Assessment of the Suitability of Raised Bed – Furrow Irrigation Technique in Saving Water for Wheat Production in New Halfa Area, Sudan

By

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DEDICATION

To my kind mother, to my father

To my wife

To my sons Tarig and Tamir, to my daughter Nowar

To my brothers and sisters

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Deep thanks and appreciations to my supervisor Dr. Abdel moneim Elamin Mohamed for his valuable, excellent supervision and guidance. Deep thanks to the International Center for Agricultural Research in Dry Areas - ICARDA for the intensive training in raised bed planting techniques and partial funding, with special regard to my joint (external) supervisor Dr. Atef Aswelam for his valuable training and support. Special thanks to the head of Capacity Development Unit- ICARDA, Mr. Charles. Thanks are also extended to the staff of ICARDA office in Cairo. The partial financial support of African Development Bank through the SARD-SC Project for conducting field experiments is gratefully appreciated. Thanks extended to Prof. Abdallh Elhagwa, the head of the Capacity Development Unit, ARC, Sudan, and to Dr. Bashir Mohamed Ahmed the National Coordinator of Agricultural Engineering Research, ARC, Sudan for their help and support Thanks are also to Dr. Abdallh Kurmot for his help and Support. Many thanks to Dr. Murari Singh (ICARDA), my colleagues Dr. Bader Eldeen Abdelgader and Hashim Abd Elkareem for assisting in statistical analysis. Thanks are also to Dr. Tag Elser Abelrahman, the dean of Faculty of Agriculture, university of Kassala, for his help. Deep thanks to the staff work in New Halfa Research Station with special regards to my assistant Mr. Mohamed Elmhabob Suliman. Special thanks to the staff of the Department of Agricultural Engineering, Faculty of Agriculture, university of Khartoum for their help and support. Thanks are extended to every one of my colleagues who assisted in one way or another to complete this work.

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Ph.D. Agric. (Agric. Engineering) Thesis

Mohamed Yousif Daffalla Ebdelrahman

Abstract: Three separate experiments were conducted through the period 2013-2016 in the Agricultural Research Station farm in New Halfa, eastern Sudan. The objectives of the study were to assess the suitability of raised bed planting for wheat crop production, as a technique to save irrigation water and increase water productivity (water use efficiency) and to determine the suitable raised bed dimensions and number of crop rows per bed. In the first experiment four sowing methods (Raised bed planting BP, Seed drilling SD, Broad Casting BC and Wide Level Disc WLD), four quantities of irrigation water (3000 W3, 4000 W4,5000 W5 and 6000 m^3/ha W6), two wheat varieties (Bohain and Imam) (120kg/ha) and two weed control treatments (herbicides treated and untreated) were examined . In the second experiment the four sowing methods, four seeding rates (SR84, SR96, SR120 and SR144 kg/ha), two wheat varieties (Bohain and Imam) and two weed control (herbicides treated and untreated) were compared. The two experiments were laid in split- split plot design with three replications. GenStat12.1 program was used for data analysis. In the third experiment Raised beds of different bed widths (80, 100 and 120cm), furrow depths (15cm and 25cm), furrow widths (30 and 40 cm) were compared with the conventionally used seed drilling on flat surface. The experimental design adopted was the Randomized Complete Block Design (RCBD) with three replications. Data was statistically analyzed using

Statistix 10 program. The Duncan's Multiple Range Test (DMRT) was used for the separation of means in all the experiments. Results showed that raised bed planting technique, herbicides treated, for the two varieties gave higher grain yield of wheat crop than the other sowing methods. Using less volume of irrigation water (4000 m^3/ha), raised bed planting technique gave the same or higher yield than what was given by the other sowing methods using more volume of irrigation water (5000 - 6000 m^3/ha), thus saved 20 - 33% of irrigation water. Using less seeding rate raised bed planting technique gave the same or higher yield than what was given by the other sowing methods by more seeding rate ,thus saved 20- 33% of seeds. Raised bed planting technique gave higher water productivity and less irrigation water irrespective of bed width and furrow dimensions, than seed drill on flat land. The 120 cm bed width used less irrigation water, higher water saving percentage but lower grain yield and lower water productivity than the 80 cm bed width due to the poor wetting pattern at the middle rows resulting from the too wide bed width. The combination 80 cm bed width, 25 cm furrow depth, 40 cm furrow width with 3 crop rows gave grain yield more than that given by seed drills by 42%, high water productivity (1.3 kg/m^3) and less irrigation water by 13%. While seed drill sowing method with basin irrigation resulted in high applied water, intensive weed infestation, low grain yield, low water productivity and more irrigation water by 17%. Raised bed planting system had no negative impact on soil salinity or on the main soil nutrients (NPK). The study recommended use of raised bed of 80 cm bed width, 25 cm furrow depth, 40 cm furrow width with 3 crop rows for wheat production in New Halfa area as a water saving technique and high water use efficiency.

تقييم مدى ملاءمة تقنية الزراعه على المساطب العالية لانتاج محصول القمح و توفير مياه الرى في منطقة حلفا الجديدة، السودان

أطروحة دكتوراة زراعة – (هندسة زراعية)

محمد يوسف دفع الله عبد الرحمن

المستخلص: تم اجراء ثلاثه تجارب منفصله خلال الفتره 2013- 2016 في مزرعة محطة البحوث الزراعية بحلفا الجديده، شرق السودان بغرض معرفة مدى ملاءمة نظام الزراعه على المساطب العالية لانتاج القمح و كتقنية لتوفير مياه الري و رفع كفاءة انتاجية الماء (كفاءة استخدامها). كذلك بغرض تحديد الابعاد المناسبه للمسطبه و بطن المسطبه بالاضافه لتحديد عدد صفوف المحصول علي ظهر المسطبه. في التجربة الأولى تمت المقارنة بين أربعة طرق لزراعة القمح وهي طريقة الزراعة على المساطب العالية، طريقة الزراعه بالسطارة، طريقة النثر ثم التسريب وطريقة الزراعة بالقرص العريض وبين أربع كميات من مياه الري وهي 3000 ، 4000 ، 5000 و6000 متر^3/فدان و صنفين مجازين من القمح هما بوهين وإمام بمعدل بذر120 كجم/هكتار وطريقتين لمكافحة الحشائش هما الرش بالمبيدات وعدم الرش. التجربة الثانية تضمنت نفس معاملات التجربة الأولى الا ان كميات مياه الري في التجربة الأولى قد استبدلت بأربع معدلات تقاوي هي 84 ، 96 ، 120 و144 كجم/هكتار. المعاملات في التجربتين قد وضعت في تصميم القطع المنشقة في ثلاثة مكررات، تم تحليل البيانات بواسطة برنامجGenStat12.1 . في التجربة الثالثة تمت المقارنة بين ثلاثة أبعاد لعرض المسطبة وهي 80 ، 100 و120 سم وبين عمقين لبطن المسطبة هما 15 و25 سم وبين عرضين لبطن المسطبة هما 30 و40 سم والزراعه بواسطة السطارة تم وضع المعاملات في تصميم القطاعات العشوائية الكاملة في ثلاث مكررات. وتمت زراعه صنف واحد هوالصنف بوهين بمعدل بذر120 كجم/هكتار. تم تحليل البيانات بواسطة برنامج Statistix 10 كما تم استخدام اختبار دنكن لتحديد اقل فرق معنوى بين المتوسطات في كل التجارب. اظهرت النتائج ان نظام الزراعة في المساطب العالية ، المعامل بمبيدات الحشائش، أعطى نفس الانتاجيه او اعلي بالنسبة لوحدة المساحة و وحدة المياه في الصنفين باستعمال كمية مياه أقل (4000 متر^3/هكتار) من التي تم تحقيقها بالطرق الأخرى بكميات مياه أعلى (5000- 6000 متر^3/هكتار) مما أدى الى توفير 20-33 % من مياه الري. اوضحت النتائج كذلك ان الزراعة بنظام

المساطب العالية قد اعطت نفس الانتاجيه أو اكثرباستعمال معدل بذر أقل من التي تم تحقيقها بالطرق الاخرى بمعدلات بذر أعلى مما أدى الى توفير 20-33 % من البذور. كذلك أشارت النتائج بان طريقة الزراعة على المساطب العالية بغض النظر عن أبعاد المسطبة وبطن المسطبة قد نتج عنها كفاءة أعلي لاستخدام مياه الري و استهلاك مياه أقل مقارنة بالزراعة بالتسطير على السطح و الري بالغمر. المسطبة بعرض 120 سم نتج عنها اقل استهلاك لمياه الري و بالتالي نسبة توفير لمياه الري أعلى مقارنة بالمساطب بابعاد 80 و100 سم ولكنها أعطت إنتاجية أقل بالنسبة لوحدة المساحة و وحدة المياه وذلك لضعف البلل في منطقة وسط المسطبة بسبب العرض غير المناسب للمسطبة. التركيبة مسطبة بعرض 80 سم، بطن مسطبة بعمق 25سم و عرض 40 سم و ثلاثه خطوط محصول علي ظهر المسطبة قد اعطت أنتاجية أعلي بحوالي 42% مقارنة بالزراعة بالتسطير و الري بالغمر. و أعلى إنتاجية بالنسبة لوحدة مياه الري 1.3 كجم/م^3، و كمية أقل من مياه الري بنسبة 13%. في حين ادت طريقة الزراعة بالتسطير و الري بالغمر الي استهلاك حجم أكبر من مياه الري بنسبة 17% ,مما أدي إلى تدني الإنتاجية بسبب كثافة نمو الحشائش. اشارت النتائج الي ان طريقة الزراعة علي المساطب العالية لم تؤدي الي اي تغيير سلبي في ملوحة التربة أو في العناصر الرئيسية (النيتروجين،الفوسفور و البوتاسيوم).

توصي الدراسة باستخدام نظام الزراعة بالمساطب العالية بالتركيبة: مسطبة بعرض 80 سم، بطن مسطبة بعمق 25سم و عرض 40 سم و ثلاثه خطوط محصول علي ظهر المسطبة لزراعة محصول القمح في منطقة حلفا الجديدة كوسيلة لتوفير مياه الري و رفع كفاءة استخدامها.

CHAPTER ONE

INTRODUCTION

Agriculture in Sudan is the principal source of income and livelihood for 60 to 80% of the population (Elgali,2010). Agriculture is divided into two main sectors; irrigated and rainfed. The irrigated sector covers about 1.8 million ha including the Gezira, Rahad, New Halfa, Elsuki,White Nile and Blue Nile schemes. Gezira, Rahad and New Halfa are considered the most important, and they produce cotton, groundnut, wheat, sorghum and vegetables (Mahir and Abdelaziz, 2010).

Sudan has the largest irrigated area in sub - Saharan Africa and ranked second only to Egypt on the continent in terms of irrigated agriculture. Commercial agricultural activities are mostly concentrated in a belt across the center of the country, known as the central clay plain, which extends approximately 1100 km from south to north between latitudes 10º and 14º North, in the arid, semi - arid dry Savannah zone (UNEP, 2007).

Agriculture in Sudan accounts for 97% of the country's water use (Sullivan, 2010, Barton and Writer, 2012).The diversion of water to mechanized farms and intensive cultivation by rural farmers is contributing to the spread of arid conditions across Sudan (Barton and Writer,2012). Water is in high demand to meet the needs of the rapid population growth and food production and plans to expand agriculture through irrigation further raises the demand for water (Taha, 2010). Water requirement will become severe if the environmental factors are considered, such as increased desertification and degradation, which have intensified Sudan's water problems (Ashok, 2008).

Mahgoub (2014) stated that Sudan would face water deficit if it implemented its policy to extensively increase the area of irrigated land.

Wheat is a cereal grain grown all over the world. It is the third most produced cereal after maize and rice and the staple food of millions of people. The world map (2017) shows a list of top ten wheat producers in the world. The European Union, which is an amalgamation of several European nations, tops the list. However, among other nations, China is the world's second largest wheat producing nation, followed by Russia, USA and Canada. The total world wheat production between 1996-2011 is listed in Table 1.1.

Sudan total cereals production is usually sufficient to meet domestic needs, especially in terms of sorghum and millet, but is a net importer of wheat (Ahmed, 2010). Wheat imports started to increase since 1990s up to 2006 which reflected the change in the population feeding patterns (Abbadi and Ahmed, 2006). Bread consumption has been widespread in both rural areas as a consequence of changing tastes, convenience and consumer subsidies. Table 1.2 shows the wheat production in Sudan from 1999 to 2004 and from 2010 to 2014. Sudan imports of wheat during 2009- 2014 shown in Table 1.3. Moreover, according to Sudan tribune (2014), Sudan imports about 2millions metric tons yearly which costs about 1.5 milliard Dollars. They added that Sudan wheat production covers about 35% of its demand in the best situations. Wheat is a strategic crop in Sudan produced under irrigation during the dry and comparatively cool and short growing season (November - March).The main production areas of wheat in Sudan are the Northern State and in the central clay plains in the schemes of Gezira (168,000 ha) New Halfa (25,200 ha) and Rahad (18,900 ha) in the semi arid climate.

Table 1.1 World wheat production (1996-2011)

year	Production (millions metric tons)
1996	585.4
1997	613.4
1998	593.6
1999	587.6
2000	586.1
2001	589.7
2002	574.7
2003	560.3
2004	633.3
2005	628.7
2006	605.9
2007	607.0
2008	683.4
2009	685.6
2010	651.1
2011	704.1

Source: FAO (2012)

Table 1.2 Total wheat productions in Sudan (1999-2014)

Year	Wheat production (tons)
1999	214,000
2000	266,000
2001	247,000
2002	321,000
2003	405,000
2004	290,600
2010	192,000
2011	265,000
2012	324,000
2013	467,000
2014	564,000

Source: FAO (2012) and Aiz Eldeen (2015)

Salih (2012) mentioned that wheat areas increased from less than 27,000 ha in the early 60ś to 360,000 ha in the 90ś. Areas declined during 2000- 2005 due to the unavailability of credits and late provision of inputs. During 2006 - 2010 areas increased to around 277,000 ha as a result of encouraging production policies and the expansion into new areas. He added that the major constraints limiting wheat production in Sudan are mainly heat and moisture stresses and low soil fertility, weed and aphid infestations, stem rust in the eastern parts of the Sudan, lack of clear sustainable strategic production and marketing policies and weak technology transfer.

Table1.3 Sudan imports of wheat (2009-2014)

Year	Imports (tons)	Cost (million USA $)
2009	1,608,002	696
2010	2,620,027	977
2011	1, 717,544	711
2012	2,053,963	810
2013	2,314,240	1,027
2014	2,177,962	1,046

Source: Aiz Eldeen (2015)

In New Halfa scheme wheat is planted by drills or broadcasted using the wide level disc and irrigated by flood irrigation (basin irrigation). The field is divided into small units which render the work to be laborious, time consuming and also considerable amount of water is lost due to uncontrollable application of irrigation water and by evaporation.

Ageeb (1993) stated that the soil of the irrigated schemes of central and eastern Sudan is relatively uniform, fairly leveled, calcareous heavy cracking vertisol. Drainage is impeded by the extremely low hydraulic conductivity (1.5 cm/h) of the soil. As a result, waterlogging is frequent in poorly managed soils. He also added that poor crop establishment of wheat is a major cause of low yield on the heavy clay soils, which constitutes 90% of the total cropped area. The problem is mainly related to one or more of the following factors: inadequate land preparation including field leveling, excessive water application at the planting time and improper seed placement. In addition to that high temperatures and water shortage are common occurrences and resulted in low yield.

Dawelbeit and Babiker (1997) found that in the irrigated vertisol of Rahad scheme in Sudan drilling in rows as well as ridging after broadcasting resulted in significantly greater yield than broadcasting alone.

Since the balance between water demand and water availability has reached critical levels in many regions of the world and increased demand for water and food production is likely in the future, a sustainable approach to water resource management in agriculture is essential. The sustainable water management concept refers to all practices that improve crop yield and minimized non- beneficial water losses (Nhantumbo, *et al*, 2010).

The principle of bed planting consists basically of sowing crops on ridges or beds instead of the flat surface of field and applying irrigation water and other inputs via surrounding furrow (RBM, 2008). Bed planting provides a water saving alternative, where the crop is planted on beds and irrigation water is applied to furrows. This saves water up to 40% as illustrated by Khan *et al* (2012). They added that in wheat 4 rows of plants are sown in pairs on either side of a 60 cm beds alternated by 25 cm wide furrows. So water, in contrast to flood irrigation, is applied to less than ⅓ of the field and to the plants resulting in marked saving. They also mentioned that a very conservative estimate indicates that farmers can grow an additional one acre for every two acres if they plant the crop on bed. Crop planted on beds receives water through seepage, it is not in contact with flooded water and consequently lodges less than surface planted crop. Moreover, they stated that bed planting crop gave higher yields due to robust plant growth and more open space available to plants on either side of the row which allows more sun and aeration to the plant. Bed planted crop yields well even at low seed rates. Bed planting system facilitates a pre - seeding irrigation to eliminate the first generation of weeds. The system allows mechanical cultivation as an alternative method of weed control during the crop cycle, it also makes hand weeding an economic option (Sayre and Ramos 1997).

Strip irrigation as compared to the conventional basin irrigation reduces irrigation time by 30%, improves plant stand, reduces cost, facilitates combine harvesting and results in comparable or better grain yield (Salih, 1992). Furrow irrigation between 40 cm or 60 cm ridges as compared to basin irrigation reduces crust formation and waterlogging hazards (Babiker and Mohamed 1992). Fadl (1974) mentioned that wheat crop factor (ETc/ETo) reaches a peak of 1.2 during heading and flowering time, when irrigated at 14 - day intervals, it used 500 mm of water per season. However, Ahmed (1992) found that in the Northern State of Sudan, wheat requires about 640 mm of water to produce 4 ton/ha of grain. Beecher *et al*.(2005) stated that the permanent raised beds are the recommended irrigation design to achieve high yields in many irrigated crops on heavy clay soils. Aggarwal *et al*. (2000) and Jat *et al*. (2005) reported significantly higher yield and water use efficiency of maize on raised beds than under flat planting. Maize and wheat planted on raised beds recorded about 7.8% and 22.7% higher water use efficiency than under flat layout (Ram *et al*. 2011).

Objectives: The main objective of this study is to assess the suitability of raised bed planting for wheat crop production and the specific objectives are:

1- To assess raised bed planting as a technique to save irrigation water and increase water use efficiency.

2- Determination of suitable dimensions of raised bed and the suitable number of crop rows per bed.

CHAPTER TWO

LITERAETURE REVIEW

2.1 Methods of irrigation:

Water is the basic need of plants for all metabolic and production processes. Crops differ in their structures and habits, their water requirements thus vary widely. Water management pertains to optimum and efficient use of water for best possible crop production keeping water losses to the minimum. Serious losses in irrigation water occur unless properly monitored while irrigating fields. Majumdar (2004) stated that various methods are adopted to irrigate crops and the main aim is to store water in the effective root zone uniformly and in maximum quantity possible ensuring water losses to the minimum.

Irrigation methods are classified, according to Majumdar (2004) as follows:

1- Surface irrigation
2- Subsurface or sub irrigation
3- Overhead or sprinkler irrigation
4- Drip irrigation

2.1.1Surface irrigation methods:

Surface irrigation refers to irrigating lands by allowing water to flow over the soil surface from a supply channel at the upper reach of the field (Majumdar , 2004). Principles involved in surface irrigation are:

(i) Field is divided into plots or strips to uniformly irrigate the soil to a desired depth throughout the field.

(ii) Water is discharged at the highest level of the field allowing water to flow down the gentle slope by gravity.

(iii) Water loss by run-off or deep percolation is avoided.

(iv) Efficiency of irrigation is kept at a high level.

(v) Size of stream should be such as to have an adequate control of water.

Surface irrigation includes methods such as border, check, contour check, contour ditch, furrow, corrugations, basin and ring methods. The land surface is either completely or partially wetted while irrigating the crops.

2.1.1.1 Furrow irrigation:

Furrow irrigation according to Majumdar (2004) refers to irrigating land by constructing furrows between two rows of crops or alternately after every two rows of crops. It wets the land surface only partly and water in the furrow moves laterally by capillarity to the unwetted areas below the ridges and also downward to wet the root zone soil. Furrow irrigation saves a considerable amount of water by reducing the evaporation loss. Evaporation is low as only a part of the land surface is wetted. The saving may be as much as 30 percent over other methods of surface flooding i.e. border strip or check basin method. Besides, it is helpful to irrigate crops like bean, tomato and potato that are sensitive to wet soils at the base of plants and to crops such as sugarbeet and safflower that are susceptible to fungal diseases like root rot. Usually furrows are constructed after every row of crops. Groundnut and vegetable crops such as onions, cabbage and chilies are laying out furrows after every two rows of crops. This practice saves more water than when furrows are made after each row of crops. Besides, it prevents an accumulation of salt near the plant bases in areas where salts are a problem. Furrows are constructed down the slope and the supply channel is built across the slope at the upper reach of the field.

a. Furrow spacing:

Furrow spacing varies usually from 45 to 150 cm (for sugar cane) depending on crops, crop spacing and their cultural practices, soil characteristics allowing the lateral movements of water to wet the soil below the ridges and machinery used. Furrows are spaced wider up to 180 cm for orchard crops on soils with greater permeability. Usually, the spacing between furrows is narrower in sandy soils and wider in heavy soils. This is to ensure that water spreads laterally into the soil below ridges and downwards in the effective rooting depth uniformly. The depth of the furrows is usually from 20 to 30 cm, shallower in lighter soils and deeper in heavier soils. The cross section of furrows is designed to carry sufficient water to wet the whole length of the furrow and the soils between furrows by capillary. In high rainfall areas drainage provision is necessary at the end of the furrows. Length of furrows varies from 45 to 300 m. they are shorter in coarse soils and longer in heavier soils. When the slope is from 0.05 to 0.3 percent, furrows are 200 to 250 m long in medium (loam) soils and 300 to 450m long in heavy soils (Majumdar, 2004).

b. Wetting patterns in furrow:

Brovwer *et al* (1990) mentioned that as the root zone in the ridge must be wetted from the furrow, the downward movement of water in the soil is less important than the lateral (or sideways) water movement. Both lateral and downward movement of water depends on soil type. Figures 2.1 showed the wetting pattern in different soil types.

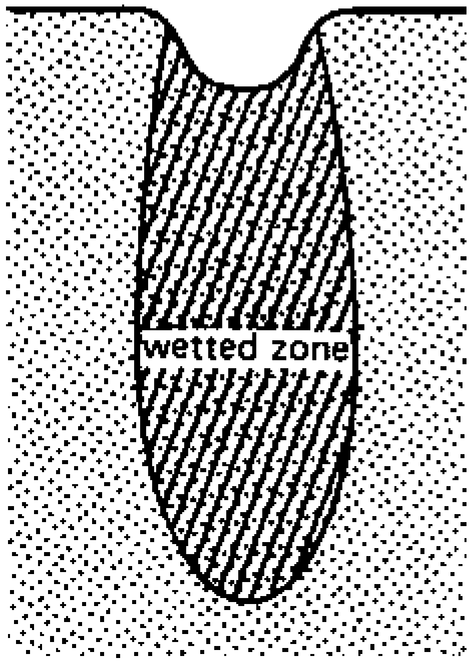


Fig 2.1 a wetting pattern in sand solis

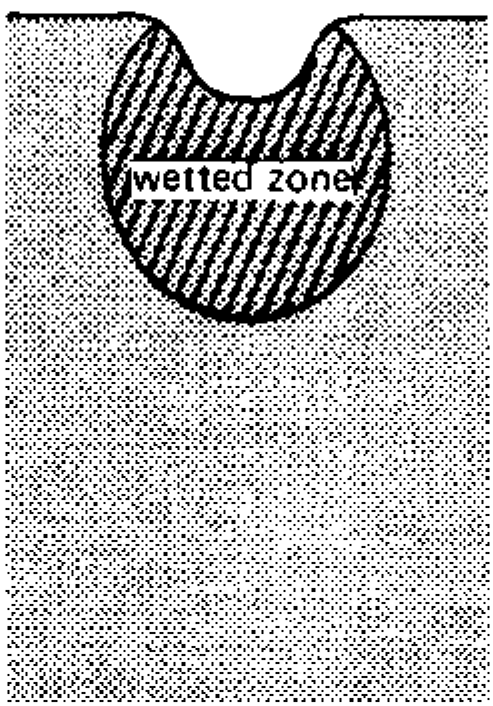


Fig 2.1 b wetting pattern in loam soils

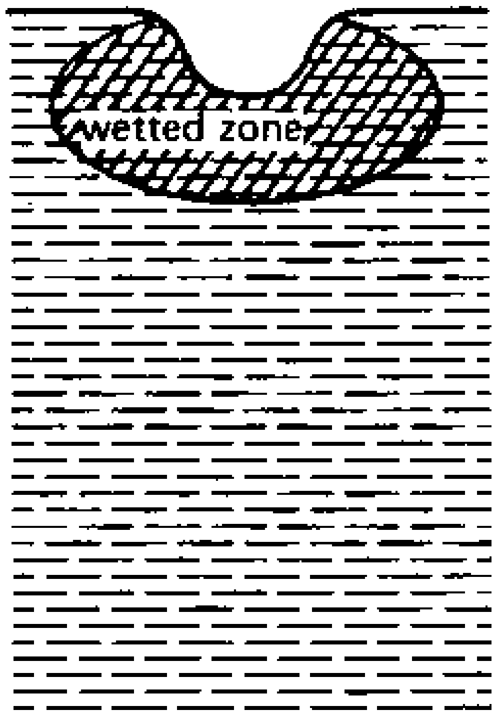


Fig 2.1 c wetting pattern in clay soils

Brovwer *et al* (1990) added that poor wetting patterns can be caused by:

- Unfavorable natural conditions (compact layer, different soil types, uneven slope).

- Poor management (stream size too long or too small, stopping the inflow too soon).

- poor layout (furrow spacing too wide). If the furrow spacing is too wide then root zone will not be adequately wetted (Fig 2.2) the spacing of the furrow needs careful selection to ensure adequate wetting of the entire root zone.

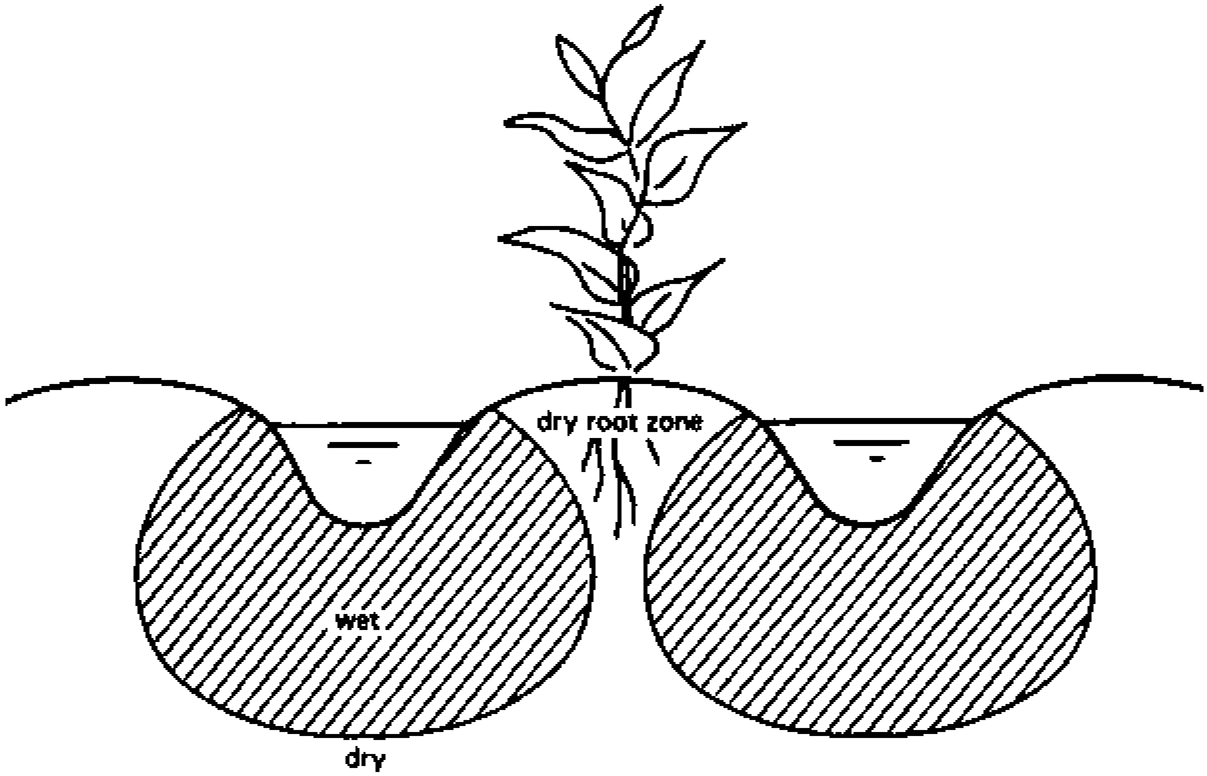


Fig 2.2 Poor wetting pattern

They added that in an ideal situation adjacent wetting patterns overlap each other, and there is an upward movement of water (capillary rise) that wets the entire ridge thus supplying the root zone with water (Fig 2.3).

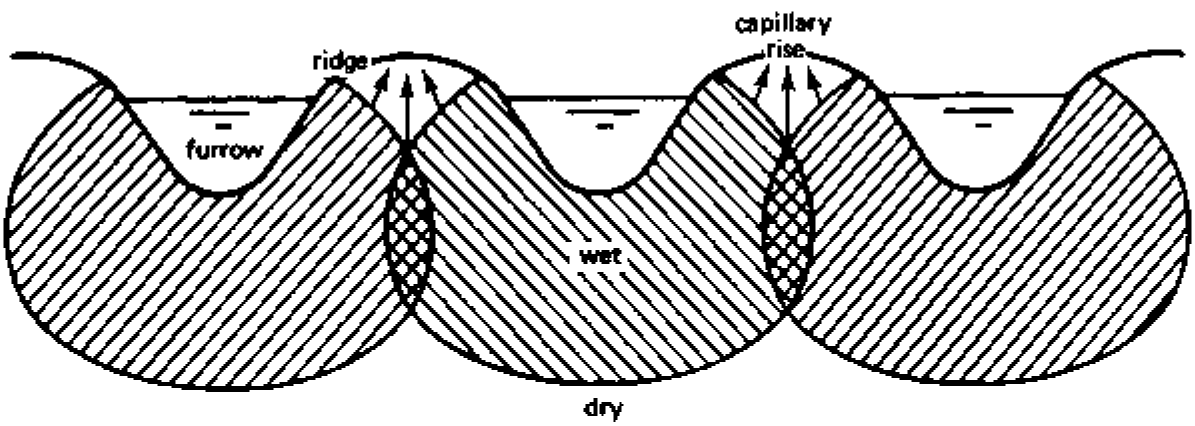


Fig 2.3 Ideal wetting pattern

c. Advantages and limitations of furrow irrigation:

Majumdar (2004) mentioned that the advantages of the method are:

(i) Great saving of water over other flooding methods.

(ii) Variable sizes of streams can be used.

(iii) A large size stream can by controlled by discharging water in several furrows.

(iv) The water application efficiency is very high.

(v) Wide ranges of soils can be irrigated.

(vi) Losses of water by evaporation, run-off and deep percolation are reduced.

(vii) There is no erosion hazard.

(viii) Furrows act as drainage channel in high rainfall areas.

(ix) Furrows are helpful in lands with high salt concentration as salts accumulate on the upper part of the ridges and crop planted at the lower end of the ridges is safer.

Limitations of the methods are:

(i) Land requires precise grading to a uniform slope.
(ii) Labor requirement is high for grading land and making furrows.
(iii) Skilled labor is necessary to control water in furrows.

(iv) Erosion of furrow bed is anticipated if furrows are not properly graded.

(v) The methods are unsuitable for light irrigation.

d. Classification of furrow irrigation methods:

1- Straight graded furrow irrigation
2- Straight level furrow irrigation
3- Contour furrow irrigation
4- Alternate furrow irrigation
5- Raised bed and furrow irrigation

e. Raised bed and furrow irrigation:

Raised bed of 1 to1.5 m width or wide ridges alternating with furrows are often constructed for growing vegetables crops, particularly those vegetable crops that creep on soil surface. Two rows of plants are usually grown on the two sides of bed or ridge. A furrow runs between two rows of adjacent ridges or beds and supplies water to the plant rows. The method assures saving of large amount of water (Majumdar , 2004).

2.1.2 Subsurface irrigation methods:

Subsurface irrigation involves irrigation to crops by applying water from beneath the soil surface either by constructing trenches or installing underground perforated pipe lines or tile lines. Water is discharged into trenches and allowed to stand during the whole period of irrigation for lateral and upward movement of water by capillarity to the soil between trenches (Majumdar ,2004).

2.1.2.1 Advantages and limitations of subsurface irrigation:

Advantages of this methods of irrigation as stated by Majumdar (2004) are that:

(i) Soil water can be maintained at a suitable tension favorable for good plant growth and high yields.

(ii) Evaporation loss from soil surface is held at minimum resulting in saving of water.

(iii) Labor cost of water application is very low.

(iv) Supply ditches may serve as drainage ditches in humid areas.

(iv) It can be used for soils having a low water holding capacity and high infiltration rate where surface methods can not be adopted and the sprinkler irrigation is expensive.

Limitations are that:

(i) Presence of a high water table or impervious subsoil is a prerequisite for adopting this method.

(ii) Good quality water must be available.

(iii) There are chances of saline and alkali conditions being developed by upward movement of salts with the water.

(iv) Soils should have a good hydraulic conductivity for upward movement of water.

2.1.3 **Overhead or sprinkler irrigation:**

sprinkler irrigation refers to application of water to crops in form of spray from above the crop like rain. It is also called the overhead irrigation as water is allowed to fall as spray from above the crop. Water under pressure is carried and sprayed into the air above the crop through a system of overhead perforated pipes, nozzle lines or through nozzles fitted to riser pipes attached to a system of pipes laid on the ground.

2.1.3.1 Advantages and disadvantages of sprinkler irrigation:

Sprinkler irrigation has many advantages over the surface irrigation as stated by Majumdar (2004). The principal advantages are that:

(i) Water use is economized as losses by deep percolation can be totally avoided.

(ii) Small and frequent applications of water can be made.

(iii) water-application efficiency is usually very high.

(iv) There is very little waste of land for laying out the system.

(v) Measured amount of water can be applied.

(vi) Land leveling is not necessary.

(vii) It can be adopted even in undulating topography.

(viii) It is adopted where water is scare and high priced.

(ix) Soil water can be easily maintained at a favorable tension for optimum growth and yield.

(x) Application of fertilizers, pesticides and herbicides can be easily made along with irrigation water.

(xi) Crops can be saved from frost damage.

(xii) Uniform application of water can be made in highly porous soils and
(xiii) high yields or good quality fruits and vegetables are obtained.

Principal limitations are:

(i) High capital investment is involved in installation.
(ii) Operating cost of sprinkler is higher.
(iii) Technical personnel for operation and maintenance are required.
(iv) Clean water is needed to avoid clogging of nozzles.
(v) Mechanical difficulties are expected.
(vi) Areas with hot winds are unsuitable.
(vii) It is not adopted in places where plenty of cheap water is available as surface methods are more useful and less costly.
(viii) Pipe system laid on the soil surface may interfere with farm operations and movements of implements and animals.

2.1.4 **Drip irrigation method:**

Drip irrigation method, also called trickle irrigation, refers to the application of water at a slow rate drop by drop through perforations in pipes or through nozzles attached to tubes spread over the soil to irrigate a limited area around the plant. It achieves wetting of even smaller surface area than in case of furrow irrigation. A precise amount of water as equal to daily consumptive use or the depleted soil water as changing with time can be applied.

2.1.4.1Advantages and limitations of drip irrigation:

The method has various advantages as stated by Majumdar (2004).These are:

(i) Considerable saving of water.

(ii) High water application efficiency.

(iii) Loss of water through evaporation and seepage is reduced.

(iv) Physical conditions of soils are maintained in congenital form for plants by maintaining optimum soil-water-air balance around plant bases.

(v) Localized application of fertilizers is made with irrigation water.

(vi) Brackish water can be used more safely.

(vii) Weeds and pest problems are at minimum.

(viii) The method can be adopted in sloping lands and irregular topography without any erosion hazard.

Limitations are:

(i) Initial cost of installation of the system is high, but it works out much cheaper than sprinkler system considering the saving of water in drip irrigation.

(ii) The method is profitable only in areas where irrigation water is scarce and costly, particularly in arid regions and for growing high value crops.

2.2 Water saving approaches:

Some innovative technologies/ practices of water saving in some countries as mentioned by ICID (2008) include:

2.2.1 System modernization:

In South Africa, an innovative decision support called Water Administration System (WAS) has been developed. The WAS is used by Water User Associations (WUA) on irrigation schemes in managing their water accounts and water supply to clients through rivers, canal network and pipelines. It replaces the old manually operated water distribution system commonly used on government irrigation schemes. By enabling water supply of the required volume at the requested time. WAS facilitates efficient water use at the farm level and increase in the water productivity. Field measurements have shown that losses were reduced by up to 20% through improved water releases in canals and rivers.

In South-East of Spain, to cope with water scarcity and enhance economic condition of irrigators, the Irrigators Community of the Murica Regional Government prepared and implemented a project for modernization of the traditional irrigation system of Mula, It comprised a centralized control system which allows monitoring of the pumping station operation, surveillance of wells filtering status, locating of failures, daily volumes of water delivered to each irrigator, opening and closing of the flow regulating valves, fertigation of plots and billing of the water used. Innovative features of the project consist of a Water Teller and Water Account Book provided to each irrigator. The Water Teller is analogous to bank's ATM and provides irrigators 24-hours service. The key improvements achieved through the modernization project were (a) overall reduction in annual water losses in the Irrigation Community from 1.2 million m³ to 0.17 million m³ (b) sustainable exploitation of the aquifer, (c) saving in pumping energy, lower cost of water to irrigators and (d) an increased crop productivity and quality of fruits (ICID ,2008).

2.2.2 Water efficient regimes:

In China, due to decreasing water supply for agriculture various water efficient regimes (WEI) for rice irrigation were tested which are (a) combining shallow water layer with wetting and drying (SWD), (b) alternate wetting and drying (AWD) and (c) semi – dry cultivation (SDC). Compared to traditional rice irrigation (TRI) i.e. continuous flooding irrigation. The irrigation water use has been reduced by 3-1%, 7-25% and 20-50% under SWD, AWD and SDC, respectively. Due to adoption of WEI, there is a decrease in the percolation and seepage losses and also in the evapo-transpiration. The alternate wetting and drying (AWD) irrigation for rice has become popular in Philippines, Bangladesh and Vietnam. In this method, farmers irrigate their fields only after a certain number of days when the ponded water disappears. With the optimal management, this technology reduces the amount of water required by about 25% without reduction in yields. Scientists at the International Rice Research Institute (IRRI) have developed a simple tool to help farmers make decisions on when to irrigate. They found that when field water level recedes to 15 cm below the soil surface, soil water tension in the root zone is always <10 kpa, ensuring good yield (ICID ,2008).

In Brazil, rice irrigation using center pivot system reduced water by 50% compared to surface systems. With surface irrigation the total application depth was1100 mm, while with pivot irrigation it was 550 mm. The center pivot also facilitated multiple crop rotations over the years, adding valuable nutrients to the soil and improving its texture. As a result of the various new practices, it was possible to harvest 6500 kg/ha/year (ICID ,2008).

2.2.3 Improved irrigation methods:

ICID (2008) stated that pressurized water application methods (sprinkler and micro irrigation) are considered as the leading water saving technologies in irrigated agriculture. At present, of the total world irrigated area, about 15% (44million ha) is equipped with pressurized methods, comprising sprinkler irrigation (35million ha) and micro irrigation (9miilion ha). Most of the pressurized irrigated area is concentrated in Europe and Americas. There is a vast range of sprinkler and micro irrigation systems suiting small and large farm sizes, soil and crop types.

2.2.4 On – farm irrigation scheduling:

South African Sugarcane Research Institute (SASRI) has developed an innovative decision support system called (Mycanesim) by deploying the sophisticated information and communication technology. This system combined with participatory methods has achieved substantial improvement in water use efficiency and sugarcane yields for the benefit of small – scale growers. The system consists of a sugarcane simulation model an on- line weather database and a communication network which automatically provides farmers with near real-time field –specific irrigation advice and yield estimates using cell phone text message (SMS). More extensive information is provided to the advisory support structure by FAX and internet. The system has been adopted by large number of small holders as well as commercial growers (ICID, 2008).

In South Africa and Australia, a simple mechanical device called a ‘Wetting Front Detector (WFD)’, which provide information about the depth of water penetration in the soil profile and helps them to make a decision about the timing and duration of the next irrigation, thereby improving on-farm water

application efficiency leading to water saving. To help irrigators, an interactive visualization tool ‘The Fullstop Game’ is provided on a specially developed website (ICID, 2008). The irrigators can type their application rate and days since last irrigation and the visualization game shows them how deep the wetting front should penetrate down into the soil for drip and sprinkler irrigation.

In China a new irrigation approach called Controlled Alternate Partial Root-zone Irrigation (CAPRI) also called partial root-zone drying (PRD) was applied to improve crop water use efficiency without significant yield reduction. PRD involves alternate drying and wetting of subsections of the plant root zone by exploring the plant physiological and biochemical responses. It involves part of the root system being exposed to drying soil while the remaining part is irrigated normally. The wetted and dried sides of the root system are alternated with a frequency according to soil drying rate and crop water requirement. In general, the CAPRI reduced the irrigation water requirement up to 50% without reduction of crop yield (ICID ,2008).

2.2.5 Controlled Drainage:

ICID (2008) mentioned that controlled drainage helps in saving freshwater by providing part of the consumptive use through capillary rise from shallow water tables. The objective of controlled drainage is to reduce subsurface drainage intensity during specific period of time by temporarily raising the level of the drain outlet. Capillary rise from the raised water table contributes in moisture supply to the root zone. Experimental works in Egypt showed that up to 40% of the total water requirement could be saved through controlled drainage. In the case of paddy rice, the water saving could exceed 50%.

2.2.6 Use of Poor Quality Water:

Use of partially treated or untreated sewage water irrigation for growing vegetables, fodder for livestock and paddy is a common established practice in peri-urban areas of most developing countries. International Water Management Institute (IWMI) has estimated about 20 million ha under wastewater irrigation' worldwide. As per United Nations Development Program (UNDP) more than 800 million farmers are engaged in urban and peri-urban agriculture worldwide. In Israel of the 500 million m^3 of the wastewater generated, 50% is treated to secondary level and 40% is treated to tertiary level. The treated wastewater is used for irrigation by blending with freshwater and through drip irrigation. The most well-known formal program for drainage water reuse is in Egypt, presently, about 2 million ha have been provided with subsurface drainage in the Nile Delta. In 1997 about 4.4 km^3 of drain water was reused in Egypt. Reuse of agricultural drainage water is an effective option to reduce pressure on freshwater supplies (ICID, 2008).

2.2.7 Raised bed planting:

In Sudan, Ebelhady *et.al* (2006) concluded that wheat bed planting system could be adopted in the irrigated vertisols of Sudan with reduced seed rate and more efficient irrigation water utilization if the suitable seeding machine is made available. They added, due to high competition among different water users during the winter season and the high cost of wheat seeds, bed planting with suitable machine and low seed rate (92kg/ha) could improve water management, reduce time of seeding and reduce seed rate by about 36% over the recommended (143kg/ ha).

In India, Ram *et al*., (2011) stated that there has been an increase in the development, evaluation and adoption of raised bed planting technology for a wide range of crops in northwestern India. This interest has arisen from the initial success with planting wheat on raised bed, from associated opportunities for intercropping and crop diversification and from the large irrigation water saving being achieved on bed. Raise bed offers possibilities of diversifying to water logging sensitive crops such as soybean and maize during the monsoon season, and of increasing yields by irrigation of winter crops sensitive to water logging, such as chickpea.

In Pakistan, Hassan *et al*., (2005) indicated that for maize crop there was an increase of 30% , 32% , and 65% in grain yield , water saving , and water productivity, respectively, under permanent raised bed compared to basin. Similarly, permanent raised beds demonstrated 13%, 36% and 50% higher grain yield, water saving and water productivity, respectively, for the wheat crop. Weed infestation was also 24% and 31% lower for maize and wheat crops, respectively, under permanent raised bed, which maintained lower soil bulk density and high infiltration rates. Partial budgeting showed that raised bed generated 54% and 35% increased net benefit for maize and wheat crops, respectively.

In Pakistan, also, in order to save water, Paddy crop was grown on beds and furrows which utilize much less water than the traditional flooding method. The results of the experiments carried out over three years revealed that the water use efficiency of rice under bed and furrow systems can be raised up to 0.39 kg/m^3 of water compared to 0.20 kg/m^3 commonly obtained under the traditional flood irrigation method. Transplanting of two rows of paddy seedlings on beds (at 22 cm spacing) and compacted furrows gave 32% saving in water. In addition, the weed infestation was found to be much less and there was no significant evidence of salinity build up on beds compared with the traditional methods. Similar practice of growing rice on ridges and furrow has been found successful in Egypt. Here, rice seedlings are transplanted in furrows in hills at 10 cm apart and in two rows 20 cm apart. In the traditional method farmers apply 15,000 m^3/ha, while in the new method about 9,000 m^3/ha are applied with average rice yield of 9 tons/ha (Kulkarni, 2011).

Gill *et al.,* (2005) concluded that crops can successfully be grown on raised beds only if requisite equipment and technologies are available for modification and re- shaping of beds and sowing of crops on beds. Selection of crops varieties suitable for sowing on bed is very important on the basis of root system, growth pattern and required intercultural operations. It has been observed that planting of wheat, cotton and other crops on beds may save up to 50 - 60% of irrigation water. Growing crops on beds also saves other resources such as labor and energy to considerable extents.

In an experiment conducted in the Huang - Huai plain of China, comprised planting winter wheat in three patterns, namely, furrow irrigated a raised bed planting (FIRB), mulched ridge and furrow planting (MRFP) and conventional flat planting (FP), Zhang *et al.,* (2007) indicated that FIRB and MRFP pattern had lower water consumption than the FP pattern due to decrease of irrigation amount and control of evaporation from top soil. The water consumption was 354.5 mm for FIRB and 323.6 mm for MRFP which were 12 and 20 % lower than FP. the water use efficiency for FIRB and MRFP was 2.26 and 2.16 kg/ m^3 which was 20.2 and14.9% higher than FP, respectively. They concluded that the FIRB system has higher yield than MRFP.

Freeman *et al.,* (2007) found that bed planted wheat offered crop rotation opportunities and field access flexibility for fertilizer application and weed control. A study by Tripathi *et al.,* (2005) indicated that bed planted wheat varieties demonstrated over 50% less lodging compared with flat planting.

Farmers in the Yaqui Valley of Sonora, Mexico switched to bed planting with 2 or 3 rows of wheat on top of the beds that are 70 – 80 cm wide with furrow irrigation as opposed to flat planting in solid stands and flood irrigation (Sayre and Moreno Ramos, 1997). By switching, they were able to reduce water requirements by 25%, offer more opportunity for mechanical weed control, reduce tillage and reduce incidence of lodging

Research conducted in Egypt by ARC in collaboration with ICARDA where improved technologies of irrigation were compared to the conventional system (basin flooding) showed that by using the wide spacing furrow and bed planting technique, water consumption by crops fell by 30%, with correspondingly lower pumping cost, labor costs for land preparation, irrigation, and weed control were also reduced by 35%. However, yields were the same or higher and farmers net incomes increased by 15% with less water used, crop water productivity increased by over 30% and the net return per unit of water was 20% higher compared to conventional furrow irrigation (IBM,2008).

In India in rice - wheat planting system (R-W), Singh *et al.,* (2005) indicated that raised bed planting system promotes crop intensification and diversification besides saving irrigation water. Raised bed system, saves 30-40% water as compared to conventional flood irrigation practice. Benefits of raised bed system also include (i) fewer weeds, (ii) facilitates seeding into relatively dry soils (iii) vigorous and better crop stands, (iv) savings of costly seed (v) reduced crop-lodging and seed and fertilizer contact (vi) better drainage, improved rainwater conservation; and crop productivity and (vii) minimizes wilt infestation in crops like pigeon pea and avoids temporary water logging problems. The raised bed planting system is gradually becoming popular amongst the R-W farmers as it allows light and frequent watering, needed to address terminal heat stresses due to climate change. The performance of raised bed system further improves when the system is coupled with precision laser land leveling.

2.2.8 Indirect Approach of Water Saving:

There are some indirect ways of demand management leading to water saving in crop production. These are as follows:

2.2.8.1 Virtual Water Trade:

Chapagan and Hoekstra (2004) stated that when a country imports a tonne of wheat or maize, it is in effect, also importing virtual water, i.e. the water required to produce that crop. Trade in virtual water generates water saving for importing countries. Global water saving as a result of international trade of agricultural products has been estimated at about 350 billion m^3/year. ICID (2005) reported that to maintain food security or food self-sufficiency, many countries in the arid and semi-arid regions have over exploited their renewable water resources. Trade can help mitigate water scarcity if water-short countries can afford to import food from water-abundant countries. But political and economic factors are stronger drivers and barriers than water.

2.2.8.2 Reducing wastage along the Food Chain:

Lundqvist *et al* (2008) mentioned that by minimizing losses and wastage along the food chain, the need for an additional food production – and therefore water – can be curtailed. A large part of food produced at the field level is lost or wasted before it arrives on our plates. In developing countries, a lot of produce perishes right on the farm, in the storage, during transport. Finally, substantial losses occur during consumption and to a lesser extent during retail, from discarded perishable products, product deterioration and the food that gets thrown into the garbage bin. According to the report as much as 30% of the food produced is thrown away that is equivalent to an estimated 40 BCM of water, enough to meet the needs of 500 million people.

2.3 Wheat water requirements:

For high yields wheat crop water requirements (ETm) are 450 to 650 mm depending on climate and length of the growing periods. The crop coefficient (Kc) relating maximum evapotranspiration (ETm) to reference evapotranspiration (ETo) is : during the initial stage 0.3 - 0.4(15 to 20 days), the development stage 0.7 - 0.8 (25 to 30 days), the mid- season stage 1.05 - 1.2 (50 to 65 days), the late- season stage 0.65 - 0.7(30 to 40 days), and at harvested 0.2 - 0.25 (FAO, 2013).

Fischer *et al.,* (2007) estimated future increase in irrigation water requirements by over 50% in developing regions and by about 16% in developed regions. The largest relative increases of irrigation water requirements are projected to occur in Africa.

2.4 Salinity:

Irrigation systems are never fully efficient, some water is always lost in canals and on the farmer's field. Part of this seeps into the soil, while this help leach salt out the root zone, it will also contribute to raise the water table; a high water table is risky because it may cause the salts to return to the root zone, both the water losses and the water table must be strictly controlled. This requires careful management of the irrigation. Provin and Pitt (2002) stated that salinity is of greatest concern in soils that are:

- Irrigated with water high in salts.

-Poorly drained, allowing for too much evaporation from the soil surface.

- Naturally high in salts because very little salt leaches out.

- In areas where the water table is shallow.

- In seepage zones, which are areas where water from other location seep out. They concluded that the major source of salinity problems is usually irrigation water.

2.5 Water productivity (Water use efficiency):

In the agricultural sector, the concept of water use efficiency, is often used to highlight the relationship between crop growth development and the amount of water used. Once the crop water requirement is known, improving the efficiency of the irrigation application is a key strategy for water saving in agriculture. The term (efficiency) is commonly used to indicate the level of performance of the system (Mancosu, *et al.*, 2015).

The term water productivity is expressed as agricultural production per unit of water applied, diverted or consumed to produce a crop. An increase in water productivity ameliorates grain in crop yield. The increase of water productivity could be the solution for food needs accompanying the projected population growth (Playan and Mateos, 2006). Many strategies are implemented to improve water productivity, starting with the optimal choice of irrigation system, followed by the application of proper irrigation scheduling in terms of both timing and quantity of water applied and concluded with the choice of the best crop management with regards to the soil and climate conditions (Mancosu, *et al.*,2015). They added that the application of efficient water management strategies is the key element to increase water productivity. Water productivity (WP) can be expressed as follows:

WP (kg/m^3) = yield (kg/ha)/ irrigation water (m^3/ha)

Water use efficiency is a term commonly used to describe the relationship between water (input) and the agricultural product (output); it can be divided into three types: economic water use efficiency which refers to the economic profits and cost of water use in agriculture production, technical water use efficiency which seeks the ratio between yield and the total water used during the growing season and the hydraulic water use efficiency which is the ratio between the net crop water requirement to the total water applied.(Edet and Akpan, 2007).

Improving water use efficiency is defined as increasing the amount of plant material produced per unit water used (Webber *et al.*, 2006). Passioura (2004) indicated that there are three approaches to improve crop water use efficiency. Firstly by adopting technologies those increase the proportion of water transpired by the crop to that lost due to drainage, runoff and deep seepage. The second approach is to increase the crop's capacity to produce biomass and yield per unit water used. The third approach is increasing the harvest index (ratio of economic yield to total biomass). Water use efficiency is influenced by weather conditions which affect plant growth and development and ultimately, yield (Garcia *et al.*, 2009). Elamin *et al.,* (2011) concluded that Rahad scheme has the highest water use efficiencies compared with Gezira and New Hafa schemes, they added that applying the concept of water use efficiency in irrigated schemes is highly recommended especially under water scarcity conditions.

2.6 Irrigation water measurement:

The most common structures used for measurement of water in farm irrigation practices are as follows:

a. Orifices

b. Meter gates

c. Weirs

d. Flumes

Weir: the term weir is used to denote a notch in a wall built across an irrigation channel to measure a stream flow. A weir may be rectangular, trapezoidal or triangular. Water is allowed to flow over it for measurement in an irrigation channel. Weir is a very simple device that can profitably be used to measure even small water supplies. Weirs give accurate measurements of water flow when used under properly controlled conditions. A weir can be constructed and installed in an irrigation channel easily. Floating materials do not get obstructed over the crest, which otherwise create difficulties in accurate measurement of the head. Weirs are quite durable. There are certain limitations. A weir requires a considerable fall of water surface and makes its use in a level channel impracticable. An accurate measurement of flow becomes sometimes difficult because of deposition of gravel, sand and silt in the pool above the weir, which increases the velocity of water. The pool should be cleaned of depositions occasionally.

There are many types of weirs, and the commonly used are:

(1) Rectangular weirs: A rectangular weir has a notch rectangular in shape. it is installed across an irrigation channel with notch on top. The crest, which is the bottom side of the notch, should be perfectly at right angle to the direction of the stream. The rectangular weir is the oldest and the most

popular form of weirs because of simplicity of measurement and ease of construction. The discharge through a sharp crested rectangular weir with suppressed end contractions is measured by the formula:

$$Q = 184\,X10^{-4}LH^{1.5}$$

where,

Q = discharge, l/s

L = length of crest, cm

H = height of water flowing over the crest, cm

(2) Cipolletti or trapezoidal weir: A trapezoidal weir has a notch trapezoidal in shape. It is also called as Cipolletti weir, after the Italian Engineer Cipolletti. The discharge of the weir is directly proportional to the length of the weir crest without any correction for end contractions. The weir has sides with slope of one horizontal to four vertical. The discharge through a trapezoidal weir is measured by the formula:

$$Q = 186\,X10^{-4}LH^{1.5}$$

where,

Q = discharge, l/s

L = length of crest, cm

H = head over the crest, cm

(3) The 90º triangular weir or V- notch: A 90º triangular weir has a notch with 90º angle at the crest. It is also known as 90º V- notch. It is of greater practical use than any other weir of similar size as it can be used to measure

streams from small to large ones. The weir is portable and very easy to install in a channel. Each side of the weir makes an angle of 45º with the vertical. The formula for measuring the discharge through the weir is:

$$Q = 138\, X10^{-4} H^{2.5}$$

where,

Q = discharge, l/s

H = head over the crest, cm

CHAPTER THREE

MATERIALS AND METHODS

3.1 Experimental site and location:

To assess the suitability of raised bed planting for wheat crop production three field experiments were carried out during the period 2013 to 2016 at New Halfa Research station farm ,New Halfa city, Kassala State, Eastern Sudan, (between longitudes 35º - 37º E and latitudes 15º -18º N) with an elevation of 450 m above mean sea level.

Soil samples from the experimental field were collected for analysis of main chemical and physical soil characteristics.

3.2 Experiment 1; Influence of Sowing methods on water saving and yield of wheat crop:

3.2.1Treatments:

a- Four sowing methods were tested:

1- raised bed planting (BP)

2- seed drill (SD)

3- wide level disc (WLD)

4- broadcasting (BC)

b- Four quantities of irrigation water were applied:

1- 3000 m^3/ha (W3)

2- 4000 m^3/ha (W4)

3- 5000 m^3/ha (W5)

4- 6000 m^3/ha (W6)

c- Two herbicide applications were made:

1- with herbicide application (Hw)

2- without herbicide application (Ho)

d- Two recommended wheat varieties were sown:

1-Bohaine (B)

2- Imam (I)

The treatments were laid out in a split- split plot design with three replications. The sowing methods were laid as main plots, variety was the sub plot while applied water and herbicide application were the sub sub plot. The sub plot area was $35m^2$(10x3.5). The experiment layout was illustrated in Fig 3.1.

3.2.2 Sowing methods:

Seed drill and wide level disc machines were used to sow the crop, whereas for the raised bed planting the sowing was done manually. A bed of 80 cm width, 25 cm depth and 40 cm furrow width, was made by a ridger. Three crop rows were sown manually at the top of the bed. For the broadcasting treatment, seeds were broad casted manually on the flat surface then a bed of 80 cm space was made .

As for the cultural practices, the land was prepared by ploughing, harrowing then leveling. The seeds were treated chemically. The seed rate used was

120 kg/ ha for all the treatments. Surface irrigation system was used. The first irrigation was completed on mid-December for the two seasons. The first irrigation was applied to wet the root zone. The applied water was measured using a 90º- V notch weir.

3.2.3 Irrigation water measurement:

To apply the specific amount of irrigation water a 90º triangular weir (V-notch weir) (Fig 3.2) was installed in the irrigation canal of every experimental unit. Applied water was calculated by the following equation:

$$Q = 138\ X\ 10^{-4} H^{5/2}$$

Where,

Q = discharge, l/s

H = head over the crest, cm

3.2.4 Herbicides application:

Two applications of herbicides were made, one for broad leaves plants using 2,4-D, at a rate of 2 L/ha equivalent to 1.44 kg a.i/ha, sprayed after three weeks from sowing and the other for the narrow leaves plants by Topic at a rate of 1.008 L/ha equivalent to 0.082 kg a.i/ha sprayed three days after the application of the broad leaves plants. The two applications were made by a knapsack sprayer at the volume rate of 288 L/ha

3.2.5 Measurements:

3.2.5.1 Soil moisture: soil moisture was measured before each irrigation(from the third irrigation) at 15 - 30 cm depth, using the core sample method.

Soil samples were collected by a metal core sampler, where the wet sample was weighed (W_1), then dried in an oven adjusted to 105°C for 24 hours and weighed again (W_2). The soil moisture percent (SMC %) on dry mass basis was calculated by the following formula:

$$SMC\% = \frac{W1 - W2}{W2}\ X100$$

3.2.5.2 Weed count: number of weeds per square meter was counted for each experimental unit using a quadrant of 1x1 m.

3.2.5.3 Plant height: five plants were selected randomly from each experimental unit using a metallic tap, the mean of height was then determined.

3.2.5.4 Number of spikes: number of spikes per square meter was counted and recorded for each experimental unit.

3.2.5.5 Weight of seeds per spike: ten spikes were selected randomly from each experimental unit, then thrashed , weighed and the total weight was divided by ten.

3.2.5.6 Yield: a square meter from every experimental unit was selected randomly using the quadrant frame. The plants were cut manually and thrashed by a stationary thresher. The grain and the biomass yield for every experimental unit were weight and recorded in kg/ha.

3.2.5.7 Weight of 1000 seeds: random samples of 1000 seeds from the grain yield from every experimental unit were weighed and recorded.

3.2.5.8 Water productivity (WP) Technical water use efficiency (WUE): This was calculated using the following formula, according to Ouda *et al*., (2007):

$$WP = \text{Yield (kg/ha)} / \text{Water used } (m^3/ha)$$

3.2.6 Statistical analysis: Collected data was statistically analyzed using GenStat12.1 program where Duncan's Multiple Range Test (DMRT) was used for the determination of the least significant difference (LSD).

3.3 Experiment 2: Effect of sowing method and seed rate on yield of wheat

3.3.1Treatments:

a) Sowing methods: Four sowing methods were used, and these were:

1- Bed planting (BP)

2- Seed drill (SD)

3- Wide level disc (WLD)

4- Broadcasting (BC)

b) Seed rate: Four seed rates were used as follows:

1- 84 kg/ ha.

2- 96 kg/ha.

3- 120 kg/ha.

4- 144 kg/ha.

c) Herbicides application: For a set of the treatments herbicides were applied while the other set was left without herbicides:

1-With herbicides application (Hw)

2- without herbicides application (Ho)

d) Two varieties: Two recommended wheat varieties were sown in the experiment.

1-Bohaine (B)

2-Imam (I)

The treatments were laid in a split – split plot design with three replications. The sowing method as the main plot, variety as sub plot, seed rate as sub-sub plot, and herbicide application as sub - sub plot of size of 3.5 m x 10m. The experiment layout was illustrated in Fig 3.3.

As in experiment 1, in the two seasons bed planting was made manually where three crop rows were sown in the 80 cm bed (from furrow to furrow). Seed drill and wide level disc machines were used for sowing the other treatments. Broadcasting and cultural practices as in experiment 1.

3.3.2 Measurements: soil moisture, weed count, plant height, yield and yield components were measured as in experiment 1.

3.3.3 **Statistical analysis:** The method used for the statistical analysis was the same as in experiment 1.

3.4 Experiment 3: Water saving and wheat yield as affected by bed width, furrow dimensions and number of crop rows per bed.

3.4.1Treatments:

Raised beds of different widths (80, 100 and 120 cm), two furrow depths (15 and 25cm), two furrow widths (30 and 40 cm), 3 and 4 crop rows in 80 cm bed width, 4 and 5 crop rows in 100cm bed width and 5and 6 crop rows in 120 cm bed width were compared with seed drilling in flat surface , the widely used method for sowing wheat in the heavy clayed soil of New Halfa agricultural corporation.

The treatments were laid in Randomized Complete Block Design (RCBD) with three replications. Plot size was 4 x10 m. The experiment layout was illustrated in Fig 3.4.

3.4.2 Cultural practices:

In the first season raised beds of 80cm, 100cm and 120cm width, with different furrow widths and depths , were made by a ridger (Fig 3. 5) then 120 kg /ha as recommended by ARC wheat seeds, variety Bohaine chemically treated, were sown manually in rows at the top of the bed. Bohaine is the only variety grown in New Halfa scheme, where the area is susceptible to rust disease. However, in the second season the treatments were constructed mechanically where a raised bed planting machine was delivered from ICARDA. Plate 3.1shows the raised bed planting machine.

The raised bed planting machine was designed to provide a wide range of options and flexibility to change the width of bed by sliding the ditchers right and left and changing the furrow depth through sliding up and down the ditchers and changing the furrow width by opening and closing the ditcher wings.

The drilling treatment was performed on the flat land by a seed drill machine during the two seasons.

In the raised beds treatment the irrigation water was applied in the furrows between the beds until the water covered all the furrow depth. Whereas, in the drilling method the plots were flooded until the water covered all the flat planted area as practiced by the farmers. The first irrigation was completed on mid December in the first season, whereas, in the second season the first irrigation was completed on 10th December. Six irrigations were made during every season. Nitrogen fertilizer (2N) was applied in two equals doses, before the second irrigation and before the fourth irrigation. Broad leaves weeds were controlled by 2,4-D at the rate of 2 L/ha equivalent to 1.44 kg a.i/ha. sprayed three weeks after sowing, where the narrow leaves weeds were controlled by Topic at the rate of 1.008 L/ha equivalent to 0.082 kg a.i/ha, sprayed three days after the first application. The two applications were made by knapsack sprayer at the volume rate of 288 L/ha.

Plate 3.1 Raised bed planting machine

3.4.3 Measurements:

3.4.3.1 Applied water:

The amount of applied water was measured using a 90^{o} triangular weir (V-notch weir) installed in the irrigation canal of every experimental unit. The discharge (L/min) for different weir heads was showed in Fig 3.6 and Table 1.Appendix A. Applied water was calculated by the following equation:

$$Q = 138\ X\ 10^{-4} H^{5/2}$$

where,

Q = discharge, l/s (applied water)

H = head over the crest, cm

3.4.3.2 Soil moisture:

Soil moisture was measured one day before and after each irrigation at

30-40 cm depth using the gravimetric method.

3.4.3.3 Reference crop evapotranspiration (ETo) and Crop evapotranspiration - crop water requirement mm/ day (ETc):

Reference crop evapotranspiration(ETo) and crop evapotranspiration (crop water requirement)mm/ day (ETc) were calculated using CropWAT 8 which is decision support software system developed by the Land and Water Development Division of FAO. Meteorological data for New Half area was taken from the Web Site (www.climatedada.eu). Wheat crop factor (Kc) was adopted from FAO (2013): during the initial stage 0.3 - 0.4(15 to 20 days), the development stage 0.7 - 0.8 (25 to 30 days), the mid- season stage 1.05 - 1.2 (50 to 65 days), the late- season stage 0.65 - 0.7(30 to 40 days), and at harvested 0.25 - 0.2. Irrigation interval was 12 days; root zone depth was 40 cm, and soil bulk density was 1.8gm/cm^3.

According to Michael (1978) the crop evapotranspiration was obtained using the following equation:

$$ETc = ETo.\ Kc$$

where:

ETc = Crop evapotranspiration (crop water requirement)mm/ day

ETo = Reference crop evapotranspiration mm/day

Kc = Crop factor

Water productivity (water use efficiency) was calculated as:

Water productivity (kg/m^3) = Crop yield (kg/ha)/applied water (m^3/ha)

3.4.3.4 Salinity and NPK:

Soil samples from 40-50 cm depth were taken before sowing and after harvesting then chemically analyzed for N, P, and K contents and salinity.

3.4.3.5 Crop growth performance, yield and yield components:

Plant height, number of weeds per square meter, number of spikes per square meter, number of seeds per spike and weight of 1000 seeds were measured. Grain yield for every experimental plot was recorded where many locations were randomly selected, cut, threshed mechanically and weighed.

3.4.3.6 Statistical analysis:

Collected data was statistically analyzed using Statistix 10 program where Duncan’s Multiple Range Test (DMRT) was used for the determination of the least significant difference (LSD).

W3: 3000 m³/ha W4: 4000 m³/ha, W5:5000 m³/ha, W6: 6000 m³/ha

BP: Bed Planting, SD: Seed Drill, WLD: Wide Level Disc, BC: Broad Casting

I: Imam, B: Bohain

(light grey)	Herbicides untreated
(dark grey)	Herbicides treated

Fig 3. 1 Layout of experiment (1)

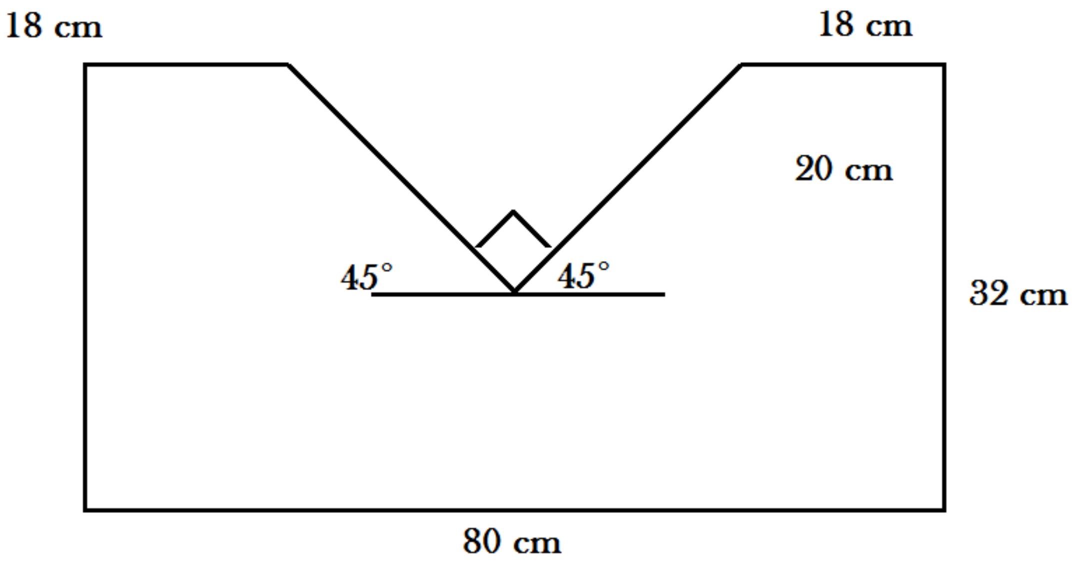
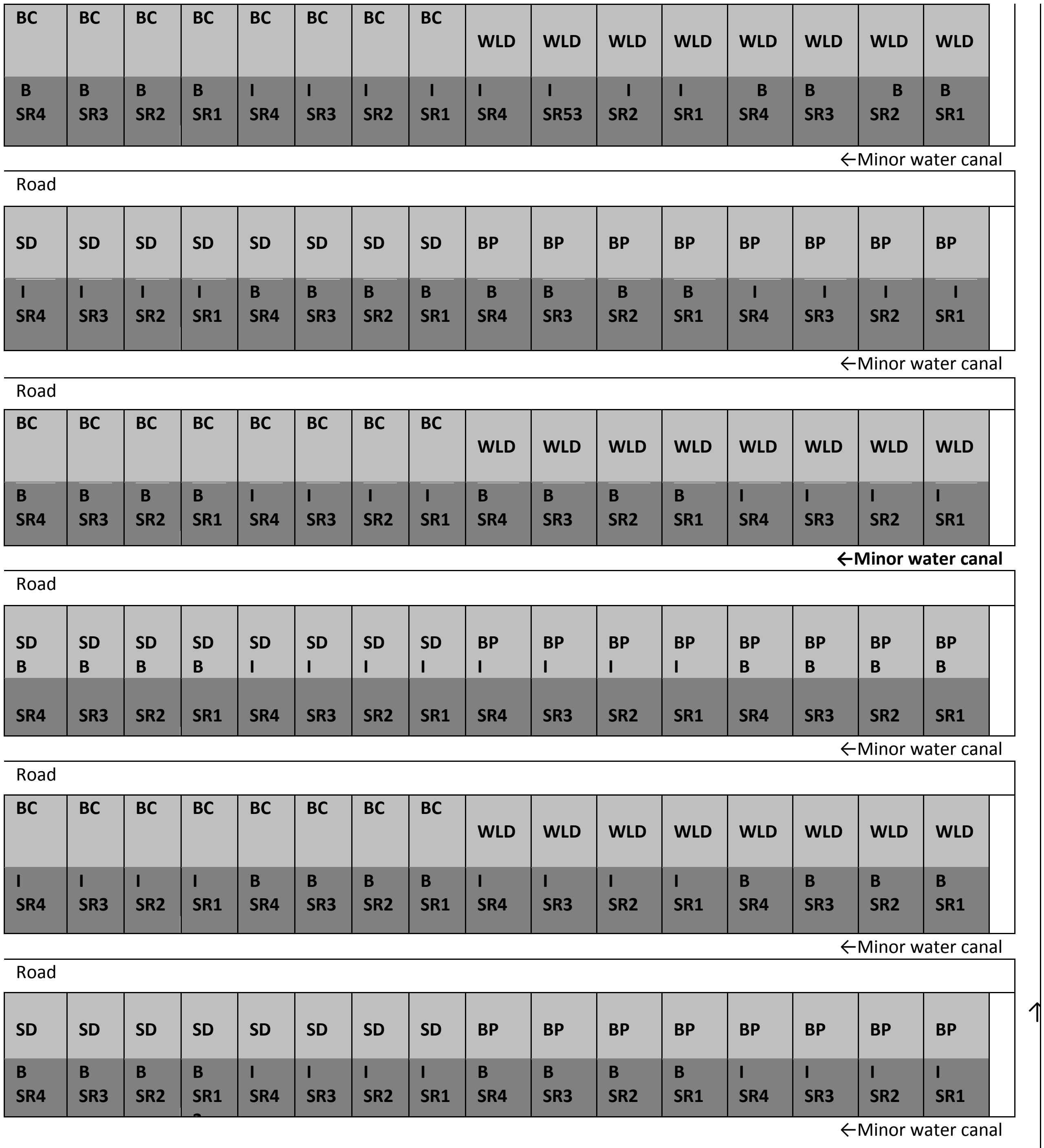


Fig.3.2 Details of a 90° v-notch weir showing typical dimensions

Source: (Michael, 1978)



BP: Bed Planting, SD: Seed Drill, WLD: Wide Level Disc, BC: Broad Casting

SR1: 84kg/ha , SR2: 96kg/ha, SR3:120kg/ha, SR4: 144kg/ha

I: Imam, B: Bohain

(light grey)	Herbicides untreated
(dark grey)	Herbicides treated

Fig 3.3 Layout of experiment (2)

Seed drill	RB120 D2 W2 R6	RB120 D1 W2 R6	RB120 D2 W1 R6	RB120 D1 W1 R6	RB100 D2 W2 R5	RB100 D1 W2 R5	RB100 D2 W1 R5	RB100 D1 W1 R5	RB80 D2 W2 R4	RB80 D1 W2 R4	RB80 D2 W1 R4	RB80 D1 W1 R4	
												←Minor water canal	
Road													
	RB120 D2 W2 R5	RB120 D1 W2 R5	RB120 D2 W1 R5	RB120 D1 W1 R5	RB100 D2 W2 R4	RB100 D1 W2 R4	RB100 D2 W1 R4	RB100 D1 W1 R4	RB80 D2 W2 R3	RB80 D1 W2 R3	RB80 D2 W1 R3	RB80 D1 W1 R3	
												←Minor water canal	
Road													
Seed drill	RB120 D2 W2 R6	RB120 D1 W2 R6	RB120 D2 W1 R6	RB120 D1 W1 R6	RB100 D2 W2 R5	RB100 D1 W2 R5	RB100 D2 W1 R5	RB100 D1 W1 R5	RB80 D2 W2 R4	RB80 D1 W2 R4	RB80 D2 W1 R4	RB80 D1 W1 R4	
												←Minor water canal	
Road													
	RB120 D2 W2 R5	RB120 D1 W2 R5	RB120 D2 W1 R5	RB120 D1 W1 R5	RB100 D2 W2 R4	RB100 D1 W2 R4	RB100 D2 W1 R4	RB100 D1 W1 R4	RB80 D2 W2 R3	RB80 D1 W2 R3	RB80 D2 W1 R3	RB80 D1 W1 R3	
												←Minor water canal	
Road													
Seed drill	RB120 D2 W2 R6	RB120 D1 W2 R6	RB120 D2 W1 R6	RB120 D1 W1 R6	RB100 D2 W2 R5	RB100 D1 W2 R5	RB100 D2 W1 R5	RB100 D1 W1 R5	RB80 D2 W2 R4	RB80 D1 W2 R4	RB80 D2 W1 R4	RB80 D1 W1 R4	
												←Minor water canal	
Road													
	RB120 D2 W2 R5	RB120 D1 W2 R5	RB120 D2 W1 R5	RB120 D1 W1 R5	RB100 D2 W2 R4	RB100 D1 W2 R4	RB100 D2 W1 R4	RB100 D1 W1 R4	RB80 D2 W2 R3	RB80 D1 W2 R3	RB80 D2 W1 R3	RB80 D1 W1 R3	↑
												←Minor water canal	

RB: Raised bed, 80,100,120cm: bed width

D1: Furrow depth 15cm, D2: Furrow depth 25cm

W1: Furrow width 30cm, W2: Furrow width 40cm

R: crop rows per bed

Figure 3. 4 Layout of experiment (3)

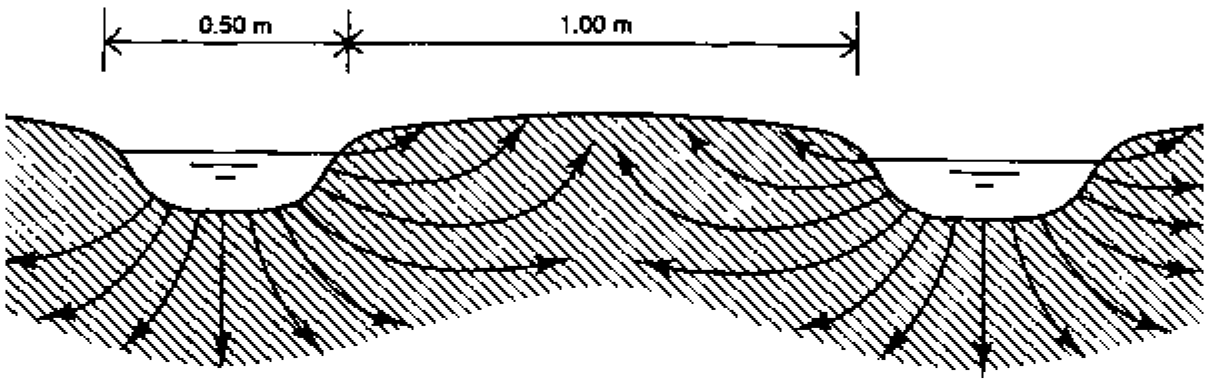


Fig 3.5 Raised bed of 100 cm bed width and 40 cm furrow width

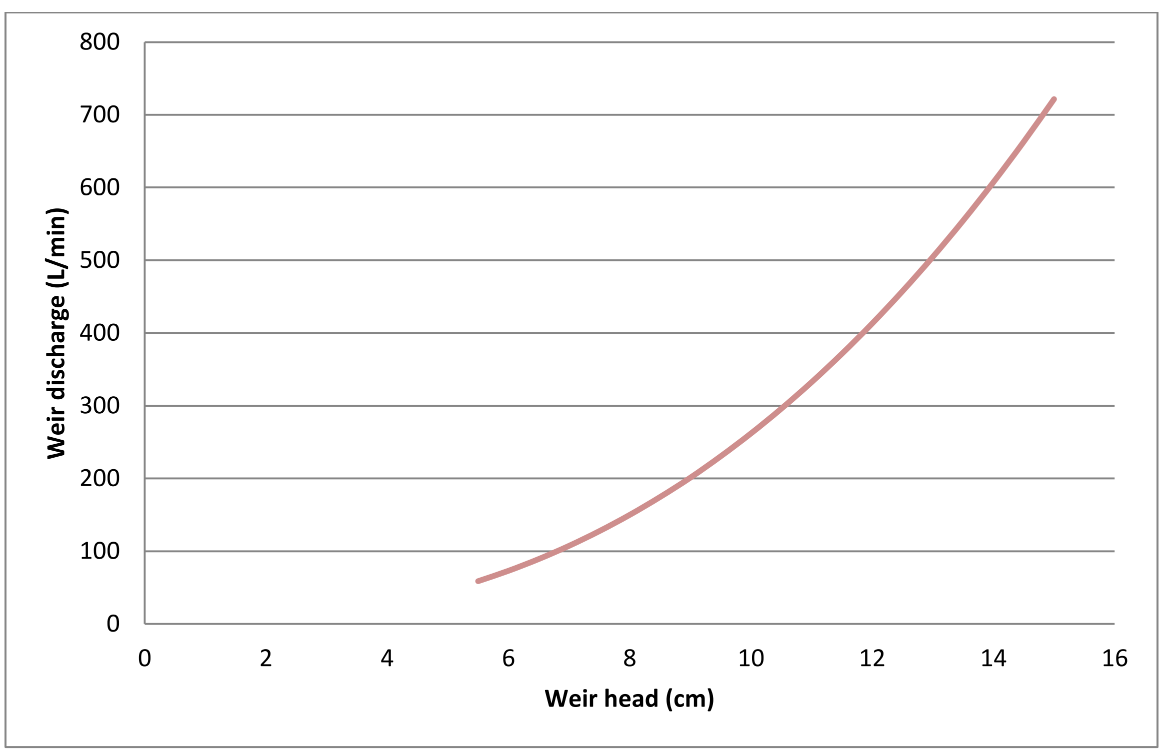


Fig 3.6 90 v-notch weir discharge (L/min.)for different weir heads

CHAPTETR FOUR

RESULTS

4.1 Effect of sowing method, water quantity, variety and chemical weed control and their interactions on plant height:

Analysis of variance indicated significant differences between sowing methods in plant height only in the second season as shown in Table 4.2, where bed planting BP resulted in the tallest plant. Analysis of variance also showed that there were significant differences between water quantities in plant height during the two seasons as shown in Tables 4.1-4.2, where W6 andW5 gave taller plants than the other water quantities. Herbicides treated plots gave significantly taller plants compared with untreated ones during the two seasons. In the second season, results obtained showed that the variety Imam (I) gave significantly taller plants than variety Bohain(B) as shown in Table 4.2.

Analysis of variance also showed significant interaction between sowing methods and applied water in plant height in the second season (Tables 4.3-4.4) where BP/W6 gave the best plant height. However, all bed planting combinations gave taller plants than other sowing methods for the same quantities of water. In the interactions between the different factors, in general, the combinations consisted bed planting, W6 or W5, herbicide treated (Hw) and I variety gave the tallest plant height as shown in Tables 4.5-4.6 and in Tables 2-19. Appendix A.

4.2 Effect of sowing method, water quantity, variety and chemical weed control and their interactions on number of heads/m^2:

Data analysis showed significant differences (p= 0.05) between water quantities in number of heads per square meter as shown in Tables 4.1-4.2, where W6 scored the biggest number of heads compared with the other treatments. This was in the first season whereas in the second season data analysis showed no significant differences between water quantities in the number of heads. Results showed highly significant differences (p= 0.001) in the number of heads in herbicides treated plots compared with untreated ones during the two seasons. Results indicated highly significant differences among the two tested varieties in the second season only where variety I gave bigger number of heads than B. Analysis of variance and LSD showed that no significant differences between the sowing methods in the number of heads . The interactions between the different factors in the number of heads per square meter during the two seasons are shown in Tables 2-19 Appendix A.

Table 4.1 Effect of sowing method, water quantity, variety and chemical weed control on growth performance, water productivity, yield and yield components of wheat (2013-2014)

treatments	Plant L. cm	Plant no./m²	Weed no/m²	Spike wt. g	1000s wt.g	WP kg/m³	B.yield kg/ha	Yield kg/ha
Bed	65.6	270	44	1.7	54	0.82	4949	3732
BC	67	244	30	1.3	56	0.41	4560	1910
SD	66.7	226	24	1.4	53	0.48	4514	2136
WLD	67.9	234	15	1.3	52	0.55	4433	2470
Mean	66.6	243.6	28	1.427	53.7	0.55	4613	2563
Cv%	3.3	6.8	22.5	3	1.3	5.6	7.4	5.8
SE+	1.29	9.59	3.636	0.0246	0.388	0.0180	196	85
LSD	4.45	33.19	12.582	0.0851	1.342	0.062	678	296
Sig.	n.s	n.s	**	**	**	**	n.s	**
W3	63.5	230	23	1.2	49	0.53	4102	1711
W4	65.5	232	31	1.4	54	0.62	4418	2417
W5	68.1	250	28	1.5	56	0.58	4778	2868
W6	69.5	261	30	1.7	56	0.53	5153	3254
Mean	66.6	243.6	28	1.427	53.7	0.55	4613	2563
Cv%	5.7	14	31.3	9.8	5.1	18.4	17.4	15
SE+	0.77	6.94	1.794	0.0285	0.562	0.0210	163	79
LSD	2.198	19.74	5.1	0.0811	1.599	0.06	465	224
Sig.	**	*	*	**	**	*	**	**
B	65.8	240	28	1.4	54	0.53	4385	2510
I	67.5	246	28	1.4	53	0.58	4841	2614
Mean	66.6	243.6	28	1.427	53.5	0.55	4613	2563
Cv%	4.3	10.2	21	4.2	1.5	7.6	6.9	7.5
SE+	0.82	7.15	1.704	0.0173	0.232	0.0122	92	55
LSD	2.681	23.32	5.556	0.0565	0.758	0.040	299	19
Sig.	n.s	n.s	n.s	n.s	n.s	*	*	*
Hw	70.6	252	15	1.6	58	0.62	5090	2825
Ho	62.7	235	45	1.2	49	0.50	4135	2299
Mean	66.6	243.6	28	1.427	53.7	0.55	4613	2563
Cv%	4.4	16.7	38.3	12.6	6.8	21.5	21.1	20.3
SE+	0.3	4.15	1.097	0.0184	0.371	0.0123	99	53
LSD	0.852	11.73	3.099	0.0521	1.050	0.0348	281	154
Sig.	**	*	**	**	**	**	**	**

Table 4.2 Effect of sowing method, water quantity, variety and chemical weed control on growth performance, water productivity, yield and yield components of wheat (2014-2015)

treatments	Plant L. cm	Plant no./m²	Weed no/m²	Spike wt. g	1000s wt.g	WP kg/m³	B.yield kg/ha	Yield kg/ha
Bed	66.75	268.6	60.7	1.612	52.50	0.77	4860	3506
BC	60.19	262.4	57.0	1.295	40.83	0.58	4759	2647
SD	60.69	242.7	71.1	1.177	46.35	0.51	4231	2323
WLD	63.21	260.2	50.2	1.333	43.65	0.56	4577	2554
Mean	62.71	258.5	59.7	1.354	45.83	0.60	4606	2758
Cv%	2.5	5.7	19.5	3.8	2.0	4.3	14.0	4.3
SE+	0.89	8.45	6.73	0.0299	0.535	0.01	373	69
LSD	3.079	29.24	23.29	0.1033	1.85	0.05	1290	237
Sig.	**	n.s	n.s	**	**	**	n.s	**
W3	59.54	249.1	61.5	1.044	37.94	0.52	4116	1584
W4	62.48	260.3	61.8	1.098	43.40	0.66	4390	2664
W5	63.81	262.8	59.6	1.450	48.19	0.65	4733	3254
W6	65.00	261.8	56.1	1.826	53.81	0.58	5186	3528
Mean	62.71	258.5	59.7	1.354	45.83	0.60	4606	2758
Cv%	4	10.1	32.4	15.8	5.9	11.2	23.3	10.9
SE+	0.509	5.33	3.95	0.0436	0.552	0.01	219	61
LSD	1.448	15.15	11.22	1.124	1.569	0.04	623	175
Sig.	**	n.s	n.s	**	**	**	**	**
B	57.90	242.1	59.2	1.350	45.85	0.61	4771	2750
I	97.52	274.9	60.2	1.359	45.81	0.60	4442	2765
Mean	62.71	258.5	59.7	1.354	45.83	0.60	4606	2758
Cv%	2.3	5.6	27.1	7.4	5.6	6.1	13.7	4.5
SE+	0.417	4.14	4.68	0.0287	0.735	0.01	182	36
LSD	1.359	13.51	15.26	0.0937	2.398	0.03	594	118
Sig.	**	**	n.s	n.s	n.s	n.s	n.s	n.s
Hw	63.24	318.1	26.6	1.474	49.69	0.65	5191	2962
Ho	62.18	198.9	92.8	1.235	41.68	0.56	4022	2554
Mean	62.71	258.5	59.7	1.354	45.83	0.60	4606	2758
Cv%	6.2	14.2	44.2	23.4	10.4	14.7	30.8	3.9
SE+	0.398	3.75	2.7	0.0323	0.485	0.01	145	39
LSD	1.125	10.59	7.62	0.0913	1.37	0.03	409	110
Sig.	*	**	**	**	**	**	**!	n.s

4.3 Effect of sowing method, water quantity, variety and chemical weed control and their interactions on number of weed/m^2:

For the first season, analysis of variance showed a highly significant difference (p= 0.001) between sowing methods and significant difference (p= 0.05) between water quantities in the number of weeds per meter square where WLD and W3 gave the lowest number of weeds compared with the other sowing methods and water quantities. Results also showed that herbicides treated plots gave the least number of weeds which was significantly different from untreated plots as shown in Tables 4.1-4.2.

Data analysis showed many interactions between treatments in the number of weeds. As for sowing methods and water quantities interaction WLD gave the least number of weeds with all the quantities of water. Where BP with w5 and w6 gave the largest number of weeds. For all combinations consisted herbicide application treated plots gave the least numbers of weeds (Tables 4.5-4.6). Results of all interactions are shown in Tables 2-19 Appendix A.

Table 4.3 Effect of interaction between sowing methods and applied water on growth performance, water productivity, yield and yield components of wheat (2013-2014)

Treatments		Plant L cm	Plant no./m²	Weed no/m²	Spike wt. g	1000s wt.g	WP kg/m³	B.yield kg/ha	Yield kg/ha
Bed	W3	62.5	281	34	1.1	48	0.67	4397	2357
	W4	64.8	260	41	1.7	56.5	0.96	4800	3694
	W5	65,6	261	53	1.8	56.1	0.84	5266	4224
	W6	69.6	278	49	2.0	55.7	0.74	5330	4651
BRC	W3	62.1	214	23	1.2	48.5	0.29	3886	1147
	W4	66.5	247	38	1.3	56.8	0.43	4387	1728
	W5	70.4	253	21	1.4	59.7	0.43	4951	2191
	W6	69	262	37	1.5	60.0	0.43	5011	2575
SD	W3	63.9	218	21	1.1	49.9	0.48	4037	1445
	W4	65.1	212	31	1.2	51.7	0.48	4210	1975
	W5	66.8	237	23	1.4	53.7	0.48	4558	2335
	W6	68.5	238	20	1.9	54.9	0.46	5251	2794
WLD	W3	65.4	209	15	1.2	48.6	0.58	4092	1894
	W4	65.6	211	13	1.3	52.2	0.58	4282	2268
	W5	69.7	250	16	1.4	53.6	0.53	4339	2724
	W6	70.7	268	14	1.5	53.0	0.50	5014	2998
Mean		66.6	243.6	28	1.427	53.7	0.55	4613	2563
Cv%		5.7	14	31.3	9.8	5.1	18.4	17.4	15
SE+		1.86	15.38	4.782	0.0552	1.048	0.04	344	161
LSD		5.436	44.4	14.28	0.1567	2.972	0.12	987	459
Sig.		n.s	n.s	**	**	*	*	*	*

Table 4.4 Effect of interaction between sowing methods and applied water on growth performance, water productivity, yield and yield components of wheat (2014-2015)

Treatments		Plant L. cm	Plant no./m²	Weed no/m²	Spike wt. g	1000s wt.g	WP kg/m³	B.yield kg/ha	Yield kg/ha
Bed	W3	63.00	271.2	65.4	1.038	41.25	0.62	4001	1870
	W4	65.5	268.8	74.3	1.336	51.17	0.92	4762	3746
	W5	69.17	273.3	52.3	1.833	55.25	0.83	5210	4135
	W6	69.33	261.3	50.6	2.242	62.33	0.69	5462	4277
BC	W3	58.75	241.7	58.3	0.957	34.92	0.46	4450	1414
	W4	58.75	251.1	59.8	0.961	37.75	0.60	4085	2410
	W5	60.92	263.8	53.8	1.461	42.67	0.62	4788	3122
	W6	62.33	292.9	56.2	1.800	48.00	0.61	5712	3646
SD	W3	55.83	247.1	70.9	1.092	3825	0.50	4687	1514
	W4	61.92	248.3	64.2	1.030	43.33	0.57	4262	2282
	W5	61.75	235.4	78.9	1.162	49.75	0.51	4097	2563
	W6	63.25	240.00	70.3	1.425	54.80	0.47	4601	2938
WLD	W3	60.58	236.3	51.5	1.087	37.33	0.51	4044	1536
	W4	63.75	272.9	48.8	1.064	41.33	0.55	4452	2222
	W5	63.42	278.8	53.2	1.343	45.80	0.64	4834	3199
	W6	65.80	252.9	47.2	1.838	50.83	0.54	4973	3254
Mean		62.71	258.5	59.7	1.354	45.83	0.60	4606	2758
Cv%		4	10.1	32.4	15.8	5.9	11.2	23.3	10.9
SE+		1.253	12.51	9.59	0.0812	1.095	0.03	532	127
LSD		3.685*	36.49	28.15	0.2303	3.117	0.08	1560	362
Sig.		*	n.s	n.s	**	*	**	n.s	**

4.4 Effect of sowing method, water quantity, variety and chemical weed control and their interactions on spike weight (g):

Analysis of variance showed that bed planting method resulted in superior spike weight during the two seasons compared with the other sowing methods as shown in Tables 4.1-4.2. Data analysis also showed highly significant differences (p=0.01) between water quantities in spike weight during the two seasons, where W6 gave the highest weights while W3 gave the lowest weights during the two seasons. Results showed high significant differences (p= 0.01) in spike weight between herbicides treated plots and untreated ones. The treated plots gave the best spike weights during the two seasons. However, no significant differences in spikes weight were observed between the two varieties during the two seasons. Data analysis showed many interactions between treatments in spike weight. However, bed planting gave the best spike weight for the two varieties during the two seasons compared with the other sowing methods as shown in Tables 2-3 Appendix A. Analysis of variance showed strong interactions (p= 0.01) between the sowing methods and water quantity (Tables 4.3-4.4). BP /W6 gave the best spike weight in the two seasons compared with the other combinations. Moreover, bed planting with less quantities of water resulted in best spike weight compared with the other sowing methods. LSD showed that BP/W4- W6 for the two varieties resulted in the best spike weights compared with other sowing methods combinations during the two seasons as shown in Tables 4.5-4.6. Results of other interactions were shown in Tables 4-19 Appendix A.

4.5 Effect of sowing method, water quantity, variety and chemical weed control and their interactions on weight of 1000 seeds (g):

Analysis of variance showed high significant differences (p=0.01) between the sowing methods in the weight of 1000 seeds during the two seasons as shown in Tables 4.1-4.2. Where BC and BP scored the highest weights and WLD scored the lowest weights in the first season, and BP and BC scored the highest and the lowest weights in the second season, respectively. Data analysis showed high significant differences(p=0.01) between water quantities in 1000 seeds weight where W5 and W6 scored the highest weights and W3 scored the lowest weights during the two seasons. No significant differences were shown between the two varieties in 1000 seeds weight during the two seasons. Results showed high significant differences (p= 0.01) in 1000 seeds weight between herbicides treated plots and untreated ones, where the treated plots gave the best 1000 seeds weights in the first and the second season. Analysis of variance showed significant interaction between sowing methods and water quantities as shown in Tables 4.3-4.4. However, BP required less volume of water W4 to give its top 1000 seeds weight while the other sowing methods required more volume of water (W6) to give the same or less 1000 seeds weight. The BP/ W4, W5, W6/Hw combinations were found to be superior in 1000 seeds weight during the two seasons(Tables 4.5-4.6). Results of the other interactions are shown in Tables 2-19 Appendix A.

4.6 Effect of sowing method, water quantity, variety and chemical weed control and their interactions on yield (kg/ha):

Analysis of variance showed highly significant differences (p=0.01) between sowing methods in grain yield during the two seasons as shown in Tables 4.1-4.2 and Fig 4.1. The method of BP followed by WLD gave the highest yields, while the lowest yields were scored by BC method. Data analysis also, showed highly significant differences in yield between water quantities, during the two seasons. W6 followed by W5 resulted in higher yields, while W3 gave the lowest yields. In the first season high yields were given by the variety I compared with B variety. Herbicides treated plots (Hw) resulted in significantly higher yields than the untreated plots (Ho) during the two seasons.

Significant interaction was detected between sowing methods and varieties in grain yield during the two seasons (Tables 2-3 Appendix A). The BP/B and I combinations gave higher yields than the other combinations. No significant differences were found in yield between the two varieties with bed planting (BP).

Results showed significant interaction between sowing method and water quantity in yield (Tables 4.3-4.4 and Fig 4.2). BP/W4, W5 and W6 gave superior yield over all other combinations. No significant differences were found in yield between W4, W5 and W6 with bed planting (BP), moreover, BP/W3 significantly exceeded BC, SD, and WLD/W3 in yield. No significant differences were found between the two varieties under bed planting for the same quantity of water during the two seasons. Significant interaction was found between the four factors (Tables 4.5-4.6). However, BP/Hw/ W6/I and BP/ Hw /W6/B followed by BP/ Hw /W5/B and BP/ Hw /W5/I followed by BP/ Hw /W4/I then BP/ Hw /W4/B in the first season and by BP/ Hw /W4/B then PB/ Hw /W4/I in the second season resulted in higher yield compared to the other combinations. Results of other interactions are shown in Tables 2-19 Appendix A.

4.7 Effect of sowing method, water quantity, variety and chemical weed control and their interactions on water productivity (kg/m³):

Analysis of variance showed high significant differences ($p = 0.01$) between sowing methods in water productivity (kg/m^3). As shown in Tables 4.1-4.2 and Fig 4.3. Bed planting was superior in water productivity. It gave 0.82kg/m^3 and 0.77kg/m^3 in the first and second seasons, respectively, whereas broadcasting resulted in the lowest water productivity in the first season (0.41 kg/m^3) and seed drill gave the lowest water productivity in the second season (0.51 kg/m^3). Data analysis showed significant differences ($p=0.05$) in the first season and highly significant differences ($p=0.01$) in the second season between water quantities in water productivity. W4 scored the highest water productivity in the first season (0.62 kg/m³) and in the second season (0.66 kg/m³). Data analysis also showed significant differences between the two varieties in water productivity in the first season but not in the second season. The variety Imam gave the highest water productivity (0.58 kg/m³) in the first season. Data analysis showed significant differences between herbicides treated and untreated plots in water productivity. The treated plots gave the highest water productivity during the two seasons (0.62 and 0.65 kg/m³ respectively).

Data analysis revealed significant interaction in the first season and highly significant interaction in the second season between sowing methods and water quantities in water productivity as shown in Tables 4.3-4.4. However, Bed planting with W4 scored the highest water productivity in the first season (0.96 kg/m³) and in the second season (0.92 kg/m³), whereas, BC, SD, WLD with the same water quantity (W4) gave 0.43, 0.48 and 0.58 kg/m³, respectively, in the first season and 0.60, 0.57 and 0.55 kg/m³, respectively, in the second season. In the interaction of the four factors, the combinations BP/W4/B/Hw (1.056 kg/m³) and BP/W4/I/Hw (1.032 kg/m³) were found superior in water productivity over all other combinations during the two seasons as shown in Tables 4.5-4.6. Results of other interactions were shown in Tables 2-19 Appendix A.

Table 4.5 Effect of interaction between sowing methods, applied water, varieties and herbicides application on growth performance, water productivity, yield and yield components of wheat (2013-2014)

treatments	Plant L. cm		Plant no./m²		Weed no/m²		Spike wt. g		1000s wt.g		WP kg/m³		B.yield kg/ha		Yield kg/ha	
	Tr	nT	Tr	nT	Tr	nT	Tr	nT	Tr	nT	Tr	nT	Tr	nT	Tr	nT
Bed W3B	61.1	58.5	350	282	9	76	1.2	1.2	53	50	0.67	0.65	4692	4006	2347	2767
BedW4B	63.7	55	258	238	25	81	2.4	1.2	65	53	1.06	0.91	5374	4126	3713	3648
BedW5B	66.8	57	223	250	33	91	2.5	1.3	65	50	0.91	0.77	5422	5422	4608	3746
BedW6B	72	63	268	232	20	111	2.7	1.3	65	49	0.82	0.72	5311	5400	4949	4284
BedW3I	66.8	63.3	278	213	11	41	1.1	1.1	47	43	0.70	0.72	4882	4010	2143	2165
BedW4I	74	66.5	298	245	15	42	2.0	1.1	61	46	1.03	0.86	4548	5150	4092	3254
BedW5I	74	64.7	297	275	20	68	2.4	1.1	66	44	0.91	0.79	5455	4769	4560	3986
BedW6I	75	68.5	318	295	6	58	2.7	1.1	65	44	0.84	0.60	5690	4918	5038	4330
BC W3B	64	54.9	187	227	12	46	1.0	1.1	47	44	0.31	0.24	3787	3624	914	742
BCW4B	75.3	64.3	262	250	7	48	1.2	1.1	59	52	0.34	0.31	4234	3718	1366	1258
BCW5B	74.8	66.5	230	223	7	16	1.5	1.3	61	58	0.41	0.29	5510	4498	2090	1488
BCW6B	73.2	67.5	305	258	4	17	1.5	1.4	61	58	0.43	0.29	5239	4536	2599	1735
BCW3I	71.3	58.3	220	223	12	22	1.2	1.3	52	51	0.55	0.41	5774	2357	1675	1260
BCW4I	67	59.3	225	252	24	73	1.4	1.3	59	57	0.55	0.53	5218	4380	2174	2114
BCW5I	74.2	66	305	252	15	46	1.5	1.4	61	59	0.55	0.48	5232	4567	2815	2376
BCW6I	73.8	61.5	258	227	18	110	1.6	1.5	62	59	0.41	0.48	5371	4901	3142	2827
SD W3B	65.8	56.8	198	190	13	33	1.0	1.1	51	51	0.50	0.46	4106	2539	1246	1380
SDW4B	67.2	57.8	211	230	13	65	1.3	1.2	58	50	0.53	0.43	4032	3516	2023	1747
SDW5B	69.5	61.2	245	285	9	30	1.7	1.3	62	48	0.53	0.50	4915	4762	2700	2520
SDW6B	68.2	63.5	270	222	16	27	2.1	1.3	65	47	0.53	0.48	4577	3446	3230	2818
SDW3I	72	60.8	250	232	9	29	1.5	0.9	49	48	0.62	0.41	5362	4135	1915	1238
SDW4I	72.2	63.2	225	182	11	36	1.2	1.2	55	44	0.72	0.31	5225	4063	2854	1279
SDW5I	71.3	65.2	233	185	7	44	1.3	1.2	61	44	0.58	0.26	5208	3341	2758	1361
SDW6I	74.1	68.3	201	257	12	25	2.5	1.5	61	47	0.53	0.34	8700	4286	3139	1985
WLDW3B	73.3	66.7	178	233	3	22	1.3	1.2	50	44	0.50	0.53	3823	3554	2201	1596
WLDW4B	70.3	65.3	203	173	5	15	1.3	1.3	55	44	0.60	0.48	4411	3487	2450	1889
WLDW5B	73.7	67.3	265	225	4	25	1.6	1.4	60	47	0.62	0.53	4728	3223	3175	2599
WLDW6B	76.2	65.3	247	283	4	14	1.6	1.4	61	44	0.58	0.50	5546	4750	3478	2995
WLDW3I	64.6	56.8	242	183	6	30	1.1	1.2	49	51	0.62	0.62	4702	4289	1906	1872
WLDW4I	67.2	59.7	273	193	7	25	1.3	1.1	59	51	0.70	0.50	5186	4046	2765	1987
WLDW5I	73.2	64.7	258	252	9	28	1.5	1.1	57	51	0.60	0.43	5076	4330	2954	2165
WLDW6I	73.5	67.8	283	258	4	35	1.6	1.2	58	49	0.55	0.36	5537	4222	3360	2160
Mean	66.6	66.6	244	244			1.247	1.247			0.55	0.55	4613	4613	2563	2563
Cv%	4.4		16.7		38.3		12.6		6.8		21.5		21.1		20.3	
SE+	2.84		27.56		7.588		0.1073		2.089		0.08		611		309	
LSD	8.01		77.3		21.399		0.3003		5.848		0.21		1712		865	
Sig.	n.s		n.s		**		n.s		n.s		n.s		n.s		*	

Table4.6 Effect of interaction between sowing methods, applied water, varieties and herbicides application on growth performance, water productivity, yield and yield components of wheat (2014-2015)

treatments	Plant L. cm		Plant no./m²		Weed no/m²		Spike wt. g		1000s wt.g		WP kg/m³		B.yield kg/ha		Yield kg/ha	
	Tr	nT	Tr	nT	Tr	nT	Tr	nT	Tr	nT	Tr	nT	Tr	nT	Tr	nT
Bed W3B	56	59	268	238	25	98	1	1	48	40	0.53	0.58	4426	3005	1613	1714
BedW4B	61.6	59	320	170	50	106	1.8	0.8	57	44	0.96	0.91	4584	4027	3852	3931
BedW5B	72.6	60	317	188	21	78	2.6	1	64	47	0.86	0.74	4985	3449	4246	3703
BedW6B	73.6	62	355	175	18	74	2.4	1.6	63	59	0.74	0.65	5321	3792	4519	3893
BedW3I	72	65	347	232	49	90	1	1.1	42	35	0.70	0.70	4330	4241	2069	2078
BedW4I	72	69	357	228	51	90	1.7	1.1	57	47	0.94	0.86	5666	4774	3775	3427
BedW5I	75.6	68	372	217	16	95	2.1	1.6	63	47	0.89	0.84	7169	5239	4351	4238
BedW6I	76.3	65	337	178	20	90	2.7	2.3	65	61	0.74	0.70	7032	5707	4567	4133
BC W3B	56.3	57	303	200	14	87	1	0.9	36	36	0.65	0.36	6252	4375	1932	1145
BCW4B	52.3	53	295	196	16	100	0.9	1	39	32	0.70	0.50	4841	4222	2779	2018
BCW5B	55	53	330	183	26	83	1.3	1.7	42	41	0.67	0.55	4822	5076	3336	2724
BCW6B	54.6	54	312	242	11	94	1.9	1.7	50	45	0.65	0.53	9828	4685	3898	3185
BCW3I	59.6	61	305	158	24	108	0.9	1	37	31	0.41	0.43	3890	3288	1270	1310
BCW4I	67	62	315	198	34	90	1.1	0.8	43	37	0.60	0.60	3792	3490	2407	2450
BRCW5I	66.3	69	326	215	11	95	1.3	1.5	45	43	0.65	0.62	4814	4438	3266	3161
BRCW6I	73.6	67	365	253	24	95	1.6	2	51	46	0.62	0.65	3463	4877	3696	3802
SD W3B	54.6	57	272	175	31	125	1.1	1	45	38	0.48	0.34	3878	3516	1440	977
SDW4B	55.3	57	287	148	25	101	1	0.9	49	42	0.72	0.36	4558	2705	2861	1414
SDW5B	52	56	255	172	55	121	1	1.3	52	45	0.62	0.46	3365	4224	3194	2254
SDW6B	56	59	290	152	64	81	1.8	0.9	60	49	0.53	0.41	6377	3593	3142	2522
SDW3I	55	56	335	207	29	99	1.2	1.1	35	35	0.79	0.41	5484	2995	2402	1243
SDW4I	67.6	67	335	223	18	112	1.8	0.9	48	34	0.77	0.43	5734	4054	3106	1747
SDW5I	71	67	352	163	25	114	1.2	1.1	58	45	0.55	0.38	4915	3878	2844	1961
SDW6I	69.6	68	325	193	25	111	1.2	1.3	60	47	0.48	0.46	4510	3924	3290	2794
WLDW3B	58	60	238	162	21	92	1.7	1.1	39	35	0.84	0.46	6242	4663	2556	1414
WLDW4B	56.3	61	293	212	22	69	1.2	1.1	45	38	0.55	0.70	5314	4639	2206	2842
WLDW5B	53.6	61	321	198	21	75	1.1	1.2	48	35	0.60	0.65	7111	4135	3031	3257
WLDW6B	53.6	59	318	160	13	79	1.8	2	59	44	0.50	0.55	6012	4642	3065	3358
WLDW3I	59.3	65	318	227	21	72	1.9	1	38	37	0.41	0.31	3010	2261	1222	953
WLDW4I	69	68	348	238	24	80	1	0.9	43	39	0.48	0.48	4236	3622	1882	1958
WLDW5I	74.3	64	360	235	22	95	1.4	0.9	53	43	0.70	0.60	4690	3398	3509	3000
WLDW6I	73.3	73	307	227	25	72	1.8	1.7	54	46	0.58	0.53	5484	3749	3427	3168
Mean	62.71		258.5		59.7		1.354		45.83		0.60		4606		2758	
Cv%	6.2		14.2		44.2		23.4		10.4		14.7		30.8		13.9	
SE+	2.288		22.38		17.29		0.1751		2.638		0.05		911		233	
LSD	6.417		62.76		48.57		0.4902		7.394		0.15		2556		653	
Sig.	*		n.s		n.s		n.s		n.s		*		n.s		*	

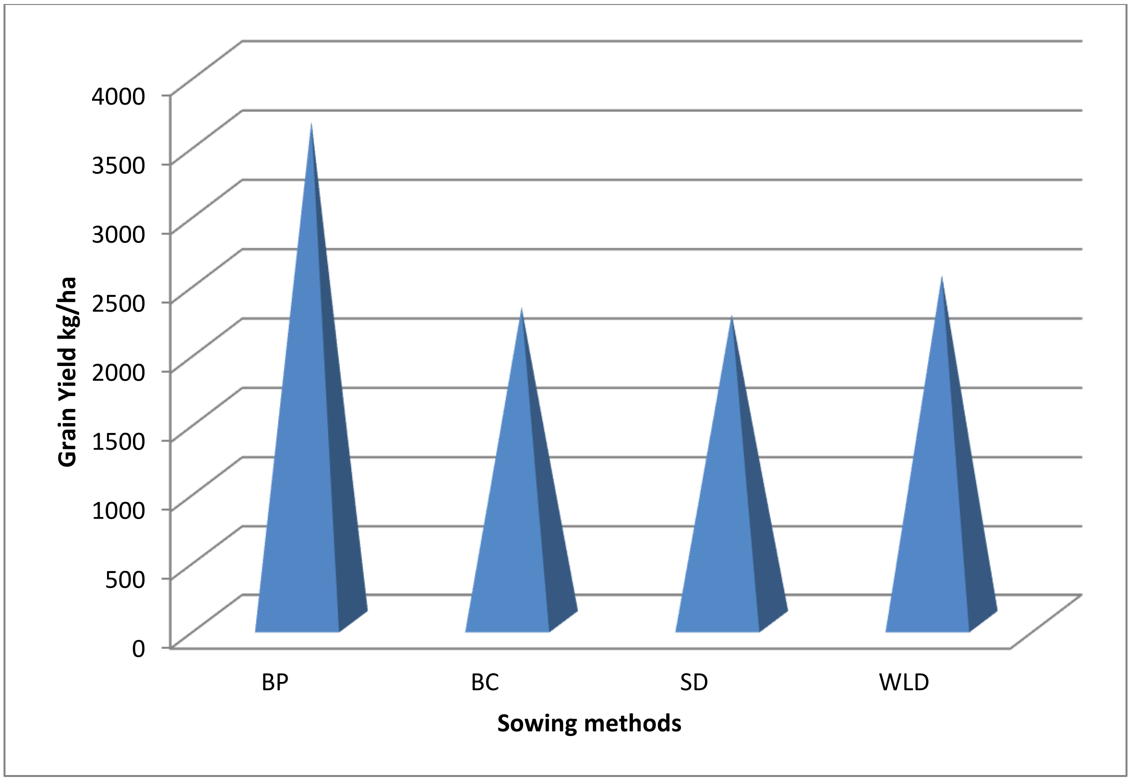


Fig 4.1 Grain yield as affected by sowing method (average of two seasons)

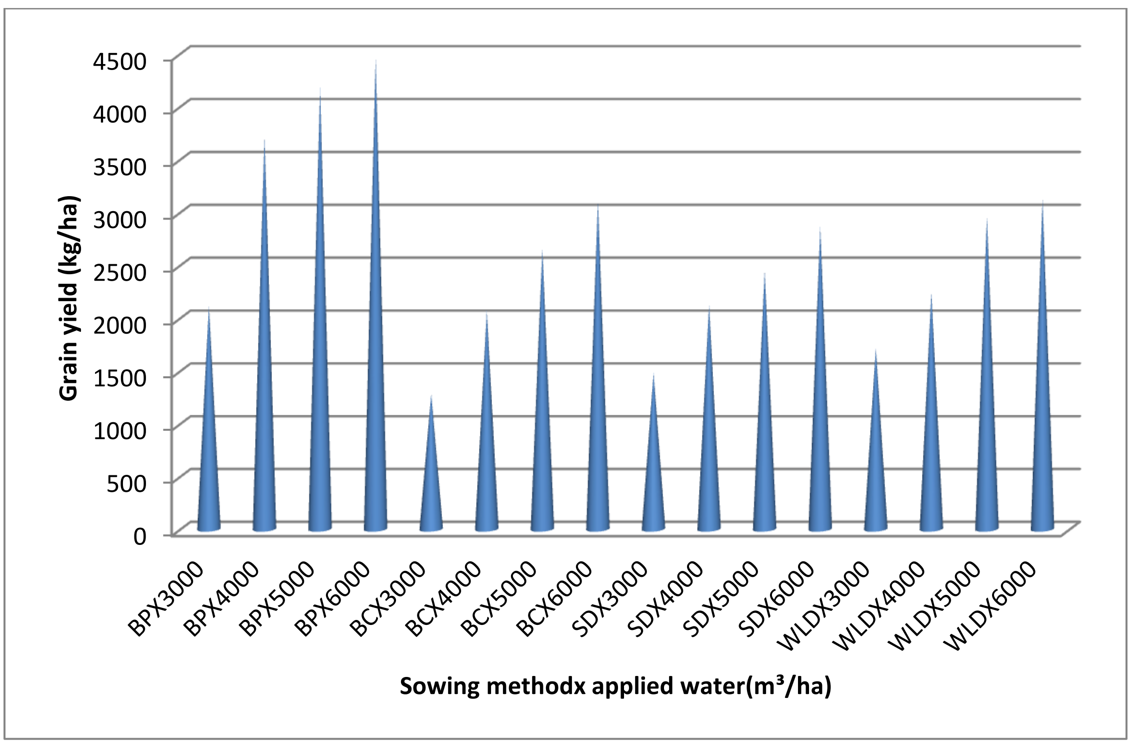


Fig 4.2 Grain yield as affected by sowing method and applied water (average of two seasons)

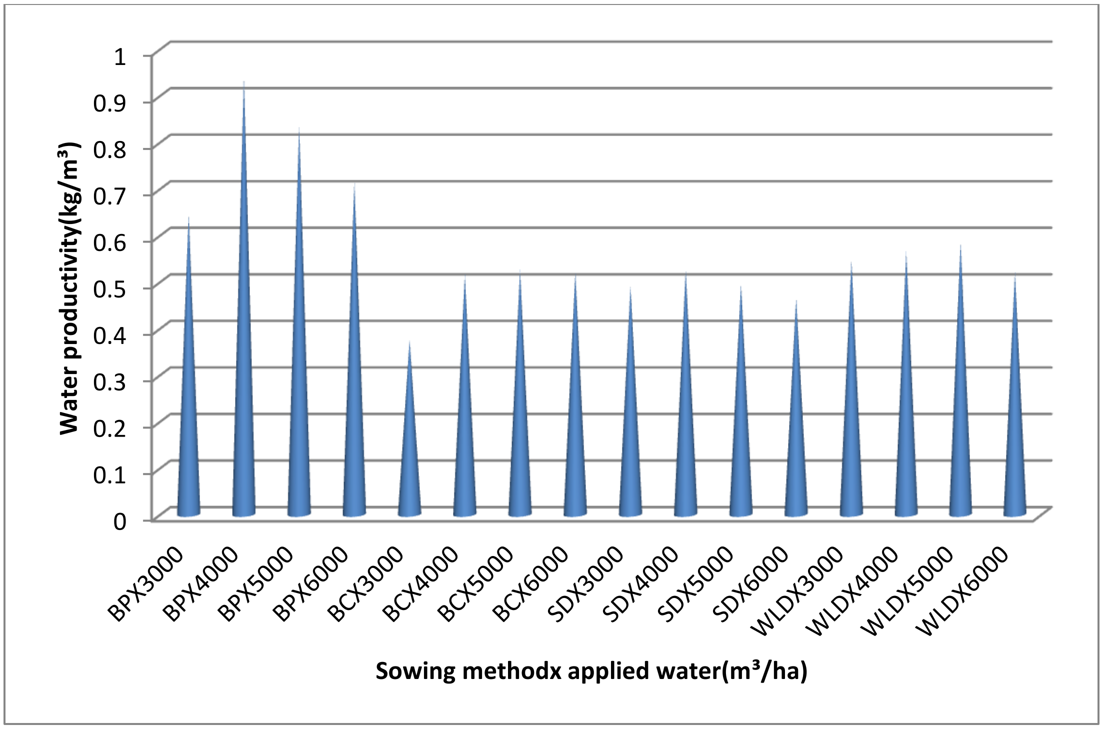


Fig 4.3 Water productivity (kg/m³) as affected by sowing method and applied water (average of two seasons)

4.8 Effect of seeding rate and its interactions with sowing method, variety and herbicide application on plant height:

Analysis of variance showed a high significant difference between seeding rates (SR) in plant height in the second season (Tables4.7- and 4.8). It was shown that SR96 and SR84 gave the taller plants while SR144 gave the shorter ones. Significant interaction was found between sowing methods and seeding rate in plant height during the second season only as shown in Tables 4.9-4.10. BP/SR84 and BP/SR96 gave the taller plants. No significant difference was found between the seeding rates for the same sowing method in plant height. SR96/I gave the taller plants than the other combinations. It was observed that, for the same seeding rate always, variety I exceeded, significantly, variety B in plant height.

Table 4.7 Effect of seeding rate on growth performance, weed infestation, yield and yield components of wheat (2013-2014)

Treatments	Plant. height cm	Plant no./m²	Weed no/m²	Spike wt. g	1000sWt.g	G.Yield kg/ha
SR84	65.2	220	63.4	1.28	40.7	2486
SR96	66	262	48.6	1.16	39.6	2606
SR120	65.5	293	37.2	1.14	39.2	2837
SR144	65.7	339	26.8	1.10	38.9	3048
Mean	65.58	279	44.0	1.17	39.6	2743
Cv%	4.2	11	7.7	8.4	4.2	8.6
SE+	0.565	2.89	0.69	0.02	0.337	60
LSD	1.607	8.23	1.961	0.0569	0.959	169
Sig.	n.s	**	**	**	**	**

Table 4.8 Effect of seeding rate on growth performance, weed infestation, yield and yield components of wheat, second season

Treatments	Plant. height cm	Plant no./m²	Weed no/m²	Spike wt. g	1000sWt.g	G.Yield kg/ha
SR84	61.8	220	70	1.4	43	1877
SR96	62.3	260	55	1.3	42	2561
SR120	61.4	299	45	1.3	42	3326
SR144	60	345	34	1.2	40	3523
Mean	61.4	281	51	1.2	42	2822
Cv%	3.6	5.1	11.5	4.5	2.5	14.1
SE+	0.455	6.3	1.2	0.0117	0.215	82
LSD	1.293	17.99	3.413	0.033	0.61	232
Sig.	**	**	**	**	**	**

Significant interaction was detected between the four factors in plant height, however, BP/SR96/I/ Hw followed by BP/SR120/I/ Hw gave the tallest plants during the two seasons as shown in Tables 4.11-4.12. Results of other interactions are shown in Tables 20-25 Appendix A.

Table 4.9 Effect of the interaction between sowing methods and seeding rate on growth performance, weed infestation, yield and yield components of wheat (2013-2014)

Treatments		Plant. height cm	Plant no./m²	Weed no/m²	Spike wt. g	1000s Wt.g	G.Yield kg/ha
Bed	SR84	66.7	224	54.2	1.48	44.3	2748
	SR96	65	269	43.3	1.43	44.4	3074
	SR120	65.2	297	35.5	1.34	43.0	3154
	SR144	65.5	337	25.0	1.29	42.0	3312
BC	SR84	65.5	229	68.4	1.14	39.1	2376
	SR96	65.2	276	52.8	1.04	37.9	2642
	SR120	63.3	294	39.1	1.11	38.4	2918
	SR144	67.4	339	27.4	1.03	37.7	3158
SD	SR84	64	213	74.2	1.25	40.0	2448
	SR96	66.2	259	53.9	1.12	38.5	2378
	SR120	66.3	299	41.0	1.08	38.2	2738
	SR144	67.4	344	30.0	1.07	38.3	2822
WLD	SR84	64.4	214	56.6	1.22	39.4	2376
	SR96	67.4	244	44.4	1.04	37.7	2328
	SR120	65.7	282	33.2	0.98	37.3	2534
	SR144	65.9	335	24.6	1.03	37.5	2899
Mean		65.58	279	44.0	1.17	39.6	2743
Cv%		4.2	11	7.7	8.4	4.2	8.6
SE+		1.897	6.67	4.164	0.0762	1.115	129
LSD		5.908	19.4	13.88	0.24*	3.46*	370
Sig.		n.s	**	**	*	*	*

Table 4.10 Effect of the interaction between sowing methods and seeding rate on growth performance, weed infestation, yield and yield components of wheat, second season

Treatments		Plant. height cm	Plant no./m²	Weed no/m²	Spike wt. g	1000s Wt.g	G.Yield kg/ha
Bed	SR84	73.3	208	58	1.7	50	2971
	SR96	73.7	253	45	1.8	49	3833
	SR120	68.4	289	36	1.7	48	3965
	SR144	65.7	359	26	1.5	45	3958
BC	SR84	55.9	247	75	1.2	40	1728
	SR96	58	268	57	1.2	39	2621
	SR120	57.2	318	47	1.1	39	3245
	SR144	55.3	350	35	1.1	39	3533
SD	SR84	59.5	213	73	1.3	42	1483
	SR96	59	247	62	1.2	40	1786
	SR120	60.7	279	51	1.2	40	2777
	SR144	60.8	318	43	1.1	40	3010
WLD	SR84	58.5	212	73	1.2	40	1327
	SR96	58.7	272	57	1.1	38	1999
	SR120	59.3	310	47	1.2	40	3317
	SR144	58.3	356	34	1.0	38	3595
Mean		61.4	281	51	1.3	42	2822
Cv%		3.6	5.1	11.5	4.5	2.5	14.1
SE+		1.896	16.98	5.7	0.0522	0.685	180
LSD		6.095	50.77	18.63*	0.169	2.113	518
Sig.		**	n.s	*	**	**	**

4.9 Effect of seeding rate and its interactions with sowing method, variety and herbicide application on number of heads/m^2:

Analysis of variance indicated highly significant differences (p=0.01) between tested seed rates in number of heads per square meter during the two seasons as shown in Tables 4.7-4.8. SR144 scored the highest number of heads during the two seasons. Whereas, the lesser heads number during the two seasons was scored by SR84. Results obtained indicated significant interaction between seeding rates and sowing methods, during the first season for SR96 (Table 4.9), where BP and BC exceeded significantly WLD in number of heads per plant. In the second season results showed no significant differences between sowing methods in the number of heads per plant for the same seeding rate (Table 4.10). Results obtained revealed that in the first season, Bed planting method, in SR84 the variety I resulted in number of heads significantly more than variety B. In SR120, SD sowing method the variety I gave number of heads more than the variety B. In SR120 and SR144 no significant differences between sowing methods in number of heads. However, in the second season results indicated that just in the SR144/ SD the variety I resulted in significantly more heads per plant than the variety B (Tables 20-21 Appendix A). Results showed no interaction between sowing methods, seeding rates, variety and herbicides in the number of heads per plant during the two seasons (Tables 4.11-12).

4.10 Effect of seeding rate and its interactions with sowing method, variety and herbicide application on number of weeds/m²:

Analysis of variance showed highly significant differences ($p= 0.01$) between seeding rates in the number of weeds/m² during the two seasons as shown in Tables 4.7 - 4.8. SR144 gave the lowest number of weeds during the two seasons while SR84 gave the highest number of weeds during the two seasons.

Data analysis showed significant interaction between sowing methods and seeding rates in number of weeds for SR84, whereas, BP/ SR84 gave significantly the lowest number of weeds compared with BC and SD for the same seeding rate during the two seasons as shown in Tables 4.9-4.10.

Significant interaction between the four factors in weeds number was found in untreated plots, during the two seasons. However, WLD/SR144/I/Ho and BP/SR144/B/ Ho combinations gave the least number of weeds during the first and second seasons, respectively. Whereas the combination SR84/I/ Ho scored the highest number of weeds during the two seasons as shown in Tables 4.11-4.12. Results of other interactions between the different factors are shown in Tables 20-25 Appendix A.

4.11 Effect of seeding rate and its interactions with sowing method, variety and herbicide application on spike weight (g):

A highly significant difference (p=0.01) was detected between the tested seeding rates in the weight of spike during the two seasons as shown in Tables 4.7-4.8. The highest spike weight was scored by SR84 during the two seasons, conversely SR144 scored the lowest spike weight during the two seasons. Results showed significant interaction (p=0.05) between sowing methods and seeding rate in spike weight as shown in Tables 4.9-4.10. Bed planting exceeded all other sowing methods in spike weight in all seeding rates. However, BP/SR84 and BP/SR96gave the highest spike weight during the first and second season, respectively, whereas WLD/SR120 and WLD/SR144 gave the lowest spike weight during the first and second season, respectively. Bed planting combinations resulted in the best spike weights during the two seasons. In the treated plots BP/SR84/B/Hw and BP/SR96/I/ Hw scored the highest spike weights during the first and second seasons, respectively, whereas the lowest spike weight was scored by WLD/SR120/ Hw and WLD/SR144/B and I/ Hw in the first and second season, respectively. Results showed no significant interaction between the four factors in spike weight in untreated plots in the first season (Table 411). In the second season the combinations BP/SR96/I/Ho and BP/SR120/I/Ho gave the highest spike weight and the combination WLD/SR144/I/Ho gave the lowest spike weight (Table 4.12). Results of other interactions are shown in Tables 20-25 Appendix A.

4.12 Effect of seeding rate and its interactions with sowing method, variety and herbicide application on weight of 1000 seeds (g):

Analysis of variance showed highly significant differences (p=0.01) between tested seeding rates in 1000 seeds weight during the two seasons as shown in Tables 4.7-4.8. SR84 resulted in the highest 1000 seeds weight during the two seasons whereas, SR144 gave the lowest weight during the two seasons. Results indicated significant interaction between seeding rate and sowing methods as shown in Tables 4.9-4.10. Bed planting resulted in significantly higher 1000 seeds weight than the other sowing methods for the same seeding rates. BP/SR96 followed by BP/SR84 scored the highest 1000 seeds weight in the first season while in the second season the highest 1000 seeds weight was scored by BP/SR84. The lowest 1000 seeds weight was scored by WLD/SR120 in the first season and by WLD/SR144 and WLD/SR96 in the second season. Significant interaction was detected between sowing methods, seeding rates and herbicide application in 1000 seeds weight during the two seasons (Tables 22-23Appendix A). All the combinations containing bed planting resulted in significantly higher 1000 seeds weight than combinations containing other sowing methods. Results during the two seasons indicated significant interactions between sowing methods, seeding rates, varieties and herbicide application in 1000 seeds weight as shown in Tables 4.11-4.12. The combination BP/SR84/B/ Hw scored the highest 1000 seeds weight during the two seasons whereas, the combination WLD/SR120/B/Ho scored the lowest 1000 seeds weight in the first season and in the second season the lowest 1000 seeds weight was scored by the combinations WLD/SR96/I Ho and WLD/SR144/I/ Ho. Results of other interactions are shown in Tables 20-25 Appendix A.

4.13 Effect of seeding rate and its interactions with sowing method, variety and herbicides application on grain yield:

Analysis of variance showed significant differences between seeding rates in grain yield during the two seasons as shown in Tables 4.7-4.8. SR144 gave the highest yield followed by SR120, while SR84 gave the lowest yield during the two seasons. No significant difference in yield was shown between sowing methods in SR84. In the second season BP/SR84 significantly exceeded BC/SR96, SD/SR96/ and WLD/SR96 in grain yield (Tables 4.9-4.10). BP/SR96 gave the highest yield compared with SR96 in the other sowing methods. BP/SR120 significantly exceeded SR120 in yield, in the other sowing methods. BP/SR144 followed by BC/SR144 significantly exceeded SR120 in yield, in the other sowing methods. Moreover, BP/SR96 significantly exceeded BC/SR50 and WLD/SR120 in yield and exceeded SD/SR120 (Tables 4.9-4.10 and Fig 4.4). In the interaction between sowing methods, seeding rates and herbicides application (Tables 22-23 Appendix A), results obtained during the two seasons showed that treated BP/SR96 ,SR120 ,SR144 exceeded treated SR96 and SR120 in other sowing methods in grain yield, whereas, there was no significant differences in yield between BP/SR96/Hw and the other combinations with SR144 in the other sowing methods. However, BP/SR144/Hw exceeded significantly SR144 in the other combinations. Significant interaction in grain yield was found between the four factors in the first season as shown in Tables 4.11-4.12. The combinations BP/SR120/B and I/Hw, BP/SR144/B and I/Hw and BP/SR96/B and I/Hw resulted in superior grain yield compared with the combinations. Results of other interactions are shown in Tables 20-25 Appendix A.

Table 4.11 Effect of the interaction between sowing method, seeding rate, variety and herbicides application on growth performance, weed infestation, yield and yield components of wheat (2013-2014)

treatments	Plant. height cm		Plant no./m²		Weed no/m²		Spike wt. g		1000s Wt.g		G.Yield kg/ha	
	Tr	nT	Tr	nT	Tr	nT	Tr	nT	Tr	nT	Tr	nT
Bed SR84B	64.5	57.7	212	208	16.7	90.3	2.30	0.77	54.5	35.0	3418	2354
BedSR96B	62.5	55.3	253	270	11.4	74.6	2.13	0.97	52.7	38.3	3785	2592
BedSR120B	66	55	295	294	8.3	63.0	1.97	0.90	50.8	35.0	3809	2664
BedSR144B	65.5	54.8	333	310	5.0	44.5	1.87	0.90	49.7	35.0	3790	2897
BedSR84I	76.2	68.5	239	238	14.2	95.7	1.93	0.93	49.7	38.0	2698	2522
BedSR96I	77.3	64.8	280	274	9.7	77.7	1.87	0.77	49.3	37.3	3619	2302
BedSR120I	74.5	65.5	304	295	7.7	63.0	1.70	0.93	47.1	39.0	3386	2755
BedSR144I	75.7	65.8	357	348	4.7	46.1	1.50	0.90	43.3	40.0	3538	3026
BRC SR84B	71.5	59.5	232	208	16.0	121.3	1.43	0.73	42.2	33.3	2273	1901
BCSR96B	68.4	61	270	257	10.0	96.3	1.27	0.73	40.7	33.3	2434	2316
BCSR120B	67.5	58.8	289	275	7.7	63.0	1.30	0.80	40.0	34.7	2861	2544
BCSR144B	65.3	61.3	327	331	4.7	45.7	1.20	0.67	40.0	32.7	3086	2635
BCSR84I	71.8	59	239	237	20.3	115.9	1.67	0.73	46.1	34.7	3264	2066
BCSR96I	70.5	61	297	279	12.0	92.8	1.47	0.70	42.0	35.7	2940	2875
BCSR120I	67.7	59	312	301	9.0	76.7	1.47	0.87	42.3	36.7	3367	2904
BCSR144I	69	58	350	349	6.3	52.7	1.37	0.87	41.3	36.7	3622	3290
SD SR84B	72.7	65.2	235	183	18.1	120.0	1.47	0.90	43.2	36.0	2383	2698
SDSR96B	74.3	66.5	291	243	11.7	94.0	1.40	0.80	42.7	34.7	2563	2033
SDSR120B	75.7	68.5	310	291	9.0	72.7	1.37	0.70	42.4	34.0	3000	2333
SDSR144B	77	69.2	350	333	7.0	54.9	1.40	0.60	42.9	32.3	3000	2146
SDSR84I	61.5	56.7	233	198	21.2	137.7	1.77	0.87	44.7	36.0	2369	2340
SDSR96I	67	56.9	237	267	13.3	96.7	1.60	0.67	43.0	33.7	2530	2388
SDSR120I	64.5	56.5	296	298	9.9	72.3	1.47	0.80	42.3	34.0	3163	2455
SDSR144I	67.2	56.2	358	336	6.7	51.4	1.50	0.77	44.9	33.3	3497	2647
WLD SR84B	68.2	60.8	223	197	16.3	119.0	1.53	0.90	42.1	36.0	2563	2083
WLDSR96B	70.2	62.7	252	232	11.3	95.2	1.30	0.67	40.7	32.3	2611	1670
WLDSR120B	69.7	61.7	301	272	9.8	73.5	1.13	0.70	39.3	33.3	2426	2215
WLDSR144B	68	63	337	317	7.3	53.4	1.27	0.80	40.7	33.6	3439	2575
WLDSR84I	68.8	59.8	239	198	20.5	70.7	1.50	0.93	42.7	37.0	2506	2354
WLDSR96I	72.7	64	269	223	15.8	55.3	1.33	0.87	41.0	36.7	2592	2441
WLDSR120I	73.4	64.7	291	266	11.7	37.6	1.30	0.80	41.0	35.7	2760	2738
WLDSR144I	71.2	64	358	329	6.3	31.3	1.30	0.73	40.7	35.0	3077	2503
Mean	65.58		279		44.0		1.17		39.6		2743	
Cv%	6.4		12.3		29.6		17.8		8.7		16	
SE+	3.805		12.16		7.434		0.1226		1.945		271	
LSD	11.021		34.13		21.14*		0.348*		5.49		760	
Sig.	*		n.s		*		*		n.s		*	

Table 4.12 Effect of the interaction between sowing method, seeding rate, variety and herbicides application on growth performance, weed infestation, yield and yield components of wheat, second season

treatments	Plant. height cm		Plant no./m²		Weed no/m²		Spike wt. g		1000s Wt.g		G.Yield kg/ha	
	Tr	nT	Tr	nT	Tr	nT	Tr	nT	Tr	nT	Tr	nT
Bed SR84B	76	69.3	208	212	15	94	2.3	1.1	60	41	3178	2729
BedSR96B	79.7	61.7	248	242	11	71	2.3	1.1	56	42	4301	3672
BedSR120B	78	49.7	287	245	8	55	2.1	1.2	53	42	4385	3698
BedSR144B	75.3	52	263	340	6	39	2.0	1.0	51	38	4090	3341
BedSR84I	76.3	71.7	202	212	16	105	2.3	1.1	56	41	2916	3062
BedSR96I	78.7	74.7	250	270	12	87	2.4	1.2	59	42	4402	2959
BedSR120I	78	68	332	293	10	70	2.2	1.2	54	42	4409	3362
BedSR144I	71.7	63.7	394	340	7	51	2.1	1.0	52	40	4534	3864
BRC SR84B	51.3	43	255	213	23	129	1.8	0.7	47	35	2153	1498
BCSR96B	53	46.7	270	222	14	101	1.7	0.7	45	34	3566	2599
BCSR120B	53	47	342	257	12	81	1.6	0.7	43	34	3355	3144
BCSR144B	54	46.7	363	308	7	63	1.6	0.7	42	34	3600	2722
BCSR84I	68.7	60.7	278	240	22	128	1.7	0.7	44	33	1901	1363
BCSR96I	73.3	59	328	250	18	96	1.6	0.7	44	34	2083	2234
BCSR120I	70	58.3	370	303	14	79	1.5	0.8	44	35	3329	3146
BCSR144I	67.7	52.7	383	345	9	59	1.5	0.8	44	35	4493	3319
SD SR84B	53.7	50.3	213	228	20	106	1.8	0.7	48	35	1822	1250
SDSR96B	53	47.7	277	215	17	112	1.7	0.7	44	35	1718	1476
SDSR120B	55	48	278	228	12	93	1.7	0.6	45	34	3523	1942
SDSR144B	54.7	51.3	301	305	10	82	1.6	0.6	44	34	3482	2330
SDSR84I	75.7	58.3	215	197	18	149	1.9	0.7	49	36	1805	1054
SDSR96I	72	63.3	253	242	12	107	1.8	0.7	47	35	2222	1726
SDSR120I	75.3	64.3	338	272	9	91	1.7	0.7	46	35	3437	2208
SDSR144I	73.3	64	380	283	7	74	1.6	0.7	45	35	3151	3079
WLD SR84B	54.3	49.3	240	225	19	`125	1.7	0.8	46	35	1363	960
WLDSR96B	53	48	295	258	14	94	1.5	0.8	42	34	2165	1754
WLDSR120B	52	49.7	313	302	13	76	1.5	1.0	43	37	3631	2503
WLDSR144B	53	46.7	368	352	9	59	1.4	0.7	41	35	3739	3079
WLDSR84I	73.7	56.7	183	200	21	125	1.7	0.7	46	33	1594	1392
WLDSR96I	72	61.7	260	275	16	105	1.5	0.6	43	32	2078	2002
WLDSR120I	71	64.3	313	314	12	88	1.5	0.7	43	35	3610	3523
WLDSR144I	71.3	62	335	370	9	58	1.4	0.6	43	32	3655	3902
Mean	61.4		281		51		1.3		42		2822	
Cv%	6.2		6.6		24.5		9.0		4.6		18.2	
SE+	2.667		25.38		7.998		0.0746		1.154		333	
LSD	7.691		71.74		18.95*		0.215*		3.258		933	
Sig.	*		n.s		*		*		n.s		n.s	

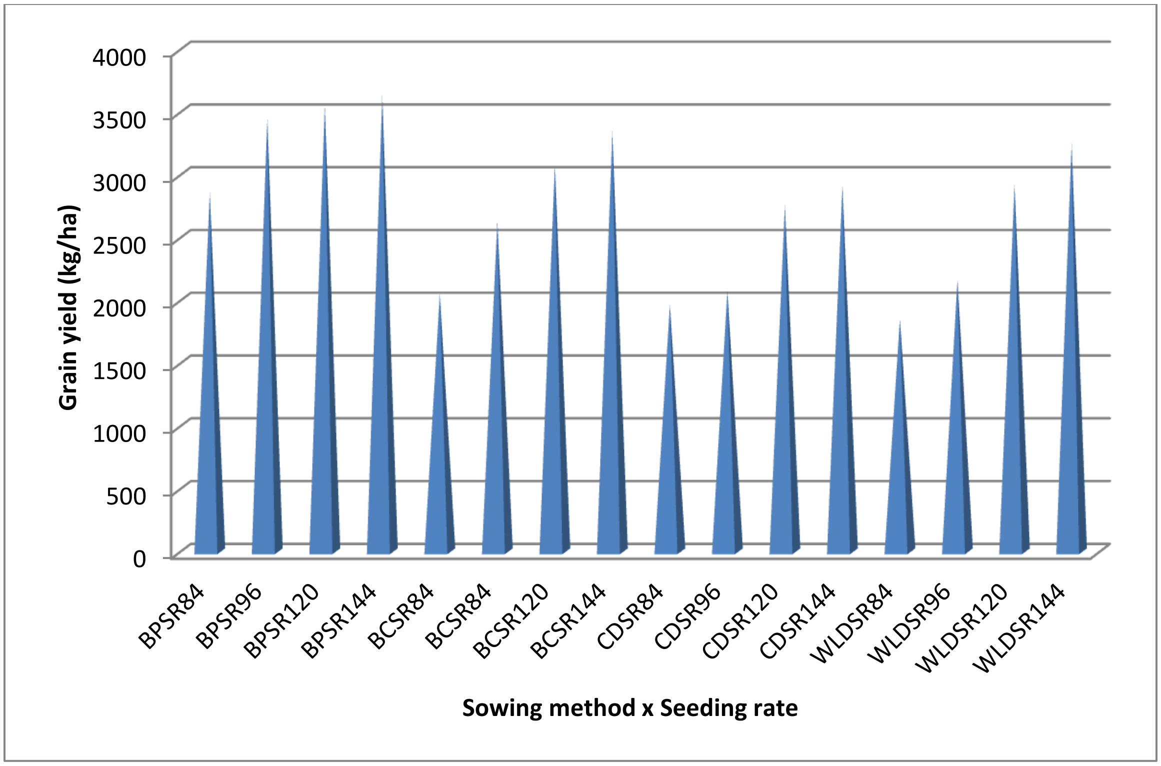


Fig 4.4 Grain yield as affected by sowing method and seeding rate (average of two seasons)

4.14 Effect of raised bed and furrow dimensions and number of crop rows per bed on plant height (cm):

Data analysis showed that there were no significant differences in plant height between most of the bed dimensions combinations during the two seasons. However, the bed combination 80x25x40x3 gave the tallest plants during the two seasons in addition to the combination 80x15x30x4 in the second season as shown in Table 4.13.

4.15 Effect of raised bed and furrow dimensions and number of crop rows per bed on number of plants/m²:

Although there were no significant differences in plants number per square meter, between bed dimensions during the two seasons, but the combination 120x25x40x5 scored the highest number of plants/m² in the first season, while the combinations 80x25x30x4 and 100x15x40x4 scored the lowest number of plants. In the second season the bed combination 80x15x30x4 scored the highest number of plants and the combination 80x15x40x3 gave the lowest number of plants as shown in Table 4.13.

4.16 Effect of raised bed and furrow dimensions and number of crop rows per bed on number of weeds/m²:

Analysis of variance showed significant differences between treatments in the number of weeds per square meter during the two seasons. However, all the combinations of 80 cm bed width scored significantly lower number of weeds than that scored by the combinations of 120 cm bed width and seed drill during the two seasons. Seed drill scored the highest number of weeds during the two seasons, while the combinations 80x15x30x3 and 80x25x40x3 scored the least number of weeds during the two seasons. Results analysis also revealed no significant differences in weeds numbers for the 80 cm bed width combinations. Also no significant differences in weeds number was found between 120 cm bed width combinations and seed drill as shown in Table 4.13.

Table4.13 Plant height, number of plants per square meter and weed intensity as affected by bed dimensions

treatments	Plant height (cm)		No. of plants /m²		No. of weeds/ m²	
	2015	2016	2015	2016	2015	2016
80x15x30x3	51.1	65.0	362	333	9.0	12.3
80x25x30x3	52.9	66.0	385	343	10.3	12.3
80x15x40x3	51.2	65.0	360	308	10.3	12.0
80x25x40x3	54.4	66.3	387	312	10.6	11.3
80x15x30x4	50.5	66.3	367	355	12.0	12.6
80x25x30x4	51.4	63.3	355	337	12.6	13.3
80x15x40x4	50.4	64.3	372	338	14.3	14.3
80x25x40x4	50.0	64.0	402	342	14.6	14.3
100x15x30x4	47.6	65.7	397	338	15.0	15.0
100x25x30x4	47.7	62.7	392	325	15.6	15.3
100x15x40x4	48.9	63.7	355	352	16.0	15.3
100x25x40x4	49.4	64.3	387	328	19.3	15.3
100x15x30x5	47.4	62.0	358	345	20.6	16.6
100x25x30x5	52.4	64.7	373	318	21.0	18.0
100x15x40x5	51.1	62.7	408	338	21.3	18.0
100x25x40x5	51.2	62.7	417	345	22.3	19.0
120x15x30x5	48.2	62.7	400	312	23.3	19.0
120x25x30x5	48.8	63.7	405	340	24.0	19.3
120x15x40x5	48.4	63.3	393	332	24.0	19.6
120x25x40x5	48.4	63.3	445	328	24.6	20.6
120x15x30x6	49.4	62.3	392	315	24.6	21.3
120x25x30x6	49.9	63.0	398	322	25.6	22.0
120x15x40x6	49.8	63.0	417	332	26.0	22.0
120x25x40x6	49.6	62.7	433	347	26.6	23.3
Seed drill	49.6	62.3	383	313	27.0	25.3
Mean	49.9	63.8	389.7	331.9	18.8	17.1
CV%	6.76	3.45	11.28	6.36	13.47	11.6
SE	1.95	1.27	25.38	12.18	1.47	1.47
LSD	5.53	3.6	72.1	34.6	4.16	3.25

4.17 Effect of raised bed and furrow dimensions and number of crop rows per bed on length of spike (cm):

Analysis of variance showed that 80 cm bed width combinations resulted in significantly taller spikes than the other tested beds during the two seasons. However, the bed combination 80x25x40x3 gave the tallest spikes over all the other bed combinations, in the first season, while 80x25x30x3 scored the tallest spikes in the second season. The results indicated no significant differences in spikes lengths within 80 cm bed width combinations except for the combinations 80x25x40x3 and 80x15x30x4, in the first season, which resulted in the tallest and shortest spikes, respectively. In the second season, although the combinations of 80 cm bed width resulted in taller spikes, but mostly not significantly different from the 100 cm bed width combinations as shown in Table 4.14.

Results indicated no significant differences in spike length between 100 cm bed width combinations which consisted of 5 rows, 120 cm bed width combinations which consisted of 5 and 6 rows and seed drill. However, the combination 120x25x40x6 gave the shortest spikes during the two seasons.

4.18 Effect of raised bed and furrow dimensions and number of crop rows per bed on spike weight (g):

Analysis of variance indicated that combinations containing 80 cm bed width resulted in significantly the highest spikes weights compared with the other combinations during the two seasons as shown in Table 4.14. The combination 80x25x40x3 scored the highest spike weight in the first season, whereas, in the second season the combinations 80x25x30x4 and 80x25x40x3 scored the highest spike weight. Results also showed that, mostly, no significant differences between 100 cm bed width combinations, 120 cm bed width combinations and seed drill in spike weight during the two seasons. The combination 120x15x30x5 scored the lowest spike weight in the first season, while the combination 120x25x40x6 gave the lowest spike weight in the second season.

4.19 Effect of raised bed and furrow dimensions and number of crop rows per bed on weight of 1000 seeds (g):

Results obtained indicated that, during the two seasons, 80 cm bed width combinations gave the highest 1000 seeds weight compared with the other bed combinations followed by100cm bed width combinations as shown in Table 4.14. The combination 80x25x40x3 gave, significantly, the highest 1000 seeds weight during the two seasons. Results also showed that mostly, no significant differences in 1000 seeds weight between 100 cm bed width combinations, 120 cm bed width combinations and seed drill during the two seasons. However, the lowest 1000 seeds weight was scored by the combination 120x25x40x6 in the first season and by seed drill in the second season.

Table 4.14 Yield components as affected by bed dimensions

treatments	Length of spike(cm)		Wt. of spike (g)		Wt. of 1000 seeds(g)	
	2015	2016	2015	2016	2015	2016
80x15x30x3	6.3	6.3	1.89	2.09	42.7	40.3
80x25x30x3	6.5	6.7	1.94	2.03	42.3	41.0
80x15x40x3	6.2	6.5	1.85	2.17	42.0	41.0
80x25x40x3	6.8	6.4	2.49	2.41	46.7	44.7
80x15x30x4	6.0	6.2	1.97	1.97	42.3	40.0
80x25x30x4	6.1	6.3	2.01	2.46	40.3	39.7
80x15x40x4	6.3	6.5	1.85	1.40	41.0	39.0
80x25x40x4	6.2	6.3	1.31	1.78	39.0	39.7
100x15x30x4	5.5	6.0	1.21	1.02	39.0	38.0
100x25x30x4	5.2	5.4	1.31	1.04	39.0	37.3
100x15x40x4	5.0	5.8	0.87	0.99	41.0	36.7
100x25x40x4	5.2	5.9	1.09	1.05	40.3	37.0
100x15x30x5	4.7	6.3	1.14	1.11	37.3	37.7
100x25x30x5	5.7	6.0	0.83	1.15	39.3	36.7
100x15x40x5	5.2	5.7	0.98	1.11	38.3	37.7
100x25x40x5	4.8	5.8	0.95	1.34	37.0	38.7
120x15x30x5	5.0	5.7	0.68	1.03	35.0	36.7
120x25x30x5	4.4	5.7	0.79	1.05	34.7	34.7
120x15x40x5	4.5	5.3	0.79	1.08	36.3	36.0
120x25x40x5	4.8	5.7	0.79	1.08	37.3	37.7
120x15x30x6	4.9	5.5	0.84	1.23	37.7	37.0
120x25x30x6	4.3	5.2	0.84	1.14	36.0	35.7
120x15x40x6	4.3	5.0	0.85	1.08	36.7	35.3
120x25x40x6	4.1	4.9	0.85	0.97	34.3	36.3
Seed drill	4.5	5.7	1.02	1.11	38.7	33.7
Mean	5.3	5.9	1.25	1.40	38.97	37.9
CV%	8.08	9.61	18.53	13.57	7.74	5.45
SE	0.25	0.33	0.13	0.11	1.74	1.19
LSD	0.70	0.92	0.38	0.31	4.94	3.39

4. 20 Effect of raised bed and furrow dimensions and number of crop rows per bed on grain yield (kg/ha):

Analysis of variance showed significant differences in grain yield (kg/ha) between beds combinations, where, 80 cm bed width combinations gave higher yields than the other combinations during the two seasons (Table 4.15 and Figs 4.5-4.6). The combination 80x25x40x3 was found superior in grain yield during the two seasons. Results also showed that 100 cm bed width combinations gave grain yield significantly more than that given by 120 cm bed width combinations and seed drill. The results showed no significant differences in grain yield between 120 cm bed width combinations and seed drill.

4.21 Effect of raised bed and furrow dimensions and number of crop rows per bed on applied water m^3/ ha:

Analysis of variance showed high significant differences ($p = 0.01$) between raised bed combinations and seed drill in the volume of applied water (m^3/ha) during the two seasons. Seed drill sowing method resulted in much applied water during the two seasons as shown in Table 4.15 and Figs 4.6-4.7. However, lower applied water was scored by 120 cm bed width combinations followed by 100 cm bed width combinations during the two seasons. In the first season the combination 120x15x40x6 scored the lowest applied water followed by 120x25x30x5 and 100x25x40x4 combinations. In the second season 120x25x40x4, 120x25x30x6 and 120x25x30x4 combinations scored the lowest applied water. However, 80 cm bed width had more applied water among raised beds, but LSD test showed no significant differences in applied water

Table 4.15 Grain yield, applied water and water productivity kg/ m³ as affected by bed dimensions

treatments	Grain yield kg/ha		applied water m³/ha		Water productivity kg/ m³	
	2015	2016	2015	2016	2015	2016
80x15x30x3	4493	4346	4030	4260	1.12	1.0
80x25x30x3	4186	4320	4063	4169	1.03	1.03
80x15x40x3	4229	4344	4022	4236	1.05	1.03
80x25x40x3	4942	5350	4054	4234	1.23	1.27
80x15x30x4	4375	4339	4135	4238	1.06	1.03
80x25x30x4	4037	3998	3953	4246	1.02	0.9
80x15x40x4	3828	4111	3958	4301	0.97	0.97
80x25x40x4	3756	3881	4039	4291	0.93	0.87
100x15x30x4	3533	3593	3965	4378	0.89	0.83
100x25x30x4	3302	3682	3994	4260	0.83	0.87
100x15x40x4	3653	3586	3962	4224	0.92	0.87
100x25x40x4	3893	3826	3842	4032	1.01	0.9
100x15x30x5	3631	3653	4003	4231	0.91	0.8
100x25x30x5	3586	3235	4147	4255	0.86	0.77
100x15x40x5	3881	3569	4150	4272	0.94	0.83
100x25x40x5	3917	3290	3941	4303	0.99	0.77
120x15x30x5	2803	2770	3929	4142	0.71	0.67
120x25x30x5	2652	3178	3835	4253	0.69	0.77
120x15x40x5	2474	3034	3960	4250	0.62	0.70
120x25x40x5	2558	2866	3998	4195	0.64	0.70
120x15x30x6	2484	2976	3900	4253	0.64	0.70
120x25x30x6	2491	2714	3922	4210	0.64	0.67
120x15x40x6	2258	2712	3830	4094	0.59	0.67
120x25x40x6	2326	2484	3893	4231	0.60	0.60
Seed drill	2909	3050	5549	5957	0.52	0.53
Mean	4385	3557	4044	4301	0.86	0.83
CV%	27.9	11.98	3.05	3.63	8.98	13.4
SE	194	348	101	127	0.03	0.09
LSD	548	699	202	256	0.126	0.183

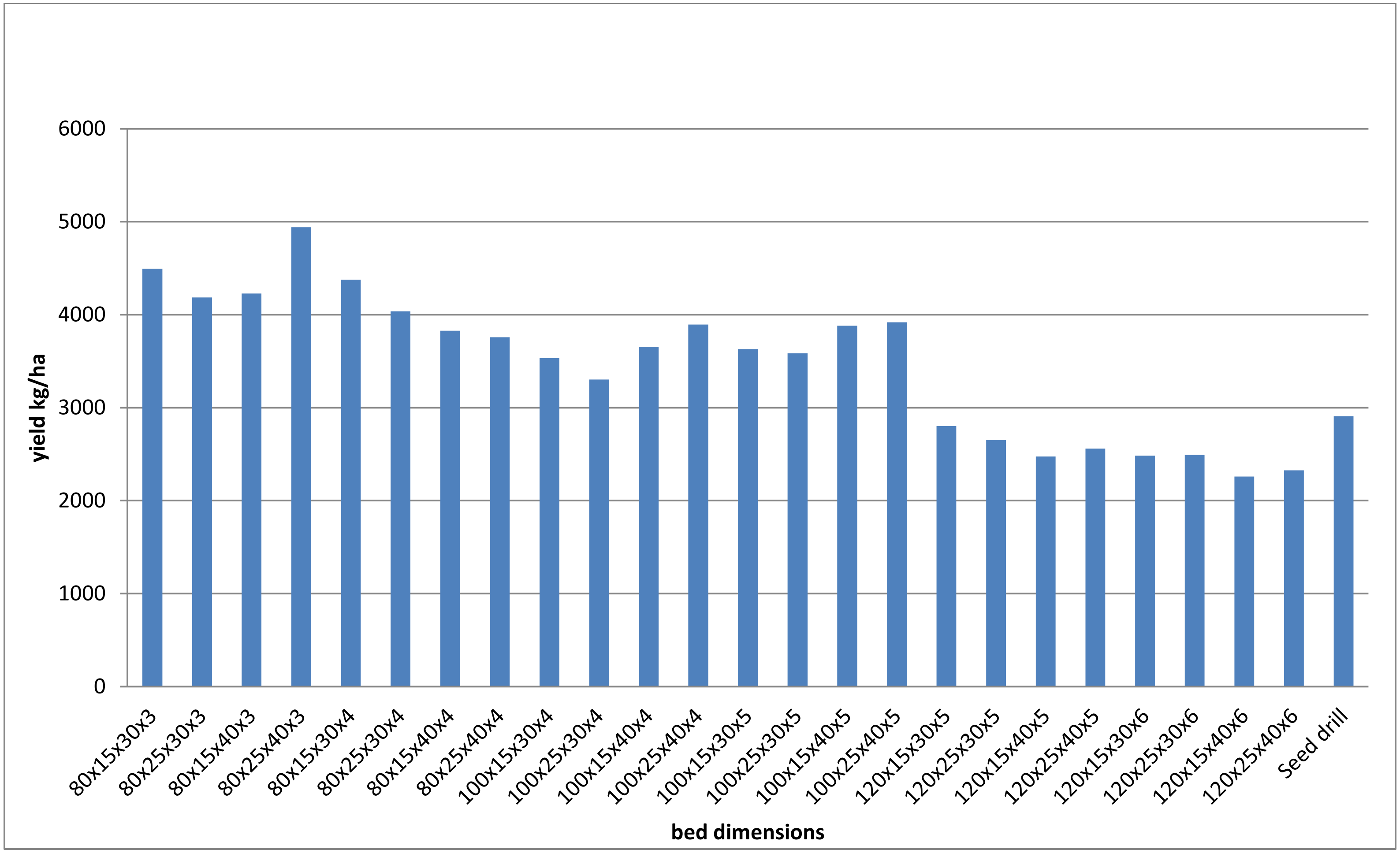


Fig 4:5 Grain yield (kg/ha) as affected by bed dimensions (2014/2015)

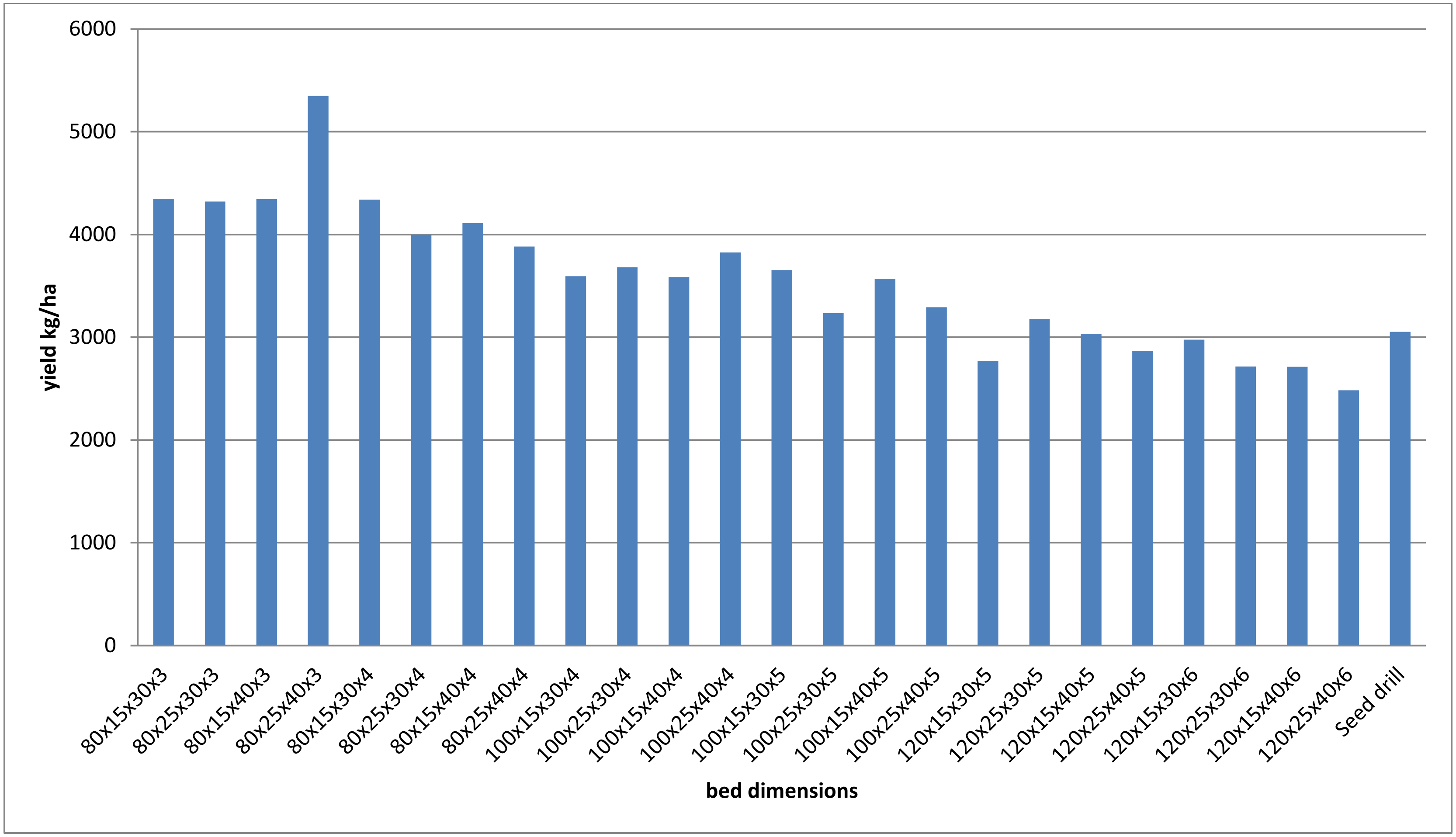


Fig 4:6 Grain yield (kg/ha) as affected by bed dimensions (2015/2016)

between the three tested raised bed widths, 80, 100 and 120 cm during the two seasons. The LSD test indicated no significant differences in the volume of applied water between the tested furrow dimensions (furrow width and furrow depth) during the two seasons except in few cases.

4.22 Effect of raised bed and furrow dimensions and number of crop rows per bed on water productivity (kg/m^3):

Analysis of variance showed that 80cm bed width combinations resulted in higher water productivity than the other raised beds combinations and seed drill sowing method during the two seasons as shown in Table 4. 15 and Figs 4.9- 4.10. The combination 80x25x40x3 scored significantly the highest water productivity during the two seasons. On the other hand, LSD test indicated that seed drill gave the lowest water productivity for the two seasons. Although not significantly different, 120 cm bed width combinations gave lower water productivity compared with 80 cm width and 100 cm bed width combinations. LSD test showed no significant differences in water productivity within the same bed width.

4.23 Effect of raised bed and furrow dimensions and number of crop rows per bed on crop water requirements (deficit) (mm):

Analysis of variance showed highly significant differences between raised bed planting method and seed drill in water deficit (mm) irrespective of bed width and furrow dimensions in the first season. During the second season the bed combinations 80x15x30x3, 80x25x40x3, 80x15x30x4, 100x25x40x4 and 120x15x30x5 resulted in water deficit significantly less than that of seed drill. However seed drill planting method gave the highest water deficit during the two seasons as shown in Table 4.16 and Figs 4.11 - 4.12.

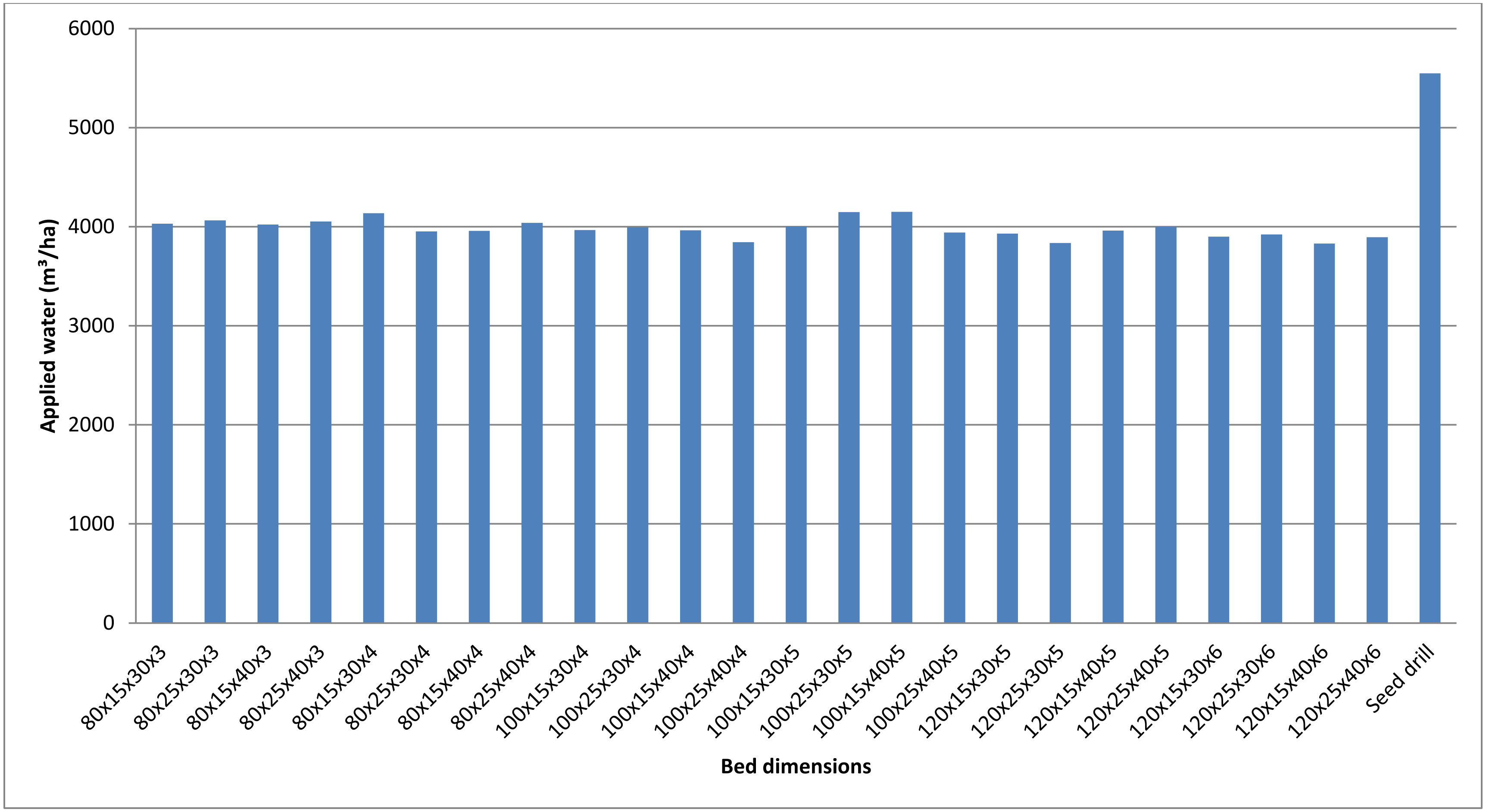


Fig 4:7 Applied water (m^3/ha) as affected by bed dimensions (2014/2015)

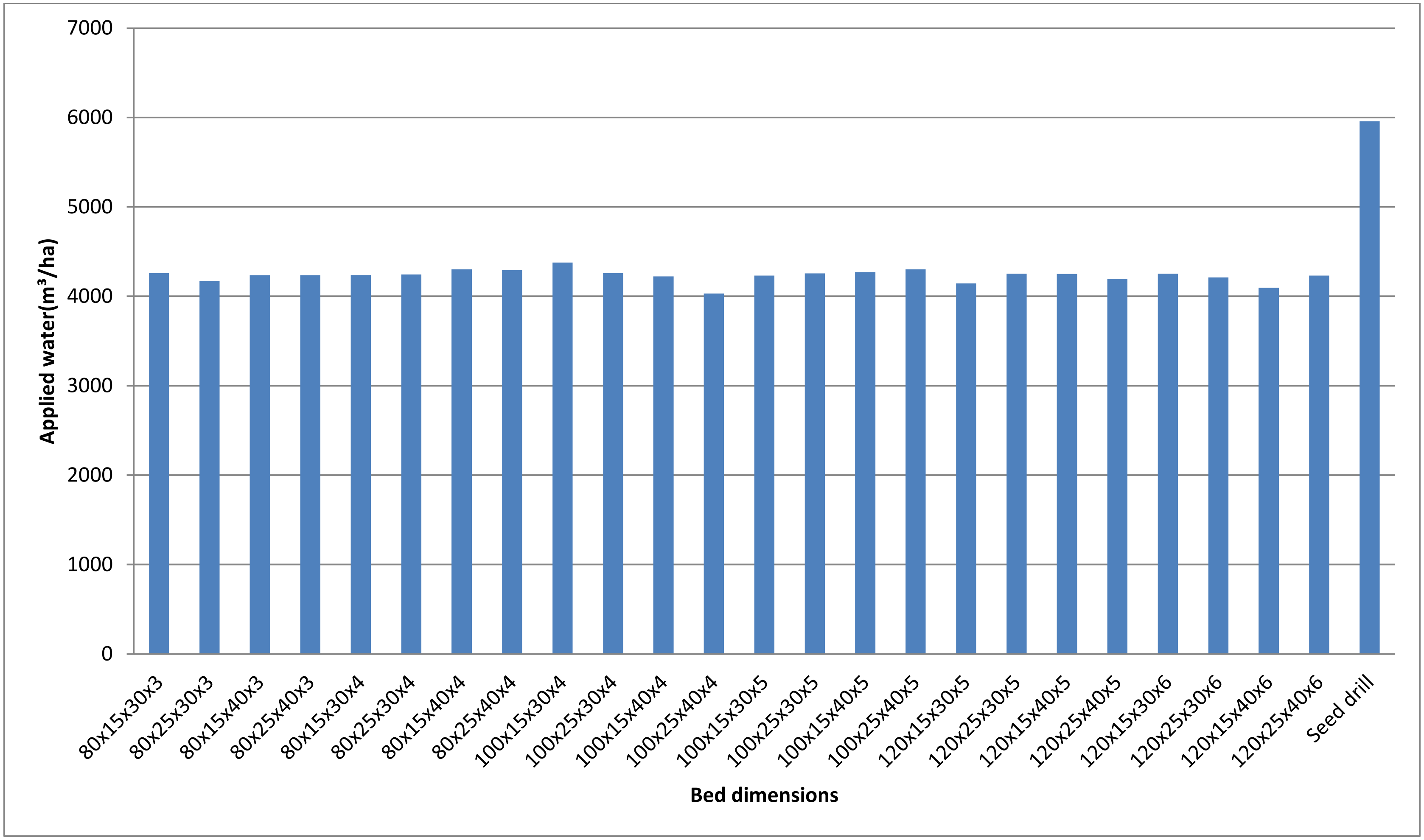


Fig 4.8 Applied water (m^3/ha) as affected by bed dimensions (2015/2016)

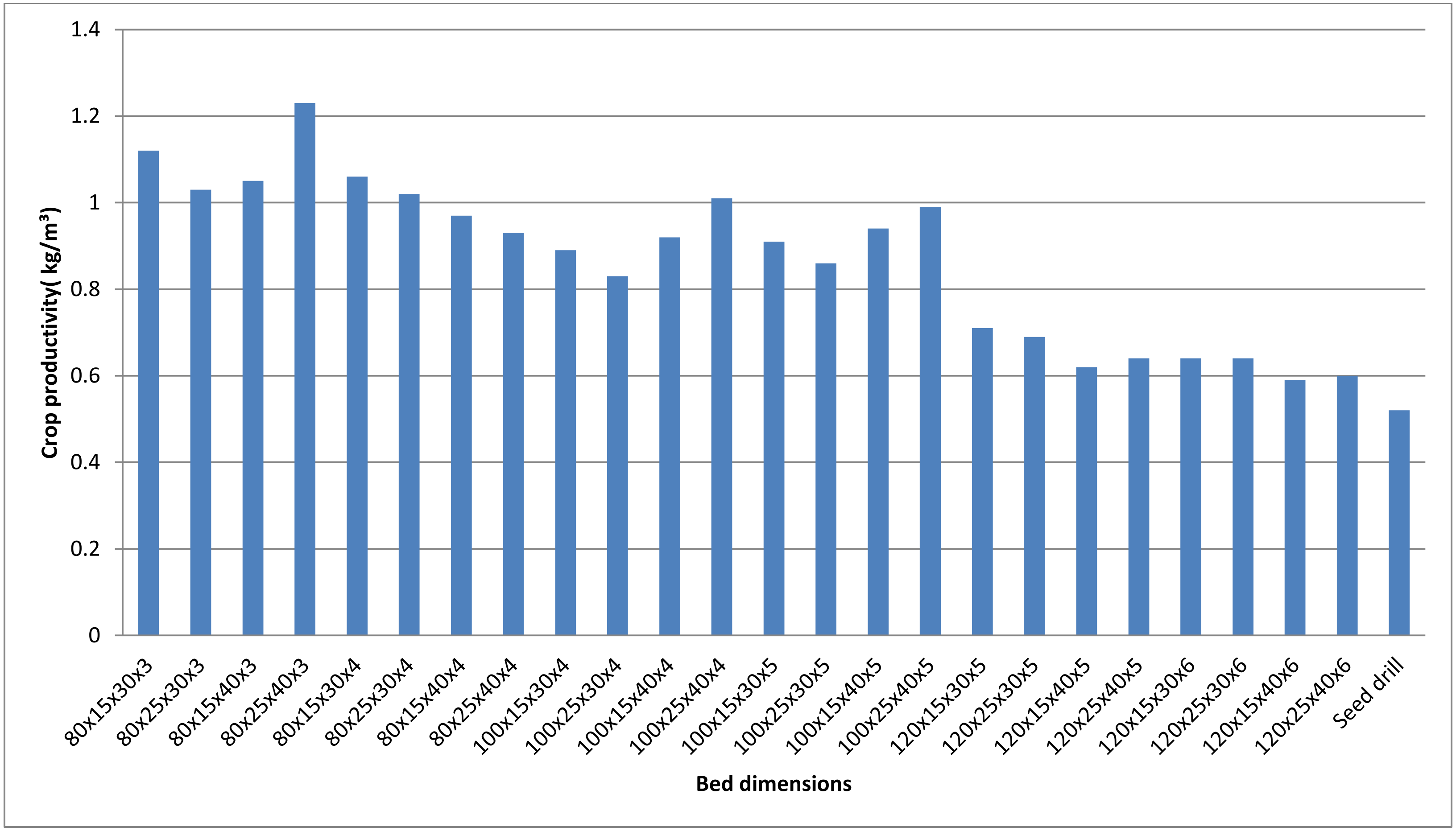


Fig 4.9 Crop productivity (kg/m³) as affected by bed dimensions (2014/2015)

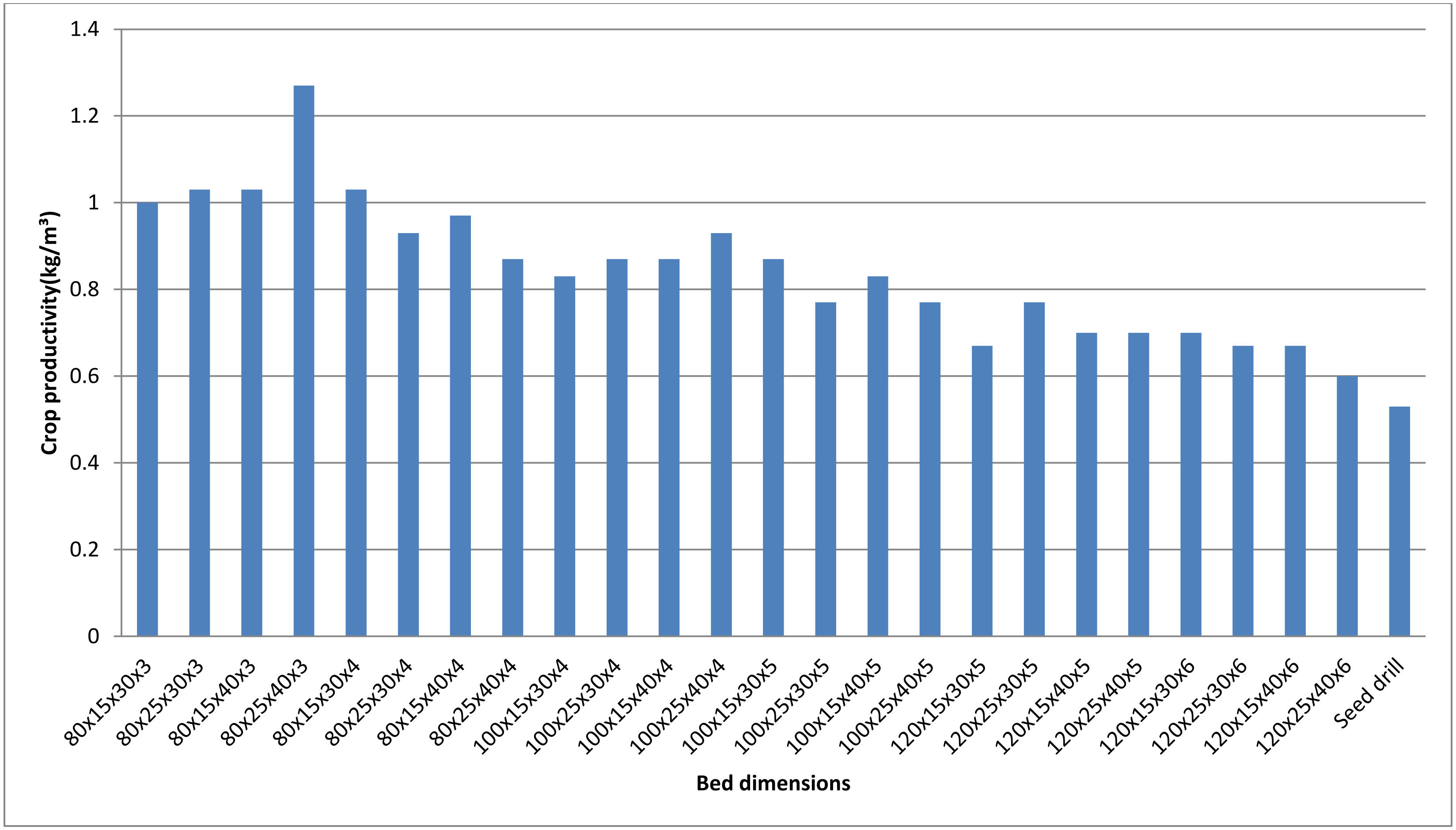


Fig 4:10 Crop productivity (kg/m³) as affected by bed dimensions (2015/2016)

No significant differences between raised bed combinations in water deficit were detected during the two seasons.

4.24 Effect of raised bed and furrow dimensions and number of crop rows per bed on water saving (%):

Analysis of variance showed significant differences between raised bed combinations and seed drill in water saving percentage during the two seasons as shown in Table 4.16. Raised bed combinations, irrespective of bed width and furrow dimensions exceeded seed drill significantly in water saving during the two seasons. Results indicated that 100 cm bed width combinations and 120 cm bed width combinations exceeded, 80cm bed width in water saving percentage in the first season. However the higher water saving was scored by the combination 100x25x40x5. The lowest water saving percentage among raised beds combinations was given by the combinations 80x15x40x4, 80x15x30x4 and 80x25x40x4 in the second season. Data analysis showed no significant differences among all the combinations of raised beds, however the higher water saving percentage was scored be the combinations 100x25x30x4, 120x15x40x5 and 120x25x30x6. High water consumption resulted from the use of seed drill during the two seasons.

Table 4.16 Crop water requirement (mm) and Water saving % as affected by bed dimensions

treatments	Crop water requirement mm		Water saving %	
	2015	2016	2015	2016
80x15x30x3	400	458	0.25 (0.08)	0.27 (0.09)
80x25x30x3	403	468	0.25 (0.08)	0.30 (0.13)
80x15x40x3	399	475	0.24 (0.07)	0.30 (0.13)
80x25x40x3	402	465	0.27 (0.09)	0.30 (0.13)
80x15x30x4	410	466	0.24 (0.07)	0.30 (0.13)
80x25x30x4	392	470	0.28 (0.10)	0.30 (0.13)
80x15x40x4	393	480	0.26 (0.08)	0.30 (0.13)
80x25x40x4	401	470	0.24 (0.07)	0.30 (0.13)
100x15x30x4	393	487	0.28 (0.10)	0.30 (0.13)
100x25x30x4	396	499	0.2 (0.10)	0.33 (0.16)
100x15x40x4	393	477	0.27 (0.10)	0.30 (0.13)
100x25x40x4	381	454	0.29 (0.12)	0.30 (0.13)
100x15x30x5	397	470	0.28 (0.10)	0.30 (0.13)
100x25x30x5	411	487	0.2 (0.09)	0.30 (0.13)
100x15x40x5	412	489	0.27 (0.10)	0.30 (0.13)
100x25x40x5	391	482	0.30 (0.16)	0.30 (0.13)
120x15x30x5	390	466	0.30 (0.13)	0.30 (0.13)
120x25x30x5	380	485	0.30 (0.13)	0.30 (0.13)
120x15x40x5	393	487	0.29 (0.12)	0.33 (0.16)
120x25x40x5	397	480	0.27 (0.10)	0.30 (0.13)
120x15x30x6	387	492	0.29 (0.12)	0.30 (0.13)
120x25x30x6	389	492	0.30 (0.13)	0.33 (0.16)
120x15x40x6	380	468	0.29 (0.11)	0.30 (0.13)
120x25x40x6	386	483	0.2 (0.11)	0.30 (0.13)
Seed drill	550	501	0.0 (+0.16)	0.00 (+0.18)
Mean	401	478	0.26	0.29
CV%	3.05	4.31	12.43	7.95
SE	0.06	16.8	0.26	0.02
LSD	20.06	33.84	0.05	0.04

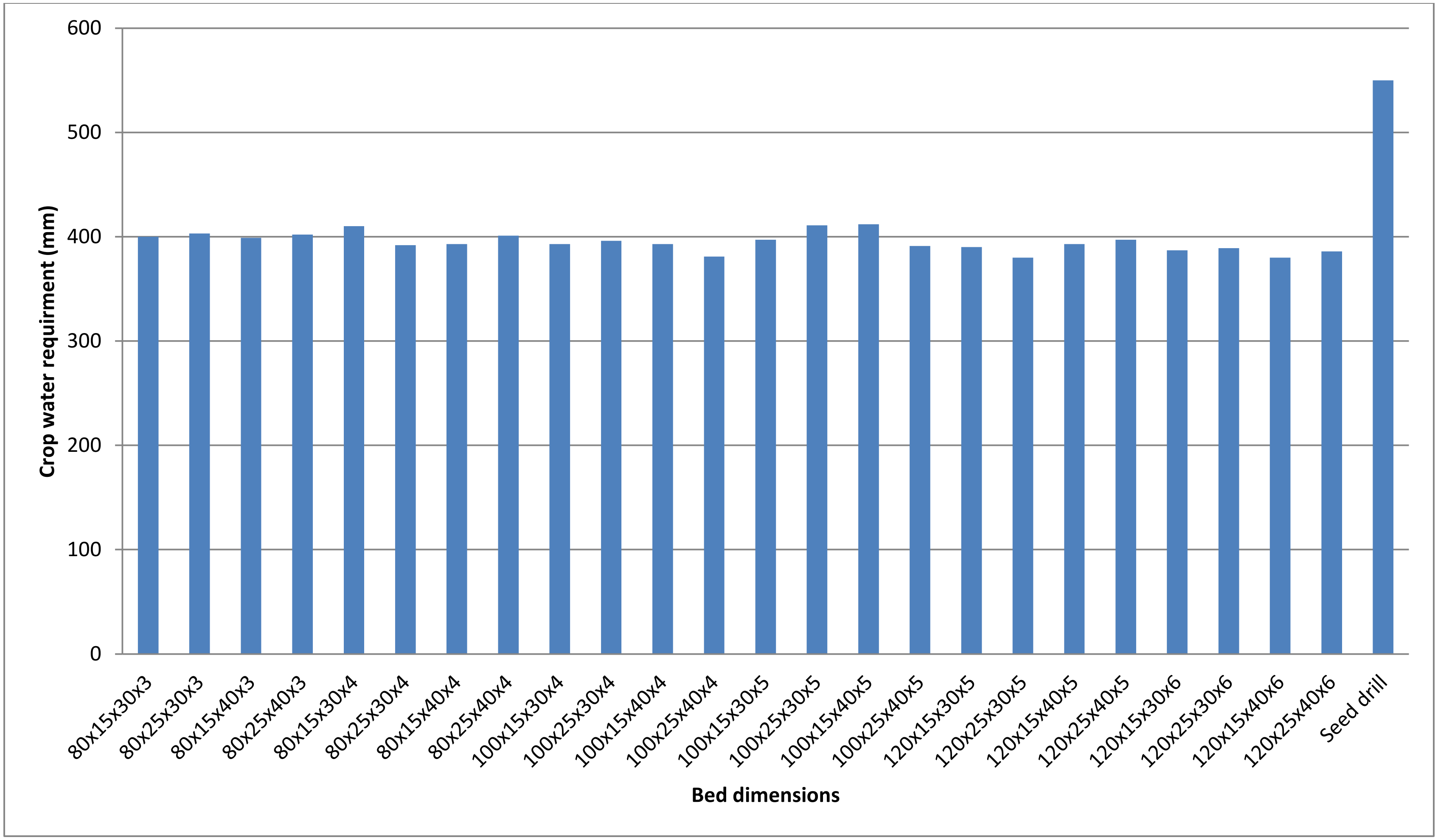


Fig 4:11 Crop water requirement (mm) as affected by bed dimensions (2014/2015)

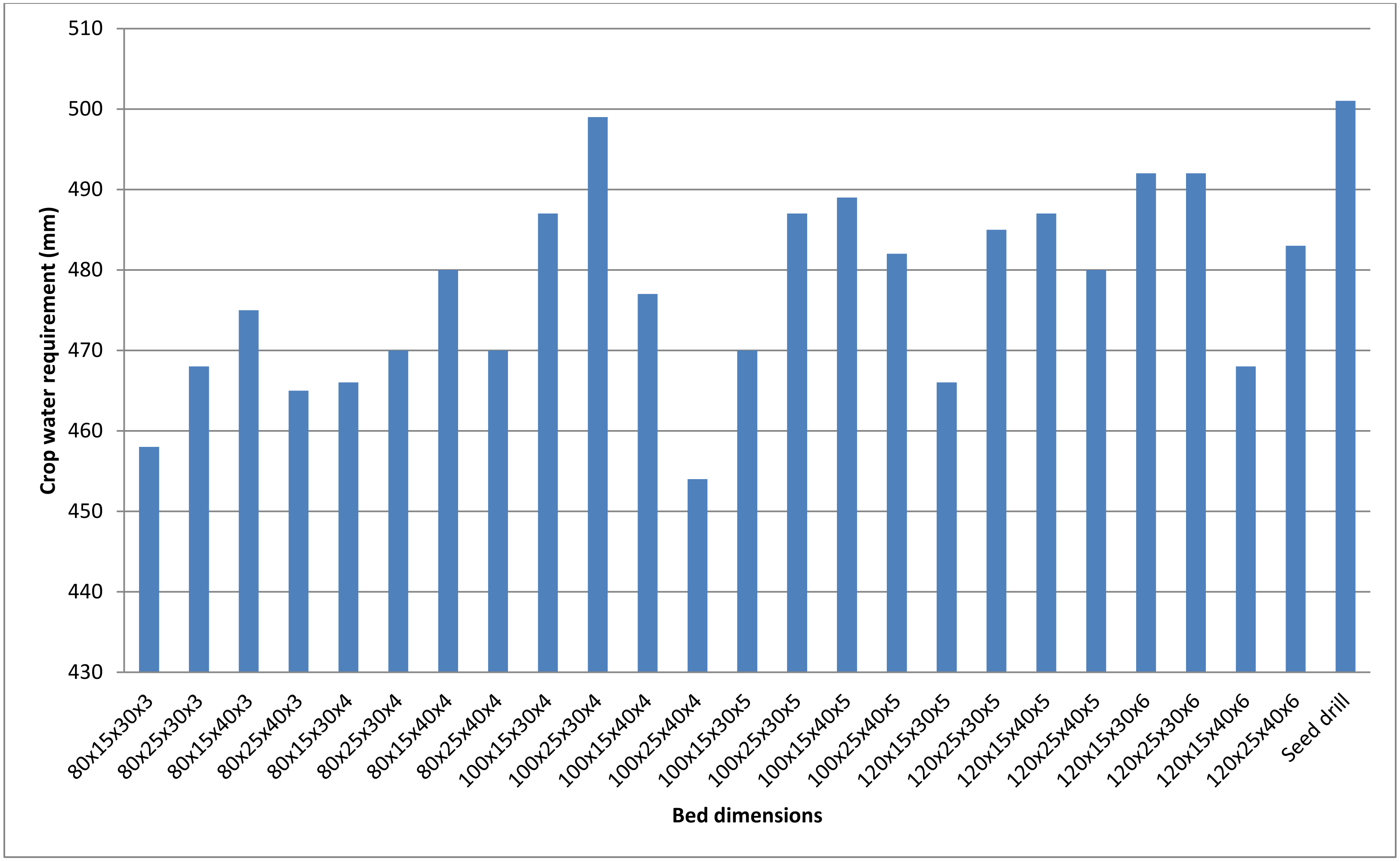


Fig 4:12 Crop water requirement (mm) as affected by bed dimensions (2015/2016)

4.25 Effect of raised bed and furrow dimensions and number of crop rows per bed on soil salinity and nutrients:

Results obtained indicated mostly no significant differences between sowing methods in salinity and soil nutrients (N, P and K) content change during the two seasons as shown in Table 26.Appendix A.

CHAPTER FIVE

DISCUSSION

5.1 Effect of water quantity, sowing method, herbicide application, variety and their interaction on plant height:

High water quantities 6000 m^3/ha and 5000 m^3/ha resulted in taller plants compared with low water quantities. This could be due to better growth conditions provided by water. Bed planting resulted in better plant height which could be due to better growth conditions provided by raised bed where irrigation water was not in contact with the plant thus avoiding water logging. Higher water quantities with raised bed planting resulted in taller plants, this could be because raised bed provided cool beds for the plants when much water was added rather than in the case of flood irrigation where excess water can lead to water logging. Higher water quantities in herbicides treated plots gave taller plants where high water quantity facilitated the growth of both the crop and the weed then, the herbicides lessened the number of weeds. Bed planting with herbicides treated plots resulted in taller plants where less weeds in raised bed due to less water on the top of the bed. This agreed with the findings of Hassan *et al.,* (2005) who found that under permanent raised bed weed infestation was 31% lower for wheat crop which maintain lower soil bulk density, and Singh *et al.,*(2005) who indicated that the benefits of raised bed included fewer weeds, vigorous and better crop stand, reduce crop lodging and minimize wilt infestation.

5.2 Effect of water quantity, sowing method, herbicide application and variety and their interaction on the number of heads/m^2:

Although it was not significantly different, raised bed planting gave the highest number of heads per square meter. This could be due to favorable growth conditions provided by raised bed system like good seedling establishment, few weeds on the top surface, minimum or no lodging, vigorous growth and better crop stand (Singh *et al.,* 2005) and good aeration. High water quantities resulted in more heads per square meter, this may be due to more tiller formation caused by cool conditions as a result of high water application. Treated plot resulted in more number of heads as a result of less weed competition which provided good growth conditions that encouraged tiller formation. Imam variety gave more number of heads as normal results of the genitical characteristic of more tiller formation.

5.3 Effect of water quantity, sowing method, herbicides application and variety and their interaction on the number of weed/m^2:

Relatively high number of weeds was given by raised bed planting. This finding disagreed with the finding of Singh *et al.,* (2005) who indicated that the benefits of raised bed included fewer weeds. It could be due to the fact that high clay content slowed the movement of water vertically giving the chance for weed to germinate inside the furrow, which was controlled later by herbicides, but as most of the weeds grew in the furrow, this had no negative impact on crop growth performance and yield. Lower quantity of irrigation water resulted in lower number of weeds this could be due to the fact that high water application encouraged weed infestation. Treated plots gave lower number of weeds as a logical result of herbicides application.

5.4 Effect of water quantity, sowing method, herbicides application and variety and their interaction on the spike weight (g):

Raised bed planting resulted in higher spike weight than the other sowing methods. High water quantity gave the best spike weight. Herbicides treated plots resulted in the best spike weight due to less weed competition. Bed planting with the two tested varieties resulted in the best spike weight compared with the other sowing methods, this is because there was no significant difference between the two varieties in spike weight, which means that the best spike weight resulted from the sowing method (raised bed planting). Moreover, raised bed planting with water quantities form W4-W6 gave higher spike weight than the other tested sowing methods with W6, which means that raised bed planting gave more spike weight with less applied water than the other sowing methods. This could be due to the reasons that the raised bed system has fewer weeds, facilitates seeding into relatively dry soils, vigorous and better crop stands and reduced crop-lodging and seed and fertilizer contact as mentioned by Singh *et al.*,(2005).

5.5 Effect of water quantity, sowing method, herbicides application and variety and their interaction on the 1000 seeds weight (g):

Raised bed planting resulted in higher 1000 seeds weight than the other sowing methods, this could be due to the higher spike weight resulting from less weed competition on the top of the beds. Higher water quantity gave the highest 1000 seeds weight due to good growth conditions provided by water specially during the vegetative stage. Herbicides treated plot resulted in higher 1000 seeds weight due to less weed competition. Raised bed planting with the variety B gave the best 1000 seeds weight. Raised bed planting required 4000 m^3/ha to give the best 1000 seeds weight while the other sowing methods required 6000 m^3/ha to give the highest weight. This could be due to the rational use of water in case of raised bed planting where water was added just in the furrows between the beds. All combinations of raised bed with herbicides treated resulted in higher 1000 seeds weight than the treated plots in the other sowing methods. This could be due to the fact that the herbicides were added in the surface of the bed where it was not exposed to leaching by irrigation water as in the case of flood irrigation. Raised bed planting/4000, 5000,6000 m^3/ha/ herbicides treated with the two varieties resulted in the highest 1000 seeds weight. This reflects the benefits of bed planting which was mentioned by Singh *et a.l.*,(2005) which agreed with the findings of RBM (2008) in Egypt who found that by using raised bed planting, with less water used, crop water productivity increased by over 30% and with the findings of Hassan *et al.,* (2005) in Pakistan who stated that the permanent raised beds demonstrated 13%, and 50% higher grain yield, and water productivity, respectively, for the wheat crop.

5.6 Effect of water quantity, sowing method, herbicides application and variety and their interaction on grain yield (kg/ha):

Results showed that the combinations of bed planting, 4000 m^3/ha, herbicides treated with Bohain or Imam gave the highest grain yield, as a result of the high seeds weight. This agreed with the findings of Hassan *et al*.,(2005) who concluded that raised bed resulted in 13% higher grain yield, for wheat, than flooding irrigation. Also agreed with the findings of Singh *et al.* (2005) who mentioned that the benefits of raised bed system also include vigorous and better crop stands, reduced crop-lodging and seed and fertilizer contact, better crop productivity and minimizes wilt infestation. Similar results were also found by Gill *et al.,* (2005) who concluded that crops can successfully be grown on raised beds if the requisite equipment and technologies are available. They added that selection of crop varieties suitable for sowing on beds is very important. The results also agreed with the findings of Beecher *et al*.,(2005) who stated that the permanent raised beds are the recommended irrigation design to achieve high yields in many irrigated crops on heavy clay soils. A crop planted on beds receives water through seepage, i.e. there is no contact with water and consequently lodges less than crops planted in the flat. A bed planted crop yields higher due to the robust plant growth and more open space available to plants on either side of the row which allows more sun and aeration to the plant as reported by Tripathi *et al.,* (2005) who stated that bed planed wheat varieties demonstrated over 50% less lodging compared with flat planting. Raised bed planting system allows light and frequent watering, needed to address terminal heat stresses due to climate change (Singh *et al., ,*2005).

5.7 Effect of water quantity, sowing method, herbicides application and variety and their interaction on water productivity (km/m^3):

Raised bed planning resulted in higher water productivity than the other sowing methods. Bed planting with 4000 m^3/ha resulted in the highest water productivity. This could be due to the fact that less water application resulted in the same or more yield due to use of bed planting technique while for the other sowing methods application of more water resulted in the same or less yield due to the fact that the same amount of water was applied to larger area. This agreed with the findings of Sayre and Moreno Ramos (1997) in Mexico, who reported that the farmers of Yanqui Sonora by switching to bed planting were able to reduce water requirements by 25%, and with the findings of Hassan *et al.,* (2005) in Pakistan who mentioned that permanent raised beds demonstrated 30% and 50% higher water saving and water productivity, respectively, for wheat crop compared to basin irrigation. and with the findings of Gill *et al.,* (2005) who observed that planting of wheat, cotton and other crops on beds may save up to 50 - 60% of irrigation water,

5.8 Effect of seeding rate and its interactions with sowing method, variety and herbicides application on plant height:

Raised bed planting with less seeding rate (96 kg/ha) with the variety Imam in herbicides treated plots resulted in taller plants. This could be due to the condition of less competition between plants for soil nutrients and other inputs like applied fertilizers (less number of plants/m^2) and because the plants in rows found free spaces for best aeration and growth conditions, less weed competitions and genetical characteristic of the variety Imam and vigorous and better crop stands as benefit of raised bed system, minimum wilt infestation and crop lodging as mentioned by Singh *et al*.,(2005).

5.9 Effect of seeding rate and its interactions with sowing method, variety and herbicides application on number of heads/m^2:

High seeding rate 144kg/ha resulted in large number of heads as a logical result, more seeds more heads. Bed planting and broad casting resulted in more heads than the other sowing methods for the same seeding rate, this could be due to more tiller formation as a result of more space provided by the raised bed technique. Also because raised bed system provides good crop establishment and vigorous growth and better growth stands as stated by Singh *et al*. (2005).

5.10 Effect of seeding rate and its interactions with sowing method, variety and herbicides application on number of weeds/m²:

Although low seeding rate (84/ha) resulted in higher number of weeds as free space encourage weed infestations, bed planting at seeding rate 84kg/ha gave the lowest number of weed. This could be because in raised bed technique less water reaches the top surface of the bed and because of good vigorous growth, better growth stand, minimum wilt infestation as benefits of raised bed system as mentioned by Singh *et al.,* (2005). These growth conditions encouraged tiller formation that smothering weeds growth, and agreed with findings of Hassan (2005) who stated that weed infestation was 24% and 31% lower for maize and wheat crops, respectively, under raised bed.

5.11 Effect of seeding rate and its interactions with sowing method, variety and herbicides application on grain yield and yield components:

Lower seeding rates in the other sowing methods than raised bed planting resulted in high spike weight and high 1000 seeds weight due to less competition between plants in nutrients and sun light, but gave lower grain yield due to lower number of heads while in raised bed planting system with lower seeding rate (96kg/ha) resulted in superior spike weight and 1000 seeds weight, meanwhile high grain yield which exceeded the grain yield resulted with the same or higher seeding rates in the other sowing methods. This could be because of the benefits of raised bed technique which include less weed infestation, vigorous growth , good crop stand, minimum lodging, and minimum wilt infestation and fertilizer contact (Singh *et al*.,2005) which encourage tiller formation which compensates for the lower number of plants/m² resulted from low seed rate and smothered the weeds. This agreed with findings of Elhady *et al.*,(2006) in Sudan who concluded that bed planting with suitable machine and low seed rate (92kg/ha) could improve water management, reduce time of seeding and reduce seed rate by about 36% over the recommended, and agreed with the finding of Singh *et al.*, (2005) who said that benefits of raised bed system included saving of costly seed.

5.12 Effect of sowing methods and bed and furrow dimensions on weed intensity:

Bed width of 80 cm gave significantly lower number of weeds than that recorded by the combinations of 120 cm bed width and seed drill during the two seasons, while seed drill resulted in the highest number of weeds during the two seasons. The highest number of weeds in seed drill plots could be due to flooding irrigation which encouraged weeds infestation as found by Singh *et al.*,(2005), while in raised bed planting, the irrigation water was applied in the furrows between the beds thus weed infestation was much less compared to flooding (basin) method. The higher number of weeds in bed width of 120 cm compared to bed width of 80 cm could be due to the less number of plants per square meter (plant intensity) in the case of bed width 120 cm, where the same seed rate (120kg/ha) was used for sowing (3-4) crop rows in bed width of 80 cm and (5-6) crop rows in bed width 120 cm. With the water shortage in middle crop rows which resulted in poor tiller formation thus lower plant intensity that encouraged weed infestation. This result disagree with the finding of RBM,2008 in Egypt, who reported that by using wide spacing furrow and bed planting technique, weed control was reduced by 35% compared to the conventional furrow irrigation. This could be due to the relatively cool weather which discourages weeds growth and improved crop growth performance, in addition to better soil permeability which secured reaching of the irrigation water to the middle crop rows.

5.13 Effect of sowing methods and bed and furrow dimensions on grain yield and yield components:

Results indicated that 80 cm bed width combinations gave significantly taller spikes, higher spike weight and best 1000 seeds weight than 100, 120 cm bed combinations and seed drill during the two seasons. The longer and heavier spikes resulted from 80 cm bed width could be attributed to the bed width where the irrigation water is able to reach all crop rows through lateral movement of water (seepage) whereas, in the 100 and 120 cm beds the irrigation water was unable to reach the middle crop rows because of poor wetting patterns caused by too wide furrow spacing as mentioned by Brovwer *et al.*,(1990) who stated that if the furrow spacing is too wide then the root zone will not be adequately wetted , thus the spacing of furrow needs careful selection. They added that different soils has different wetting patterns. In an ideal situation adjacent wetting patterns overlap each other, and there is an upward movement of water (capillary rise) that wets the entire ridge , thus supplying the root zone with water. For this ideal situation the 80 cm bed width is a suitable selection in the heavy clayed soils of low hydraulic conductivity (Ageeb, 1993). Seed drill with flood (basin) irrigation gave less spike length and weight due to weeds infestation and water lodging resulting from excessive irrigation water (Singh *et al.*, 2005). Longer and heavier spikes resulted in higher grain yield than the other combinations during the two seasons. However, the combination 80x25x40x3 was found superior in grain yield during the first and second seasons. Results also indicated that 100 cm bed width combinations gave grain yield significantly more than that given by 120 cm bed width combinations and seed drill. This agreed with the finding of Beecher *et al*., (2005), who stated that the permanent raised beds are the recommended irrigation design to achieve high yields in many irrigated crops on heavy clay soils.

5.14 Effect of sowing methods and bed and furrow dimension on quantity of applied water m^3/ha:

Seed drill sowing method resulted in high volume of applied water during the two seasons. However, the lowest applied water was scored by the 120 cm bed width combinations followed by the 100 cm bed width combinations during the two seasons. It was also noted that among raised beds more irrigation water was applied to the 80 cm bed width. LSD test showed no significant differences in applied water between the three tested raised bed widths, 80, 100 and 120 cm during the two seasons. The higher volume of water in seed drill sowing method could be due to the fact that the water was added to whole planted area (100%) in contrast to the raised bed planting where water was added in the furrows between beds. If a field of an area of one ha (200x50) taken as an example, number of furrows for 120 cm bed width is 41and for 100 cm bed width is 50 and for 80 cm bed width is 62(50/bed width), considering furrow width is 0.4 m and furrow length of 200 m, the irrigated area will equal 3280 m^2, 4000 m^2 and 4960 m^2 for the three beds, respectively. This means that the irrigation water is applied to 100% , 33%, 40% and 50% planted area in seed drill, 120,100 and 80 cm bed width, respectively. This is why 120 cm bed width resulted in lower amount of applied water compared with 80 cm and 100 cm bed width, irrespective of furrow width and depth. This agreed with findings of Khan *et al.*, (2012) who stated that in raised bed system irrigation water, in contrast to flood (basin) irrigation, is applied to less than ⅓ of the field resulting in marked water saving.

5.15 Effect of sowing methods and bed and furrow dimensions on water productivity (kg/m^3):

The 80 cm bed width combinations resulted in higher water productivity than 100, 120 cm bed width combinations and seed drill during the two seasons. Lower water productivity resulting from seed drill could be due to the high volume of applied water and low grain yield compared with raised bed planting method.

The 80 cm bed width resulted in high water productivity although more water was applied to it compared to the 100 and 120 cm bed width. this could be due to higher yield resulting from the effective irrigation which covered all crop rows in the case of the 80 cm bed width, whereas, in the case of 100 cm bed width and 120 cm bed width the irrigation water did not reach the middle rows due to the poor wetting pattern resulting from the too wide furrow spacing (Brovwer *et al.* ,1990) thus exposed the middle rows to water shortage resulting in lower yield and consequently lower water productivity. This agreed with Ram *et al.,* (2011) findings who stated that Maize and wheat planted on raised beds recorded about 7.8% and 22.7% higher water use efficiency (water productivity) than under flat layout. The results also agreed with the results reported by RBM,(2008) in Egypt and with the finding of Zhang *et al.,* (2007) who concluded that the water use efficiency for raised bed system was 2.26 kg/ m^3 which was 20.2 % higher over flat planting system and with the finding of Hassan *et al.,* (2005) in Pakistan.

5.16 Effect of sowing methods and bed dimension on crop water requirements (mm):

Irrespective of bed width and furrow dimensions, raised bed combinations resulted in crop water deficit significantly less than seed drill by 24%, which resulted in the highest water deficit during the two seasons. Results showed, mostly, no significant differences between raised bed combinations in water deficit during the two seasons. High crop water deficit in seed drill sowing method could be due to the exposure of the flat the bed to more sun light thus rapid soil drying thus more evaporation rate which resulted in lower soil moisture before the next irrigation. meanwhile high volume of applied water which resulted in high soil moisture after irrigation , this agreed with finding of Zhang *et al.,* (2007) who indicated that raised bed pattern had lower water consumption than the flooded pattern due to decrease of irrigation amount and control of evaporation from top soil. he results obtained were compatible with those of Sayre and Moreno Ramos (1997) who stated that farmers in the Mexico switched to bed planting with 2 or 3 rows of wheat on top of the beds which are 70 – 80 cm wide with furrow irrigation as opposed to flat planting in solid stands and flood irrigation. By switching, they were able to reduce water requirements by 25%.

5.17 Effect of sowing methods and bed and furrow dimensions on water saving percentage:

Raised bed combinations, irrespective of bed width and furrow dimensions gave a higher water saving percentage by 9-16% from the crop water requirement (deficit) during the two seasons. On the other hand seed drill resulted in over consumption of water by 17% form the crop water requirement. This could be due to application of high volume of water resulting from uncontrollable water application, exposure of flat irrigated area to rapid evaporation, irregular land leveling which required more water to ensure covering all planted area and weed competition. This was similar to the finding of Singh *et al.*, (2005) who stated that raised bed system saves 30-40% water as compared to conventional flood irrigation practice, and with the finding of RBM (2008) in Egypt who mentioned that in raised bed system water consumption by crops fell by 30%, and with the finding of Gill *et al.*, (2005) who stated that planting of wheat, cotton and other crops on beds may save up to 50 - 60% of irrigation water. Although it is not significantly different, 100 and 120 cm bed width combinations gave water saving percentage more than that given by 80 cm bed width. This could be due to the lower number of furrows in 100 and 120 cm bed width compared to 80 cm bed width.

5.18 Effect of raised bed and furrow dimensions and number of crop rows per bed on soil salinity and nutrients:

Results showed no significant change in soil salinity and main soil nutrients N, P and K due to the use of raised bed planting system. This agreed with finding of Kulkarni (2011) who state that there was no significant evidence of salinity build up on beds compared with the traditional methods.

CHAPTER SIX

CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions:

From the results of this study the following conclusions can be drown:

1- Raised bed planting technique resulted in higher grain yield of wheat crop than broadcasting, seed drilling and wide level disc.

2- Using less volume of irrigation water (4000 m^3/ha), raised bed planting technique gave the same or higher yield that was given by the other sowing methods using more volume of irrigation water (5000 - 6000 m^3/ha), thus saved 20 - 33% of irrigation water.

3- Using less seeding rate (96 kg/ha), raised bed planting technique gave the same or higher yield than what that was given by the other sowing methods using more seeding rate (120 - 144 kg/ha) thus saved 20- 33% of seeds.

4- Raised bed planting technique gave higher water use efficiency lower crop water requirement irrespective of bed width and furrow dimensions, than seed drill on flat land.

5- The 120 cm bed width gave lower applied water, higher water saving percentage but lower grain yield and lower water productivity than the 80 cm bed width.

6- The 80cm bed width, 25 cm furrow depth, 40 cm furrow width with 3 crop rows gave the highest grain yield (5146kg) which is more of what was given by seed drill by 42%, highest water productivity (1.3 kg/m^3) and decreased the crop water requirement by 13% to 440 mm without reduction in grain yield.

7- Seed drill sowing method with flood irrigation consumed irrigation water (525 mm) more than the crop water requirement by 17% which resulted in intensive weed infestation, low grain yield and low water productivity.

8- Raise bed planting system had no negative impact on soil salinity or on the main soil nutrients (NPK).

6.2 Recommendations:

According to the findings of this study the following recommendations can be b made:

1- Raised bed planting can be used as a technique for water saving in wheat production in the heavy clay soil of the New Half scheme.

2- The adoption of raised bed planting technique for wheat crop can minimize the seeding rate.

3- The used of 80 cm bed width, 25 cm furrow depth, 40 cm furrow width and 3 crop rows for wheat production in the heavy clay soil of the New Halfa scheme.

4- Studies to assessment the suitability of raised bed planting system for other crops are needed.

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APPENDICES

Appendix A

Table 1. 90 v-notch weir discharge (L/min.)for different weir heads

Weir head (cm)	Weir discharge (L/min.)
5.5	58.74
6.0	73.0
6.5	89.20
7.0	107.34
7.5	127.55
8.0	149.88
8.5	174.40
9.0	201.0
9.5	230.32
10.0	261.84
10.5	295.80
11.0	332.28
11.5	371.34
12.0	413.00
12.5	457.41
13.0	504.53
13.5	554.45
14.0	607.23
14.5	662.90
15.0	721.54

Appendix B

Table 1. Effect of interaction between Sowing methods and varieties on growth performance, water productivity, yield and yield components of wheat (2013-2014)

Treatments		Plant le. cm	Plant no./m²	Weed no/m²	Spike wt. g	1000s wt.gm	WP Kg/m³	B.yield kg/ha	Yield kg/ha
Bed	B	62.1	262	55	1.7	56	0.82	4968	3766
	I	69.1	277	33	1.6	52	0.82	4927	3696
BC	B	67.6	242	20	1.3	55	0.34	4392	1524
	I	66.4	245	40	1.4	58	0.50	4726	2297
SD	B	63.8	231	26	1.4	54	0.48	3986	2208
	I	68.4	220	22	1.4	51	0.48	5040	2066
WLD	B	69.8	226	11	1.4	51	0.55	4190	2544
	I	65.9	243	18	1.3	53	0.55	4673	2395
Mean		66.6	243.6	28	1.427	53.7	0.55	4613	2563
Cv%		4.3	10.2	21	4.2	1.5	7.6	6.9	7.5
SE+		1.73	13.94	4.362	0.0347	0.508	0.03	235	116
LSD		5.289	42.31	13.599	0.1055	1.556	0.08	733	353
Sig.		n.s	n.s	**	*	**	*	*	*

Table 2. Effect of interaction between Sowing methods and varieties on growth performance, water productivity, yield and yield components of wheat (2014-2015)

Treatments		Plant le. cm	Plant no./m²	Weed no/m²	Spike wt. g	1000s wt.gm	WP Kg/m³	B.yield kg/ha	Yield kg/ha
Bed	B	63.00	254.00	58.8	1.518	52.79	0.75	4198	3434
	I	70.50	283.30	62.5	1.706	52.21	0.79	5520	3581
BC	B	54.58	257.6	53.9	1.302	40.13	0.58	5513	2628
	I	65.79	267.1	60.1	1.288	41.54	0.58	4006	2666
SD	B	55.96	218.8	75.4	1.139	47.46	0.49	4049	2225
	I	65.42	266.7	66.8	1.216	45.25	0.54	4435	2424
WLD	B	58.40	237.9	48.8	1.441	43.40	0.61	5345	2717
	I	68.38	282.5	51.5	1.225	44.25	0.51	3806	2390
Mean		62.71	258.5	59.7	1.354	45.83	0.60	4606	2758
Cv%		2.3	5.6	27.1	7.4	5.6	6.1	13.7	4.5
SE+		1.067	10.28	9.44	0.0504	1.169	0.02	453	86
LSD		3.328	31.93	28.7	0.1533	3.614	0.06	1408	264
Sig.		n.s	n.s	n.s	*	n.s	*	*	*

Table 3. Effect of interaction between applied water and varieties on growth performance, water productivity, yield and yield components of wheat (2013-2014)

Treatments		Plant le. cm	Plant no./m²	Weed no/m²	Spike wt. g	1000s wt.gm	WP Kg/m³	B.yield kg/ha	Yield kg/ha
W3	B	62.7	231	27	1.1	48.7	0.48	3768	1649
	I	64.2	230	32	1.4	54.6	0.58	4438	1771
W4	B	64.9	228	27	1.5	56.2	0.58	4111	2268
	I	66.1	237	27	1.7	56.3	0.55	4726	2566
W5	B	67.1	243	20	1.2	48.8	0.58	4810	2866
	I	69.2	257	29	1.3	54.0	0.65	4747	2873
W6	B	68.6	261	30	1.5	55.3	0.58	4850	3262
	I	70.3	262	33	1.7	55.5	0.53	5453	3247
Mean		66.6	243.6	28	1.427	53.7	0.55	4613	2563
Cv%		5.7	16.7	31.3	9.8	5.1	18.4	17.4	15
SE+		1.25	11.11	2.780	0.390	0.727	0.03	220	111
LSD		3.606	31.89	7.953	0.1105	2.059	0.08	624	315
Sig.		n.s	n.s	*	n.s	n.s	n.s	*	n.s

Table 4. Effect of interaction between applied water and varieties on growth performance, water productivity, yield and yield components of wheat (2014-2015)

Treatments		Plant le. cm	Plant no./m²	Weed no/m²	Spike wt. g	1000s wt.gm	WP Kg/m³	B.yield kg/ha	Yield kg/ha
W3	B	57.29	232.1	61.6	1.043	39.58	0.53	4546	1598
	I	61.79	266.0	61.5	1.045	36.29	0.52	3686	1567
W4	B	57.13	240.1	61.2	1.083	43.29	0.68	4361	2738
	I	67.83	280.4	62.3	1.112	43.50	0.65	4421	2592
W5	B	58.40	245.6	60.0	1.499	46.79	0.64	4646	3218
	I	69.58	280.0	59.2	1.400	49.58	0.66	4817	3290
W6	B	59.12	259.4	54.3	1.775	53.75	0.57	5532	3449
	I	70.88	273.1	57.8	1.877	53.88	0.59	4843	3610
Mean		62.71	258.5	59.7	1.354	45.83	0.60	4606	2758
Cv%		4	10.1	32.4	15.8	5.9	11.2	23.3	10.9
SE+		0.750	7.73	6.73	0.0606	0.999	0.02	324	84
LSD		2.136	21.99	19.47	0.172	2.913	0.06	924	237
Sig.		**	n.s	n.s	n.s	**	n.s	n.s	n.s

Table 5. Effect of interaction between sowing methods and herbicides application on growth performance, water productivity, yield and yield components of wheat (2013-2014)

Treatments		Plant le. cm	Plant no./m²	Weed no/m²	Spike wt. g	1000s wt.gm	WP Kg/m³	B.yield kg/ha	Yield kg/ha
Bed	Hw	69.2	286	17	2.1	60.8	0.86	5172	3941
	Ho	62	354	71	1.2	47.4	0.74	4726	3523
BC	Hw	71.7	249	12	1.4	57.7	0.46	5045	2098
	Ho	62.3	239	47	1.3	54.8	0.38	4073	1726
SD	Hw	70	229	11	1.6	57.6	0.55	5266	2484
	Ho	62.1	223	36	1.2	47.5	0.41	3761	1790
WLD	Hw	71.5	244	5	1.4	56.1	0.60	4877	2784
	Ho	64.2	225	24	1.2	47.6	0.48	3986	2158
Mean		66.6	243.6	28	1.427	53.7	0.55	4613	2563
Cv%		4.4	16.7	38.3	12.6	6.8	21.5	21.1	20.3
SE+		1.36	11.25	3.953	0.0358	0.653	0.03	241	114
LSD		4.484	34.93	12.796	0.1045	1.872	0.07	735	338
Sig.		n.s	n.s	**	**	**	*	n.s	*

Table 6. Effect of interaction between sowing methods and herbicides application on growth performance, water productivity, yield and yield components of wheat (2014-2015)

Treatments		Plant le. cm	Plant no./m²	Weed no/m²	Spike wt. g	1000s wt.gm	WP Kg/m³	B.yield kg/ha	Yield kg/ha
Bed	Hw	69.96	334.0	31.3	1.926	57.54	0.79	5438	3624
	Ho	63.54	203.3	90.0	1.299	47.46	0.75	4279	3389
BC	Hw	60.63	319.9	20.1	1.264	42.83	0.62	5213	2822
	Ho	59.75	205.8	94.0	1.325	38.83	0.53	4306	2472
SD	Hw	60.17	306.3	34.1	1.293	50.83	0.60	4850	2784
	Ho	61.21	179.2	108.0	1.061	41.88	0.41	3612	1862
WLD	Hw	62.21	313.1	21.0	1.413	47.54	0.58	5263	2611
	Ho	64.21	207.3	79.3	1.253	39.75	0.54	3888	2494
Mean		62.71	258.5	59.7	1.354	45.83	0.60	4606	2758
Cv%		6.2	14.2	44.2	23.4	10.4	14.7	30.8	13.9
SE+		1.053	9.98	7.74	0.0546	0.87	0.02	426	88
LSD		3.257	30.89	24.26	0.1556	2.5	0.06	1339	264
Sig.		**	n.s	n.s	**	*	**	n.s	**

Table 7. Effect of interaction between Varieties and herbicide's application on growth performance, water productivity, yield and yield components of wheat (2013-2014)

Treatments		Plant le. cm	Plant no./m²	Weed no/m²	Spike wt. g	1000s wt.gm	WP Kg/m³	B.yield kg/ha	Yield kg/ha
B	Hw	69.7	244	11	1.6	58.6	0.58	4733	2695
	Ho	61.9	238	45	1.3	49.3	0.50	4037	2326
I	Hw	71.5	260	11	1.6	57.6	0.65	5448	2957
	Ho	63.4	233	44	1.2	49.3	0.50	4236	2273
Mean		66.6	243.6	28	1.427	53.7	0.55	4613	2563
Cv%		4.4	16.7	38.3	12.6	6.8	21.5	21.1	20.3
SE+		0.88	8.27	2.026	0.0253	0.438	0.02	135	77
LSD		2.749	25.06	6.085	0.0729	1.242	0.05	390	222
Sig.		n.s	n.s	n.s	n.s	n.s	*	n.s	*

Table 8. Effect of interaction between Varieties and herbicide's application on growth performance, water productivity, yield and yield components of wheat (2014-2015)

Treatments		Plant le. cm	Plant no./m²	Weed no/m²	Spike wt. g	1000s wt.gm	WP Kg/m³	B.yield kg/ha	Yield kg/ha
B	Hw	57.62	298.4	27.1	1.503	49.81	0.66	5494	2978
	Ho	58.17	185.7	91.4	1.197	41.90	0.55	4046	2522
I	Hw	68.85	337.7	26.1	1.446	49.56	0.64	4889	2942
	Ho	66.19	212.1	94.3	1.272	42.60	0.56	3996	2587
Mean		62.71	258.5	59.7	1.354	45.83	0.60	4606	2758
Cv%		6.2	14.2	44.2	23.4	10.4	14.7	30.8	13.9
SE+		0.576	5.59	5.4	0.0433	0.881	0.01	233	53
LSD		1.674	16.3	16.38	0.1243	2.64	0.04	686	153
Sig.		**	n.s	n.s	n.s	n.s	n.s	n.s	n.s

Table 9. Effect of interaction between applied water and herbicides application on growth performance, water productivity, yield and yield components of wheat (2013-2014)

Treatments		Plant le. cm	Plant no./m²	Weed no/m²	Spike wt. g	1000s wt.gm	WP Kg/m³	B.yield kg/ha	Yield kg/ha
W3	Hw	67.4	238	9	1.2	49.7	0.55	4642	1793
	Ho	59.5	223	37	1.1	47.8	0.50	3564	1627
W4	Hw	69.6	245	13	1.5	58.9	0.70	4778	2686
	Ho	61.4	221	48	1.2	49.7	0.55	4061	2148
W5	Hw	72.2	257	13	1.8	61.5	0.65	5194	3209
	Ho	64.1	243	44	1.3	50.0	0.50	4363	2530
W6	Hw	73.3	269	10	2.1	62.1	0.60	5746	3617
	Ho	65.7	254	50	1.3	49.7	0.46	4558	2892
Mean		66.6	243.6	28	1.427	53.7	0.55	4613	2563
Cv%		4.4	16.7	38.3	12.6	6.8	21.5	21.1	20.3
SE+		0.88	9.09	2.371	0.0386	0.769	0.03	216	109
LSD		2.487	25.51	6.651	0.1083	2.157	0.08	605	305
Sig.		n.s	n.s	n.s	**	n.s	*	n.s	*

Table 10. Effect of interaction between applied water and herbicides application on growth performance, water productivity, yield and yield components of wheat (2014-2015)

Treatments		Plant le. cm	Plant no./m²	Weed no/m²	Spike wt. g	1000s wt.gm	WP Kg/m³	B.yield kg/ha	Yield kg/ha
W3	Hw	58.88	298.3	26.7	1.068	39.96	0.60	4687	1812
	Ho	60.21	199.8	96.3	1.020	35.92	0.45	3542	1354
W4	Hw	62.64	318.8	30.1	1.251	47.79	0.71	4841	2858
	Ho	62.29	201.8	93.4	0.945	39.00	0.61	3941	2472
W5	Hw	65.80	329.2	24.6	1.617	53.17	0.70	5234	3473
	Ho	62.54	196.5	94.6	1.283	43.21	0.61	4229	3036
W6	Hw	66.33	326.0	25.1	1.916	57.83	0.60	6002	3701
	Ho	63.67	197.5	87.0	1.692	49.79	0.68	4370	3358
Mean		62.71	258.5	59.7	1.354	45.83	0.60	4606	2758
Cv%		6.2	14.2	44.2	23.4	10.4	14.7	30.8	13.9
SE+		0.759	7.52	5.49	0.0632	0.88	0.02	300	83
LSD		2.128	21.07	15.39	0.177	2.467	0.05	841	232
Sig.		*	n.s	n.s	n.s	n.s	*	n.s	*

Table 11. Effect of interaction between Sowing methods, applied water and varieties on growth performance, water productivity, yield and yield components of wheat (2013-2014)

Treatment	Plant le. cm	Plant no./m²	Weed no/m²	Spike wt. g	1000s wt.gm	WP Kg/m³	B.yield kg/ha	Yield kg/ha
Bed W3B	59.8	316	42	1.2	51.2	0.65	4349	2558
BedW3I	65.1	246	26	1.1	44.9	0.70	4447	2155
BedW4B	59.3	248	53	1.8	59.4	0.98	4750	3713
BedW4I	70.2	272	29	1.5	53.6	0.94	4848	3672
BedW5B	61.9	237	61	1.9	57.5	0.84	5422	4178
BedW5I	69.3	286	44	1.8	54.7	0.86	5112	4272
BedW6B	67.5	250	65	2.0	57.0	0.77	5357	4618
BedW6I	71.7	307	32	1.9	54.3	0.72	5304	4685
BC W3B	59.4	207	29	1.1	45.3	0.26	3706	828
BCW3I	64.8	222	17	1.3	51.7	0.48	4066	1469
BCW4B	69.8	256	28	1.2	55.3	0.34	3974	1313
BCW4I	63.2	238	48	1.4	58.2	0.53	4800	2143
BCW5B	70.7	227	12	1.4	59.2	0.36	5004	1788
BCW5I	70.1	278	30	1.5	60.2	0.53	4898	2597
BCW6B	70.3	282	11	1.4	59.6	0.36	4889	2167
BCW6I	67.7	243	64	1.6	60.4	0.50	5136	2983
SD W3B	61.3	194	23	1.1	51.2	0.43	3324	1313
SDW3I	66.4	241	19	1.2	48.6	0.53	4750	1577
SDW4B	62.5	221	39	1.2	54.1	0.48	3775	1884
SDW4I	67.7	203	24	1.2	49.3	0.50	4644	2066
SDW5B	65.3	265	19	1.5	54.7	0.53	4838	2609
SDW5I	68.3	209	26	1.3	52.7	0.41	4274	2059
SDW6B	65.8	246	22	1.7	55.8	0.50	4010	3024
SDW6I	71.2	229	19	2.0	54.0	0.43	6492	2561
WLD W3B	70	206	13	1.2	47.1	0.53	3689	1898
WLDW3I	60.7	213	18	1.1	50.1	0.62	4495	1889
WLDW4B	67.8	188	10	1.3	49.5	0.53	3948	2160
WLDW4I	63.4	233	16	1.2	54.9	0.60	4615	2376
WLDW5B	70.5	245	14	1.5	53.5	0.58	3977	2887
WLDW5I	68.9	255	18	1.3	53.8	0.50	4704	2558
WLDW6B	70.8	265	9	1.5	52.8	0.53	5148	3235
WLDW6I	70.7	271	20	1.4	53.2	0.46	4879	2760
Mean	66.6	243.6	28	1.427	53.7	0.55	4613	2563
Cv%	5.7	14	31.3	9.8	5.1	18.4	17.4	15
SE+	2.57	21.98	6.191	0.0780	1.468	0.06	464	225
LSD	7.311	62.38	17.761	0.2205	4.155	0.16	1315	636
Sig.	n.s	n.s	**	n.s	n.s	*	n.s	*

Table 12. Effect of interaction between Sowing methods, applied water and varieties on growth performance, water productivity, yield and yield components of wheat (2014-2015)

Treatment	Plant le. cm	Plant no./m²	Weed no/m²	Spike wt. g	1000s wt.gm	WP Kg/m³	B.yield kg/ha	Yield kg/ha
Bed W3B	57.50	253.3	61.5	1.005	43.83	0.55	3715	1663
BedW3I	60.33	245.0	78.2	1.285	50.50	0.94	4306	2074
BedW4B	66.33	252.5	49.5	1.783	55.50	0.80	4217	3890
BedW4I	67.83	255.0	46.2	2.000	61.33	0.70	4555	3600
BedW5B	68.50	289.2	69.3	1.072	38.67	0.69	4286	3974
BedW5I	70.67	292.5	70.5	1.387	51.83	0.90	5220	4296
BedW6B	72.00	294.2	55.2	1.883	55.00	0.86	6204	4207
BedW6I	70.83	257.5	55.0	2.483	63.33	0.72	6370	4349
BC W3B	56.83	251.7	50.7	0.953	35.83	0.50	5314	1538
BCW3I	53.00	245.5	57.8	0.937	35.50	0.60	4531	1291
BCW4B	54.17	256.7	54.5	1.500	41.67	0.60	4949	2400
BCW4I	54.33	276.7	52.7	1.817	47.50	0.60	7255	2417
BCW5B	60.67	231.7	66.0	0.962	34.00	0.43	3588	3031
BCW5I	64.50	256.7	61.7	0.985	40.00	0.61	3641	3214
BCW6B	67.67	270.8	53.2	1.422	43.67	0.64	4625	3540
BCW6I	70.33	309.2	59.7	1.783	48.50	0.63	4171	3749
SD W3B	55.83	232.3	77.8	1.058	41.50	0.40	3698	1210
SDW3I	56.17	217.5	63.3	0.983	45.67	0.54	3631	1822
SDW4B	54.17	213.3	88.0	1.180	48.17	0.54	3794	2136
SDW4I	57.67	220.8	72.5	1.333	54.50	0.47	4985	2426
SDW5B	55.83	270.8	64.0	1.127	35.00	0.60	4236	2724
SDW5I	67.67	279.2	65.0	1.077	41.00	0.60	4894	2402
SDW6B	69.33	257.5	69.8	1.143	51.33	0.47	4397	2832
SDW6I	68.83	259.2	68.2	1.517	53.67	0.47	4217	3043
WLD W3B	59.00	200.0	56.3	1.155	37.17	0.66	5453	1985
WLDW3I	59.00	252.5	45.3	1.27	41.50	0.63	4975	1087
WLDW4B	57.50	260.0	47.8	1.533	41.83	0.63	5623	2522
WLDW4I	56.67	239.2	45.8	1.950	51.67	0.53	5328	1920
WLDW5B	62.17	272.5	46.7	1.020	37.50	0.36	2635	3144
WLDW5I	68.50	293.3	52.2	1.002	41.17	0.48	3929	3254
WLDW6B	69.33	297.5	58.7	1.154	48.33	0.65	4044	3211
WLDW6I	73.50	266.7	48.5	1.727	50.00	0.55	4618	3298
Mean	62.71	258.5	59.7	1.354	45.83	0.60	4606	2758
Cv%	4.0	10.1	32.4	15.8	5.9	11.2	23.3	10.9
SE+	1.642	16.62	13.51	0.1181	1.787	0.04	702	173
LSD	4.683	47.26	38.52	0.334	5.093	0.11	2001	490
Sig.	**	n.s	n.s	n.s	n.s	**	n.s	*

Table 13. Effect of interaction between Sowing methods, varieties and herbicides application on growth performance, water productivity, yield and yield components of wheat (2013-2014)

treatments		Plant le. cm	Plant no./m²	Weed no/m²	Spike wt. g	1000s wt.gm	WP Kg/m³	B.yield kg/ha	Yield kg/ha
Bed B	Hw	65.9	275	21	2.2	61.9	0.86	4961	3922
	Ho	58.4	250	89	1.2	50.6	0.74	4738	3612
Bed I	Hw	72.5	298	13	2.1	59.6	0.86	5143	3958
	Ho	65.8	257	52	1.1	44.1	0.74	4711	3434
BC B	Hw	71.8	246	7	1.3	56.9	0.38	4692	1742
	Ho	63.3	240	32	1.2	52.8	0.29	4094	1306
BR I	Hw	71.6	252	17	1.4	58.5	0.55	5398	2450
	Ho	61.3	238	63	1.4	56.8	0.48	4051	2143
SD B	Hw	67.8	231	13	1.5	58.8	0.50	4409	2299
	Ho	59.8	232	39	1.2	49.1	0.46	3566	2117
SD I	Hw	72.4	228	10	1.6	56.5	0.60	6125	2666
	Ho	64.4	214	34	1.2	45.8	0.34	3958	1466
WLD B	Hw	73.4	223	4	1.5	56.6	0.58	4627	2820
	Ho	66.2	229	19	1.3	44.8	0.50	3754	2270
WLD I	Hw	69.6	264	6	1.4	55.7	0.62	5124	2746
	Ho	62.3	222	29	1.2	50.3	0.48	4222	2045
Mean		66.6	243.6	28	1.427	53.7	0.55	4613	2563
Cv%		4.4	16.7	38.3	12.6	6.8	21.5	21.1	20.3
SE+		1.84	16.23	4.883	0.0506	0.9	0.04	308	157
LSD		5.489	47.28	14.577	0.1439	2.542	0.10	890	449
Sig.		n.s	n.s	**	n.s	**	*	n.s	*

Table 14 . Effect of interaction between Sowing methods, varieties and herbicides application on growth performance, water productivity, yield and yield components of wheat (2014-2015)

treatments		Plant le. cm	Plant no./m²	Weed no/m²	Spike wt. g	1000s wt.gm	WP Kg/m³	B.yield kg/ha	Yield kg/ha
Bed B	Hw	66	315	29	2	58	0.77	4829	3557
	Ho	60	192	89	1.1	47	0.72	3569	3310
Bed I	Hw	73.9	353	34	1.9	57	0.82	6048	3691
	Ho	67	214	91	1.5	48	0.77	4990	3470
BC B	Hw	54.5	310	17	1.3	42	0.67	6434	2986
	Ho	54.5	205	91	1.3	39	0.48	4589	2268
BC I	Hw	66.6	328	23	1.3	44	0.58	3989	2659
	Ho	64.9	206	97	1.3	39	0.58	4022	2676
SD B	Hw	54.5	276	44	1.3	52	0.58	4546	2659
	Ho	57.4	162	107	1	43	0.38	3509	1790
SD I	Hw	65.8	337	24	1.3	50	0.65	5158	2911
	Ho	65	197	109	1.1	40	0.43	3713	1937
WLD B	Hw	55.4	293	19	1.5	48	0.62	6170	2714
	Ho	60.6	183	78	1.4	38	0.60	4519	2717
WLD I	Hw	69	333	23	1.3	47	0.53	4356	2510
	Ho	67.7	232	80	1.1	41	0.48	3259	2270
Mean		62.71	258.5	59.7	1.354	45.83	0.60	4606	2758
Cv%		6.2	14.2	44.2	23.4	10.4	14.7	30.8	13.9
SE+		1.332	12.73	10.87	0.082	1.519	0.03	538	116
LSD		3.879	37.06	31.77	0.2319	4.384	0.08	1580	333
Sig.		*	n.s	n.s	n.s	n.s	*	n.s	*

Table 15. Effect of interaction between Sowing methods, applied water and herbicides application on growth performance, water productivity, yield and yield components of wheat (2013-2014)

treatments		Plant le. cm	Plant no./m²	Weed no/m²	Spike wt. g	1000s wt.gm	WP Kg/m³	B.yield kg/ha	Yield kg/ha
Bed w3	Hw	64	314	10	1.1	49.9	0.67	4788	2246
	Ho	60.9	248	58	1.1	46.2	0.67	4008	2467
Bed w4	Hw	68.8	278	20	2.2	63.0	1.06	4961	3936
	Ho	60.8	242	62	1.1	49.9	0.96	4637	3451
Bed w5	Hw	70.4	260	26	2.5	65.3	0.91	5438	4584
	Ho	60.8	263	79	1.2	46.9	0.79	5095	3866
Bed w6	Hw	73.5	293	13	2.7	64.8	0.84	5501	4994
	Ho	65.8	263	85	1.2	46.5	0.65	5160	4306
BCw3	Hw	67.7	203	12	1.1	49.3	0.43	4781	1296
	Ho	56.6	225	34	1.2	47.7	0.34	2990	1001
BCw4	Hw	71.2	243	15	1.3	59.0	0.43	4726	1771
	Ho	61.8	251	61	1.2	54.5	0.43	4049	1687
BCw5	Hw	74.5	268	11	1.5	60.9	0.48	5371	2453
	Ho	66.3	238	31	1.3	58.6	0.38	4531	1932
BCw6	Hw	73.5	282	11	1.6	61.6	0.48	5306	2870
	Ho	64.5	243	63	1.4	58.4	0.38	4718	2280
SDw3	Hw	68.9	224	11	1.3	50.1	0.53	4735	1822
	Ho	58.8	211	31	1.0	49.6	0.43	3336	1310
SDw4	Hw	69.7	218	12	1.2	56.2	0.60	4630	2438
	Ho	60.5	206	51	1.2	47.2	0.38	3790	1514
SDw5	Hw	70.4	239	8	1.5	61.5	0.55	5062	2729
	Ho	63.2	235	37	1.2	45.8	0.38	4051	1942
SDw6	Hw	71.2	236	14	2.3	62.7	0.53	6638	3185
	Ho	65.9	239	26	1.4	47.2	0.41	3866	2400
WLDw3	Hw	69	210	4	1.2	49.5	0.58	4262	2052
	Ho	61.8	208	26	1.2	47.7	0.58	3922	1733
WLDw4	Hw	68.8	238	6	1.3	57.4	0.65	4800	2597
	Ho	62.5	183	20	1.2	47.1	0.48	3766	1937
WLDw5	Hw	73.4	262	6	1.6	58.3	0.60	4903	3065
	Ho	66	238	26	1.2	48.9	0.48	3778	2381
WLDw6	Hw	74.8	265	4	1.6	59.5	0.58	5542	3418
	Ho	66.6	271	25	1.3	46.5	0.43	4486	2578
Mean		66.6	243.6	28	1.427	53.7	0.55	4613	2563
Cv%		4.4	16.7	38.3	12.6	6.8	21.5	21.1	20.3
SE+		2	19.35	5.701	0.0759	1.484	0.05	444	220
LSD		5.88	54.65	16.412	0.2127	4.157	0.15	1250	617
Sig.		n.s	n.s	**	**	*	*	n.s	*

Table 16. Effect of interaction between Sowing methods, applied water and herbicides application on growth performance, water productivity, yield and yield components of wheat (2014-2015)

treatments		Plant le. cm	Plant no./m²	Weed no/m²	Spike wt. g	1000s wt.gm	WP Kg/m³	B.yield kg/ha	Yield kg/ha
Bed w3	Hw	64	208	37	1	45	0.60	4378	1841
	Ho	62	235	94	1	38	0.62	3622	1896
Bed w4	Hw	66.8	338	51	1.8	57	0.96	5124	3814
	Ho	64.1	199	98	0.9	45	0.89	4402	3679
Bed w5	Hw	74.1	344	18	2.4	64	0.86	6077	4298
	Ho	64.1	202	87	1.3	47	0.79	4344	3972
Bed w6	Hw	74.8	346	19	2.6	64	0.74	6175	4543
	Ho	63.8	177	82	1.9	60	0.67	4750	4013
BCw3	Hw	58	304	19	1	36	0.53	5071	1601
	Ho	59.5	179	98	0.9	34	0.38	3830	1226
BCw4	Hw	59.6	305	25	1	41	0.65	4315	2592
	Ho	57.8	197	95	0.9	34	0.55	3854	2225
BCw5	Hw	60.7	328	19	1.4	44	0.67	4817	3300
	Ho	61.1	199	89	1.6	42	0.60	4757	2942
BCw6	Hw	64.1	338	18	1.7	51	0.65	6646	3797
	Ho	60.5	248	95	1.9	46	0.60	4781	3492
SDw3	Hw	54.8	303	30	1.2	40	0.62	4678	1922
	Ho	56.8	191	112	1	37	0.38	3254	1109
SDw4	Hw	61.5	310	22	1.1	49	0.74	5146	2983
	Ho	62.3	186	107	0.9	38	0.41	3379	1579
SDw5	Hw	61.5	303	40	1.1	55	0.60	4140	3019
	Ho	62	168	118	1.2	45	0.43	4051	2107
SDw6	Hw	62.8	308	45	1.7	60	0.50	5443	3216
	Ho	63.6	173	96	1.1	48	0.43	3758	2659
WLDw3	Hw	58.6	278	21	1.1	39	0.62	4627	1889
	Ho	62.5	194	82	1	36	0.38	3463	1183
WLDw4	Hw	62.6	321	23	1.1	44	0.50	4776	2045
	Ho	64.8	225	74	1	39	0.60	4130	2400
WLDw5	Hw	64	341	21	1.6	51	0.65	5902	869
	Ho	62.8	217	85	1	39	0.62	3768	3127
WLDw6	Hw	63.5	312	19	1.8	57	0.53	5748	3247
	Ho	66.7	193	76	1.9	45	0.55	4195	3264
Mean		62.71	258.5	59.7	1.354	45.83	0.60	4606	2758
Cv%		6.2	14.2	44.2	23.4	10.4	14.7	30.8	13.9
SE+		1.685	16.4	12.26	0.1223	1.755	0.04	672	168
LSD		4.772	46.39	34.8	0.3425	4.919	0.11	1908	472
Sig.		n.s	n.s	n.s	**	n.s	**	n.s	*

Table 17. Effect of interaction between applied water, varieties and herbicides application on growth performance, water productivity, yield and yield components of wheat (2013-2014)

treatments		Plant le. cm	Plant no./m²	Weed no/m²	Spike wt. g	1000s wt.gm	WP Kg/m³	B.yield kg/ha	Yield kg/ha
W3 B	Hw	66.1	228	9	1.1	50.1	0.48	4104	1678
	Ho	59.2	233	44	1.1	47.3	0.48	3430	1622
W3 I	Hw	68.7	248	9	1.2	49.3	0.62	5179	1901
	Ho	59.8	213	30	1.1	48.3	0.55	3698	1634
W4 B	Hw	69.1	234	12	1.5	59.4	0.62	4512	2400
	Ho	60.6	223	52	1.2	49.8	0.53	3710	2136
W4 I	Hw	70.1	255	14	1.5	58.4	0.74	5045	2971
	Ho	62.2	218	44	1.2	49.6	0.55	4409	2158
W5 B	Hw	71.2	241	13	1.8	61.8	0.62	5143	3144
	Ho	63	246	40	1.3	50.7	0.53	4476	2587
W5 I	Hw	73.2	273	13	1.7	61.3	0.65	5242	3271
	Ho	65.1	241	46	1.2	49.4	0.50	4253	2472
W6 B	Hw	72.4	273	11	2.0	63.0	0.60	5167	3564
	Ho	64.8	249	42	1.3	49.5	0.48	4534	2957
W6 I	Hw	74.1	265	10	2.1	61.2	0.60	6324	3670
	Ho	66.5	259	57	1.4	49.8	0.43	4582	2825
Mean		66.6	243.6	28	1.427	53.7	0.55	4613	2563
Cv%		4.4	16.7	38.3	12.6	6.8	21.5	21.1	20.3
SE+		1.39	13.87	3.541	0.0536	1.039	0.04	297	154
LSD		3.954	39.1	9.962	0.1502	2.91	0.11	4104	430
Sig.		n.s	n.s	**	n.s	n.s	*	n.s	*

Table 18. Effect of interaction between Applied water, varieties and herbicides application on growth performance, water productivity, yield and yield components of wheat (2014-2015)

treatments		Plant le. cm	Plant no./m²	Weed no/m²	Spike wt. g	1000s wt.gm	WP Kg/m³	B.yield kg/ha	Yield kg/ha
W3 B	Hw	56.2	270	23	1.1	42	0.62	5198	1884
	Ho	58.3	194	101	1	37	0.43	3890	1313
W3 I	Hw	61.5	326	31	1	38	0.58	4176	1740
	Ho	62	206	92	1	35	0.46	3197	1397
W4 B	Hw	56.4	299	29	1.2	48	0.74	4824	2923
	Ho	57.8	182	94	1	39	0.62	3898	2551
W4 I	Hw	68.9	339	32	1.3	48	0.70	4858	2794
	Ho	66.7	222	93	0.9	39	0.60	3984	2390
W5 B	Hw	58.3	306	31	1.7	52	0.70	5071	3451
	Ho	57.7	185	89	1.3	42	0.60	4222	2986
W5 I	Hw	71.8	353	18	1.5	55	0.70	5398	3492
	Ho	67.3	208	100	1.3	44	0.62	4238	3089
W6 B	Hw	59.5	319	27	2	58	0.60	6883	3658
	Ho	58.7	206	82	1.6	50	0.55	4178	3240
W6 I	Hw	73.1	333	24	1.9	58	0.60	5122	3744
	Ho	68.5	213	92	1.8	50	0.58	4582	3475
Mean		62.71	258.5	59.7	1.354	45.83	0.60	4606	2758
Cv%		6.2	14.2	44.2	23.4	10.4	14.7	30.8	13.9
SE+		1.094	10.77	8.62	0.0886	1.392	0.03	435	114
LSD		3.067	30.19	24.35	0.2483	3.928	0.08	1220	320
Sig.		n.s	n.s	n.s	n.s	n.s	**	n.s	*

Table 19. Effect of interaction between sowing methods, seeding rate and variety on growth performance, weed infestation, yield and yield components of wheat (2013-2014)

Treatment	Plant. height cm	Plant no./m²	Weed no/m²	Spike wt. g	1000s Wt.g	G.Yield kg/ha
Bed SR84B	61.1	210	53.5	1.53	44.8	2885
Bed SR84I	72.3	239	54.9	1.43	43.8	2611
BedSR96B	58.9	262	43.0	1.55	45.5	3190
BedSR96I	71.1	277	43.7	1.32	43.3	2959
BedSR120B	60.5	295	35.7	1.43	42.9	3238
BedSR120I	70	300	35.3	1.32	43.0	3070
BedSR144B	60.2	322	24.7	1.38	42.4	3343
BedSR144I	70.8	353	25.4	1.20	41.7	3283
BC SR84B	65.5	220	68.6	1.08	37.8	2088
BCSR84I	65.4	238	68.1	1.20	40.4	2666
BCSR96B	64.7	263	53.2	1.00	37.0	2376
BCSR96I	65.8	288	52.4	1.08	38.8	2909
BCSR120B	63.2	282	35.3	1.05	37.3	2702
BCSR120I	63.3	307	42.8	1.17	39.5	3134
BCSR144B	63.3	329	25.2	0.93	36.3	2861
BCSR144I	63.5	350	29.5	1.12	39.0	3456
Bed SR84B	68.9	209	69.0	1.18	39.6	2542
Bed SR84I	59.1	216	79.5	1.32	40.3	2354
SDSR96B	70.4	267	52.8	1.10	38.7	2299
SDSR96I	62	252	55.0	1.13	38.3	2458
SDSR120B	72.1	301	40.8	1.03	39.5	2666
SDSR120I	60.5	397	41.1	1.13	38.2	2808
SDSR144B	73.1	342	31.0	1.00	37.6	2573
SDSR144I	61.7	347	29.0	1.13	39.1	3072
WLD SR84B	64.5	210	67.7	1.22	39.0	2323
WLD SR84I	64.33	218	45.6	1.22	39.8	2429
WLDSR96B	66.4	242	53.3	0.98	36.5	2141
WLDSR96I	68.3	246	35.6	1.10	38.8	2515
WLDSR120B	65.7	286	41.7	0.92	36.3	2321
WLDSR120I	69.1	278	24.7	1.05	38.3	2750
WLDSR144B	65.5	327	30.4	1.03	36.2	3007
WLDSR144I	67.6	343	18.8	1.02	37.8	2791
Mean	65.58	279	44.0	1.17	39.6	2743
Cv%	4.2	11	7.7	8.4	4.2	8.6
SE+	3.396	9.58	5.207	0.0884	1.345	182
LSD	10.083	27.25	15.754	0.265*	3.948*	514
Sig.	*	n.s	*	*	*	*

Table 20. Effect of interaction between sowing methods ,seeding rate and variety on growth performance, weed infestation, yield and yield components of wheat, second season

Treatment	Plant. height cm	Plant no./m²	Weed no/m²	Spike wt. g	1000sWt. g	G.Yield kg/ha
Bed SR84B	72.7	210	54	1.7	51	2954
Bed SR84I	74	207	61	1.7	49	2988
BedSR96B	70.7	245	41	1.7	49	3986
BedSR96I	76.7	260	49	1.8	50	3682
BedSR120B	63.8	266	32	1.7	48	4042
BedSR120I	73	313	40	1.7	48	3886
BedSR144B	63.7	352	23	1.5	45	3715
BedSR144I	67.7	367	29	1.5	46	4200
BC SR84B	47.2	234	76	1.2	41	1826
BCSR84I	64.7	259	75	1.2	39	1632
BCSR96B	49.8	246	58	1.2	40	3082
BCSR96I	66.2	289	57	1.2	39	2160
BCSR120B	50	299	47	1.2	39	3250
BCSR120I	64.3	337	47	1.2	40	3238
BCSR144B	50.3	336	35	1.1	38	3161
BCSR144I	60.2	364	34	1.1	40	3905
Bed SR84B	52	221	63	1.2	42	1536
Bed SR84I	67	206	84	1.3	43	1430
SDSR96B	50.3	246	65	1.2	40	1598
SDSR96I	67.7	248	60	1.3	41	1975
SDSR120B	51.5	253	52	1.2	39	2731
SDSR120I	69.8	305	50	1.2	40	2822
SDSR144B	53	203	46	1.1	39	2906
SDSR144I	68.7	332	41	1.2	40	3115
WLD SR84B	51.8	233	72	1.2	40	1162
WLD SR84I	65.2	192	73	1.2	40	1493
WLDSR96B	50.5	277	54	1.2	38	1961
WLDSR96I	66.8	268	60	1.1	38	2040
WLDSR120B	50.8	308	44	1.2	40	3067
WLDSR120I	67.7	314	50	1.1	39	3566
WLDSR144B	49.8	360	34	1.1	38	3408
WLDSR144I	66.7	353	34	1.0	37	3778
Mean	61.4	281	51	1.3	42	2822
Cv%	3.6	5.1	11.5	26.5	2.5	14.1
SE+	2.176	21.12	6.148	0.0576	0.847	259
LSD	6.577	60.8*	19.22*	0.177*	2.47*	734
Sig.	*		*	*	*	*

Table 21. Effect of interaction between sowing methods ,seeding rate and herbicides application on growth performance, weed infestation, yield and yield components of wheat (2013-2014)

treatments		Plant. height cm	Plant no./m²	Weed no/m²	Spike wt. g	1000s wt.g	G.Yield kg/ha
Bed SR84	Hw	70.3	226	15.4	2.12	52.0	3058
	Ho	63.1	223	93.0	0.85	36.5	2438
Bed SR96	Hw	69.9	267	10.5	2.00	51.0	3701
	Ho	60.1	272	76.1	0.87	37.8	2446
Bed SR120	Hw	70.3	300	8.0	1.80	48.9	3598
	Ho	60.3	295	63.0	0.92	37.0	2710
Bed SR144	Hw	70.6	345	4.8	1.68	46.5	3662
	Ho	60.3	329	45.3	0.90	37.5	2962
BCSR84	Hw	71.7	336	18.2	1.55	44.2	2770
	Ho	59.3	223	118.6	0.73	34.0	1985
BCSR96	Hw	69.5	284	11.0	1.37	41.3	2688
	Ho	61	268	94.6	0.72	34.5	2597
BCSR120	Hw	67.6	300	8.3	1.38	41.2	3113
	Ho	58.9	288	69.8	0.83	35.7	2724
BCSR144	Hw	67.2	338	5.5	1.28	40.7	3355
	Ho	59.7	340	49.2	0.77	34.7	2964
SDSR84	Hw	67.1	234	19.7	1.62	43.9	2376
	Ho	60.9	191	128.8	0.88	36.0	2520
SDSR96	Hw	70.7	264	12.5	1.50	42.9	2546
	Ho	61.7	255	95.3	0.73	34.2	2210
SDSR120	Hw	70.1	303	9.4	1.42	42.4	3082
	Ho	62.5	294	72.5	0.75	34.0	2393
SDSR144	Hw	72.1	354	6.8	1.45	43.9	3250
	Ho	62.7	335	53.2	0.68	32.8	2395
WLDSR84	Hw	68.5	231	18.4	1.52	42.4	2534
	Ho	60.3	197	94.9	0.92	36.5	2218
WLDSR96	Hw	71.4	260	13.6	1.32	40.8	2602
	Ho	63.3	228	75.3	0.77	34.5	2057
WLDSR120	Hw	71.6	296	10.8	1.22	40.2	2592
	Ho	63.2	269	55.8	0.75	34.5	2477
WLDSR144	Hw	69.6	348	6.8	1.28	40.7	3259
	Ho	63.5	323	42.4	0.77	34.3	2539
mean		65.58	279	44.0	1.17	39.6	2743
Cv%		6.4	12.3	29.6	17.8	8.7	16
SE+		2.252	8.52	5.605	0.0971	1.494	192
LSD		6.621	24.1	16.45*	0.284*	4.3*	540
Sig.		n.s	n.s	*	*	*	*

Table 22. Effect of interaction between sowing methods ,seeding rate and herbicides application on growth performance, weed infestation, yield and yield components of wheat, second season

treatments		Plant. height cm	Plant no./m²	Weed no/m²	Spike wt. g	1000s Wt.g	G.Yield kg/ha
Bed SR84	Hw	76.2	205	16	2.3	58	3046
	Ho	70.5	212	100	1.1	41	2894
Bed SR96	Hw	79.2	249	11	2.4	57	4351
	Ho	68.2	256	79	1.2	42	3317
Bed SR120	Hw	78	309	9	2.2	53	4397
	Ho	58.8	269	63	1.2	42	3530
Bed SR144	Hw	73.5	379	7	2.1	52	4270
	Ho	57.8	340	45	1.0	39	3602
BCSR84	Hw	60	267	22	1.7	45	2026
	Ho	51.8	226	128	0.7	34	1430
BCSR96	Hw	63.2	299	16	1.6	44	2825
	Ho	52.8	236	98	0.7	34	2417
BCSR120	Hw	61.7	356	13	1.6	44	3341
	Ho	52.7	280	80	0.7	34	3146
BCSR144	Hw	60.8	373	8	1.5	43	4046
	Ho	49.7	327	61	0.7	34	3019
SDSR84	Hw	64.7	214	19	1.9	48	1814
	Ho	54.3	213	128	0.7	36	1152
SDSR96	Hw	62.5	265	15	1.8	46	1970
	Ho	55.5	228	110	0.7	35	1601
SDSR120	Hw	65.2	308	11	1.7	46	3480
	Ho	56.2	250	92	0.7	34	2074
SDSR144	Hw	64	341	9	1.6	45	3317
	Ho	57.7	294	78	0.7	35	2705
WLDSR84	Hw	64	212	20	1.8	46	1478
	Ho	53	213	125	0.7	34	1176
WLDSR96	Hw	62.5	278	15	1.5	43	2122
	Ho	54.8	267	99	0.7	33	1879
WLDSR120	Hw	61.5	313	12	1.5	43	3622
	Ho	57	308	82	0.8	36	3012
WLDSR144	Hw	62.2	352	9	1.4	42	3696
	Ho	54.3	361	59	0.7	33	3492
mean		61.4	281	51	1.3	42	2822
Cv%		6.2	6.6	24.5	9	4.6	18.2
SE+		2.187	19.68	6.754	0.062	0.88	233
LSD		6.584	56.92	20.32*	0.186*	2.54*	656
Sig.		**	n.s	*	*	*	n.s

Table 23. Effect of interaction between seeding rate, variety and herbicides application on growth performance, weed infestation, yield and yield components of wheat (2013-2014)

treatments		Plant. height cm	Plant no./m²	Weed no/m²	Spike wt. g	1000s Wt.g	G.Yield kg/ha
SR84 B	Hw	69.2	225	16.8	1.68	45.5	2659
	Ho	60.8	199	112.7	0.83	35.1	2258
SR84 I	Hw	69.5	238	19.1	1.72	45.8	2710
	Ho	61	218	105.1	0.87	36.4	2321
SR96 B	Hw	68.9	267	11.1	1.53	44.2	2849
	Ho	61.4	250	90.0	0.79	34.7	2153
SR96 I	Hw	71.9	271	12.7	1.57	43.8	2921
	Ho	61.7	261	80.6	0.87	35.8	2501
SR120 B	Hw	69.7	299	8.7	1.44	43.1	3024
	Ho	61	283	68.0	0.78	34.3	2438
SR120 I	Hw	70	301	9.5	1.48	43.2	3168
	Ho	61.4	290	62.4	0.85	36.3	2712
SR144 B	Hw	69	337	6.0	1.43	43.3	3329
	Ho	62.1	323	49.6	0.74	33.4	2563
SR144 I	Hw	70.8	356	6.0	1.42	42.6	3434
	Ho	61	341	45.4	0.82	36.3	2866
Mean		65.58	279	44.0	1.17	39.6	2743
Cv%		6.4	12.3	29.6	17.8	8.7	16
SE+		2.169	6.14	3.53	0.053	0.881	135
LSD		6.56	17.33*	9.8*	0.149*	2.471	380
Sig.		n.s		*	*	n.s	*

Table 24. Effect of interaction between seeding rate, variety and herbicides application on growth performance, weed infestation, yield and yield components of wheat, second season

treatments		Plant. height cm	Plant no./m²	Weed no/m²	Spike wt. gm	1000sWt. gm	G.Yield kg/ha
SR84 B	Hw	58.8	229	19	1.9	50	2129
	Ho	53	220	113	0.8	37	1610
SR84 I	Hw	73.6	220	19	1.9	49	2054
	Ho	61.8	212	127	0.8	36	1718
SR96 B	Hw	59.7	273	14	1.8	47	2938
	Ho	51	234	94	0.8	36	2376
SR96 I	Hw	74	273	14	1.8	48	2695
	Ho	64.7	259	99	0.8	36	2230
SR120 B	Hw	59.5	305	11	1.7	46	3722
	Ho	48.6	258	76	0.9	37	2822
SR120 I	Hw	73.7	338	11	1.7	47	3696
	Ho	63.8	296	82	0.8	37	3060
SR144 B	Hw	59.3	349	8	1.7	45	3727
	Ho	49.2	326	61	0.8	35	2868
SR144 I	Hw	71	373	8	1.7	46	3958
	Ho	60.6	335	61	0.8	35	3540
Mean		61.4	281	51	1.3	42	2822
Cv%		6.2	6.6	24.5	9	4.6	18.2
SE+		1.079	11.33	3.028	0.0293	0.527	168
LSD		3.034	31.77	8.49*	0.821	1.481	474
Sig.		*	n.s	*	n.s	n.s	n.s

Appedix C   Table 1. Soil nutrients and salinity as affected by bed dimensions

treatments	E.CdS m-1		N Ppm		K ppm		P Meq/l	
	2015	2016	2015	2016	2015	2016	2015	2016
80x15x30x3	0.80	0.85	52	43	1.50	1.43	0.17	0.23
80x25x30x3	0.87	0.87	46	48	1.83	1.89	0.30	0.20
80x15x40x3	0.94	0.92	76	52	1.99	1.48	0.27	0.30
80x25x40x3	0.91	0.87	76	66	1.89	1.59	0.33	0.33
80x15x30x4	0.96	0.75	129	165	1.66	1.10	0.30	0.33
80x25x30x4	0.85	0.89	107	140	1.43	1.36	0.33	0.40
80x15x40x4	0.77	0.77	104	137	1.31	1.03	0.37	0.33
80x25x40x4	0.80	0.83	96	127	1.38	1.37	0.30	0.30
100x15x30x4	0.81	0.83	76	70	1.69	1.84	0.23	0.30
100x25x30x4	1.17	1.31	95	84	1.87	1.82	0.27	0.27
100x15x40x4	0.95	0.86	70	115	1.59	1.46	0.27	0.30
100x25x40x4	0.84	0.90	108	131	1.08	1.45	0.33	0.30
100x15x30x5	0.83	0.87	95	123	1.15	1.52	0.37	0.33
100x25x30x5	0.83	0.83	78	119	1.20	1.52	0.30	0.30
100x15x40x5	0.78	0.85	107	108	1.30	1.66	0.30	0.23
100x25x40x5	0.83	0.81	80	79	1.30	1.48	0.17	0.23
120x15x30x5	0.97	0.98	75	128	1.89	1.69	0.30	0.33
120x25x30x5	0.96	0.84	119	131	1.60	1.37	0.30	0.37
120x15x40x5	0.82	0.93	114	143	1.69	1.43	0.23	0.27
120x25x40x5	0.84	0.77	93	140	1.11	1.06	0.23	0.20
120x15x30x6	1.0	0.79	81	72	1.3	1.48	0.30	0.33
120x25x30x6	0.87	0.90	68	64	1.59	1.71	0.33	0.37
120x15x40x6	0.91	0.83	58	46	1.41	1.63	0.23	0.23
120x25x40x6	0.81	0.93	66	47	1.31	1.21	0.23	0.30
Seed drill	0.89	0.92	90	89I	1.31	1.21	0.23	0.27
Mean	0.88	0.88	86	99	1.50	1.46	0.28	0.29
CV%	20.3	21.3	21.5	5.2	27.7	33.9	30.9	25.4
SE	0.15	0.11	10.7	2.94	0.24	0.29	0.5	0.04
LSD	0.29	0.31	30.5	8.34	0.68	0.81	0.14	0.12