quantitative and qualitative terms. The value of the total yield is not merely the total bulk, but is related to quality of the yield (size per unit, colour, appearance, oil composition). The optimum population is the one that produces the greatest returns to the grower (farmer) per unit area.

Light has a pronounced effect on stem growth. In the dark, etiolation is extreme. Internodes of shaded plants such as in the dense stands are more etiolated (Gardner *et al.*, 1985). This means plants in dense stands (high population) have most of their internodes in the shade. This will contribute to etiolation taking place making the plants to grow taller. Growing tall could also be because there is competition for light. As the plants compete for this essential factor light, each of them will tend to grow taller to intercept light. When the population is not high, it is expected that competition for light is not high and each plant will receive the right amount of light that it will need for its biochemical processes to make food (Gardner *et al.*, 1985).

It is also expected that when plant density is high, nutrient elements in the soil may not be enough for all the plants, therefore resulting in competition. Increase in nutrient competition may affect plant growth. The plants may not grow to their full height because indispensable elements will not be adequate. For instance, when an element like nitrogen is in short supply the result is stunted growth. Not only nitrogen may be in short supply when crop stand is high. Essential elements such as potassium and phosphorus may also be inadequate causing poor root development which results in poor water and nutrient absorption and may cause stunting (Gardner *et al.*, 1985).

It is also expected that high plant density depletes water in the soil resulting in competition for the same. When water is in short supply for plants, growth is affected. The plants may grow slowly and ultimately get stunted. Shortage of water may cause plants to mature early in preparation for making new seeds. Therefore, high plant density may affect maturity time frame (Gardner *et al.*, 1985).

2.2 Effects of plant density on plant growth, development and yield of oil crops

The yield per unit area is equal to the yield per plant times the number of plants per unit area. When the population is below the level at which competition among plants occurs, increasing the population will have only an indirect effect on individual plant performance (Janick, 1986). The yield per unit area will rise in direct proportion to the population increase. As soon as competition among plants occurs, however, the yield per plant will decrease (Janick, 1986). Sunflower yield components are: number of plants per hectare, number of seeds per head and mean seed weight. Zaffaroni and Schneiter (1991) reported that yield components of sunflower were affected by an interaction of environmental factors, cultivar, row arrangement and plant population. Seed per head was significantly influenced by plant density (Zaffaroni and Schneiter, 1991). As plant density increased from 35, 000, 50, 000 to 65,000 plants per hectare, both number of seeds per head and seed weight decreased. These compensatory effects explain why no yield differences, as a response to various plant populations, are commonly observed (Zaffaroni and Schneiter, 1991).

Sunflower plant population below 49 421 plants/ha has been reported not to influence plant height (Bhatti *et al.*, 1999; Majid and Schneiter, 1988). Sunflower plants at 27,227 plants /ha had significantly larger seeds than sunflower plants at 49, 504 plants /ha (Bhatti *et al.*, 1999; Majid and Schneiter, 1988). Each head weighed 34.02 g more at 27, 227 plants /ha than at 49, 504 plants /ha (Bhatti *et al.*, 1999; Majid and Schneiter, 1988). Competition for water, sunlight and nutrients by sunflower plants at high plant population densities led to reduced seed size, head diameter and decreased number of seeds per head (Zaffaroni and Schneiter, 1991). As sunflower population increased from 35,000 to 65,000 plants per hectare, oil content increased by 0.1%, but the increase was not large enough to affect oil yield (Zaffaroni and Schneiter, 1991). Other researchers have observed a similar trend (Robinson *et al.*, 1980). Vranceanu (1977) reported that sunflower achenes produced at low plant populations had a greater percent hull resulting in decreased oil kernel percent.

2.3 Effects of plant density on vegetative growth of safflower

2.3.1 Plant height

Few studies documenting the response of safflower to plant population have been reported. Oad *et al.* (2002) reported that as safflower plant density increased from 74,074 (45 cm x 30 cm) to 266, 667 (25 cm x15 cm) plant height decreased. The average plant height for the densities 74 074, 129 870 and 266 667 plants per hectare were 131, 126 and 120.23 cm, respectively (Oad *et al.*, 2002). Similar results have been reported by Qayyum *et al.* (1986). Qayyum *et al.* (1986) reported that safflower height decreased with increase in plant density. However, Abel (1976) reported that safflower planted at a density of 430, 547 plants per hectare were taller by 3 cm than plants at a density of 258, 328. Miller and Fick (1978) also reported that plant height in safflower increased as plant density increased.

2.3.2 Plant biomass

Safflower plant density has a significant effect on plant biomass (Blackshaw, 1993). Increasing safflower plant density from 10 to 160 plants/m^2 increased shoot biomass production (Blackshaw, 1993). The differences in biomass due to density were evident 6 weeks after emergence and remained evident until maturity (Blackshaw, 1993). Blackshaw (1993) further reported that the effect of safflower plant density on canopy light interception was greatest early in the growing season prior to stem elongation. This is a critical time for safflower since many weeds become established during this period (Mündel *et al.*, 1992) and subsequent competition is strongly influenced by development during this early growth phase.

2.3.3 Number of branches

Branching of safflower depends on plant population, sowing date, cultural practices and environmental factors such as moisture supply (Gibbon and Pain 1985). Gibbon and Pain (1985) reported that branching of safflower was encouraged by topping. As plant density increased from 300, 000 to 600, 000 plants per hectare the degree of branching decreased (Peterson 1965; Oad *et al.* 2002). Oad *et al.* (2002) reported that as plant density increased from 74, 074 to 266, 667 plants per hectare, the number of branches per plant decreased by 50%. The number of branches per plant at 74, 074 (45 cm x 30 cm), 101, 010 (45 cm x 22 cm), 181, 818 (25 cm x 22 cm), and 266, 667 (25 cm x 15 cm) plants per hectare, were 12.9, 9.65, 6.80 and 6.55, respectively (Oad *et al.*, 2002). This was attributed to the ability of safflower to compensate for low plant population by increasing branching and other yield components as long as moisture reserves were present (Mündel, 1969). However, Azari and Khaejhpour (2003) reported no significant effect on number of branches per plant in safflower plant densities of 300, 000, 400, 000 and 500, 000 plants per hectare.

2.3.4 Plant diameter (spreading)

Safflower plants planted at 431, 000 plants /ha had canopies 8 cm deeper than those at 258, 000 plants/ha (Abel 1976). No other reports in literature are available on the effect of plant density on safflower plant spread.

2.3.5 Days to maturity

Increasing row distance from 30 cm to 60 cm and plant density from 300, 000 plants/ha to 500, 000 plants/ha enhanced most of the developmental stages of safflower (Azari and Khaejhpour 2003). Oad *et al.* (2002) reported that increasing safflower plant density from 74, 074 plants per hectare (45 cm x 30 cm) to 266, 667 plants per hectare (25 cm x 15 cm) delayed crop maturity by 19 days. Safflower plant density of 74 074, 190 476 and 266 667 plants per hectare, matured in 147.80, 161.85 and 166.75 days, respectively (Oad *et al.*, 2002). Mündel *et al.* (1994) also reported that closer row spacing of safflower increased days to maturity.

2.4 Yield Components

The primary yield components of safflower are number of capitula (flowers) per plant, number of achenes per capitulum and achene weight (Gonzalez *et al.*, 1994). The optimum plant population required in achieving the maximum achene and oil yield depends on the interaction of genotype, environment and other factors of production that will allow full agronomic expression of a given cultivar (Gonzalez *et al.*, 1994). This interaction requires an evaluation of the safflower management system, including the response of safflower cultivars to plant density.

2.4.1 Flower number

Gonzalez *et al.* (1994) reported that even though flower number is genetically controlled, it does respond with various degrees of flexibility to plant density. Increasing safflower plant density from 247, 000, 494,000 to 741, 000 plant/ha, significantly reduced number of flowers produced per plant from 9.3, 6.4 and 4.7, respectively (Gonzalez *et al.*, 1994). Similarly, Ehsanzadeh and Baghdad- Abadi (2003) reported that increasing safflower plant density from 166, 000 to 500, 000 plants/ha significantly reduced the number of flowers produced per plant. Oad *et al.* (2002) reported that increasing safflower plant density from 74, 074 (45 cm x 30 cm), 129, 870 (35 cm x 22 cm) and to 266, 667 (25 cm x 15 cm) plants/ha significantly reduced the number of flowers per plant to 59.00, 39.35 and 18.15, respectively. Nasr *et al.* (1976) in a two year study reported that increasing safflower plant density from 133, 333 to 533, 333 plants per hectare reduced the number of flowers produced per plant. Increasing plant density from 133, 333 to 533, 333 plants/ha, reduced flower number on average by 31-47%, depending on the year of study (Nasr *et al.*, 1976). The reduction in flower number/plant was attributed to competition for plant growth resources such as light, nutrients and water (Oad *et al.*, 2002).

2.4.2 Number of seeds

Gonzalez *et al.* (1994) reported that number of seeds per safflower capitulum was influenced by plant density. Increasing safflower plant density from 247, 000 to 741, 000 plant /ha reduced the number of achenes produced per capitulum from 24.8 to 20.1, respectively (Gonzalez *et al.*, 1994). Abel (1976) reported that increasing safflower plant density from 258, 000 to 431, 000 plants/ha reduced the number of achenes per capitulum from 27 to 25, respectively. While Alessi *et al.* (1981) reported that increasing safflower plant density from 860, 000 plants/ha to 1, 280, 000 plants/ha, significantly reduced seed yield. Blackshaw (1993) reported that increasing safflower plant density from 100, 000 to 700, 000 plants/ha increased the number of achenes/capitulum produced and remained constant after wards showing no effect of safflower plant density on seed yield after a density of 700, 000 plants/ha.

2.4.3 Seed yield

Safflower plants are reported to have a high capacity to compensate for seed yield in relation to increasing plant density (Gonzalez *et al.*, 1994). As plant population density increased, achene (seed) yield per plant decreased (Gonzalez *et al.*, 1994), with maximum achene yield per plant obtained at the lowest plant density of 247, 000 plants/ha. Increasing safflower plant density from 247, 000 to 741, 000 plants/ha, decreased seed weight by 4.2 % (Gonzalez *et al.*, 1994). However, plant population density did not influence safflower seed yield/ha (Gonzalez *et al.*, 1994). The stability in seed yield across all plant population (247,000, 370, 500, 494, 000, 617, 500 and 741, 000 plants/ha was attributed to compensatory effect produced by the changes in number of plants per unit area and yield/plant (Gonzalez *et al.*, 1994). There was a highly significant cultivar and environmental interaction on safflower seed yield (Gonzalez *et al.*, 1994). From a 3-year study in Nebraska, Peterson (1965) reported that as safflower plant density increased from 300, 000 to 600, 000 plants/ha, achene (seed) yield decreased. Alessi *et al.* (1981) reported similar results when they obtained a highest safflower seed yield at a plant population of 217, 000 plants/ha compared to 1, 280, 000 plants/ha. Oad *et al.* (2002) reported that increasing safflower plant density from 74, 074 to 266, 667 plants/ha decreased seed yield/ha by 37%. The highest seed yield was obtained with a safflower plant density of 74, 074 plants/ha (45 cm x 30 cm). Abel (1976) reported no yield differences between safflower plant population of 258, 000 and 431, 000 plants/ha; their analysis of yield components indicated that fewer achenes per capitulum and lighter achenes were produced at the higher plant population.

2.5 Oil content

In a research to find the effects of irrigation regimes, planting dates, nitrogen levels and row spacing on safflower cultivars, Abel (1976) reported that increasing safflower plant density from 258, 328 to 430, 547 plants/ha reduced safflower oil content from 41.9 to 40.5%, respectively. Similarly, Oad *et al.* (2002) in a research of inter and intra row spacing effect on the growth, seed yield and oil content of safflower reported that increasing safflower plant density from 74, 074 (45 cm x 30 cm), 129, 870 (35 cm x 22 cm) to 266, 667 (25 cm x 15 cm) reduced safflower oil content from 31.63, 30.50 and 29.63%, respectively. Nasr *et al.* (1976) also in their research to find out the effects of nitrogen fertilizers and population rate, spacing on safflower yield and other characteristics reported that increasing safflower plant density from 133, 333 (75 cm x 10 cm) to 533, 333 (37.5 cm x 5 cm) plants/ha had insignificant effect on safflower oil seed content. Gonzalez *et al.* (1994) reported that safflower plant density did not have a significant influence on safflower seed oil content. However, they reported a significant effect of safflower cultivar and environmental factors influence on safflower seed oil content. Fick (1978) reported that climatic conditions such as temperature and precipitation significantly influence safflower seed oil content.

CHAPTER 3

MATERIALS AND METHODS

3.1 Experimental site

Two field experiments were conducted at the Botswana College of Agriculture Content Farm, situated at Notwane, Sebele, (24^0 35' S: 25^0 58' E ;) at an altitude of 998 m above sea level. The experimental site has an average maximum and minimum temperature varying between 33.1–34.7 ^{0}C and 19.2 – 19.5 ^{0}C, respectively (Ramolemana, 1999). However, during the cold months April and August the average maximum and minimum temperatures ranges between 26 -34 ^{0}C and 7-16 ^{0}C, respectively. The soils are deep sandy loam. The rainfall amount varies between 250 - 600 mm per annum (Emongor *et al.*, 2012).

3.2 Experimental design

The experimental design was a randomized complete block design with three replications. The experiment was blocked because the land where the experiment was done had a slope of about 1%. The treatments were plant densities at 250, 000 (20 cm x 20 cm), 222, 222 (15 cm x 30 cm), 166, 667 (20 cm x 30 cm), 133, 333 (25 cm x 30 cm), 125, 000 (20 cm x 40 cm), and 100, 000 (20 cm x 50 cm). The treatments were randomized within the experimental blocks. Safflower was planted in single rows in experimental units measuring 5 m x 5 m. Seeds were sown at a depth of 6 mm. Two trials were done. The first trial was from 8th February 2010 to 31st July 2010 and the second trial was from 1st August 2010 to 31st January 2011.

3.3 Crop husbandry

Primary tillage was done using a mouldboard plough. Then secondary tillage was done with a disc harrow to make fine tilth. Weeding was done by hoeing between rows to control weeds because safflower at rosette stage is a poor weed competitor (Dajue and Mündel, 1996). Other management practices such as fertilizer application, irrigation and pest control were carried out when necessary. Fertilizer application was at 40 kg of nitrogen per hectare using 2:3:2 (Kynoch). The crop was irrigated once a week to a depth of 6 mm using sprinklers.

3.4 Dependent variables determined

The dependent variables determined were plant height, leaf area, leaf number, number of branches per plant, plant spread, root length, number of flowers per plant, flower heads per plant, number of seeds per flower head, flower head size, weight of 100 seeds, seed yield and oil content.

3.5 Determination of plant height

Plant height was measured on 20 plants randomly sampled from each replication. Plant height was measured from the ground to the top of the plant using a metre ruler. This was measured at 4, 8, 12, 16, 20 and 25 weeks after emergence (WAE).

3.6 Determination of leaf number and leaf area

Leaf number and leaf area were determined from five plants randomly sampled at 25 WAE per treatment per replicate. Leaf number was counted. The leaf area was determined using a leaf area meter (WC 230 PCM, Delta T Devices, Cambridge, England).

3.7 Root depth, stem dry matter and water content determination

Root length was determined from five plants per treatment per replication. The plants were thoroughly watered 24 hours before sampling. The plants were removed from the soil using a digging fork and to ensure that at least 99% of the roots were removed from the soil. This was done 25 WAE. The roots were cut from the plant, washed to remove the soil before measuring. Root length was determined using a metre ruler. The vegetative part of the plant was weighed and put in weighed paper bags. The weighed paper bags and vegetative parts were put in an oven and dried at 66°C for 72 hours. The dried samples were weighed to determine dry matter of the plant. Water content of the plant was calculated by subtracting the dry weights from the fresh weights.

3.8 Determination of number of branches per plant

Twenty plants per treatment per replication were randomly sampled. The branches were counted on each sampled plant.

3.9 Determination of flower heads (capitula) per plant

Twenty plants per treatment per replication were randomly sampled and the numbers of flower heads were counted.

3.10 Determination of flower head size

Twenty plants were randomly sampled per treatment per replication and the flower head size (diameter) was determined using vernier callipers (Storm vernier callipers, CEN 6421).

3.11 Determination of seed number per flower

Twenty flower heads were randomly sampled per plant and five plants were sampled per treatment per replicate were used. The seed numbers per flower head were counted.

3.12 Hundred seed weight

Hundred seed weight was determined by weighing 100 representative seeds per treatment per replication. Weighing was done using a digital balance (Adam Equipment, Model PGW 4502e).

3.13 Determination of plant spread

Twenty plants were randomly sampled per treatment per replication. Plant spread was determined by measuring the plant spread (diameter) using a metre ruler.

3.14 Temperature

The temperature of the experimental site was monitored daily using weather station. The minimum and maximum temperatures of the experimental site are shown in Appendix A and B.

3.15 Extraction of safflower oil

Safflower oil was extracted by pressing safflower seeds using an electric oil expeller (Oil Love, National ENG CO.LTD). The oil expeller was preheated to a temperature of 180 - 200°C for twenty minutes. Safflower seeds (1 kg) were used for oil extraction. The oil yield was determined by weighing the oil expressed. The oil yield was expressed as a percentage of the seed that was used for expressing the oil.

3.16 Data Analysis

The data collected was subjected to analysis of variance (ANOVA) using Statistical Analysis System (SAS, 2011) programme. Where a significant F- test was observed, treatment means were separated using the Least Significant Difference (LSD) at P=0.05. Appropriate regression models were used to analyze the response of safflower plants to increasing plant density (Snedecor and Cockran, 1989).

4.0 RESULTS

4.1 Plant height

Plant density had a significant ($P < 0.05$) effect on plant height of safflower (Figure 1). In both trials increasing plant density of safflower significantly ($P < 0.01$) decreased plant height (Figure 1). In seasons 1 and 2, increasing plant density from 100, 000 plants/ha to 250, 000 plants/ha, linearly reduced plant height by 21.3 ($r = 0.91$) and 13.2 % ($r = 0.91$), respectively (Figure 1). Safflower plants grown in summer (season 2 – August to January) were significantly shorter ($P < 0.001$) than plants grown in winter (season 1 – February – July) (Figure 1). Safflower plants grown in winter were significantly taller by 35.2% than plants grown in summer (Figure 1).

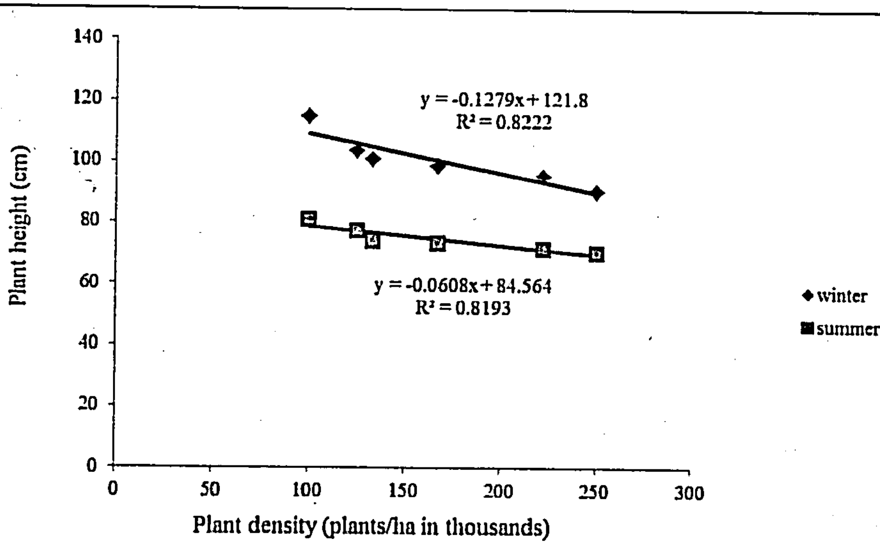

Figure 1. Effect of Plant density on plant height

4.2 Plant biomass (dry weight)

Plant density had a significant ($P < 0.01$) effect on plant dry weight. In both trials increasing plant density of safflower significantly ($P < 0.01$) decreased plant dry weight (Figure 2). In seasons 1 and 2, increasing plant density from 100, 000 plants/ha to 250, 000 plants/ha, linearly reduced plant dry weight by 50 % ($r = 0.95$) (Figure 2). Safflower plants grown in winter had significantly ($P < 0.001$) higher dry matter than plants grown in summer (Figure 2). Safflower plants grown in winter were significantly heavier by 17% ($r = 0.94$) than plants grown in summer (Figure 2).

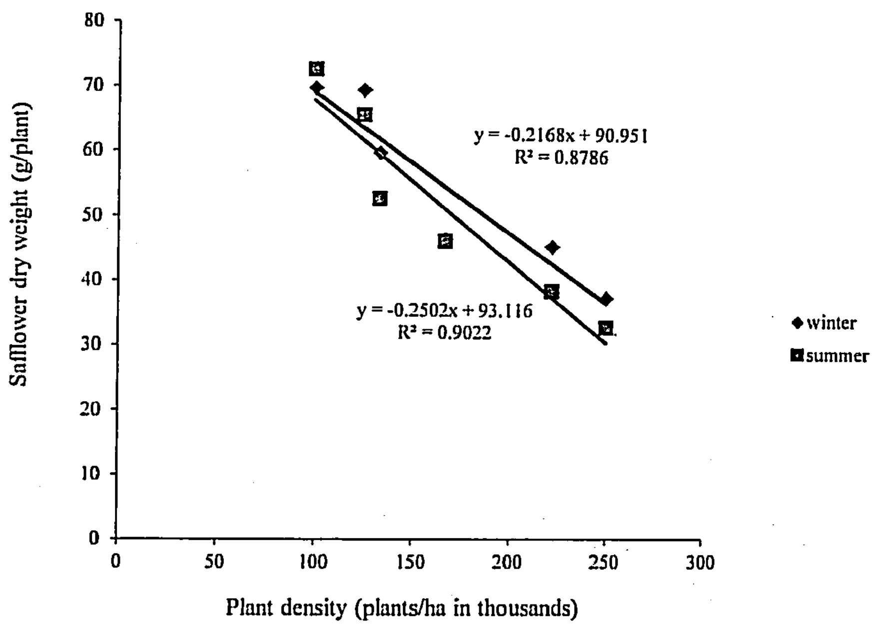

Figure 2. Effect of plant density on dry weight

4.3 Branch number

Plant density significantly ($P < 0.05$) reduced the number of branches produced by safflower plants. Increasing safflower plant density from 100, 000 to 250, 000 plants/ha significantly reduced the number of branches per plant (Figure 3). The decrease in branch number with increasing plant density was linear (Figure 3). Increasing plant density of safflower from 100, 000 to 250, 000 plants/ha reduced plant branch number by 37 ($r = 0.98$) and 54.7% ($r = 0.95$) in winter and summer, respectively (Figure 3). Safflower plants grown in winter significantly ($P \leq 0.001$) produced twice more branches than plants grown in summer (Figure 3).

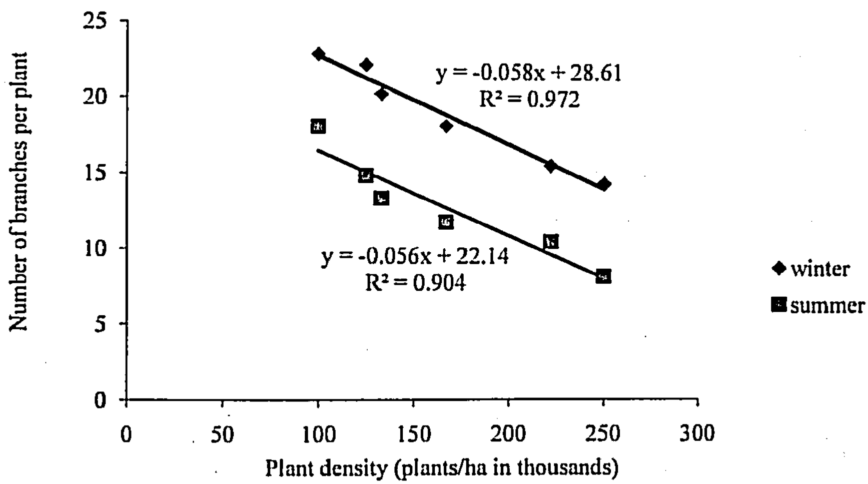

Figure 3. Effect of plant density on branch number of safflower

4.4 Leaf number

Increasing safflower plant density from 100, 000 to 250, 000 plants/ha, significantly ($P \leq 0.01$) reduced leaf number per plant (Figure 4). Increasing plant density from 100, 000 to 250, 000 plants/ha linearly reduced leaf number/plant by 39.2 ($r = 0.96$) and 39% ($r = 0.97$) in winter and summer, respectively (Figure 4). Safflower plants grown in winter significantly ($P \leq 0.01$) produced more leaves than plants grown in summer (Figure 4).

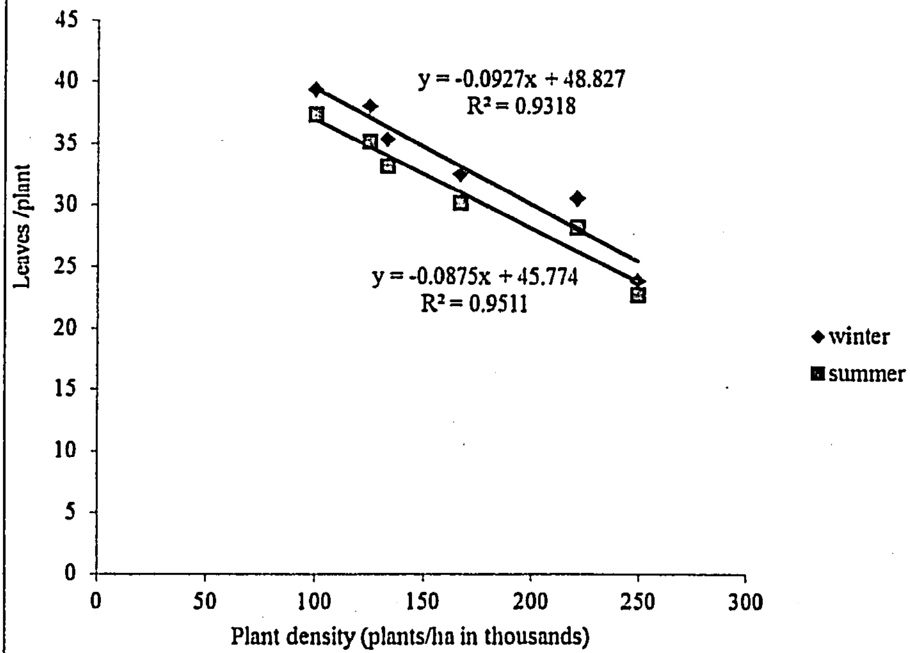

Figure 4. Effect of plant density on leaf number

4.5 Leaf area

Safflower plant density had a significant ($P \leq 0.05$) effect on leaf area (Figure 5). As plant density increased from 100, 000 to 250, 000 plants/ha, leaf area significantly ($P \leq 0.05$) decreased (Figure 5). Leaf area decreased quadraticaly by 19.5 ($r = 0.81$) and 53% ($r = 0.88$) in winter and summer, respectively (Figure 5). However, safflower plants grown in winter had significantly ($P < 0.05$) larger leaf area than summer grown plants (Figure 5).

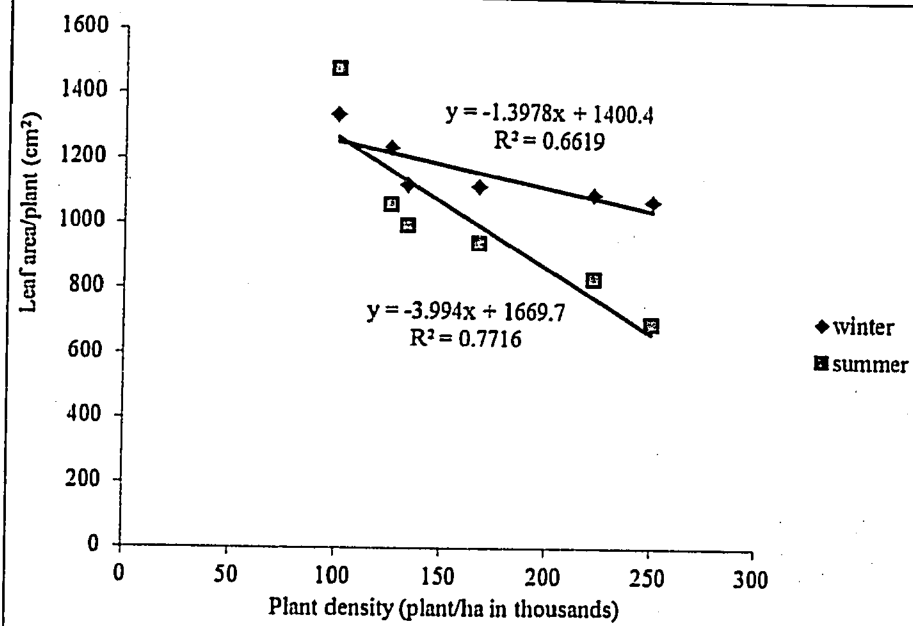

Figure 5. Effect of Plant density on leaf area of safflower

4.6 Root length

Plant density had a significant ($P < 0.01$) effect on root length (Figure 6). In both trials, increasing plant density of safflower significantly ($P < 0.01$) decreased plant root length (Figure 6). In season 1 and 2, increasing plant density from 100,000 to 250, 000 plants/ha, linearly reduced plant root length by 28.1 ($r = 0.92$) and 54.4%, ($r = 0.93$) respectively (Figure 6). Safflower plants grown in summer had significantly ($P < 0.001$) shorter roots than plants grown in winter (Figure 6).

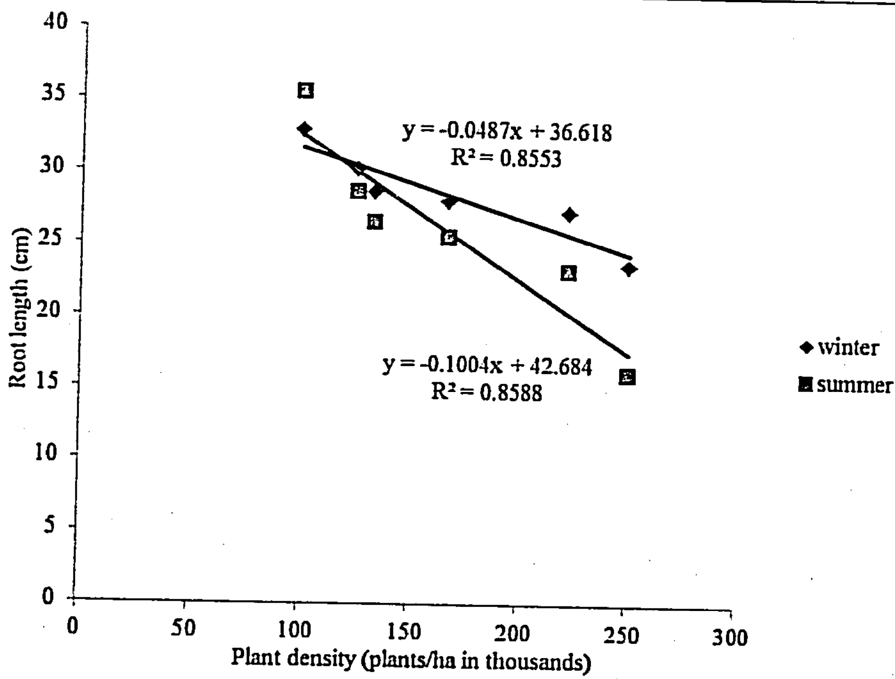

Figure 6. Effect of plant density on safflower root length

4.7 Plant spread

In both trials, increasing plant density of safflower significantly ($P < 0.01$) decreased plant spread (Figure 7). In season 1 and 2, increasing plant density from 100,000 to 250, 000 plants/ha, linearly reduced plant spread by 39.6 ($r = 0.98$) and 54.4% ($r = 0.94$), respectively (Figure 7). Safflower plants grown in summer had significantly ($P < 0.001$) smaller spread than plants grown in winter (Figure 7).

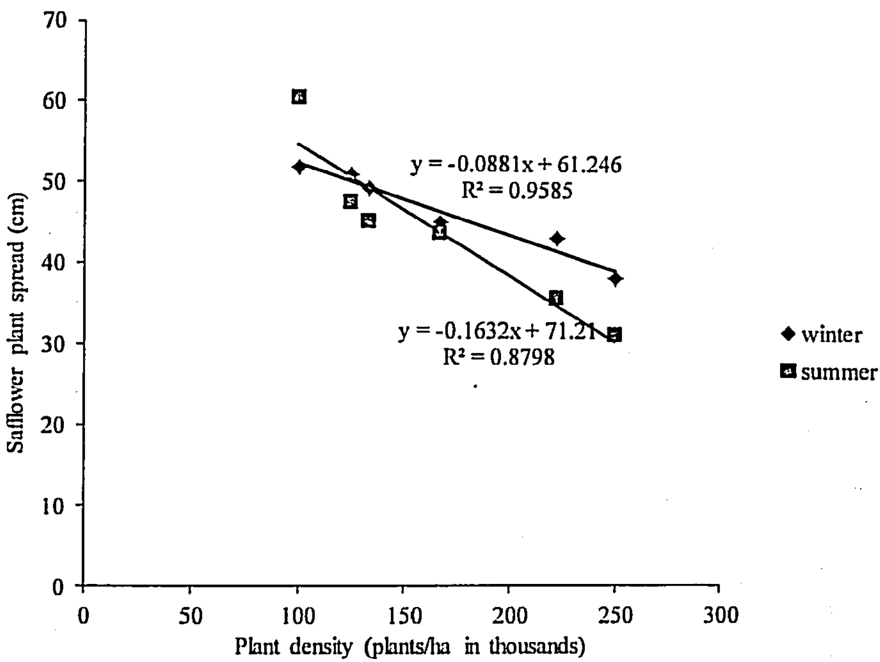

Figure 7. Effect of plant density on plant spread

4.8 Flower size

Safflower plant density did not have a significant ($P < 0.05$) effect on flower size in trial 1(Figure 8). However, in season 1 (winter), as safflower plant density increased, flower size tended to decrease (Figure 8). As plant density increased from 100, 000 plants to 250, 000 plants/ha, flower size decreased linearly by 12.7% ($r = 0.92$) in trial 1(winter) (Figure 8). In trial 2, (summer) plant density significantly reduced flower size (Figure 8). As plant density increased from 100, 000 plants to 250, 000 plants/ha, flower size decreased linearly ($r = 0.91$) (Figure 8). Safflower plants grown in summer significantly ($P < 0.01$) produced larger flowers than plants grown in winter (Figure 8).

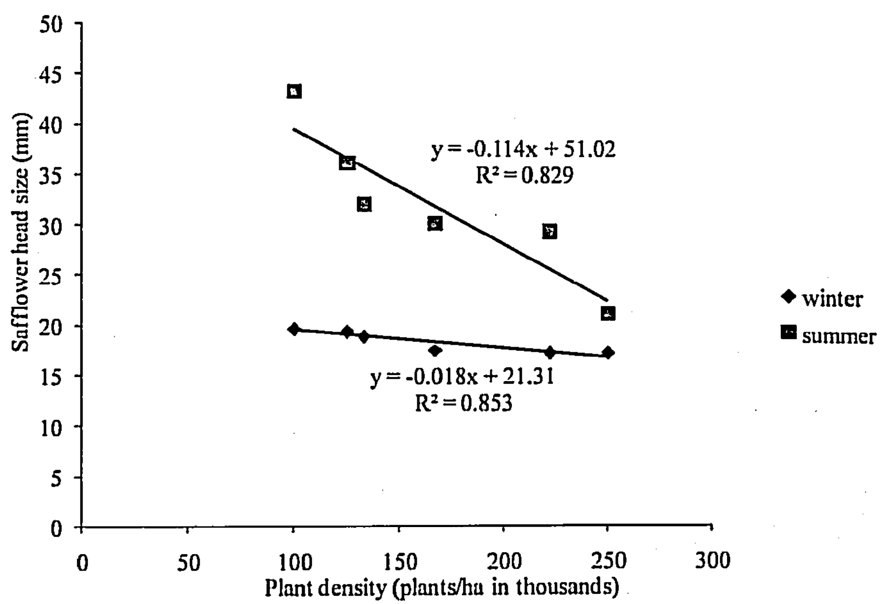

Figure 8. Effect of plant density on flower head size

4.9 Flower number

Plant density had a significant ($P < 0.01$) effect on flower number (Figure 9). In both trials, increasing plant density of safflower significantly ($P < 0.01$) decreased flower number per plant (Figure 9). Increasing plant density from 100,000 to 250, 000 plants/ha, reduced flower number/plant linearly by 39.5 ($r = 0.98$) and 50.5% ($r = 0.96$), in winter and summer, respectively (Figure 9). Safflower plants grown in summer had significantly ($P < 0.001$) fewer flowers than plants grown in winter (Figure 9).

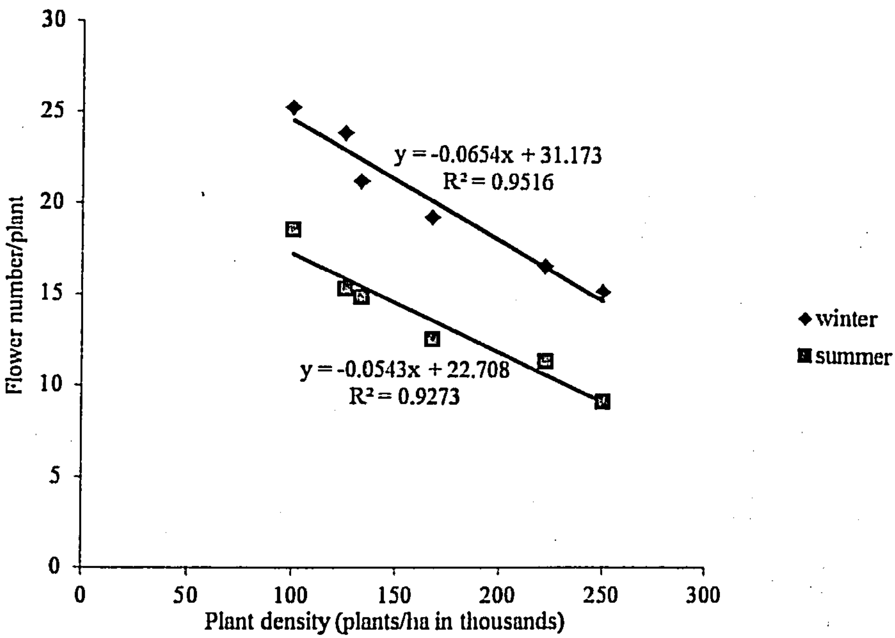

Figure 9. Effect of plant density on flower number

4.10 Seed number

Plant density significantly ($P < 0.05$) affected the number of seeds/capitulum (Figure 10). Increasing plant density from 100, 000 to 250, 000 plants/ha significantly ($P \leq 0.01$) reduced seed number per capitulum linearly in both trials (Figure 10). The reduction in seed number/capitulum was 45 ($r = 0.98$) and 39% ($r = 0.95$) in winter and summer, respectively (Figure 10). Safflower plants grown in winter produced more seeds per capitulum than summer grown plants (Figure 10).

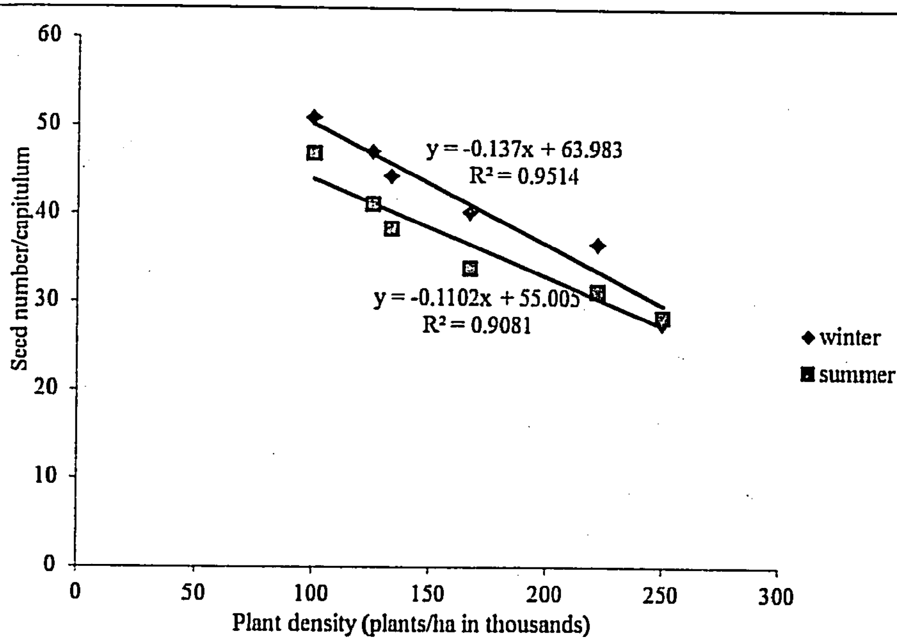

Figure 10. Effect of plant density on seed number

4.11 Hundred Seed weight

Plant density did not have a significant effect on 100–seed weight of safflower (Figure 11). However, lower plant densities in both trials tended to have a higher 100–seed weight than higher plant densities (>133, 333 plants/ha) (Figure 11). There was no significant difference in 100 – seed weight of safflower plants grown either in winter or summer (Figure 11).

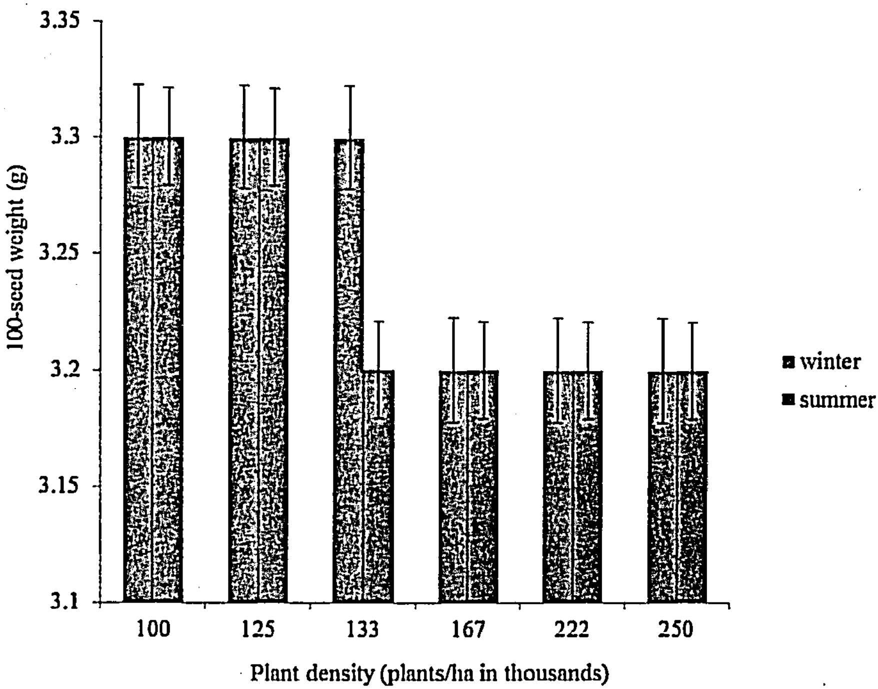

Figure 11. Effect of plant density on 100-seed weight

4.12 Seed yield

Plant density had a significant ($P < 0.01$) effect on seed yield of safflower (Figure 12). In both trials increasing plant density of safflower significantly ($P < 0.01$) decreased seed yield (Figure 12). In seasons 1 and 2, increasing plant density from 100, 000 plants/ha to 250, 000 plants/ha, linearly reduced seed yield by 67.9 ($r = 0.97$) and 69.8% ($r = 0.93$), respectively (Figure 12). Safflower plants grown in winter produced significantly ($P < 0.01$) higher seed yield than plants grown in summer (Figure 12). The winter grown safflower on average yielded 1.5 times higher seed yield/ha than summer grown safflower (Figure 12). The highest seed yield was obtained in safflower plant density of 100, 000 plants/ha which yielded 4258 and 2879 kg/ha in winter and summer, respectively (Figure 12).

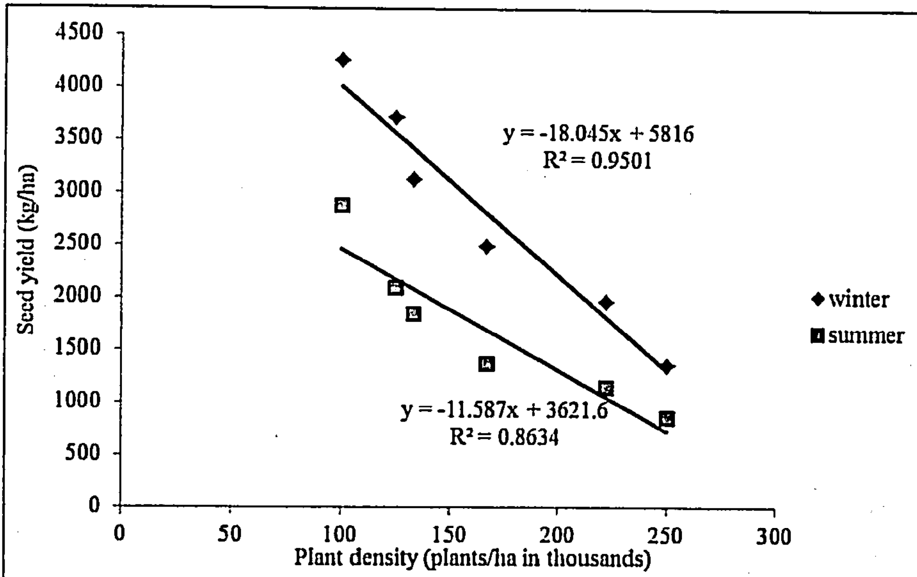

Figure 12. Effect of plant density on safflower seed yield

4.13 Seed oil content

Plant density had a significant ($P < 0.01$) effect on seed oil content of safflower (Figure 13). In both trials, increasing plant density of safflower significantly ($P < 0.01$) decreased seed oil content (Figure 13). In seasons 1 and 2, increasing plant density from 100, 000 plants /ha to 250, 000 plants /ha, linearly reduced seed oil content by 14.7 ($r = 0.87$) and 20.8% ($r = 0.97$), respectively (Figure 13). Safflower plants grown in summer produced seed with significantly ($P < 0.001$) higher oil content than plants grown in winter (Figure 13). The highest seed oil content was obtained in safflower plant density of 100, 000 plants/ha in winter and summer which produced 18.4 and 19.2%, respectively (Figure 13). The lowest seed oil content was in plant density of 250, 000 in winter and summer which produced 15.7 and 15.2%, respectively (Figure 13).

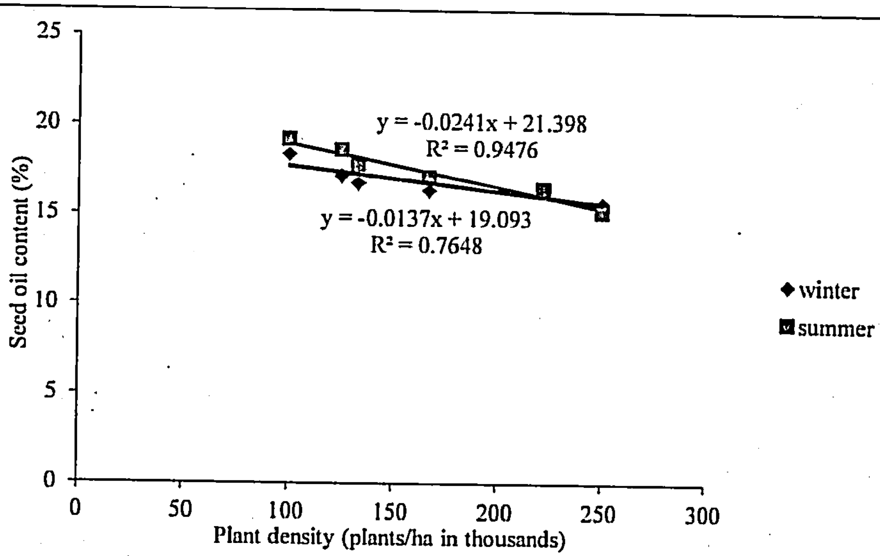

Figure 13. Effect of plant density on seed oil content

CHAPTER 5

DISCUSSION

5.1 Plant height

Increasing safflower plant density from 100, 000 to 250, 000 plants/ha significantly reduced plant height. Similar results have been reported by Oad *et al.*, (2002) and Qayyum *et al.*, (1986) who all reported a decrease in safflower plant height with increasing plant density. The reduction in plant height with increase in plant density was attributed to competition for essential growth factors such as light, nutrients and water. Safflower plants grown in winter were significantly taller than plants grown in summer. The difference in safflower plant height due to growth season was attributed to the difference between night and day temperatures (DIF). On average the difference between day and night temperatures during the experimentation period in winter and summer was 16.4 and 17.3^{o}C, respectively (November-December). However, during the elongation phase of safflower in May-June (winter) and November-December (summer), the DIF was 20.7 and 14^{o}C, respectively, explaining the difference in plant height between winter and summer grown safflower plants. It has been known since the early 1940's that changes in day temperature and night temperature have morphological effects on the stem extension (Went 1944). The use of the difference between day temperature and night temperature (DIF) to control the height of plants has been demonstrated on a wide range of species (Myster and Moe, 1995). The higher the day temperature relative to the night temperature (DIF), the greater the stem elongation (Berghage and Heins, 1991; Erwin *et al.*, 1989 a,b; Karlsson *et al.*, 1989). Increasing the day temperature relative to the night temperature increases internode elongation for many plant species (Berghage and Heins, 1991; Myster and Moe, 1995; Dole and Wilkins, 2005). The higher positive DIF and chilling morning temperatures (8.4 - 1.2°C) in winter increased stem elongation and hence taller safflower plants grown in winter than summer grown safflower plants where DIF was lower and the morning temperatures were not chilling (17.2 – 18 °C). The positive DIF in winter might have promoted biosynthesis of gibberellins which are known to promote cell and internode elongation hence explaining the increase in safflower plant height (Taiz and Zeiger, 2002).

5.2 Plant biomass (dry weight)

Increasing safflower plants density from 100, 000 to 250, 000 plants/ha significantly reduced plant biomass by 50%. On average higher plant dry weight was recorded in plant density of 100, 000 plants/ha compared to a density of 250, 000 plants/ha. The reduction in dry matter due to increasing plant density was attributed to competition for essential plant growth factors such as water, light, nutrients and photoassimilates. The reduction in plant biomass due to increasing plant density can also be explained by the reduction in leaf number and area, leading to low photosynthetic area, photoassimilates and net assimilation rate (NAR). Crop growth rate equilibrium as plant density increases occurs through adjustments of leaf area index (LAI) and/or NAR (Board 2000). The higher the density of plants in a particular crop stand, the more mutual competition for water, nutrients and light. Under such conditions the photosynthetic rate is decreased in shaded leaves whereas the rate of respiration is increased. As the crop density is increased and mutual shading is intensified, NAR is reduced (Mengel and Kirby, 2001;

Marschner 2005). Greater NAR in lower safflower plant density (100, 000 plants/ha) could explain the high plant biomass, yield and yield components compared to higher safflower plant densities (>100, 000 plants/ha). Greater light interception per unit LAI has been associated with NAR advantage for low plant populations (Carpenter and Board, 1997). Blackshaw (1993) reported that as safflower plant density increased, shoot biomass increased up to a density of 70 plants/m^2 and remained unchanged with increasing plant density.

Winter grown safflower plants accumulated more dry matter (plant biomass) than summer grown plants (116 days after emergence – DAE) because of the longer maturation period (138 DAE). The longer growth period of winter grown safflower implies longer leaf area duration (LAD) than summer grown safflower. There is a positive linear correlation between yield (biomass or dry matter) and LAD in most crops (Heggenstaller *et al.*, 2009; Evans *et al.*, 1976). Leaf area duration which is the integral of LAI from emergence to physiological maturity significantly determines yield of many crops (Emongor 2007). The higher plant biomass accumulated by the plants grown in winter than in summer can also be explained by the higher DIF in winter. Shang *et al.*, (2003) reported that negative DIF significantly reduced shoot and stem dry mass of snapdragon (*Antirrhinum majus* L.).

5.3 Branch number

Increasing safflower plant density from 100, 000 to 250, 000 plants/ha significantly reduced the number of branches produced. Oad *et al.* (2002) reported similar results when they observed a 50% reduction in branch number as safflower plant density increased from 74, 074 to 266, 667 plants/ha. Peterson (1965) reported that as safflower plant density increased from 300, 000 to 600, 000 plants/ha, branch number/plant decreased by 50%. Gibbon and Pain (1985) reported that branching in safflower depended on plant population, sowing date, cultural practices and environmental factors such as moisture supply. The reduction in branch number due to increased plant density was attributed to lack of available space to branch. Safflower seems to use available space to produce branches because Mündel (1969) reported that safflower can compensate for low plant population by increasing branching. Salisbury and Ross (1992) reported that long days have a suppressive effect on branching. This may explain why the summer grown safflower plants in the current study had fewer branches than winter grown safflower plants.

5.4 Leaf number and area

Increasing safflower plant density from 100, 000 to 250, 000 plants/ha significantly reduced leaf number and area. The decrease in leaf area of safflower plants with increase in plant density was attributed to the decrease in leaf number. The decrease in both leaf number and leaf area was attributed to the mutual competition for water, nutrients and light. The high DIF in winter compared to summer may also help to explain the reduction in leaf number and area because temperature in influences plant growth and developmental rate, but besides it may affect plant photoperiodic response (Wallace *et al.*, 1993).

5.5 Root length

Increasing safflower plant density from 100, 000 to 250, 000 plants/ha significantly reduced safflower root length. The reduction in root length due to high plant density was attributed to competition for soil moisture and supply of mineral nutrients. Tisdale *et al.* (1993) reported that internal moisture stress causes reduction in root growth both in cell division and cell elongation and hence total root growth. Roots grow best when soils are well supplied with moisture (Tisdale *et al.*, 1993).

Winter grown safflower plants had significantly longer roots than summer grown safflower because the low temperature in winter reduced soil water evaporation, therefore more moisture retention in the deeper parts of the soil hence deeper root growth. The high temperatures in summer promoted soil water evaporation and shallow rooting. Root systems adapt rapidly and grow into the wet zone if only part of the root system is wetted (Faust 1989). In dry soils mechanical impedance and low soil water potential restrict root growth (Marschner 2005). Increasing soil water content relieves stress factors for root and there is a much lower impairment to root growth by mechanical impedance. The high soil temperatures in summer might also have restricted safflower root growth. Root growth is limited by low (sub optimal) or high (supra optimal) soil temperatures (Marschner 2005). The temperature optimum varies among plant species and tends to be lower for root growth than for shoot growth (Brauwer, 1981).

5.6 Plant diameter (spreading)

In both trials increasing plant density of safflower significantly decreased plant spread. The decrease in plant spread with increase in plant density was attributed to competition for the available nutrients and water. The reduction of safflower plant spread with increasing plant density was also attributed to the reduction in plant branching caused by increasing plant density. Blackshaw (1993) reported that canopy development in safflower was influenced by agronomic practices such as plant density, fertilizer application and irrigation. While Abel (1976) reported that increasing safflower plant density from 258, 328 to 430,547 plants/ha, increased plant canopy by 8 cm. Mündel (1996) reported that low plant density in safflower promoted branching and plant spread. The temperature differences between winter and summer may explain the differences in plant spread between winter and summer grown safflower, with lower temperatures and higher positive DIF in winter promoting plant spread than in summer.

5.7 Yield components

The yield components of safflower are flower (capitula) number/plant, flower size, number of achenes (seed) per capitula, and achene weight (100-seed weight). Even though yield components are under genetic control, they do respond with various degrees of flexibility to plant density (Gonzalez *et al.*, 1994). In the current study, increasing safflower plant density from 100, 000 to 250, 000 plants/ha, significantly decreased capitula (flower) number/plant, capitula size, achene (seed) number per capitula and achene weight (100-seed weight). The decrease in the yield components with increase in plant density was attributed to inter and intra plant competition for light, nutrients and water necessary for growth and development. Gonzalez *et al.* (1994) reported that the number of capitula per plant and achenes per capitula decreased significantly with increasing safflower plant density from 247, 000 to 741, 000 plants/ha. They further reported a 50% reduction in the number of capitula per plant as plant density increased from 247, 000 to 741, 000 plants/ha. In the current study, flower (capitula) number/plant, achene number per capitula and achene weight (100-seed weight) decreased by 39.5 and 50%, 45 and 39%, 3.3 and 3.6%, in winter and summer, respectively as plant density increased from 100, 000 to 250, 000 plants/ha. Oad *et al.* (2002) reported that increasing safflower plant density from 74, 074 to 266, 667 plants/ha significantly decreased capitula number per plant by 69%. While, Nasr *et al.* (1976) in a two year study reported that increasing safflower plant density from 133, 333 to 533, 333 plants/ha decreased capitula number/plant by 31- 47%, depending on the year of study. Ehsanzdeh and Baghda-Abadi (2003) reported that increasing safflower plant density from 166, 000 to 500, 000 plants/ha significantly reduced the capitula number/plant. Increasing safflower plant density from 258, 000 to 431, 000 plants/ha, reduced the achene number per capitulum from 27 to 25 (Abel 1976).

The higher number of capitula/plant, achene number/capitulum and achene weight in winter compared to summer grown safflower plants was attributed to longer maturation period in winter (138 days after emergence) compared to summer (116 days after emergence) as influenced by temperature. Optimum temperatures produce high- quality plants most rapidly while tolerable temperatures allow plants to continue growing but may result in long production times or low quality (Nau 1993). Average daily temperature controls the rate of plant development. The high average daily temperatures in summer accelerated safflower growth and reduced the maturation period by 22 days and reduced the yield components compared to winter grown safflower.

5.8 Seed yield

Increasing safflower density from 100, 000 to 250, 000 plants/ha significantly reduced seed yield by 67.9 and 67.8% in winter and summer, respectively. The reduction in seed yield with increase in plant density was attributed to mutual competition for nutrients, water and sunlight. Mutual shading resulting from high plant density was believed to have led to light being the limiting factor to high seed yield. In safflower plants with plant density greater than 100, 000 plants/ha, the photosynthetic rate and NAR rate were decreased as evidenced by reduction in leaf number and area, and plant biomass (dry matter) as plant density increased. The reduction in safflower seed yield due to increasing plant density was also explained by the reduction in capitula size, capitula number/plant, achene number per capitulum and achene weight (100-seed weight) which are the primary yield components of safflower.

Peterson (1965) reported that as safflower plant density increased from 300, 000 to 600, 000 plants/ha, seed (achene) yield decreased. Alessi *et al.* (1981) reported similar results when they obtained the highest safflower seed yield/ha at a plant density of 217, 000 plants/ha compared to 1, 280, 000 plants/ha. Oad *et al.* (2002) reported that increasing safflower plant density from 74, 074 to 266, 667 plants/ha decreased seed (achene) yield/ha by 37%.

The higher seed yield obtained in winter grown safflower irrespective of plant density than summer grown safflower could be explained by the longer growth and maturation period (138 days after emergence) in winter, resulting in higher dry matter accumulation and partitioning to grain formation. The higher average temperatures in summer resulted in faster growth and maturation period (116 days after emergence) which resulted in low dry matter production and seed yield.

5.9 Oil yield

Increasing safflower plant density from 100, 000 to 250, 000 plants/ha significantly reduced seed oil content. The reduction in seed oil content with increase in plant density was attributed to mutual competition for plant nutrients, water and sunlight. Abel (1976) reported that increasing safflower plant density from 258, 328 to 430, 547 plants/ha, reduced safflower seed oil content from 41.9 to 40.5%. Similar results were reported by Oad *et al.* (2002) who found that increasing safflower plant density from 74, 074 to 266, 667 plant/ha resulted in seed oil content reduction from 31.63 to 29.63%. Similar results have been reported by Nasr *et al.* (1976). However, Gonzalez *et al.* (1994) reported no significant effect of safflower plant density on seed oil content, but found a significant effect on cultivar and environment interaction on safflower seed oil content. Fick (1978) reported that climatic conditions such as temperature and precipitation influenced safflower seed oil content. The longer growth and maturation period of the winter grown safflower compared to the summer grown safflower, that resulted in higher dry matter accumulation, yield components and partitioning of photoassimilates to oil production, explains why winter grown safflower had higher seed oil content than summer grown safflower.

CHAPTER 6

CONCLUSIONS AND RECOMMENDATIONS

6.1 CONCLUSION

Increasing safflower plant density from 100, 000 to 250, 000 plants/ha reduced plant vegetative growth, root growth, yield components, seed yield and seed oil content of safflower. Plant density had no effect on the maturation period, but season had. Winter grown safflower produced higher quality plants than summer grown safflower in terms of vegetative growth, reproductive growth, seed yield and seed oil content.

6.2 RECOMMENDATIONS

From the results of the current study, for safflower production in Botswana it is recommended that it should be planted at 50 cm (between the rows) and 20 cm (between plants) resulting in a population of 100, 000 plants/ha. It is also recommended that a similar trial be repeated in several parts of Botswana and lower than 100, 000 plants/ha should be included in the study.

REFERENCES

Abel, G. H. (1976). Effects of irrigation regimes, planting dates, nitrogen levels and row plant density on Safflower cultivars. Agronomy Journal 68:448-451.

Alessi, J., Power, J. F and Zimmerman, D. C. (1981). Effects of seeding date and population on water use efficiency and safflower yield. Agronomy Journal 73:783-787.

Azari, A. and Khajehpour, M. R. (2003). Effects of planting pattern on growth, development, yield components and seed yield of safflower, local variety of Isfahan, Koseh, in spring planting. Journal of Science Technology of Agronomy and Natural Resources 7 (1):155-167.

3arnett, D. (1999). Botswana-economy: Diversification the watchword for Botswana, Africa's model economy. Agency France- Presse- October 14, 1999.

3assil E. S and Kaffka S. R (2001). Response of safflower (*Carthamus tinctorius L*) to saline soils and irrigation I. Consumptive water uses. Agricultural Water Management 54: (2002) 67-80

ierghage, R. D. and Heins, R .D. (1991) Qualification of temperature effects on stem elongation in Poinsettia .Journal of American Society Horticultural Science 116:14-18.

ergland, D. R, Riveland, N. and Bergman, J. (2007). Safflower Production A-870 Environment – Natural Resources, Agronomy Journal 26:249-256.

hatti, M. H., Nelson, L. A. Baltensperger, D. D. Lyon, D. J. Kachman, S. D. and Frickel, G. E. (1999). Influence of planting dates and populations on seed yield and plant characteristics of sunflower in the high plains. Journal of Production Agriculture 12(1):38-42.

IDPA, (2005). Botswana Institute for Development Policy Analysis. The potential for Diversification in Botswana, Ostrich Products case study 28p.

Blackshaw, R. E. (1993). Safflower (*Carthamus tinctorius*) density and row plant density effects on competition with green foxtail (*Setaria viridis*). Weed Science 41:403-408.

Blandy, F. (2009). Botswana mulls life after diamonds. The Namibian, http://www.namibian.com.na/index.php?id=28&tx_ttnews%5Btt_news%5D=60849&no_cache=1

Board, J. E. (2000). Light interception efficiency and light quality affect yield compensation of soybean at low plant populations. Crop Science 40:1285-1294.

Brauwer, R. (1981). Coordination of growth phenomenon within a root system of maize plants. Plant Soil 63:65-72.

Carpenter, A. C. and Board J. E. (1997). Branch yield components controlling soybean yield stability across plant population. Crop Science 37:1520-1526.

Chavan, V. M. (1961). Niger and Safflower. Indian Central Oilseeds Committee Publication, Hyderabd, India pp.57-150.

Dajue, L. and Münde l, H. H. (1996) Safflower (*Carthamus tinctorius*) L. promoting the conservation and use of underutilized and neglected crops. International Plant Genetic Resources Institute 83p.

Dole, M. J. and Wilkins, H. F. (2005). Floriculture, Principles and Species. Prentice Hall. Incorporation 1023p.

Ehsanzadeh, P and Baghdad-Adadi Z. (2000). Yield, yield components and growth characteristics of two safflower genotypes under varying plant densities. Journal of Science and Technology of Agriculture and Natural Resources 7(1):129-140.

Emongor, V. E. (2007). Gibberellic acid (GA_3) influence on vegetative growth, nodulation and yield of cowpea (*vigna unguiculator* (L.) walp). Journal of Agronomy 6(4):509-517.

Emongor, V. E. (2010). Safflower (*Carthamus tinctorius L).* The underutilized and neglected crop. Asian Journal of Plant Sciences 9(6): 299-306.

Emongor, V. E., Macheng, B. J. and Kefilwe, S. (2012). Effects of secondary sewage effluent on the growth, development, fruit yield and quality of tomatoes (*Lycopersicon lycopersicum (L).* Karten). Acta Horticultural 944:29-39.

Erwin, J. E, Heins, R. D. Berghage, R. and Carlson, W. (1989a). How can temperatures be used to control plant stem elongation? Minnesota State Florist Bulletin 38 (3):1-5.

Erwin, J. E, Heins, R. D. and Karlson, M. G. (1989b). Thermorphogenesis in *Lilium longiflorum.* American Journal of Botany 76:47-52.

Evans, L. T., Wardlow, I. F. and Fischner, R. A. (1976). Wheat. In: Evans, L. T. (Ed), Crop Physiology: some case history, Cambridge University Press, pp. 101-149.

FAO (2010). Crops –FAO Statistics safflower production 567p.

Faust, M. (1989). Physiology of Temperate Zone Fruit Trees. John Wiley and Sons 338p.

Fick, G. N. (1978). Breeding and genetics. In; J. F. Carter Safflower Science and Technology Agronomy Monograph 19:279-338.

Garcia, A. (2009). Diabetic cookbook Blog, http//:www.diabeticcookbookblog.com.

Gardner, F. P., Pearce, R. B. and Mitchell, R. L. (1985). Physiology of Crop Plants. Iowa State University Press Ames 327p.

Gibbon, D. and Pain, A. (1985). Crops of the Drier Regions of the Tropics, Longman Singapore 156p.

Gonzalez, J. L., Schneiter, A. A. Riveland, N. R. and Johnson, B. L. (1994). Response of hybrid and open- pollinated safflower to plant population, Agronomy Journal 86: 1070-1073.

Heggenstaller, A. H., Liebnan, M. and Anex, R. P. (2009). Growth analysis of biomass production in sole- crop and double-crop corn systems. Crop Science 49:2215-2224.

Janick, J. (1986). Horticultural Science, 4th Edition, Freeman and Company.

Karlson, M. G. Heins, R. D. Erwin, J. E. and Berghage, R. D. (1989). Temperature and Photosynthetic photonflux influence chrysanthemumshoot development and flower initiation under short day conditions. Journal of American Society Horticultural Science 114:158-163.

Knowles, P. F. (1965). Report of Sabbatical Leave, Report for University of California, Davis, CA, 48p.

Knowles, P. F. and Ashri, A. (1995). Safflower: *Carthamus tinctorius* (Compositae). *In* J. Smartt and N. W. Simmonds Evolution of crop plants, Longman, Harlow, UK, pp 47-50.

Kwarteng, J. A. and Towler, M. J. (1994). West African Agriculture. Macmillan. London. UK, 321p.

Landau, S., Friedman, S., Brenner, S., Bruckental, I., Weinberg, Z. G., Ashbell, G. Hen-Y. Dvash, L. and Leshem, Y. (2004). The value of safflower (*Carthamus tinctorius*) hay and silage grown under Mediterranean conditions as forage for dairy cattle. Journal of Livestock Production Sciences 88:263-271.

Majid, H. R and Schneiter, A. A. (1988). Semi dwarf and conventional height sunflower performance of five plant populations. Agronomy Journal 80:821-824.

Marschner, H. (2005). Mineral Nutrition of Higher Plants. 2nd Edition, Academic Press 889p.

Mengel, K. and Kirkby, E. A. (2001). Principles of Plant Nutrition, 5th Edition. Kluwer Academic Publishers 849p

MoA, (2009). Ministry of Agriculture, African Development Bank, Botswana, 2009-2013 Country Strategy Paper, Government Printers, Gaborone 36p.

Mohler, R. S. and Boudreaux, M. D. (1967). Safflower - Wikipedia, the free encyclopedia.mht. http://www.nationmaster.com/encyclopedia/Safflower.

Mündel, H. H. (1969). Effects of rainfed and irrigated conditions on yield of indigenous and exotic varieties of safflower (Carthamus tictorius L.). Madras Agricultural Journal 56:772-777.

Mündel, H. H., Morrison, R. J. Blackshaw, R. E. and Roth, B. T. (1992). Safflower Production on the Canadian Prairies. Agricultural Canadian Research Station, Lethbridge/ Alberta Safflower Growers Association with funding by Farming for the Future Project No. 87-0016. Alberta Agricultural Research Institute 35 p.

Mündel, H. H., Morrison R. J., Eentz, T., Blachshaw, R. E., Roth, B. T., Kiehn, F., and Vandeberg A. (1994). Row spacing and seeding rates to optimize safflower yield. Canadian Journal of Plant Science 74:319-321

Myster, J. and Moe, R. (1995). Effect of diurnal temperature alterations on plant morphology in some green house crops. A Mini Review on Horticultural Science 62:205-215.

Nasr, H.G., Katkhuda, N. and Tannir, L. (1976). Effect of N fertilizer and population rate, spacing on safflower yield and other characteristics. Agronomy Journal 70:683-685.

Nau, J. (1993). Ball Culture Guide. The Encyclopedea of Seed Germination. 2nd Edition, Ball Publishing, Batavia Illinois 143p.

NDP, (2003). National Development Plan 9, Government Printers, Gaborone 610p.

Ngugi, D. N., Karau, P. K. and Nguyo, W. (1990). 3rd Edition, East African Agriculture. Macmillan London, UK 330p.

Oad, F. C, Samo, M. A, Qayyum, S. M, and Oad, N. L. (2002). Inter and intra row plant density effect on growth, seed yield and oil content of safflower (*Carthamus tictorius L.*). Asian Journal of Plant Sciences 1: 18-19.

Peterson, W. (1965). Safflower culture in the west central plains. USDA-ARS and University of Nebraska (Lincoln) Agricultural Experimentation Station. Agricultural Information. Bulletin,300, 22p.

Qayyum, S. M., Rajput, M. R., Sodhro, K. D. L., Tunio, K. D. L and Khan, M. A. (1986). Effect of different row plant density on growth and yield of safflower. Sesame and Safflower News Letter 2:74.

Ramolemana, G. M. (1999). The phosphorus and nitrogen nutrition of bambara groundnut (Vigna subterranea (L.) Verdc.) in Botswana soils, An exploratory study. PhD Thesis, Wageningen University and Research Centre, The Netherlands 90p.

Robinson, R. G., Ford, J. H., Lueschen, W. E., Rabus, D. L., Smith, L. J., Warnes, D. D and Wiersma, J. V. (1980). Response of safflower to plant population. Agronomy Journal 72:869-871

Rowland, J. R. J (1993). Dryland Farming in Africa. Macmillan Publishing company, Hong Kong 336p.

Salisbury, F. B. and Ross, C. W. (1992). Plant Physiology, 4th Edition, Wadsworth Publishing Company, California 682p.

SAS (2011). SAS user's guide: basic, version 5. Cary, NC: SAS Institute Incorporation.

SemBiosys (2009). Canadian company develops safflower as anew source of insulin. http://www.isb.vt.edu/artcles/oct0605.htm.

Shang, H., Deitzer, G. F. and Lea-Cox, J. D. (2003). Differential temperature (DIF) effects on the growth, morphology and flowering of *Antirrhinum majus* L. (snapdragon) cultivars. Acta Horticulturae 624:177-183.

Smith, J. R. (1996). Safflower, AOCS Press, Champaign, IL, USA. 624 p.

Snedecor, G. W. and Cochran W. G. (1989). Statistical Methods. 8th Edition. Iowa State University Press 503p.

Stone, L. R., Goodrum, D. E., Jaafar, M. N. and Khan, A. H. (2001). Rooting front and water depletion depths in grain sorghum and sunflower. Agronomy Journal 93(5):1105-1110.

Taiz, L. and Zeiger, E. (2002). Plant Physiolgy, 3rd Edition. Sinauer Associates.Inc.USA 690p.

Tisdale, S. L. Nelson, W. L. Beaton, J. D. and Havlin, J. I. (1993). Soil Fertility and Fertilizers. 5th Edition, Macmillan Publishing Company. New York 634p.

Vranceanu, A. V. (1977). The Safflower, Ediciones Mundi- Prensa, Madrid, Spain 379p.

Wallace, D. H., Zobel, R. W. and Yourstone, K. S. (1993). A whole-system re-consideration of paradigms about photoperiod and temperature control of crop yield. Theoritical Application Genetics 86:17-26.

Wang, G. and Yili, L. (1985). Clinical application of safflower (*Carthamus tinctorius),* Zhejiang Traditional Chinese Medical Science Journal 1: 42-43.

Weiss, E. A. (1983). Oilseed crops. Safflower, Longman Group Limited, Longman House, London UK, pp. 216-281.

Went, F. W. (1944). Plant growth under controlled conditions. Thermoperiodicity in growth and fruiting of tomato. American Journal of Botany 31:135-150.

Zaffaroni, E. and Schneiter, A. A. (1991). Sunflower population as influenced by plant type, plant population and row arrangement. Agronomy Journal 83:113-118.

Zhenshun D., Xiping, S. and Fang, Z. (1992). The effects of Chinese medicine Shu-jing Drip on cerebral artery blood flow of atherosclerosis of 30 cases. Journal of Shanxi Traditional Chinese Medicine 8(2):12-13.

Appendix A

Maximum and minimum temperatures for winter planting 2010

	Feb			Mar			Apr			May			Jun			Jul		
Day	Max	Min	DIF	Max	Min	DIF	Max	Min	DIF	Max	Min	DIF	Max	Min	DIF	Max	Min	DIF
1	35.2	18.4	16.8	31.6	16.3	15.3	21.6	18.6	3	27.5	13.4	14.1	20.8	2.1	18.7	23.9	4.3	19.6
2	33.3	19.5	13.8	33.9	15.6	18.3	24.7	17.4	7.3	26.6	13.9	12.7	21.6	2.3	19.3	22.4	4.6	17.8
3	33	19.3	13.7	31	18.6	12.4	25.5	17.8	7.7	20.5	14.6	5.9	21.9	1.1	20.8	22.6	4.3	18.3
4	35.5	19.7	15.8	29.6	16.2	13.4	27.5	15.7	11.8	23	15	8	22.4	1.2	21.2	19.6	4.7	14.9
5	31.7	18.6	13.1	29.8	16.7	13.1	26.2	17.5	8.7	26	8.8	17.2	24.7	1.8	22.9	21.6	9	12.6
6	33.2	19.4	13.8	30.5	16.6	13.9	25	17.8	7.2	25.6	8.5	17.1	25.3	2	23.3	25.6	13.1	12.5
7	34.5	19.5	15	31.5	15.5	16	28.2	16.6	11.6	26.1	10.6	15.5	24.4	1.5	22.9	23.7	4.6	19.1
8	34.1	17.6	16.5	30.6	11.6	19	29.9	14.2	15.7	23.1	10.9	12.2	26.2	2.1	24.1	21	5	16
9	33	16.9	16.1	32.6	13.6	19	32.6	18.2	14.4	27.8	11.6	16.2	24.1	4.6	19.5	20.3	1.2	19.1
10	32.2	14.1	18.1	35.2	13.5	21.7	31.2	17.8	13.4	29.8	14.1	15.7	22.1	3.9	18.2	24	0.4	23.6
11	36	15.5	20.5	35.2	15.2	20	25.6	14.9	10.7	27.4	8.2	19.2	20.5	9	11.5	25.3	1.7	23.6
12	37.5	15.1	22.4	37	16.2	20.8	27.4	12	15.4	25.5	5.2	20.3	21.6	6	15.6	15.1	1	14.1
13	39.4	14.6	24.8	38.2	16.9	21.3	27.2	14.2	13	25.4	7.2	18.2	27.1	4.7	22.4	18.2	-4	22.2
14	37.1	17.1	20	36	17.7	18.3	25.4	12.5	12.9	25	12.2	12.8	27.4	2	25.4	22.6	1.1	21.5
15	28.6	19	9.6	31.1	17.6	13.5	28.5	12.2	16.3	27	11.2	15.8	13.2	6.6	6.6	22.7	3.1	19.6
16	33.1	19.1	14	31.1	19.2	11.9	29.5	10.6	18.9	24.6	11.2	13.4	15.6	-2.2	17.8	19.9	-1.7	21.6
17	32.1	20.4	11.7	33.9	16.2	17.7	30.7	10.8	19.9	23.4	11.1	12.3	17	-4	21	24.1	-1.9	26
18	31.6	17.9	13.7	35.2	14.6	20.6	31.6	14	17.6	22.2	5.6	16.6	17.9	-3.4	21.3	20.8	-0.9	21.7
19	32	19.5	12.5	26.7	19.2	7.5	30.4	14.8	15.6	24.6	5.5	19.1	16.8	-4	20.8	21.1	-2.4	23.5
20	31.2	20	11.2	34.2	18.2	16	24.6	15	9.6	24.3	5.5	18.8	21.1	-3.2	24.3	22.1	-3	25.1
21	30.6	17.8	12.8	32.1	14.9	17.2	25.2	10.9	14.3	24	5.5	18.5	20	-2	22	22.6	-0.5	23.1
22	32.2	17.5	14.7	31.5	16.5	15	26.6	15.6	11	24.1	5.7	18.4	21.6	-2.3	23.9	22.4	2	20.4
23	32.9	19.2	13.7	31.6	15.5	16.1	27.1	13.4	13.7	23.6	6.1	17.5	22.5	-1.2	23.7	23	3.1	19.9
24	32.1	20	12.1	26.6	19	7.6	15.4	14.5	0.9	24.8	4	20.8	22	-1.8	23.8	23	2.5	20.5
25	22.6	20.9	1.7	33.8	17.5	16.3	15.8	13.4	2.4	25.6	3.9	21.7	24	-0.6	24.6	26.1	7.8	18.3
26	27.4	16.6	10.8	33	20	13	14.9	13.1	1.8	25.1	2.6	22.5	24.3	-0.8	25.1	24.6	10.6	14
27	38.1	17.6	20.5	30.6	21.1	9.5	16.6	14.1	2.5	26.1	3.4	22.7	24.8	-0.4	25.2	25.6	5.5	20.1
28	31.1	20	11.1	34.6	18.9	15.7	19.4	15.2	4.2	27.5	4.1	23.4	22.4	1.5	20.9	26.6	3.9	22.7
29				24.1	20.9	3.2	25.1	11	14.1	26.2	4.3	21.9	21.2	4.5	16.7	25.7	3.1	22.6
30				31.1	18.5	12.6	27.3	12	15.3	12.4	9.9	2.5	23.1	4.1	19	24.1	7.1	17
31				33.6	17.6	16				19.9	8.1	11.8			0	25.6	3.5	22.1

Appendix B

Maximum and minimum temperatures for summer planting 2010

	Aug			Sep			Oct			Nov			Dec			Jan		
Day	Max	Min	DIF	Max	Min	DIF	Max	Min	DIF	Max	Min	DIF	Max	Min	DIF	Max	Min	DIF
1	24.4	5.2	19.2	29.9	5.4	24.5	29.7	8.3	21.4	34	16.3	17.7	33.4	16	17.4	34.4	19.9	14.5
2	23	3.5	19.5	33.4	5.5	27.9	30.4	9.6	20.8	34.1	17.2	16.9	31.4	17	14.2	27.6	19.5	8.1
3	22.7	1.7	21	33.5	7.6	25.9	37.4	10.3	27.1	33.8	15.6	18.2	35.8	19	16.8	31.1	20.4	10.7
4	24	1.6	22.4	30	9.7	20.3	37.5	13.4	24.1	38	15	23	36.6	17	20	31.1	18.6	12.5
5	24	2.5	21.5	34.1	7	27.1	28	19.4	8.6	39.1	15.4	23.7	36.6	16	20.7	32.6	20.2	12.4
6	26.8	3.3	23.5	32.5	7.1	25.4	34.6	14.2	20.4	37.4	15.9	21.5	33.2	16	17.6	28.9	19.4	9.5
7	26	6	20	34.6	8.1	26.5	33.9	17.2	16.7	34.9	15.2	19.7	29.1	20	9.1	25.5	15.6	9.9
8	25.1	3.4	21.7	29.6	14.1	15.5	36.7	15.8	20.9	34.8	18.2	16.6	31.2	20	10.9	25.2	14.4	10.8
9	26.1	3.3	22.8	29.4	11.9	17.5	38	15.9	22.1	30	17.8	12.2	33.7	21	13.2	26.9	14.2	12.7
10	26.6	3.9	22.7	29.1	12.9	16.2	39.2	18.1	21.1	29.9	15	14.9	35	18	17	31.6	14	17.6
11	19.4	2.4	17	29.7	7	22.7	35.6	16	19.6	35	11	24	36.8	18	18.8	31.6	17.6	14
12	19.4	0.1	19.3	31.4	6.9	24.5	37.6	16.4	21.2	38.5	18.2	20.3	26.6	21	6.1	31.1	19.3	11.8
13	28.2	-0.5	28.7	32	7.2	24.8	30	18.1	11.9	39.5	12	27.5	24.1	17	7.2	29.4	16.9	12.5
14	28.4	3.7	24.7	32.5	8.4	24.1	29.9	20.5	9.4	32.1	18.3	13.8	21.1	18	3.1	30	19.5	10.5
15	29.2	4.1	25.1	33.5	5.2	28.3	27.2	9.5	17.7	28.2	20	8.2	28.8	19	9.8	30.1	19	11.1
16	29.9	2.9	27	34.9	7.9	27	28.5	6.8	21.7	30.1	19.5	10.6	31.6	18	13.5	27.8	20.1	7.7
17	25	6.1	18.9	28.7	11.9	16.8	27.6	13	14.6	30.1	15.9	14.2	34.2	16	18.7	31	19.9	11.1
18	26.6	2.6	24	29	10.8	18.2	32	13.2	18.8	20.2	17.5	2.7	33.9	19	14.9	25.1	18.3	6.8
19	30.6	4.2	26.4	32.5	10.8	21.7	35.2	15.3	19.9	34.9	15.5	19.4	34	19	15.4	29.9	20.2	9.7
20	26.5	3.7	22.8	34.1	11	23.1	36.7	12.4	24.3	33.1	15	18.1	29.8	17	12.6	31.1	20	11.1
21	23.5	7.5	16	29.3	13.9	15.4	37.1	16.6	20.5	34.6	15.9	18.7	31.2	17	14	28.5	21.6	6.9
22	31.4	3.6	27.8	28.6	7.4	21.2	34.4	19.5	14.9	32.4	22.4	10	33.5	17	16.3	29.2	20.8	8.4
23	27.1	4.5	22.6	33.6	5.5	28.1	35.6	20.5	15.1	34.4	19.3	15.1	36.2	20	16.2	31.1	20.9	10.2
24	25.1	4.5	20.6	34.7	13.4	21.3	37.6	18.4	19.2	29.3	20	9.3	32	19	12.7	27.6	18	9.6
25	23	8.1	14.9	35.2	13.7	21.5	32	14.9	17.1	27.8	18.3	9.5	36.4	18	18	29.2	20.5	8.7
26	27.9	8	19.9	34.9	12.9	22	35.1	10	25.1	28	18.3	9.7	31	21	10.3	31.1	20.6	10.5
27	30.3	6.5	23.8	31	10.5	20.5	34.4	17.1	17.3	33.4	16.7	16.7	30.5	19	11.5	32.1	19.2	12.9
28	28.7	10	18.7	23.7	13.4	10.3	34.9	19	15.9	36.9	17	19.9	34.4	16	18.2	33.2	19.5	13.7
29	31.6	8.1	23.5	26	10.7	15.3	35.5	10.5	25	37.6	22	15.6	34.9	18	16.7	32.8	19.8	13
30	29	8.3	20.7	29	8.3	20.7	35	17.4	17.6	28.2	20	8.2	33.5	21	12.5	31.6	17.4	14.2
31	18.6	6	12.6				35.6	17	18.6				33.9	20	13.9	29.4	19	10.4