EFFECT OF SOWING DEPTH AND ROW SPACING ON GERMINATION STAND ESTABLISHMENT AND YIELD OF WHEAT

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CERTIFICATE

*This is to certify that thesis entitled, "***EFFECT OF SOWING DEPTH AND ROW SPACING ON GERMINATION STAND ESTABLISHMENT AND YIELD OF WHEAT***" submitted to the Faculty of Agriculture, Sher-e-Bangla Agricultural University, Dhaka, in partial fulfilment of the requirements for the degree of* ***MASTER OF SCIENCE (M.S.) in AGRONOMY****, embodies the result of a piece of bona-fide research work carried out by* ***RAZIYA TARAFDER****, Registration no.* ***09-03398*** *under my supervision and guidance. No part of the thesis has been submitted for any other degree or diploma.*

I further certify that such help or source of information, as has been availed of during the course of this investigation has duly been acknowledged.

Dated:
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DEDICATED TO

MY BELOVED PARENTS

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EFFECT OF SOWING DEPTH AND ROW SPACING ON GERMINATION STAND ESTABLISHMENT AND YIELD OF WHEAT

ABSTRACT

A field experiment was conducted at the agronomy field of Sher-e-Bangla Agricultural University, Dhaka during November, 2013 to March, 2014 to evaluate the influence of sowing depth and row spacing on germination, stand establishment and yield of wheat cv. BARI Gom-27. The experiment was carried out in Randomized Complete Block Design (RCBD) design with three replications having three sowing depths (2, 4 and 8 cm) and four row spacings (15, 20, 25 and 30 cm). Results showed that sowing depths had significant influence on emerged seedling m^{-2}, seedling length, root length seedling^{-1}, number of roots plant^{1}, number of tillers plant^{-1}, total dry matter plant^{-1} , 1000 grain weight, grain yield and straw yield while length of spike, number of spikelet spike^{-1}, number of grains spike^{-1} were non significant. Row spacing showed significant effect on emerged seedling m^{-2}, seedling length, root length of seedling, number of roots plant^{-1}, number of tillers plant^{-1}, total dry matter plant^{-1}, length of spike, number of spikelet spikes^{-1}, number of grains spike^{-1} and grain yield. The result from 4 cm sowing depth showed best performances in the case of grain and straw yield. The highest grain yield (3.98 t ha^{-1}) and straw yield (5.09 t ha^{-1}) were obtained from 4 cm sowing depth. Similarly the highest grain yield (3.81 t ha^{-1}) was also produced from 20 cm row spacing, whereas, 15 cm row spacing produced the lowest grain yield (3.23 t ha^{-1}). The highest straw yield was observed with 4 cm sowing depth and the lowest with 8 cm sowing depth. As an interaction effect of treatments, 4 cm sowing depth and 20 cm row spacing produced the highest grain yield (4.53 t ha^{-1}) of wheat.

LIST OF CONTENTS

CONTENTS (Cont'd)

CONTENTS (Cont'd)

CONTENTS (Cont'd)

LIST OF TABLES

LIST OF FIGURES

CONTENTS (Cont'd)

LIST OF APPENDICES

LIST OF ABBREVIATIONS

AEZ	Agro-Ecological Zone
Anon.	Anonymous
AIS	Agriculture Information Service
BAU	Bangladesh Agricultural University
BBS	Bangladesh Bureau of Statistics
BNNC	Bangladesh National Nutrition Council
BARI	Bangladesh Agricultural Research Institute
CV %	Percent Coefficient of Variance
cv.	Cultivar (s)
DAS	Days After Sowing
et al.	And others
etc.	et cetera (and other similar things)
FAO	Food and Agricultural Organization
L.	Linnaeus
LSD	Least Significant Difference
i.e.	id est (that is)
MoP	Muriate of Potash
SAU	Sher-e-Bangla Agricultural University
SRDI	Soil Resources and Development Institute
TSP	Triple Super Phosphate
UNDP	United Nations Development Programme
var.	Variety
viz.	Namely

Chapter 1

Introduction

CHAPTER 1

INTRODUCTION

In Bangladesh, wheat (*Triticum aestivum* L.) is the second important cereal crop. The area under wheat cultivation during 2009-2010 was about 3 lakh 73 thousand 538 hectare producing 901 thousand mt tons of wheat with an average yield of 2.28 ton ha^{-1} (BBS, 2011). It contains carbohydrate (78.1%), protein (14.17%), minerals (2.1%), fat (2.1%) and considerable proportion of vitamins (Peterson, 1965). Though wheat is an important cereal crop in Bangladesh, its average yield is low compared to that of some other wheat growing countries of the world. Among the related factors sowing seeds is important as it contributes to achieving a good crop stand establishment and higher yield. The use of optimum sowing depth is generally viewed as a desired goal for all crop establishment systems. Too shallow sowing results in poor germination due to inadequate soil moisture at the top soil layer (Desbiolles, 2002). On the other hand, deep sowing can also significantly reduce crop emergence and yield (Aikins *et al.*, 2006). Root length decreased with increase in sowing depth (BARI, 1989-90). The root length & root diameter at different growth stages determine the water and nutrient uptake capacity of the plant. The seminal roots that grow in the early stage of the wheat, their functions being concerned with absorption of water and nutrient for the growth of the young plant appear to be functional throughout life of plant. The extent of their development and depth to which they descend is influenced by the depth at which the seeds are sown (Percival, 1985). Emergence percentage decreases with increased sowing depth (Andrews *et al.*, 1991). Seeds which fall on the shallower depth are at risk of germination due to less imbibitions and seed soil contact. On the other hand the seeds which fall below the optimum depth fail to emerge. If the seeds are placed deeper than the length of coleoptiles the seedlings have to push or displaced the superficial mechanical obstacles (Bouaziz *et al.*, 1990). Short coleoptile is primarily responsible for poor seedling emergence under dry land farming (Singh *et al.*, 1985). Plant emerged from deep sowing depth might have spent most of the stored energy for increasing its coleoptiles length development during the seedling emergence and the metabolites translocated toward root development is comparatively lower (Percival, 1985). Mesocotyl length increased with the increase of sowing depth. Sowing depth is one of the important factors in crop management of field crops and vegetables (Campbell *et al*., 1991). Spikes plant^{-1}, spikelets spike^{-1} and kernels spike^{-1} at higher at sub optimal seeding densities and this sub optimal density depend mainly upon seeding depth (Darwinkel, 1978). Wheat is generally planted by broadcast method by most of the farmers in our country, only progressive farmers and research scientists use line sowing. Now a day due to infestation of weeds, it has become important to sow the crops in lines with suitable row spacing, which besides facilitating inter-culture and convenient herbicide application for effective and efficient weed control may also help in intercropping and reducing the seed rate per hectare without any adverse effect on the final grain yield. Due to the above mention usefulness of proper row spacing it may be helpful to increase and improve the yield components of wheat crop. If a row distance is too wide, solar radiation that falls between crop rows remains un-utilized. On the other hand, plants become crowded and they suffer from mutual shading if the row distance is too narrow. A uniform distribution and proper orientation of plants over a cropped area are needed for greater light interception throughout the crop profile and maximum photosynthetic efficiency by all the leaves of a plant (Evers *et al*., 2009) Widening row spacing leads to reduced biomass and tillers plant^{-1} basis which is related to the reduction in light interception by the wheat canopy in the wide rows which in turn reduces assimilate production. Reduction in vegetative growth in wide rows translates into a significant reduction in grain yield which is strongly associated with the loss of spike density. The number of plants established and the number of spikes produced decreased as row spacing increased **(**Lafond, 1994). Yield can be increased by reducing row spacing to have an even plant-to-plant distribution that could weaken competition. So, the depth of seed placement and the distance from the adjacent row both influence crop performance.

Keeping these views in mind the present experiment was conducted with a view :

- to find out the effect of depth of sowing on germination, stand establishment, growth and yield of wheat
- to optimize a row spacing towards better yield of wheat
- to evaluate the interaction of sowing depth and row spacing on yield component of wheat.

Chapter 2

Review of Literature

CHAPTER 2

REVIEW OF LITERATURE

2.1 Effect of sowing depth

2.1.1 Emerged seedling m^{-2}

Amin *et al.* (2004) conducted an experiment to test different sowing depth of wheat. Increasing the seeding depth over 4 cm, spike m^{-2} was significantly reduced. This was mainly due to the less number of emergence percentages, which ultimately caused the lowest number of plants m^{-2}. The emergence percent was highest in 2 cm seeding depth, but total number of spike was less than that of 4 cm.

Ehsanullah *et al.* (1999) reported that depth of sowing significantly affected population m^{-2}. Minimum plant population (193.04) was recorded at 5cm sowing depth and maximum (243.48) at 3 cm sowing depth.

Loeppky *et al*. (1989) observed the effects of sowing depths on yield and plant survival in 14 field trials in winter wheat which was sown into standing stubble on several Saskatchewan soil types. The influence of sowing depth and date on winter growth and development was also investigated in a hand sown trial on conventional summer fellow. Increases in sowing depth as small as 17 mm resulted in significantly deeper crown placement and delayed plant emergence. Delayed deep sowing resulted in reduction in the numbers of tillers plant^{-1} and fewer ear m^{-2} of row in the following year.

2.1.2 Stand establishment

Yagmur and Kaydan (2009) found that seedling establishment was greatest when plants sown at 5 cm and 7 cm. The numbers of seedlings increased with sowing depths up to 7 cm, sowing beyond a depth of 7 cm was associated with significant reductions in the number of seedlings.

Shaner *et al.* (1978) observed the effect of seeding depth on the yield and competitive ability of two wheat cultivars (Anna and Inia 66 R). Surface sowing resulted in poor establishment, though yield increased with increasing seed rate. Stands were satisfactory at the other sowing depths (2, 4 and 7 cm).

2.1.3 Plant height

Alam *et al.* (2014) revealed that plant height responded significantly due to sowing depth. The tallest plant (93.75 cm) was found in the 4 cm sowing depth and the shortest one (91.24 cm) in 8 cm sowing depth.

Keshtkar *et al.* (2009) conducted an experiment under a controlled environment to study the effects of different temperature regimes (15/10°C, 20/15°C, and 25/20°C day/night) and sowing depths (0, 2, 4, and 6 cm) on the seedling emergence and early growth (height gain) of wheat (cv. Marvdasht) and wild barley (*Hordeum spontaneum*). The maximum plant height (H_{max}) was observed at the surface planting for both plants. At all temperature regimes, the time taken to reach 50% of the (H_{max} i.e. H_{50}) increased linearly with the sowing depth but at higher temperatures, the accelerated growth rate reduced the H_{50}. The wild barley seedling emergence and height gain rate, as expressed relative to those of wheat, revealed the highest superiority of wheat over wild barley at 25/20°C and the sowing depth of 4 cm.

Silva (1991) reported that wheat cv. Candeias when sown at 3.5, 7.0, 10.5 or 14.0 cm soil depth showed grain yield of 5.25-5.86 t ha^{-1}, 1000 grain weight 39.2-40.2 g and plant height which were not significantly affected by sowing depth.

Shahbaz *et al.* (1988) conducted a field trial in 1982 on a moderately calcareous silty clay loam soil at Islamabad where wheat cv. C-518 and C-591 (both tall) and Punjab -81 and Lyallpur-73 (both semi dwarf) were separated into 2 grades by size and sown at depths of 5 or 10 cm. It was found that seed size had no effect on seedling emergence, plant height and grain yield.

2.1.4 Number tiller plant^{-1}

Alam *et al.* (2014) reported that sowing depth exerted a significant influence on the production of effective tillers plant^{-1}. The highest number of effective tillers plant^{-1} (4.09) was obtained from 4 cm sowing depth and the lowest one (3.90) was obtained from 8 cm sowing depth.

2.1.5 Days to 50% flowering

Silva (1991) sowed wheat cv. Candeias at 3.5, 7.0, 10.5 or 14.0 cm soil depth and found that the number of ears m^{-2} was not significantly affected by sowing depth. Plant density decreased and the number of ears plane increased significantly with increased sowing depth. The number of days to emergence increased with increased sowing depth. The number of days to flowering was greatest with sowing at 3.5 cm lest with sowing at 14 cm depth.

2.1.6 1000 grain weight

Alam *et al.* (2014) observed that, 1000-grain weight was significant with different sowing depths. The highest 1000-grain weight (51.18 g) was resulted from 4 cm sowing depth and the lowest (49.10 g) was in 8 cm sowing depth.

Wajid *et al.* (1997) evaluated wheat cultivars Pirsabak-85, Khyber-87, Pirsahak-91 and Kaghan-93 at sowing depths of 5 and 9 cm at Peshwar, Pirsabak and Jamra during 1994-95 and found that cultivars planted at Pirsabak had the highest 1000- grain weight (41.22 g), Khyber-87 had the highest 1000-gain weight (41.71 g).

Silva (1991) sowed wheat cv. Candelas at 3.5, 7.0, 10.5 or 14.0 cm soil depth and found that the 1000 grain weight (39.2-40.2 g) was not significantly affected by sowing depths (25cm vs. 50 mm), two row spacing (18 vs. 36 cm) and two sowing depths.

Vedrov and Frolov (1990) observed a micro plot trial on Chemozem soil with spring wheat cv. Dvulineinaya, Skala and Udarintsawith. The 1000 grain weights of 36 - 45, 30 - 38 and 22 - 26 g respectively were found when sown at depths of 3, 5, 7 and 9 cm. Grain yield decreased from 198 - 244 g at a sowing depth of 3 cm to 79 - 145g from seeds sown 9 cm deep. Reductions were more marked in the small seeded cv. Udarintsa.

2.1.7 Spike length

Alam *et al.* (2014) reported that spike length did not show significant variation due to different sowing depth. The longest spike (11.14 cm) was obtained from 4 cm sowing depth and the shortest one (10.93 cm) was found at 8 cm sowing depth.

2.1.8 Number of spikelets spike^{-1}

Alam *et al.* (2014) found that, the number of spikelets spike^{-1} was differed significantly among different sowing depth. The highest number of spikelets spike^{-1} (14.15) was obtained from 4 cm sowing depth and the lowest number (12.87) was obtained from 8 cm sowing depth.

2.1.9 Number of grain spike^{-1}

Alam *et al.* (2014) reported that sowing depth had significant effect on the number of grains spike^{-1}. The maximum number of grains spike^{-1} (40.70) was obtained from 4 cm sowing depth and the minimum one (39.42) was observed at 8 cm sowing depth.

Amin *et al*. (2004) conducted an experiment to test different sowing depth of wheat. Significantly higher number of grains spike^{-1} was recorded from 8 cm depth. Generally deeper the planting depth greater was the success. This was rather expected because lesser number of seedlings emerged from deeper planted seeds and sparsely populated plants had better growth.

Wajid *et al*. (1997) evaluated wheat cultivars Pirsabak-85, Khyber-87, Pirsahak-91 and Kaghan-93 at sowing depths of 5 and 9 cm at Peshwar, Pirsabak and Jamra during 1994-95 and found that grains spike^{-1} were maximum at Peshawar (39). Sowing depth of 5 cm gave highest grains spike^{-1} (38). Khyber-87 had the highest grains spike^{-1} (39).

Silva (1991) sowed wheat cv. Candeias at 3.5, 7.0, 10.5 or 14.0 cm soil depth and found that the number of grains ear^{-1} was not significantly affected by sowing depth. Plant density decreased and the number of ears plant^{-1} increased significantly with increased sowing depth.

2.1.10 Grain yield

Alam *et al*. (2014) conducted an experiment to study the effect of sowing depth on the yield of spring wheat. The experiment consisted of two factors i.e. three sowing depths viz. 2 cm, 4 cm, 8 cm and two modern wheat varieties viz. Bijoy and Prodip. Results indicated that the effect of sowing depth was significant on almost all the parameters except spike length. Sowing on 4 cm depth gave the highest grain yield (3.88 t ha^{-1}) followed by 2 cm (3.75 t ha^{-1}) and 8 cm sowing depth (3.62 t ha^{-1}). Significant variation was found due to different varieties in respect of all the parameters studied. Bijoy produced the highest grain yield (3.92 t ha^{-1}) and the lowest one was produced by Prodip (3.57 t ha^{-1}). Bijoy produced the highest grain yield (4.06 t ha^{-1}) when sown on 4 cm depth.

Amin *et al.* (2004) reported that the number of spikes m^{-2} was less than the number of tillers m^{-2}. Significantly highest grain yield was obtained with 4 cm sowing depth and the lowest (4189 kg ha^{-1}) from 8 cm depth and they were significantly different. Al Amin *et al.* (1994) observed that sowing of seeds deeper than 4 cm greatly reduced yield.

Wajid *et al.* (1997) evaluated wheat cultivars Pirsabak-85, Khyber-87, Pirsahak-91 and Kaghan-93 at sowing depths of 5 and 9 cm at Peshwar, Pirsabak and Jamra during 1994-95 and found that Khyber-87 had the highest spikes m^{-2} and yield.

McLeod *et al.* (1996) conducted a factorial experiment with combination of two rates (30 vs. 60 kg ha^{-1}) to study plant establishment, grain yield and grain quality of winter wheat. They found that there was no significant difference due to sowing depth. Deep sowing reduced plant establishment to grain yield in only two of 11 sites when humid conditions prevailed. For winter wheat production in the semiarid prairie it was recommended that sowing depth be shallow (about 25 mm), sowing rate be 60 kg ha^{-I}.

Singh *et al.* (1994) reported that sowing 125 kg seed ha^{-1} at 5 cm depth gave the highest wheat yield. Harbir *et al.* (1991) showed that wheat cv. Wil 316, WH 291and WI-I 147 at 4 cm soil depths in a sandy loam soil at Hisar in 1985-86 and 1986-87 and observed that grain yield was highest in both cropping years in WH 316, and from sowing at 5.5 cm depth. Grain yield was strongly and positively correlated with percent emergence and seedling length. The optimum sowing depth was calculated to be 4.63-4.89 cm depending on cultivar.

Silva (1991) reported that wheat cv. Candelas when sown at 3.5, 7.0, 10.5 or 14.0 cm soil depth produced the grain yield of 5.25-5.86 t ha^{-1}. However, Loeppky *et al.* (1989) observed the effects of sowing depths on yield and plant survival in 14 field trials in winter wheat that was sown into standing stubble on several Saskatchewan soil types. The influence of sowing depth and date on winter growth and development was also investigated in a hand sown trial on conventional summer fellow. Delayed deep sowing resulted in fewer ear m^{-2} of row. Winter survival was significantly higher for shallow sown treatments in 4 of 7 trials that experienced differential winterkill. A significant yield advantage (11%) was observed with shallow sowing in 4 or 6 trials that escaped serious winter damage. In contrast, improved winter survival and/or yield advantages were never obtained with increased sowing depths.

Shahbaz *et al.* (1988) conducted a field trial in 1982 on a moderately calcareous silty clay loam soil at Islamabad where wheat cv. C 518 and C 591 (both tall) and Panjab - 81 and Lyallpur 73 (both semi dwarf) were separated into 2 grades by size and sown at depths of 5 or 10 cm and found that seed size had no effect on seedling emergence, plant height and grain yield. Grain yields were much higher 76.5 g/plot) from sowing at 10 cm depth than at 5 cm (44.4g). Sowing at 10 cm depth also increased total emergence. Among cultivars, grain yields ranged from 18.8 g in C 518 to 74.4 g in Lyallpur-73.

Jepsen (1985) reported that on an average sowing depth of 2-4 cm gave the highest yields in winter wheat and barley. Deeper sowing normally reduced yields and depths of 8-12 cm caused late emergence and a large yield loss.

During 1970-72, Borse and Mohajan (1980) reported that the yield components and average grain yields of wheat cv. Sonalika were increased from 2.92 - 3.51 t ha^{-1} with increase in N rates from 50 to 100 and 150 kg ha^{-1}, respectively and from 2.99 to 3.47 and 3.6 t ha^{-1} with increase in sowing rate from 50-100 and 150 kg ha^{-1}. Crops sown at 4-5 cm deep gave higher yields (3.85 t ha^{-1}) than those sown 8-10 cm deep (3.31 t ha^{-1}).

Singh *et al*. (1970) conducted a two year field trials at Madras, India and the result revealed that grain yields of 4041 and 4647 kg ha^{-1} were shown sowing seeds at depths of 2.5 and 6.0 cm respectively. In 3 year field trials with winter wheat cultivar, Spaldon and Derco (1969) recorded economically profitable yield at seeding depth of 3.5 cm. On the other hand Stickler (1962) observed that 6.25 cm seeding depth gave yield significantly higher than 3.75 cm depth.

2.1.11 Straw yield

Alam *et al.* (2014) revealed that straw yield of wheat was also significantly influenced by different depth of sowing .The maximum straw yield (4.50 t ha^{-1}) was observed at 4 cm sowing depth and lowest one (4.25 t ha^{-1}) at 8 cm sowing depth.

2.2 Effect of row spacing

2.2.1 Emerged seedling m^{-2}

Amjad and Anderson (2006) reported that average plant numbers were reduced in the wider rows in all experiment. This result, possibly related to increased competition for water as the seeds were placed closer together in the wide rows, may also have been related to reduction in wheat grain yield.

Hussain *et al*. (2003) reported that different row spacing significantly affected plant population m^{-2}, number of spikes m^{-2}, 1000 grain weight, biological yield and grain yield. Number of grains spike^{-1}, spikelets spike^{-1}, spike length and harvest index remained non significant while maximum 1000 grain weight (48.70 g) were recorded at wider row spacing of 60 cm.

Zhenhua *et al*. (1995) reported that yield tended to increase with increasing population up to 6750000 seedlings ha^{-1} and then decrease. They also noted that plant density decreased plant height. green leaves area plant^{-1} and dry weight per plant in spring but did not affected grain weight.

2.2.2 Plant height

Ahmed (2003) observed that row spacing had no effect on plant height. However, Mallik *et al.* (1996) observed that the plant height was greater at 15 cm row spacing while tiller plant^{-1}, spike length and number of spikes m^{-2} were greater at wider row spacing. They also observed that number of grains spikes^{-1}, grain weight spikes^{-1}, 1000 seed weight, biological yield and harvest index were not significantly affected by row spacing. Grain yield and straw yield were highest at 15 cm row spacing and decreased at wider row spacing.

2.2.3 Number of leaves plant^{-1}

Ahmed (2003) showed that number of leaves plant^{-1} significantly influence row spacing at 57 DAS, 71 DAS and 85 DAS, except 64 DAS.

2.2.4 Number of tiller Plant^{-1}

Pandey *et al*. (2013) reported that wheat cultivated in 20 cm rows produced significantly more effective tillers compared to 15 and 25 cm rows.

Ahmed (2003) conducted an experiment, the treatments include three row spacings (20, 30 and 40 cm) and three plant spacings (3, 6 and 12 cm). The data on number of tillers plant^{-1}, number of leaves plant^{-1} and leaves area index (LAI) and total dry matter (g) were recorded on 57, 64, 71.78 and 85 days after sowing (DAS). Number of tillers plant^{-1} differed at all sampling dates except 85 DAS.

Ayaz *et al*. (1999) showed that maintenance of optimum row spacing can help to optimize tillering capacity and may better ensure wheat yield . On the other hand. Ali *et al.* (1996) found that tillers were more in wider row spacing (37.5 cm) followed by 25 cm and 12.5 cm row spacing.

Kirkland (1993) explained that optimal row spacing plays crucial role to improve the crop productivity as plants growing in too wider rows may not efficiently utilize the light, water and nutrient resources; whereas growing in too narrow rows may result in severe inter-row competition (Ali *et al*., 1999).

Singh and Srivastava (1991) worked on wheat cv. Shekhar, grown at Allahabad, Uttar Pradesh in rabi season of 1981 to 1982 and by their field trial grain yield of wheat was 4.50, 4.02 and 3.84 t ha^{-1} with the spacing of 10 x 18, 10 x 23 and 10 x 28 cm respectively. They observed that tiller numbers, grains spike^{-1} and 1000 grain weight increased with increasing spacing.

Khan and Makhdum (1988) noted that the number of fertile tillers m^{-2} and number of grains ear^{-1} were great at the highest planting density but number of spikelets ear^{-1} was unaffected by planting density.

2.2.5 1000 grain weight

Hussain *et al.* (2003) observed that the highest 1000 grain weight (48.70g) was recorded at wider row spacing of 60cm. The biological yield (14.13 t ha^{-1}) and grain yield (5.65 t ha^{-1}) were also observed in cross drill sowing (30 x 30 cm).

Mostafa *et al.* (1990) conducted an experiment during rabi season of 1980-82 to observed the effect of row spacing and depths of seedling of wheat cv. Inia-

66. The treatments included were four row spacings (15.23, 20.32, 25.40 and 30.48 cm) and three depths of seedings (2.54. 5.08 and 7.62 cm) showed that some characters were significantly influenced due to spacing.

Chata and Nazir (1984) carried out a field experiment on sandy clay loam soil at Faisalabad, Pakistan and found highest grain number per ear and the greatest 1000 grain weight when sown in rows 20 cm apart.

2.2.6 Length of spike

Ahmed (2003) concluded that lengths of spike, 1000 grain weight, grain yield, straw yield were significantly influenced. On the other hand Hussain *et al*. (2003) observed that the number of grains spike^{-1}, spikelets spike^{-1}, spike length and harvest index were non significant with respect to different row spacing.

2.2.7 Number of spikelets spike^{-1}

Hussain *et al*. (2012) conducted an experiment to appraise the performance of wheat (*Triticum aestivum* L.) cultivars, differing in tillering capacity and stature, grown under divergent row spacing and showed that wheat sown under narrow row spacing, 15 cm wide rows in particular, produced higher wheat yield due to significant increase in productive tillers. Increase in number of grains spike^{-1} and 1000-grain weight, from wider row spacing (30 cm), could not compensate the drastic decrease in productive tillers resulting in severe decrease in grain yield. Wheat cultivars with low tillering ability, such as TD-1 and SH-06, planted under narrow row spacing (15 & 20 cm, respectively) produced higher grain yield, whereas high tillering cultivar AS-02 produced better grain yield in wider rows. In conclusion, planting of low tillering dwarf cultivar (TD-1) in narrow (15 cm) rows and low tillering cultivar (SH-06) in medium rows (20 cm) resulted in more productivity owing to substantial rise in fertile tillers.

Ogunlela *et al*. (2000) investigated that row spacing did not influence grain and straw yields, grain weight, spikelets spike^{-1} and spike length of wheat but wider rows enhanced productive tillers and grains spike^{-1}.

2.2.8 Number of grains spike^{-1}

Bakht *et al.* (2007) revealed that maximum grain yield (3528 kg ha^{-1}), number of grains spike^{-1} (68) and thousand grain weight (45 g) was recorded in those plots where row spacing was kept at 30 cm. Similarly, minimum grain yield (1891 kg ha^{-1}) was noted in 60 cm row spacing.

Ercoli and Masoni (1995) reported that above ground biomass of wheat progressively decreased with increasing row spacing. Grain yield of wheat progressively decreased as row spacing increased, but was not affected by row orientations. Number of spikes m^{-2} was the yield component most affected by row spacing.

Porter *et al*. (1995) concluded that, there were no significant differences among treatments for total above ground dry matter, number of grains per area, grain weight, or grain yield. These findings indicated that there were no negative effects of wide-row planting on wheat yields.

Yoon *et al.* (1991) concluded that number of spikes m^{-2} increased with narrow row spacing. Grain yields were highest with the 19 cm row spacing in wheat. However, Ahmad *et al.* (1984) studied on row spacing and weed control on growth and yield of wheat. They reported that increasing row spacing increased 1000 grain weight but decreased the numbers of grain spike^{-1}. They mentioned that grain yields increased significantly at wide row spacing.

2.2.9 Grain yield

Pandey *et al.* (2013) concluded that the grain yield was not affected by the row spacing treatment**.** On the other hand, Zhou *et al*. (2011) found that wheat yields were highest for 14 cm row spacing with yields ranked 14 > 7 > 24.5 > 49 cm.

Ali *et al*. (2010) found that maximum grain yield (4.13 t ha^{-1}) was obtained where moderate seed rate of 150 kg ha^{-1} was used by planting wheat during second fortnight of November and 22.50 cm apart rows gave higher grain yield than 15.00 cm and 11.25 cm. Straw yield increased with the increase in seed rate and showed superiority of 11.25 cm over 15.00 cm and 22.50 cm row spacing. Maximum harvest index values of 48.14% were recorded at seed rate of 150 kg ha^{-1} with 22.50 cm row spacing.

Yagmur and Kaydan (2009) studied the effects of sowing depths (3, 5, 7, 9 cm) on grain yield and yield components of wheat cultivars in Eastern Turkey and found grain yield and yield components to be positively correlated with coleoptiles length. The results showed marked decline in grain yield and yield components among wheat varieties with shorter coleoptiles and deep sowing. The highest yield and grain yield (2.98 t ha^{-1}) were obtained with the cultivar sown at a depth of 5 cm while sowing at a depth of 9 cm significantly reduced grain yield of all the varieties tested.

Amjad *et al*. (2006) concluded that wider row spacing of 240 and 360 mm consistently reduced wheat yield and increased grain protein and small grain screenings compared with a narrow row spacing of 180 mm.

Competition for light penetration, water and essential nutrients availability can thus be manipulated to enhance production potential of wheat by sowing under apposite row spacing (Chen & Neill, 2006).

Hong Yong *et al.* (2006) studied the effects of different row spacing on soil evaporation, evapotranspiration (ET) and grain yield of winter wheat *(Triticum aestirum),* a field experiment was conducted art the Luancheng Agroecological Station of Chinese Academy of Science between 2002 and 2003. The result showed soil evaporation and ET increased when row spacing increased and water use efficiency decreased. The 7.5 and 30 cm row spacing showed difference at other growing stages. Soil evaporation measured under 7.5 cm row spacing decreased 13.26 mm and 29.04 mm, ET decreased 22.76 mm and 51.88 mm, water use efficiency increased 0.11 kg ITI^{-3} and 0.23 kg m"¯' than that of 15 cm and 30 cm row spacing.

Thorsted *et al*. (2006) explained that improved grain yield of wheat in wider rows might be due to increased inter-specific interactions and decrease in intra-specific competition during the entire growing season. On the other hand, Ahmed (2003) observed that plant spacing did not have any effect on yield and components. The interaction effect of row spacing and plant spacing did not show any significant effect on yield and yield components. The maximum grain yield (1.97 t ha^{-1}) was obtained 20cm row spacing and 3cm plant spacing. He observed closer row and plant spacing contribute higher yield in wheat.

Hussain *et al.* (2003) conducted an experiment in Pakistan to determine the effect of different row spacing (8, 18, 30, 45 and 60 cm) and 30 x 30 cm^2 cross drill method sowing on grain yield and yield components of wheat cv. inqilab 91. The different row spacing significantly affected plant population m^{-2}, number of spike m^{-2}, 1000 grain weight, biological yield and grain yield.

Anderson and Garlinge (2000) showed that yields of wheat and barley increased as the spacing between rows is decreased similarly narrow row spacing consistently produced higher grain yield than wide row spacing. Assenheimer *et al.* (1999) reported that row spacing of 20 cm resulted in significantly higher wheat grain yield in comparison with 30 cm row spacing.

Fonts *et al.* (1997) studied that grain yield of wheat decreased linearly with increase in row spacing. Mortality increased with increasing row spacing. Dawood (1996) conducted an experiment on maintaining row spacing of 10. 18 and 26 cm and given 90 kg N in 3 or 4 splits applications at different growth stages. He observed that grain yield increased with increasing row spacing.

Ercoli and Mason (1995) observed that grain yield progressively decreased as row spacing increased but was not affected by row orientations.

However, Srivastava *et al.* (1996) reported that grain yield was not affected by row spacing in wheat.

Lafond (1994) reported that cereals grown in widely spaced rows may compensate the lower number of spikes with higher grains per spike of bold size and thus yielded similar to moderate yields of cereals grown with narrow row spacing.

Marko (1994) reported that increases in row spacing in wheat decreased grain yield from 6.37 t at a spacing of 0.06 m to 6.09 t ha^{-1} at 0.15 m. Yunusa *et al.* (1993) also suggested that increasing the row spacing to 360 mm for wheat is likely to cause some reduction in grain yield.

Raj *et al.* (1992) reported that row spacing (15, 22.5 or 30 cm) had no effect on grain yield of wheat but the yields were lower in the wider row spacing (30 cm). Fatyga (1991) reported that highest average yields of wheat 2.85-2.92 t ha^{-1} were obtained with 25 cm row spacing.

Kumar *et al.* (1991) reported that higher sowing rates coupled with decrease in row spacing increased the number of tillers m^{-2} and grain yields of wheat. Solie *et al.* (1991) reported that the closest row spacing gave the highest wheat yield in a trial of three row spacing of 7.5, 15.0 and 23.0 cm.

Tompkins *et al.* (1991) reported that grain yield increased as row spacing decreased. Grain weight was slightly higher with wide row spacing in wheat. Sharma and Thakur (1990) investigated that grain yield was non-significantly affected by sowing wheat either at 22 or 30 cm row spacing. Rajput *et al.* (1989) reported that maximum grain yield was obtained when wheat was sown at row spacing of 30 cm.

Nemeth and Korosa (1987) observed that the plant spacing had no effect on gain and straw yields, grain and straw ratio, number of ears, number of productive tillers or grain weight. From 22 field trials Burch (1986) found that grain yield was substantially reduced when wheat was sown on rows wider than the standard 18 cm spacing. Narrow rows consistently out yielded wider rows for wheat. Patel *el al.* (1986) opined that sowing wheat in rows 22.5 cm apart was the best in terms of operational convenience, grain yield and net returns.

2.2.10 Straw yield

Malik *et al*. (1996) concluded that grain and straw yields were high with 15 cm row spacing and decreased with increased row spacing while harvest index was not affected significantly by row spacing.

2.2.11 Harvest index

Bakht *et al*. (2007) found that wheat sown under different row spacing, 30 cm row apart was superior to other row spacing. Ahmed *et al.* (2003) concluded that maximum grain yield and harvest index (%) of wheat can be obtained with row spacing of 20 cm. Malik *et al*. (1996) concluded that grain and straw yields were high with 15 cm row spacing and decreased with increased row spacing while harvest index was not affected significantly by row spacing.

Chapter 3

Materials & Methods

CHAPTER 3

MATERIALS AND METHODS

This chapter deals with the materials and methods of the experiment with a brief description on experimental site, climate, soil, land preparation, planting materials, experimental design, land preparation, fertilizer application, irrigation and drainage, intercultural operation, data collection, data recording and their analysis. The details of investigation for achieving stated objectives are described below.

3.1 Site description

The experiment was conducted at the Sher-e-Bangla Agricultural University research farm, Dhaka, during the period from November 2013 to March 2014. The experimental site was located at 23°77′ N latitude and 90°37′ E longitude with an altitude of 9 m.

3.2 Agro-ecological Zone

The experimental site belongs to the agro-ecological zone of “Madhupur Tract”, AEZ-28. This was a region of complex relief and soils developed over the Madhupur clay, where floodplain sediments buried the dissected edges of the Madhupur Tract leaving small hillocks of red soils as ‘islands’ surrounded by floodplain. For better understanding, the experimental site is shown in the AEZ Map of Bangladesh in Appendix I.

3.3 Climate and weather

The geographical location of the experimental site was under the sub-tropical climate characterized by three distinct seasons. The monsoon or rainy season extending from May to October which is associated with high temperature, high humidity and heavy rainfall. The winter or dry season from November to February which is associated with moderately low temperature and the pre-monsoon period or hot season from March to April which is associated with some rainfall and occasional gusty winds. Information regarding monthly maximum and minimum temperature, rainfall, relative humidity and sunshine during the period of study of the experimental site was collected from Bangladesh Meteorological Department, Agargaon and is presented in Appendix III.

3.4 Soil

The soil of the experimental area belonging to the Madhupur Tract. Top soil was silty clay in texture, red brown terrace soil type, olive–gray with common fine to medium distinct dark yellowish brown mottles. Soil pH was 5.6 and had organic carbon 0.45%. The land was well drained with good irrigation facilities. The experimental site was a medium high land. It was above flood level and sufficient sunshine was available during the experimental period. The morphological characters of soil of the experimental plots are as following - Soil series: Tejgaon, General soil: Non-calcareous dark grey. The physicochemical properties of the soil are presented in Appendix II.

3.5 Planting materials

BARI Gom-27 was used as planting material for the present study. This variety is recommended for rabi season. The feature of this variety is presented below:

Height	: 95-100 cm
Number of tiller plant^{-1}	: 4-5
Spike emergence	: 60-65 days
Maturity	: 105-110 days
Number of grain spike^{-1}	: 45-50
Grain colour	: White, shiny
Size	: Medium
1000 grain weight	: 35-40 g
Yield	: 3.5-5.4 t ha^{-1}

3.6 Treatment

There were two sets of treatments in the experiment. The treatments were sowing depth and row spacing. They are shown below:

Factor A: Sowing depths

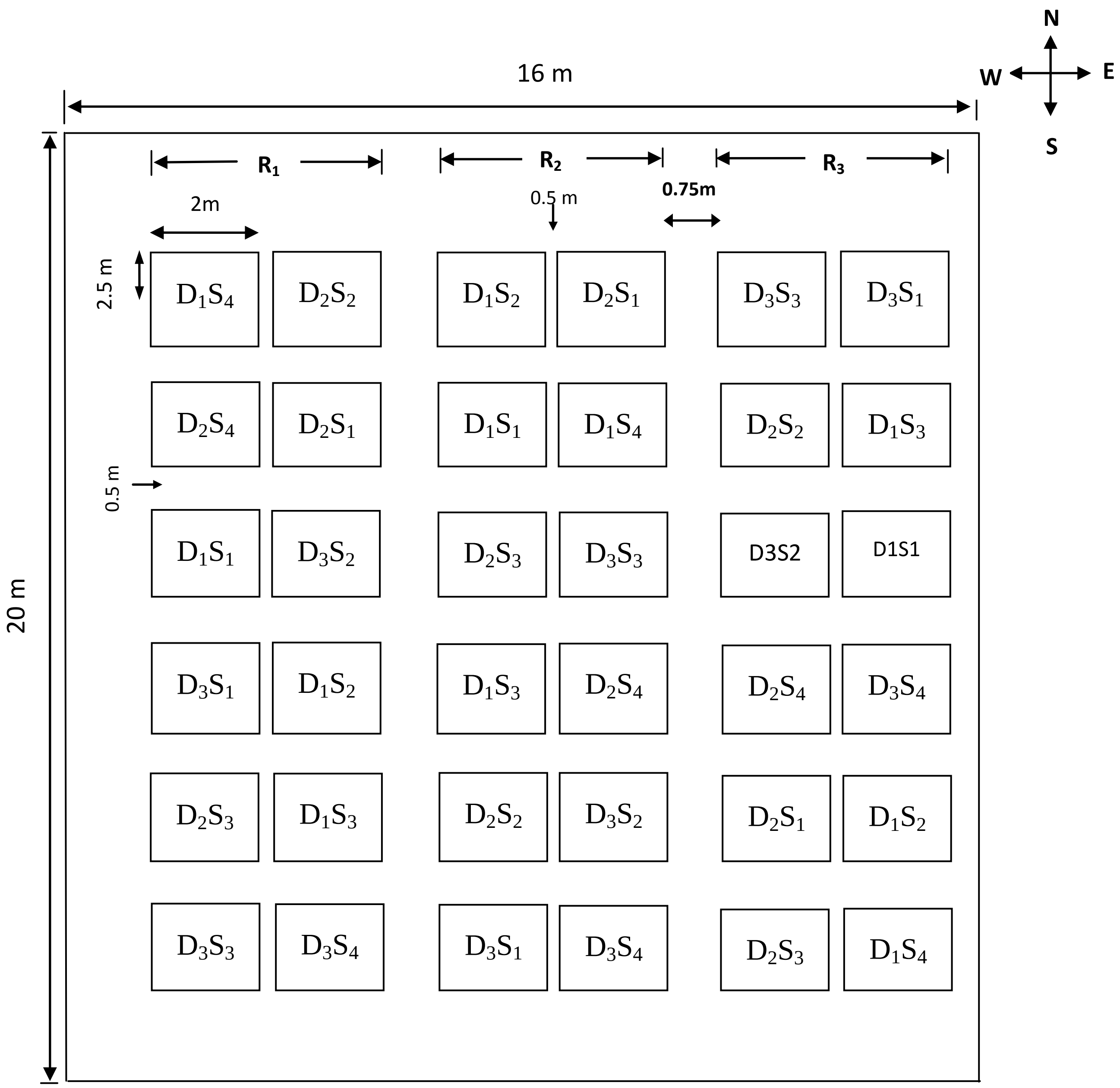
i. 2 cm
ii. 4 cm
iii. 8 cm

Factor B: Row spacings

i. 15 cm
ii. 20 cm
iii. 25 cm
iv. 30 cm

3.7 Experimental design

The experiment was laid out in Randomized Complete Block Design (RCBD) with three replications. The experimental field was divided into 3 blocks. Each block was again divided into 12 plots. The total numbers of unit plots of the experiment were 36 (3 × 12). The size of the unit plot was 2.5 m × 2 m (5 m^2). The treatments were randomly distributed to each block following the experimental design (Figure 1).



Unit plot size = 2.5 m × 2 m, Legend:

Plot spacing = 0.5 m $D_{1=}$ 2 cm, $D_{2=}$ 4 cm, $D_{3=}$ 8 cm

Between replication = 0.75 m $S_{1=}$ 15 cm, $S_{2=}$ 20 cm, $S_{3=}$ 25 cm, $S_{4=}$ 30 cm

Figure 1: Field layout of the experiment in Randomized Complete Block Design (RCBD).

3.8 Seed collection

The seeds of the crop were collected from Bangladesh Agricultural Research Institute (BARI), Joydebpur, Gazipur.

3.9 Preparation of the field

The selected plot for the experiment was opened in 20 November, 2013 with a power tiller and was exposed to the sun for a week. Larger clods were broken into small pieces. Weeds and stubbles were removed. Final ploughing and land preparation were done on 27 November, 2013 and a desired tilth was obtained finally for seed sowing. Layout was done as per experimental design on 29 November, 2013.

3.10 Fertilizer application

The field was fertilized with Urea, TSP, MoP and Gypsum. The full doses of all fertilizers and one third of urea were applied as basal dose to the individual plot during final land preparation. The first split of urea was applied at crown root initiation (21 days after sowing) stage and the second split of urea was applied at prior to spike initiation stage (55 days after sowing) as top dressing.

Nutrient	Source	Dose (kg ha^{-1})
N (Nitrogen)	Urea (46% N)	220
P (Phosphorus)	TSP (20% P_2O_5)	180
K (Potassium)	MoP (50% K_2O)	50
S (Sulphur)	Gypsum (18% S)	120

Source: Krishi Projukti Hatboi (BARI, 2008)

3.11 Sowing of seeds

Seeds were sown continuously in line on 30 November, 2013 as per experimental treatment. After sowing, seeds were covered with soil and slightly pressed by hand.

3.12 Intercultural operations

The details of different cultural operations performed during the course of experimentation are given below:

3.12.1 Irrigation and drainage

The experimental field was irrigated with adequate water and was maintained throughout the crop growth period. Two irrigations were given at crown root initiation (21 days after sowing) stage and prior to spike initiation stage (55 days after sowing). A good drainage facility was also maintained for immediate release of excess water from the field.

3.12.2 Weeding

The experimental plots were infested with some common weeds, which were removed twice by uprooting. First weeding was done from each plot at 20 DAS and second weeding was done from each plot at 55 DAS.

3.12.3 Plant protection measures

Plants were infested with aphid; which was successfully controlled by application of insecticides such as Malathion 57 EC @ 2 ml/liter of water. Crop was protected from birds and rats during the grain-filling period. For controlling birds, a guard was deploid especially during February to harvest.

3.13 Harvesting and post-harvest operation

The wheat plant was harvested depending upon the maturity of plant. Harvesting was done manually from each plot on 16 March, 2014. Maturity of crop was determined when 80% of the grains become white shiny in color. The harvested crop of each plot was bundled separately, tagged properly and brought to the threshing floor. Proper care was taken for harvesting, threshing and cleaning of wheat seeds. Fresh weight of grain and straw were recorded plot wise. The grains were cleaned and sun dried. The weight was adjusted to a moisture content of 12%. Straw was also sun dried properly. Finally, grain and straw yield m^{-2} were recorded and converted to t ha^{-1}.

3.14 Recording of plant data

During the study period, data were recorded on physical characteristics and yield components for all the treatments on five randomly selected plants per plot in each replication as follows:

3.14.1 Germination parameters

a) Emerged seedling m^{-2}

3.14.2 Stand establishment parameters

a) Seedling length (cm)
b) Root length $seedling^{-1}$ (cm)
c) Roots $plant^{-1}$ (no.)

3.14.3 Crop growth parameters

a) Plant height (cm)
b) Leaves $plant^{-1}$ (no.)
c) Total dry matter weight $plant^{-1}$ (g)
d) Days to 50% flowering
e) Tillers $plant^{-1}$ (no.)

3.14.4 Yield contributing parameters

a) Spike length (cm)
b) Spikelet $spike^{-1}$ (no.)

c) Grains spike^{-1} (no.)

d) Weight of 1000-grains (g)

3.14.5 Harvest yields

a) Grain yield (t ha^{-1})

b) Straw yield (t ha^{-1})

c) Biological yield (t ha^{-1})

d) Harvest index (%)

3.15 Procedure of recording data

Emerged seedling m^{-2}

The seedling m^{-2} was recorded in number (no.) at the time of 5, 8, 11and 14 DAS. A quadrate of 1 m^{2} was placed at three different spots of each plot. The seedling m^{-2} was determined by counting the number of seedling for 1 m^{2}.

Seedling length (cm)

Seedling length was recorded at 11, 14 and 17 DAS. Data were recorded as the average of 5 plants selected at random of each plot. The length of the seedling was determined by measuring the distance from the base to the tip of the leaves by uprooting the seedling.

Root length (cm)

Root length was recorded at 11, 14 and 17 DAS. Data were recorded as the average of 5 plants selected at random of each plot. The length of the root was determined by measuring the distance from the base to the tip of the root by uprooting the seedling.

Roots plant^{-1} (no.)

The number of total roots plant^{-1} was recorded at 11, 14 and 17 DAS by counting total roots as the average of 5 plants selected at random by uprooting the seedling.

Plant height (cm)

The height of plant was recorded at 32, 42, 52, 62, 72 DAS and at harvest. Data were recorded as the average of 5 plants selected at random in each plot. The height of the plant was determined by measuring the distance from the soil surface to the tip of the leaves before spike initiation and to the tip of spike after spike initiation.

Leaves plant^{-1} (no.)

The number of leaves plant^{-1} was recorded at 32, 42, 52, 62, 72 DAS and at harvest by counting total leaves as the average of 5 plants selected at random of each plot.

Total dry matter weight plant^{-1} (g)

Total dry matter weight plant^{-1} was recorded at 32, 42, 52, 62, 72 DAS and at harvest by drying plant samples. The plant samples were oven dried at 72°C temperature until a constant level from which the weight of total dry matter were recorded. Data were recorded as the average of 5 sample plant plot^{-1} selected at random and expressed in gram.

Total tillers plant^{-1} (no.)

The number of total tillers plant^{-1} was recorded at 32, 42, 52, 62, 72 DAS and at harvest by counting total tillers as the average of 5 plants selected at random of each plot.

Days to 50% flowering

Days to 50% flowering were considered when 50% of the plants within a plot were showed up with spikes. The number of days to 50% flowering was recorded from the date of sowing.

Spike length (cm)

Measurement of spike length was taken from base of the spike to the tip of the spikelet. Each observation was an average of 5 spikes.

Spikelet spike^{-1} (no.)

The total number of spikelet spike^{-1} was collected from the randomly selected 5 plants in each plot and then average number of spikelet spike^{-1} was calculated.

Grains spike^{-1} (no.)

The total number of grains was collected from the randomly selected 5 plants in each plot and then average number of grains spike^{-1} was calculated.

Weight of 1000-grains (g)

One thousand cleaned dried seeds were counted randomly from the total cleaned harvested grains of each individual plot and then weighed with a digital electric balance at the stage the grain retained approximately 12% moisture and the mean weight were expressed in gram.

Grain yield (t ha^{-1})

The grain of each plot, 1 m^2 was harvested, cleaned, threshed, dried in the sun for 2 days and weighed. Finally, grain yield m^{-2} was converted and expressed in t ha^{-1} on approximately 12% moisture basis.

Straw yield (t ha^{-1})

The dry weight of straw of each plot, 1 m^2 was harvested, cleaned, threshed, dried in the sun for 2 days and weighed. Finally, straw yield m^{-2} was converted and expressed in t ha^{-1}.

Biological yield (t ha^{-1})

Biological yield is the summation of grain yield and straw yield. It was calculated as the following formula:

Biological yield (t ha^{-1}) = (Grain yield + Straw yield) t ha^{-1}.

Harvest index (%)

Harvest index denotes the ratio of economic yield to biological yield and was calculated with the following formula:

$$\text{Harvest index (\%)} = \frac{\text{Economic yield}}{\text{Biological Yield}} \times 100$$

It was expressed in percentage.

3.16 Statistical analysis

The data obtained for different characters were statistically analyzed following the analysis of variance (ANOVA) techniques to obtain the level of significance by using MSTAT-C computer package program. The significant differences among the treatment means were compared by Least Significant Difference (LSD) at 5% levels of probability.

Chapter 4

Results and Discussion

Chapter 4

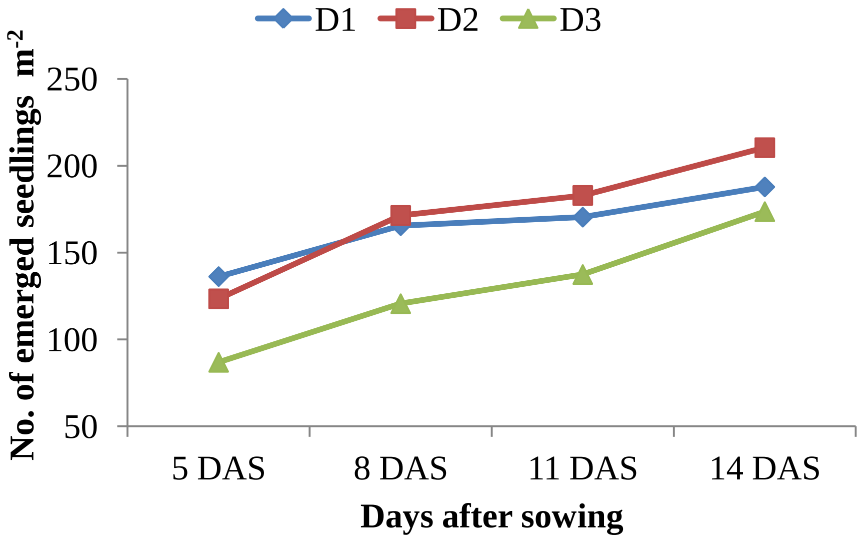
RESULTS AND DISCUSSION

The results obtained with different sowing depths and row spacings and their combinations are presented and discussed in this chapter. Data about germination, stand establishment, growth parameters, yield contributing characters and grain yield of wheat have been presented in both Tables and Figures and analyzes of variance and corresponding degrees of freedom have been shown in the Appendix.

4.1 Emerged seedlings m^{-2}

4.1.1 Effect of sowing depth

Different sowing depths had significant effect on number of emerged seedling m^{-2} of wheat (Figure 2 and Appendix IV). At 5 DAS the highest number of emerged seedlings m^{-2} (136.2) were obtained from 2 cm sowing depth which was statistically similar with 4 cm sowing depth and the lowest number of emerged seedlings m^{-2} (86.86) was recorded from 8 cm sowing depth. At 8 and 11 DAS the highest number of emerged seedlings m^{-2} (171.4 and 182.9, respectively) were obtained from 4 cm sowing depth which was statistically similar with 2 cm sowing depth and lowest number of emerged seedlings m^{-2} (120.6 and 137.4, respectively) were recorded from 8 cm sowing depth. At 14 DAS the highest number of emerged seedlings m^{-2} (210.4) was recorded from 4 cm sowing depth and lowest number of emerged seedlings m^{-2} (173.6) was found at 8 cm sowing depth which was statistically similar with 2 cm sowing depth. This findings is similar with Seeiso *et al.* (2011); Azad (1999). Seeiso *et al.* (2011) reported that the emergence percentage declined as the depth of sowing increased. Azad (1999) mentioned that sowing depth influenced the emergence of seedling. On the other hand, Yagmur (2009) observed that seedling establishment was greatest among plants sown at 5 and 7 cm.



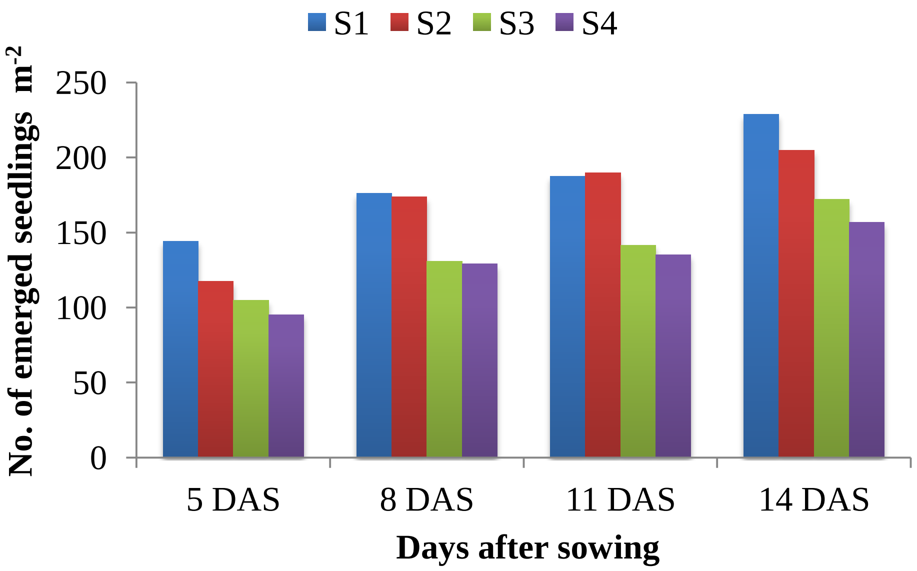
D_1=2 cm; D_2=4 cm; D_3=8 cm

Figure 02. Effect of sowing depth on the number of emerged seedlings m^{-2}

(LSD $_{(0.05)}$ =13.26, 13.15, 16.25 and 16.39 at 5, 8, 11 and 14 DAS, respectively)

4.1.2 Effect of row spacing

Different row spacings had significant effect on number of emerged seedlings m^{-2} of wheat (Figure 3 and Appendix IV). At 5 DAS the highest number of emerged seedlings m^{-2} (144.3) were obtained from 15 cm row spacing and the lowest number of emerged seedlings m^{-2} (95.30) were recorded from 30 cm row spacing which was statistically similar with 25 cm row spacing. At 8 DAS highest number of emerged seedlings m^{-2} (176.2) were obtained from 15 cm row spacing which was statistically similar with 20 cm row spacing and the lowest (129.2) were recorded from 30 cm row spacing which was statistically similar with 25 cm row spacing. At 11 DAS highest number of emerged seedlings m^{-2} (189.7) were obtained from 20 cm row spacing which was statistically similar with 15 cm row spacing and the lowest number of emerged seedlings m^{-2} (135.3) were recorded from 30 cm row spacing which was statistically similar with 25 cm row spacing. At 14 DAS the highest number of emerged seedlings m^{-2} (228.9) were recorded from 15 cm row spacing and the lowest number of emerged seedlings m^{-2} (156.7) were found 30 cm row spacing which was statistically similar with 25 cm row spacing.



S_1=15 cm; S_2=20 cm; S_3=25cm; S_4=30 cm

Figure 03. Effect of row spacing on the number of emerged seedlings m^{-2} of wheat. LSD $_{(0.05)}$ = 15.32, 15.19, 18.77 and 18.92 at 5, 8, 11, and 14 DAS, respectively)

4.1.3 Interaction effect of sowing depth and row spacing

Interaction of sowing depths and row spacings showed significant effect on number of emerged seedlings m^{-2} (Table 1 and Appendix IV). At 5 DAS the highest number of emerged seedlings m^{-2} (180.9) were recorded from the combination of 2 cm sowing depth with 15 cm row spacing and the lowest (71.78) were recorded from 8 cm sowing depth with 30 cm row spacing. At 8 DAS the highest number of emerged seedlings m^{-2} (217.2) were recorded from combination of 4 cm sowing depth with 20 cm row spacing and the lowest (116.4) were recorded from 8 cm sowing depth with 25 cm row spacing. At 11 DAS the highest number of emerged seedlings m^{-2} (235.7) were recorded from combination of 4 cm sowing depth with 20 cm row spacing and the lowest

(129.3) were recorded from 8 cm sowing depth with 30 cm row spacing. At 14 DAS the highest number of emerged seedlings m^{-2} (264.4) were recorded from the combination of 4 cm sowing depth with 15 cm row spacing and the lowest (151.4) were recorded from 8 cm sowing depth with 30 cm row spacing.

Table 1. Interaction effect of sowing depths and row spacings on number of emerged seedlings m^{-2} of wheat

Treatment combination	Number of emerged seedlings m^{-2} at			
	5 DAS	8 DAS	11 DAS	14 DAS
D_1S_1	180.9 a	202.7ab	215.3 ab	243.0 ab
D_1S_2	141.6 bc	181.9 b	183.6 b	185.8 de
D_1S_3	119.0 cd	139.9 c	148.0 c	170.7 d-f
D_1S_4	103.3 de	137.7 c	134.7 c	151.9 f
D_2S_1	168.0 ab	200.3ab	210.9 ab	264.4 a
D_2S_2	114.1 d	217.2 a	235.7 a	229.7 bc
D_2S_3	100.9 de	136.1 c	143.1 c	180.6 d-f
D_2S_4	110.8 d	131.9 c	141.8 c	166.9 d-f
D_3S_1	83.89 e-f	125.7 c	136.7 c	179.1 d-f
D_3S_2	96.67 d-f	122.1 c	150.0 c	199.1 cd
D_3S_3	95.11 d-f	116.4 c	133.8 c	164.7 ef
D_3S_4	71.78 f	118.1 c	129.3 c	151.4 f
LSD $_{(0.05)}$	26.53	26.31	32.51	32.77
CV (%)	13.56	10.19	11.74	10.15

D_1=2 cm; D_2=4 cm; D_3=8 cm
S_1=15 cm; S_2=20 cm; S_3=25cm; S_4=30 cm

4.2 Seedling length (cm)

4.2.1 Effect of sowing depth

The length of seedling was significantly influenced by different sowing depths except 11 DAS (Table 2). At 14 and 17 DAS the highest seedling length (19.02 cm and 21.43 cm, respectively) was obtained from 4 cm sowing depth which was statistically similar with 2 cm sowing depth and the lowest Seedling length

(17.34 and 19.37 cm, respectively) was recorded from 8 cm sowing depth which was statistically similar with 2 cm sowing depth.

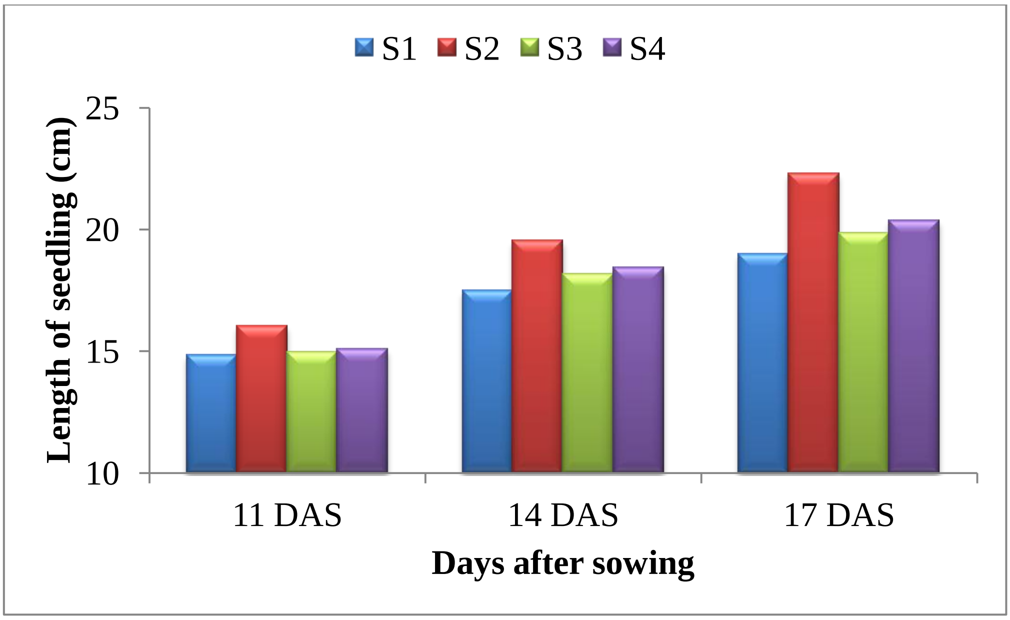
Table 2. Effect of sowing depth on length of seedling of wheat

Treatment	Length of seedling (cm) at		
	11 DAS	14 DAS	17 DAS
D_1	15.52	18.83 ab	20.36 ab
D_2	15.70	19.02 a	21.43 a
D_3	14.49	17.34 b	19.37 b
LSD $_{(0.05)}$	NS	1.56	1.88
CV (%)	13.45	10.01	10.86

D_1=2 cm; D_2=4 cm; D_3=8 cm

4.2.2 Effect of row spacing

Seedling length was significantly influenced by different row spacing except 11 DAS (Figure 4). At 14 DAS highest seedling length (19.54 cm) was obtained from 20 cm row spacing which was statistically similar with 25 cm and 30 cm row spacing and the lowest seedling length (17.49 cm) was recorded from 15 cm row spacing which was statistically similar with 25 cm and 30 cm row spacing. At 17 DAS highest seedling length (22.31cm) was obtained from 20 cm row spacing which was statistically similar with 30 cm row spacing and the lowest seedling length (19.00 cm) was recorded from 15 cm row spacing which was statistically similar with 25 cm and 30 cm row spacing.



S_1=15 cm; S_2=20 cm; S_3=25cm; S_4=30 cm

Figure 4. Effect of row spacing on the length of seedling of wheat at (LSD $_{(0.05)}$ = NS, 1.80 and 2.17 at 11, 14 and 17 DAS, respectively)

4.2.3 Interaction effect of sowing depth and row spacing

Interaction of sowing depth and row spacing showed significant effect on seedling length except 11 DAS (Table 3). At 14 and 17 DAS the highest seedling length (20.69 cm and 23.47 cm, respectively) were recorded from combination of 4 cm sowing depth and 20 cm row spacing and the lowest (16.09 cm and 17.43 cm, respectively) were recorded from 8 cm sowing depth with 15 cm row spacing.

Table 3. Interaction effect of sowing depth and row spacing on length of seedling of wheat

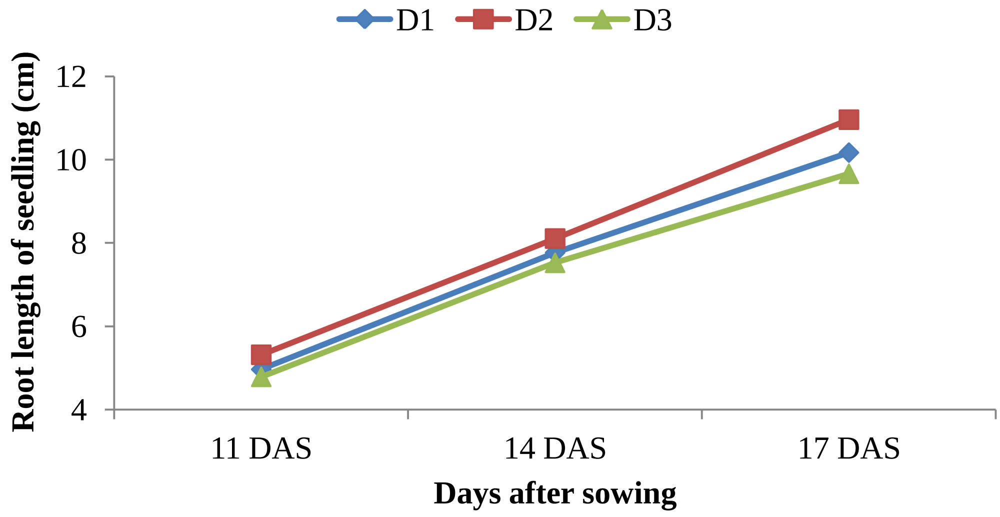
Treatment combination	Length of seedling (cm) at		
	11 DAS	14 DAS	17 DAS
D_1S_1	15.30	18.17 a-c	19.16 bc
D_1S_2	16.09	19.59 ab	22.15 ab
D_1S_3	15.46	18.72 a-c	19.91 a-c
D_1S_4	15.24	18.85 a-c	20.21 a-c
D_2S_1	15.45	18.21 a-c	20.39 a-c
D_2S_2	16.37	20.69 a	23.47 a
D_2S_3	15.53	18.69 a-c	20.97 a-c
D_2S_4	15.47	18.50 a-c	20.91 a-c
D_3S_1	13.79	16.09 c	17.43 c
D_3S_2	15.67	18.34 a-c	21.31 ab
D_3S_3	13.94	17.02 bc	18.74 bc
D_3S_4	14.59	17.92 a-c	19.99 a-c
LSD $_{(0.05)}$	NS	3.12	3.75
CV (%)	13.45	10.01	10.86

D_1=2 cm; D_2=4 cm; D_3=8 cm
S_1=15 cm; S_2=20 cm; S_3=25cm; S_4=30 cm

4.3 Root length of seedling (cm)

4.3.1 Effect of sowing depth

Root length of seedling was significantly influenced by different sowing depths except 14 DAS (Figure 5). At 11 DAS the highest root length of seedling (5.32 cm) was obtained from 4 cm sowing depth which was statistically similar with 2 cm sowing depth and the lowest root length of seedling (4.79) was recorded from 8 cm sowing depth which was statistically similar with 2 cm sowing depth. At 17 DAS the highest root length of seedling (10.96 cm) was obtained from 4 cm sowing depth and the lowest root length of seedling (9.66 cm) was recorded from 8 cm sowing depth which was statistically similar with 2 cm sowing depth.

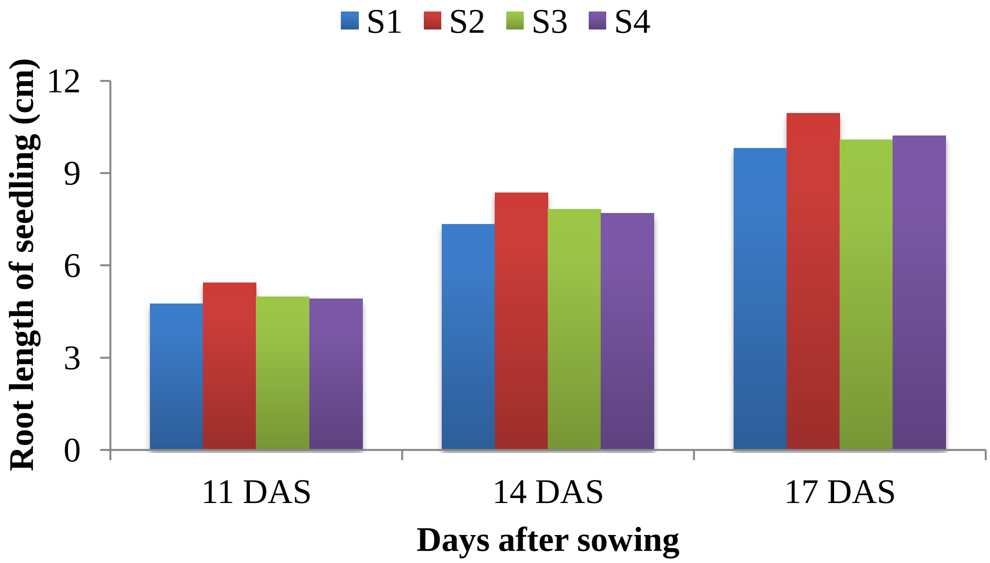


D_1=2 cm; D_2=4 cm; D_3=8 cm

Figure 5. Effect of sowing depth on the root length of seedling of wheat (LSD $_{(0.05)}$ = 0.41, NS and 0.73 at 11, 14 and 17 DAS, respectively)

4.3.2 Effect of row spacing

Root length of seedling was significantly influenced by different row spacing (Figure 6). At 11 DAS the highest root length of seedling (5.44 cm) was obtained from 20 cm row spacing which was statistically similar with 25 cm row spacing and the lowest root length of seedling (4.76 cm) was recorded from 15 cm row spacing which was statistically similar with 25 cm and 30 cm row spacing. At 14 DAS the highest root length of seedling (8.36 cm) was obtained from 20 cm row spacing which was statistically similar with 25 cm and 30 cm row spacing and the lowest root length of seedling (7.33 cm) was recorded from 15 cm row spacing which was statistically similar with 25 cm and 30 cm row spacing. At 17 DAS highest root length of seedling (10.94 cm) was obtained from 20 cm row spacing which was statistically similar with 30 cm row spacing and the lowest root length of seedling (9.80 cm) was recorded from 15 cm row spacing which was statistically similar with 25 cm and 30 cm row spacing.



S_1=15 cm; S_2=20 cm; S_3=25cm; S_4=30 cm

Figure 6. Effect of row spacing on the root length of seedling of wheat (LSD $_{(0.05)}$ = 0.47, 0.70 and 0.85 at 11, 14 and 17 DAS, respectively)

4.3.3 Interaction effect of sowing depth and row spacing

Interaction of sowing depth and row spacing showed significant effect on root length of seedling (Table 4). At 14 DAS the highest root length of seedling (5.99 cm) was recorded from combination of 4 cm sowing depth and 20 cm row spacing which was statistically similar with D_1S_2, D_2S_3, D_2S_4 and the lowest (4.10 cm) was recorded from 2 cm sowing depth with 25 cm row spacing. At 14 and 17 DAS the highest root length of seedling (8.71 and 7.08 cm, respectively) were recorded from combination of 4 cm sowing depth and 20 cm row spacing and the lowest (7.08 and 9.32 cm, respectively) was recorded from 8 cm sowing depth and 15 cm row spacing.

Table 4. Interaction effect of sowing depth and row spacing on root length of seedling of wheat

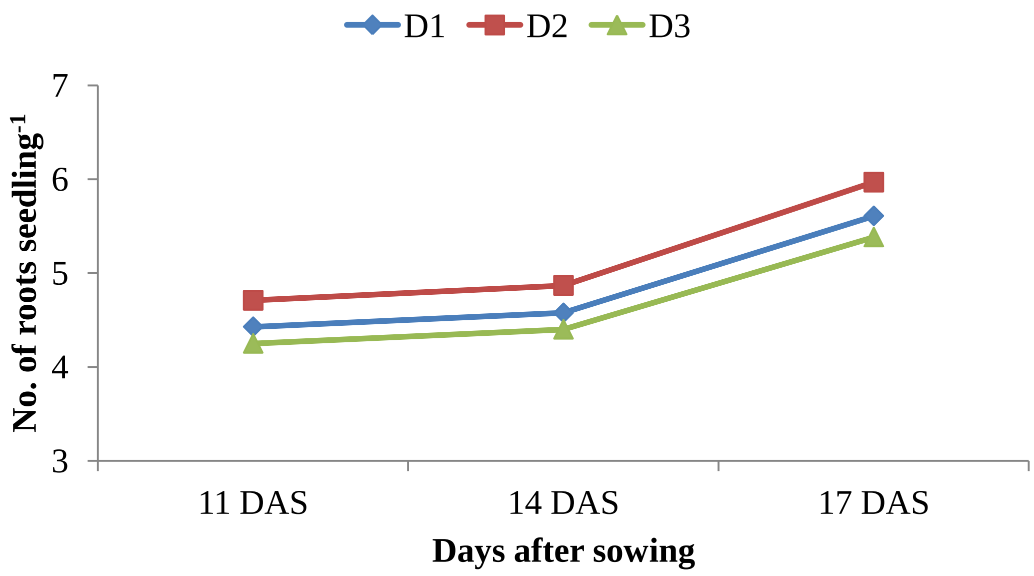
Treatment combination	Root length of seedling (cm) at		
	11 DAS	14 DAS	17 DAS
D_1S_1	4.80 b	7.29 bc	9.54 cd
D_1S_2	5.38 ab	8.34 ab	11.03 ab
D_1S_3	5.10 b	7.68 a-c	9.82 b-d
D_1S_4	4.59 b	7.76 a-c	10.29 b-d
D_2S_1	4.83 b	7.62 a-c	10.55 a-d
D_2S_2	5.99 a	8.71 a	11.83 a
D_2S_3	5.19 ab	8.26 a-c	10.87 a-c
D_2S_4	5.27 ab	7.84 a-c	10.59 a-d
D_3S_1	4.65 b	7.08 c	9.32 d
D_3S_2	4.96 b	8.02 a-c	9.95 b-d
D_3S_3	4.65 b	7.52 a-c	9.57 b-d
D_3S_4	4.89 b	7.48 bc	9.79 b-d
$LSD_{(0.05)}$	0.81	1.21	1.47
CV (%)	9.56	9.13	8.44

D_1=2 cm; D_2=4 cm; D_3=8 cm
S_1=15 cm; S_2=20 cm; S_3=25cm; S_4=30 cm

4.4 Number of roots seedling^{-1}

4.4.1 Effect of sowing depth

Number of roots seedling^{-1} of wheat varied significantly due to sowing depths (Figure 7). At 11 and 17 DAS maximum number of roots seedling^{-1} (4.71 and 5.97 cm, respectively) were recorded from 4 cm sowing depth whereas minimum (4.25 and 5.38 cm, respectively) were recorded for 8 cm sowing depth which was statistically similar with 2 cm sowing depth. At 14 DAS maximum number of roots seedling^{-1} (4.87) was obtained for 4 cm sowing depth which was statistically similar with 2 cm sowing depth. On the other hand, minimum number of roots seedling^{-1} (4.40) was obtained for 8 cm sowing depth which was statistically similar with 2 cm sowing depth.



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D_1=2 cm; D_2=4 cm; D_3=8 cm

Figure 7. Effect of sowing depth on the no. of roots seedling^{-1} of wheat (LSD $_{(0.05)}$ = 0.27, 0.37 and 0.33 at 11, 14 and 17 DAS, respectively)

4.4.2 Effect of row spacing

Different row spacing had significant effect on number of roots seedling^{-1} (Table 5). Results showed that the highest number of roots seedling^{-1} (4.89) at 11 DAS was observed in 20 cm row spacing which was statistically similar with 30 cm row spacing. On the other hand, the lowest number of roots seedling^{-1} (4.07) was obtained from 15 cm row spacing. At 14 and 17 DAS, the highest number of roots seedling^{-1} (5.07 and 6.00, respectively) was observed in 20 cm row spacing which was statistically similar with 30 cm row spacing and the lowest number of roots seedling^{-1} (4.28 and 5.33, respectively) was obtained from 15 cm row spacing which was statistically similar to 25 cm row spacing and 30 cm row spacing.

Table 5. Effect of row spacing on number of roots seedling^{-1} of wheat

Treatment	Number of roots seedling^{-1} at		
	11 DAS	14 DAS	17 DAS
S_1	4.07 c	4.28 b	5.33 b
S_2	4.82 a	5.07 a	6.00 a
S_3	4.38 b	4.47 b	5.58 b
S_4	4.58 ab	4.64 ab	5.70 ab
LSD $_{(0.05)}$	0.31	0.43	0.38
CV (%)	7.05	9.45	6.86

S_1=15 cm; S_2=20 cm; S_3=25cm; S_4=30 cm

4.4.3 Interaction effect of sowing depth and row spacing

Number of roots seedling^{-1} was significantly varied due to interaction of different sowing depth and row spacing (Table 6). At 11 DAS, the highest number of roots seedling^{-1} (5.20) was recorded from combination of 4 cm sowing depth with 20 cm row spacing which was statistically similar to D_1S_2, D_2S_4 and the lowest (3.93) was recorded from 8 cm sowing depth with 15 cm row spacing. At 14 DAS, the highest number of roots seedling^{-1} (5.47) was recorded from combination of 4 cm sowing depth with 20 cm row spacing which was statistically similar to D_1S_2, D_2S_4, D_3S_2 and the lowest (4.07) was recorded from 8 cm sowing depth with 15 cm row spacing. At 17 DAS, the highest number of roots seedling^{-1} (6.60) was recorded from combination of 4 cm sowing depth with 20 cm row spacing and the lowest (5.20) was recorded from 8 cm sowing depth with 15 cm row spacing.

Table 6. Interaction effect of sowing depth and row spacing on no. of roots seedling^{-1} of wheat

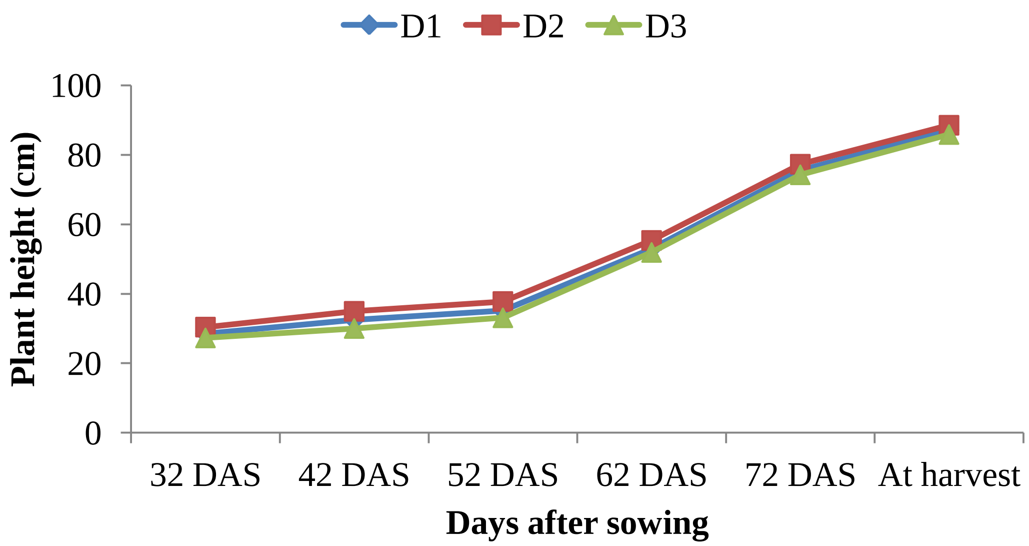
Treatment combination	Number of roots seedling^{-1} at		
	11 DAS	14 DAS	17 DAS
D_1S_1	4.07 de	4.23 cd	5.33 bc
D_1S_2	4.73 a-c	5.00 ab	5.80 bc
D_1S_3	4.40 b-e	4.47 b-d	5.53 bc
D_1S_4	4.51 b-d	4.60 b-d	5.77 bc
D_2S_1	4.20 de	4.53 b-d	5.47 bc
D_2S_2	5.20 a	5.47 a	6.60 a
D_2S_3	4.53 b-d	4.60 b-d	5.87 b
D_2S_4	4.90 ab	4.87 a-c	5.93 b
D_3S_1	3.93 e	4.07 d	5.20 c
D_3S_2	4.53 b-d	4.73 a-d	5.60 bc
D_3S_3	4.20 de	4.33 b-d	5.33 bc
D_3S_4	4.33 c-e	4.47 b-d	5.40 bc
LSD $_{(0.05)}$	0.53	0.74	0.66
CV (%)	7.05	9.45	6.86

D_1=2 cm; D_2=4 cm; D_3=8 cm
S_1=15 cm; S_2=20 cm; S_3=25cm; S_4=30 cm

4.5 Plant height (cm)

4.5.1 Effect of sowing depth

Plant height of wheat differed significantly due to different sowing depth at 32, 42 and 52 DAS but it was not significant at 62, 72 DAS and at harvest (Figure 8). At 32, 42 and 52 DAS highest plant height (30.41, 34.95 and 37.78, respectively) was obtained from 4 cm sowing depth. At 32 and 52 DAS the lowest plant height (27.30 and 33.09 cm) was recorded from 8 cm sowing depth which was statistically similar with 2 cm sowing depth. On the other hand, at 42 DAS the lowest plant height (30.01 cm) was found at 8 cm sowing depth. Similar result was observed by Vedrov and Frolov (1990) who reported that epicotyle length increased and plant height decreased with increasing sowing depth. At 62, 72 DAS and at harvest, there was no significant difference in plant height. At 62, 72 DAS and at harvest, maximum plant height (55.35, 77.28 and 88.50 cm, respectively) at 4 cm depth and the minimum (51.90, 74.25 and 85.84 cm, respectively) was recorded at 8 cm depth. These treatments on plant height were similar over the growing season. Such opinion was also given by Azad (1999) who mentioned that sowing depth failed to show any significant influence on plant height. Silva (1991) reported that plant height was not significantly affected by sowing depth.



D_1=2 cm; D_2=4 cm; D_3=8 cm

Figure 8. Effect of sowing depth on the plant height of wheat (LSD $_{(0.05)}$ = 1.80, 1.79, 2.16, NS, NS and NS at 32, 42, 52, 62, 72 DAS and at harvest, respectively)

4.5.2 Effect of row spacing

Row spacing had significant effect on plant height at 32, 42 and 52 DAS but none of the row spacing were significant with respect to plant height at 62, 72 DAS and at harvest (Table 7). At 32, 42 and 52 DAS the tallest plant (30.46, 33.98 and 37.13 cm, respectively) were observed from 20 cm row spacing which was statistically at par with 25 cm and 30 cm row spacing. However, the shortest plant (27.06, 31.19 and 33.56 cm, respectively) was observed from 15cm row spacing. Younas (1993) also observed that plant height was significantly affected by different planting patterns. Rajput *et al.* (1989) reported that plant height was increased with increase in row spacing whereas, Pandey *et al.* (2013) observed that plant height was not affected significantly by row spacing.

Table 7. Effect of row spacing on the plant height of wheat

Treatment	Plant height (cm) at					
	32 DAS	42 DAS	52 DAS	62 DAS	72 DAS	Harvest
S_1	27.06 b	31.19 b	33.56 b	51.60	73.31	85.79
S_2	30.46 a	33.98 a	37.13 a	55.35	77.54	89.30
S_3	28.40 ab	31.97 ab	35.08 ab	52.94	75.69	86.20
S_4	29.11 ab	32.77 ab	35.64 ab	53.71	76.18	87.22
LSD $_{(0.05)}$	2.07	2.06	2.49	NS	NS	NS
CV (%)	7.38	6.5	7.21	9.5	7.79	5.96

S_1=15 cm; S_2=20 cm; S_3=25cm; S_4=30 cm

4.5.3 Interaction effect of sowing depth and row spacing

The interaction between sowing depth and row spacing was significant on plant height at 32, 42 and 52 DAS (Table 8). Maximum plant height was recorded from the treatment combination of 4 cm sowing depth and 20 cm row spacing (D_2S_2) at 32, 42 and 52 DAS (32.80, 36.93 and 40.68 cm, respectively) which was statistically similar with D_1S_2, D_2S_3 and D_2S_4 treatment combinations whereas the minimum plant height (25.73, 28.90 and 32.22 cm, respectively) were obtained from combination of 8 cm sowing depth with 15 cm row spacing (D_3S_1). None of the interaction was found significant with respect to plant height at 62 DAS, 72 DAS and at harvest.

Table 8. Interaction effect of sowing depth and row spacing on plant height of wheat

Treatment combination	Plant height (cm) at					
	32 DAS	42 DAS	52 DAS	62DAS	72 DAS	Harvest
D_1S_1	26.63 cd	31.73 c-e	33.98 cd	51.01	73.67	86.07
D_1S_2	29.97 a-c	33.67 a-c	36.66 a-c	54.71	77.80	88.67
D_1S_3	28.40 b-d	32.13 c-e	34.90 b-d	52.90	74.66	86.40
D_1S_4	29.20 b-d	32.36 b-e	35.19 b-d	53.18	75.92	87.00
D_2S_1	28.80 b-d	32.93 b-d	34.48 b-d	53.37	74.73	86.80
D_2S_2	32.80 a	36.93 a	40.68 a	58.01	80.60	92.15
D_2S_3	29.80 a-c	34.07 a-c	37.22 a-c	54.46	76.53	87.13
D_2S_4	30.25 ab	35.87 ab	38.74 ab	55.56	77.26	87.93
D_3S_1	25.73 d	28.90 e	32.22 d	50.40	71.53	84.50
D_3S_2	28.60 b-d	31.33 c-e	34.06 cd	53.33	74.23	87.07
D_3S_3	27.00 b-d	29.72 de	33.11 cd	51.47	75.87	85.07
D_3S_4	27.87 b-d	30.08 de	32.99 cd	52.40	75.37	86.73
$LSD_{(0.05)}$	3.59	3.57	4.32	NS	NS	NS
CV (%)	7.38	6.5	7.21	9.5	7.79	5.96

D_1=2 cm; D_2=4 cm; D_3=8 cm
S_1=15 cm; S_2=20 cm; S_3=25cm; S_4=30 cm

4.6 Number of leaves plant^{-1}

4.6.1 Effect of sowing depth

Number of leaves plant^{-1} of wheat varied significantly due to sowing depths at all stages of growth except 32 DAS (Table 9). At 42 DAS maximum number of leaves plant^{-1} (18.77) was recorded from 4 cm sowing depth whereas minimum (14.16) was recorded for 8 cm sowing depth. At 52 and 72 DAS maximum number of leaves plant^{-1} (27.06 and 26.55, respectively) was obtained for 4 cm sowing depth which was statistically similar with 2 cm sowing depth on the other hand, minimum number of leaves plant^{-1} (22.93 and 22.10, respectively) was obtained for 8 cm sowing depth which was statistically similar with 2 cm sowing depth. However, at 62 DAS, 4 cm sowing depth scored maximum number of leaves plant^{-1} (29.56) which was statistically similar with 2 cm sowing depth and minimum number of leaves plant^{-1} (25.44) was obtained form 8 cm sowing depth.

Table 9. Effect of sowing depth on number of leaves plant^{-1} of wheat

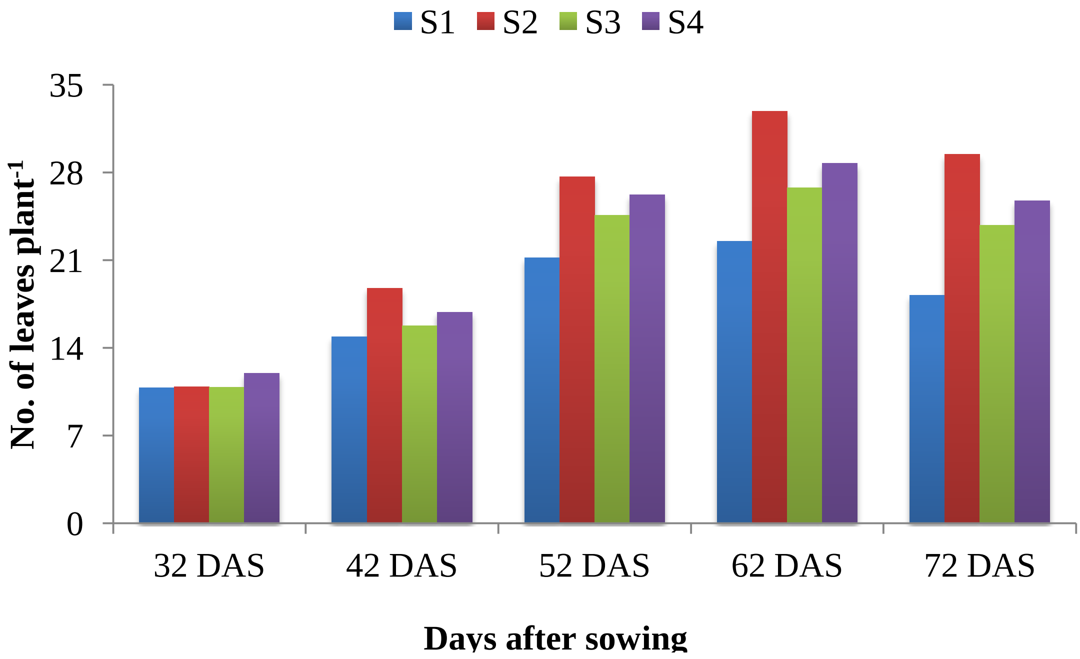
Treatment	Leaves plant^{-1}				
	32 DAS	42 DAS	52 DAS	62 DAS	72 DAS
D_1	11.08	16.85 b	24.78 ab	28.28 a	24.30 ab
D_2	11.37	18.77 a	27.06 a	29.56 a	26.55 a
D_3	11.03	14.16 c	22.93 b	25.44 b	22.10 b
LSD $_{(0.05)}$	NS	1.82	2.68	2.61	2.77
CV (%)	10.15	12.44	12.69	11.12	13.47

D_1=2 cm; D_2=4 cm; D_3=8 cm

4.6.2 Effect of row spacing

Row spacing had significant effect on number of leaves plant^{-1} throughout the growing period (Figure 9). Results showed that the highest number of leaves plant^{-1} (11.98) at 32 DAS was observed in 30 cm row spacing which was statistically similar with 20 cm and 25 cm row spacing. On the other hand, the lowest number of leaves plant^{-1} (10.84) was obtained from 15 cm row spacing, which was statistically similar to 20 cm and 25 cm row spacing. At 42 DAS, the highest number of leaves plant^{-1} (18.80) was observed in 20 cm row spacing which was statistically similar with 30 cm row spacing and the lowest number of leaves plant^{-1} (14.92) was obtained from 15 cm row spacing, which was statistically similar to 25 cm row spacing. At 52 DAS, highest number of leaves plant^{-1} (27.67) was observed in 30 cm row spacing which was statistically at par with 20 cm and 25 cm row spacing. On the other hand, the lowest number of leaves plant^{-1} (21.21) was obtained from 15 cm row spacing.

However, at 62 and 72 DAS highest number of leaves plant^{-1} (32.92 and 29 .47, respectively) was obtained from 20 cm row spacing and the lowest number of leaves plant^{-1} (22.54 and 18.24, respectively) was obtained from 15 cm row spacing. These results corroborated with the findings of Ahmed (2003) who showed that number of leaves plant^{-1} significantly influenced by row spacing.



S_1=15 cm; S_2=20 cm; S_3=25cm; S_4=30 cm

Figure 9. Effect of row spacing on the no. of leaves plant^{-1} of wheat (LSD $_{(0.05)}$ = 1.11, 2.10, 3.09, 3.02 and 3.20 at 32, 42, 52, 62 and 72 DAS, respectively)

4.6.3 Interaction effect of sowing depth and row spacing

Number of leaves plant^{-1} was significantly varied due to interaction of different sowing depth and row spacing (Table 10). At 32 DAS, the highest number of leaves plant^{-1} (12.67) was recorded from combination of 2 cm sowing depth with 30 cm row spacing and lowest (9.07) was recorded from 2 cm sowing depth with 20 cm row spacing. At 42, 52 and 62 DAS, interaction of 4 cm sowing depth with 20 cm row spacing recorded the highest number of leaves plant^{-1} (21.13, 30.53 and 36.25, respectively). On the other hand, the lowest number of leaves plant^{-1} at 42, 52 and 62 DAS (13.33, 19.33 and 19, respectively) was obtained from 8 cm sowing depth and 15 cm row spacing combination. At 72 DAS highest number of leaves plant^{-1} (33.47) was obtained from interaction of 4 cm sowing depth and 20 cm row spacing and the lowest number of leaves plant^{-1} (17.53) was obtained from combination of 4 cm sowing depth and 15 cm row spacing.

Table 10. Interaction effect of sowing depth and row spacing on no. of leaves plant^{-1} of wheat

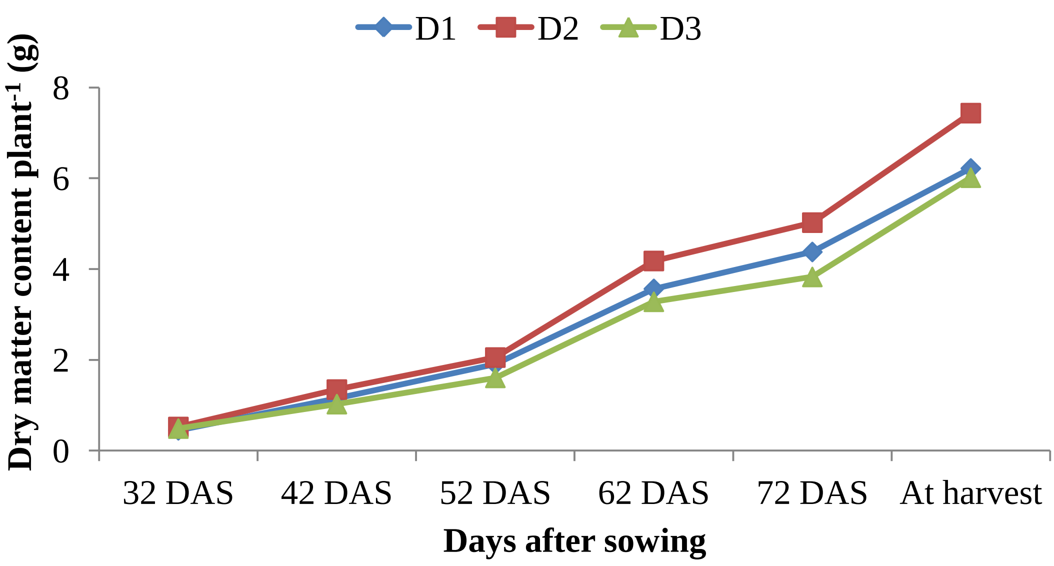
Treatment combination	Leaves plant^{-1} at				
	32 DAS	42 DAS	52 DAS	62 DAS	72 DAS
D_1S_1	11.87 ac	15.31 de	21.67 de	23.34 de	18.24 ef
D_1S_2	9.067 d	19.93 ab	27.00 ad	32.63 ab	29.47 ab
D_1S_3	10.73 bd	15.63 de	24.13 be	27.80 bd	23.80 cd
D_1S_4	12.67 a	16.53 b-e	26.33 ad	29.33 bc	25.77 bd
D_2S_1	10.53 cd	16.13 c-e	22.62 c-e	25.27 cd	1.092 g
D_2S_2	11.73 ac	21.13 a	30.53 a	36.25 a	29.07 ac
D_2S_3	10.73 bd	18.33 a-d	27.07 a-c	27.33 cd	23.26 de
D_2S_4	12.47 ab	19.47 a-c	28.03 ab	29.39 bc	25.50 bd
D_3S_1	10.13 cd	13.33 e	19.33 e	19.00 e	17.53 f
D_3S_2	12.00 ac	15.33 de	25.47 ad	29.87 bc	33.47 a
D_3S_3	11.20 a-c	13.33 e	22.60 c-e	25.33 cd	27.20 bd
D_3S_4	10.80 a-d	14.65 e	24.33 be	27.57 bd	28.00 a-d
LSD $_{(0.05)}$	1.92	3.64	5.35	5.23	5.55
CV (%)	10.15	12.44	12.69	11.12	13.47

D_1=2 cm; D_2=4 cm; D_3=8 cm
S_1=15 cm; S_2=20 cm; S_3=25cm; S_4=30 cm

4.7 Total dry matter plant^{-1} (g)

4.7.1 Effect of sowing depth

The production of dry matter plant^{-1} was significantly influenced by different sowing depth (Figure 10). At 32 DAS, higher amount of total dry matter production plant^{-1} (0.52 g) was recorded from 4 cm sowing depth which was statistically similar with 8 cm sowing depth whereas lower amount (0.45 g) was recorded from 2 cm sowing depth. At 42 and 72 DAS the highest amount of dry matter production plant^{-1} (1.34 and 5.02 g, respectively) was obtained for 4 cm sowing depth and the lowest amount (1.03 and 3.83 g, respectively) was obtained from 8 cm sowing depth. At 52 DAS, 4 cm sowing depth showed higher amount of total dry matter production plant^{-1} (2.05 g) which was statistically similar with 2 cm sowing depth and lower amount (1.61 g) was obtained form 8 cm sowing depth. On the other hand higher amount of total dry matter production plant^{-1} (4.18 and 7.44 g at 62 DAS and at harvest, respectively) was recorded from 4 cm sowing depth and lower dry matter production (3.28 and 6.01 g at 62 DAS and at harvest, respectively) recorded from 8 cm sowing depth which was statistically similar with 2 cm sowing depth. The results uphold with the findings of Seeiso *et al.*(2011) who reported that seedlings from deep sown seeds produced low seedling biomass.

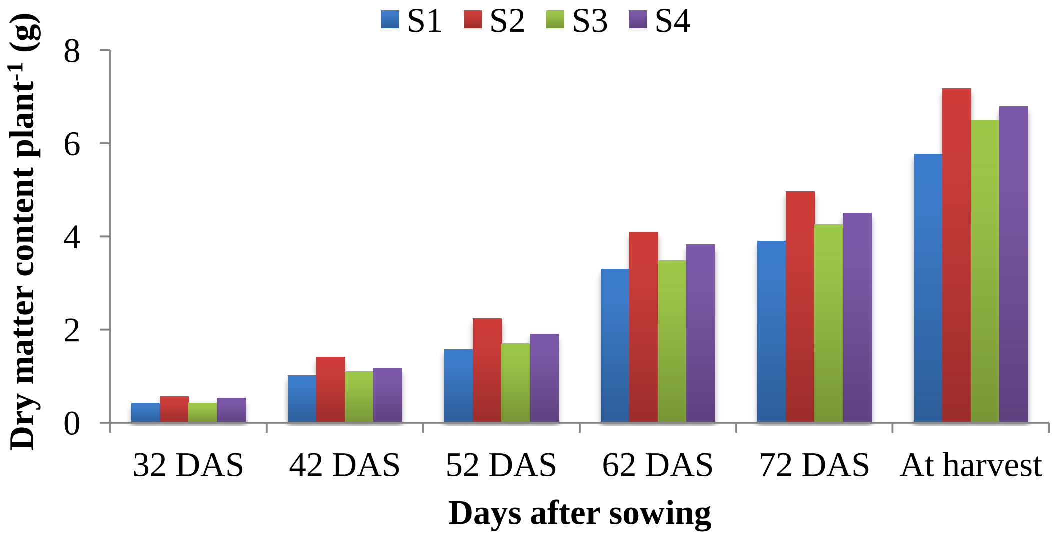


D_1=2 cm; D_2=4 cm; D_3=8 cm

Figure 10. Effect of sowing depth on the dry matter content plant^{-1} of wheat (LSD $_{(0.05)}$ = 0.05, 0.12, 0.19, 0.33, 0.40 and 0.50 at 32, 42, 52, 62, 72 DAS and at harvest, respectively)

4.7.2 Effect of row spacing

Different row spacing had significant effect on total dry matter production plant^{-1} (Figure 11). Results showed that the highest total dry matter production plant^{-1} (0.57 g) was observed in 20 cm row spacing at 32 DAS which was statistically similar with 30 cm row spacing and lowest was recorded from 25 cm row spacing which was statistically similar with 15 cm row spacing. However, At 42, 52 and 72 DAS the highest dry matter production plant^{-1} (1.41, 2.24 and 4.97 g, respectively) was obtained from 20 cm row spacing and the lowest (1.01, 1.57 and 3.91 g, respectively) was obtained from 15 cm row spacing which was statistically at par with 25 cm row spacing. At 62 DAS, the highest dry matter production plant^{-1} (4.09 g) was observed in 20 cm row spacing which was statistically similar with 30 cm row spacing and the lowest dry matter production plant^{-1} (3.30 g) was obtained from 15 cm row spacing, which was statistically similar to 25 cm row spacing. On the other hand, at harvest, the highest dry matter production plant^{-1} (7.17 g) was observed in 20 cm row spacing which was statistically at par with 30 cm row spacing and the lowest (5.767 g) was obtained from 15 cm row spacing.



S_1=15 cm; S_2=20 cm; S_3=25cm; S_4=30 cm

Figure 11. Effect of row spacing on the dry matter content plant^{-1} of wheat (LSD $_{(0.05)}$ = 0.05, 0.14, 0.22, 0.38, 0.46 and 0.58 at 32, 42, 52, 62, 72 DAS and at harvest, respectively)

4.7.3 Interaction effect of sowing depth and row spacing

Interaction of sowing depth and row spacing showed significant effect on total dry matter production plant^{-1} (Table 11). At 32 DAS, the highest dry matter plant^{-1} (0.65 g) was recorded from combination of 4 cm sowing depth with 20 cm row spacing and the lowest (0.35 g) was recorded from 2 cm sowing depth with 25 cm row spacing which was statistically similar with D_2S_3 and D_3S_1 treatment combination. However, at 42, 52, 62, 72 DAS and at harvest interaction of 4 cm sowing depth with 20 cm row spacing recorded the highest total dry matter production plant^{-1} (1.63, 2.52, 4.67, 5.93 and 8.38 g, respectively). On the other hand, the lowest dry matter plant^{-1} at 42, 52, 62, 72 DAS and at harvest (0.88, 1.44, 3.0, 3.45 and 5.42 g, respectively) was obtained from 8 cm sowing depth and 15 cm row spacing combination.

Table 11. Interaction effect of sowing depth and row spacing on dry matter content plant^{-1} of wheat

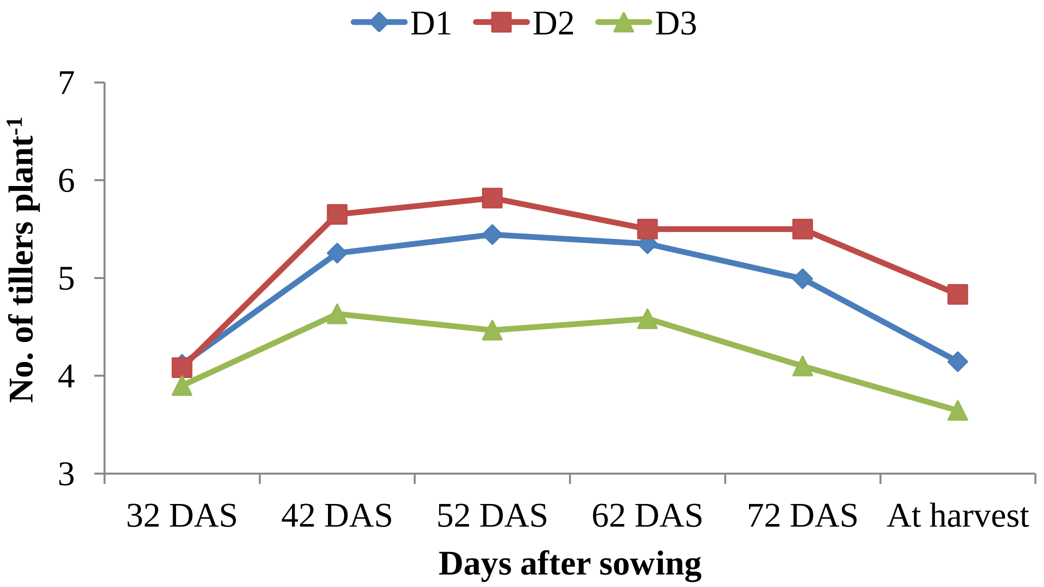
Treatment combination	Dry matter content plant^{-1} (g) at					
	32 DAS	42 DAS	52 DAS	62 DAS	72 DAS	Harvest
D_1S_1	0.36 d	0.93 ef	1.51 e	3.32 d-f	3.73 de	5.68 de
D_1S_2	0.55 b	1.47 ab	2.43 a	3.96 b-d	4.68 b	6.70 bc
D_1S_3	0.35 d	1.01 d-f	1.65 c-e	3.11 ef	4.41 b-d	6.10 c-e
D_1S_4	0.54 b	1.20 cd	2.04 b	3.87 b-d	4.69 b	6.39 c-e
D_2S_1	0.50 bc	1.22 d	1.76 b-e	3.58 c-f	4.54 bc	6.20 c-e
D_2S_2	0.65 a	1.63 a	2.52 a	4.67 a	5.93 a	8.38 a
D_2S_3	0.44 cd	1.30 bc	1.91 b-d	4.19 a-c	4.67 b	7.39 ab
D_2S_4	0.49 bc	1.23 b-d	2.02 bc	4.29 ab	4.96 b	7.77 a
D_3S_1	0.42 cd	0.88 f	1.45 e	3.00 f	3.46 e	5.42 e
D_3S_2	0.50 bc	1.14 c-e	1.77 b-e	3.66 b-e	4.29 b-d	6.44 bd
D_3S_3	0.48 bc	1.00 d-f	1.55 d-e	3.15 ef	3.70 de	6.00 c-e
D_3S_4	0.55 b	1.08 c-f	1.66 b-e	3.31 d-f	3.86 c-e	6.19 c-e
LSD $_{(0.05)}$	0.09	0.25	0.38	0.65	0.79	1.00
CV (%)	12.01	12.2	12.13	10.5	10.63	8.98

D_1=2 cm; D_2=4 cm; D_3=8 cm
S_1=15 cm; S_2=20 cm; S_3=25cm; S_4=30 cm

4.8 Number of tillers plant^{-1}

4.8.1 Effect of sowing depth

Number of tillers plant^{-1} was significantly influenced by sowing depth at all stages of growth except 32 DAS (Figure 12). At 42, 52, 62 DAS and at harvest maximum number of tillers plant^{-1} (5.65, 5.82, 5.50 and 4.83, respectively) were obtained for 4 cm sowing depth which was statistically similar with 2 cm sowing depth on the other hand minimum number of tillers plant^{-1} (4.63, 4.47, 4.58 and 3.65, respectively) were obtained for 8 cm sowing depth. However, at 72 DAS, 4 cm sowing depth scored maximum number of tillers plant^{-1} (5.50) and minimum number of tillers plant^{-1} (4.10) was obtained form 8 cm sowing depth. This result similar was with Alam *et al*. (2014) who observed that the highest number of effective tillers plant^{-1} was obtained from 4 cm sowing depth and the lowest one was obtained from 8 cm sowing depth.

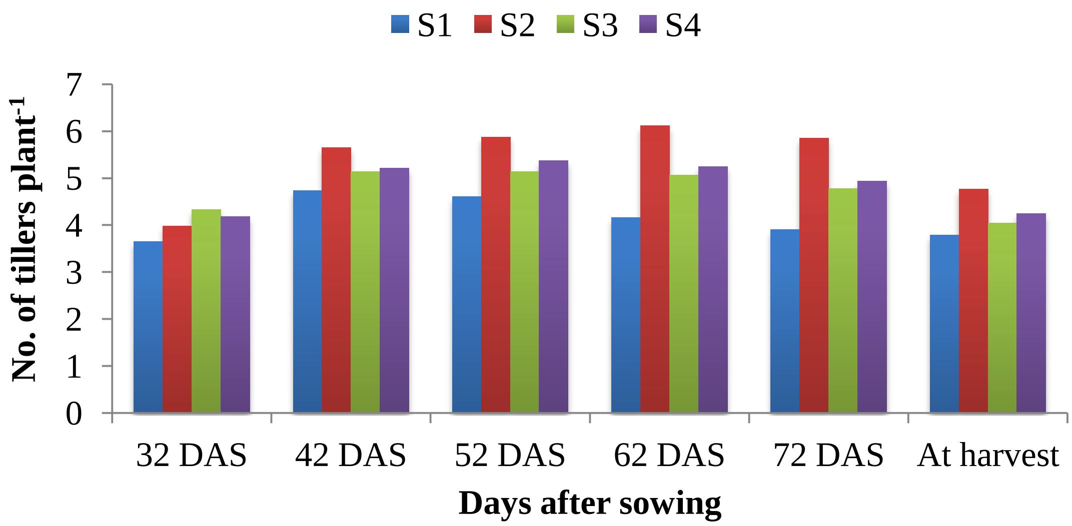


D_1=2 cm; D_2=4 cm; D_3=8 cm

Figure 12. Effect of sowing depth on the no. of tillers plant^{-1} of wheat (LSD $_{(0.05)}$ = NS, 0.50, 0.48, 0.37, 0.45 and 0.34 at 32, 42, 52, 62, 72 DAS and at harvest, respectively)

4.8.2 Effect of row spacing

Number of tillers plant^{-1} was significantly influenced by row spacings at all stages of growth (Figure 13). Results showed that the maximum number of tillers plant^{-1} (4.33) was observed in 25 cm row spacing at 32 DAS which was statistically similar with 20 cm and 30 cm row spacing and minimum number of tillers plant^{-1} (3.64) was recorded from 15 cm row spacing which was statistically similar with 20 cm row spacing. At 42 DAS the maximum number of tillers plant^{-1} (5.64) was observed in 20 cm row spacing which was statistically similar with 25 cm and 30 cm row spacing and minimum number of tillers plant^{-1} (4.73) was recorded from 15 cm row spacing which was statistically similar with 25 cm and 30 cm row spacing. At 52 DAS the maximum number of tillers plant^{-1} (5.87) was observed in 20 cm row spacing which was statistically similar with 30 cm row spacing and minimum number of tillers plant^{-1} (4.60) was recorded from 15 cm row spacing which was statistically similar with 25 cm row spacing. At 62 and 72 DAS the maximum number of tillers plant^{-1} (6.11, 5.84, respectively) was observed in 20 cm row spacing and minimum number of tillers plant^{-1} (4.16, 3.90, respectively) was recorded from 15 cm row spacing. Pandey *et al.* (2013) found similar result who observed that wheat cultivated at 20 cm row spacing produced significantly more tillers as compared to 15 and 25 cm row spacing. At harvest the maximum number of tillers plant^{-1} (4.77) was observed in 20 cm row spacing which and minimum number of tillers plant^{-1} (3.78) was recorded from 15 cm row spacing.



S_1=15 cm; S_2=20 cm; S_3=25cm; S_4=30 cm

Figure 13. Effect of row spacing on the no. of tillers plant^{-1} of wheat (LSD $_{(0.05)}$ = 0.46, 0.58, 0.56, 0.43, 0.52 and 0.40 at 32, 42, 52, 62, 72 DAS and at harvest, respectively)

4.8.3 Interaction effect of sowing depth and row spacing

Interaction of sowing depth and row spacing showed significant effect on number of tillers plant^{-1} (Table 12). At 32 DAS, the maximum number of tillers plant^{-1} (4.60) was recorded from combination of 2 cm sowing depth with 30 cm row spacing and minimum (3.27) was recorded from 2 cm sowing depth with 20 cm row spacing. However, at 42, 52, 62, 72 DAS and at harvest interaction of 4 cm sowing depth with 20 cm row spacing recorded the maximum number of tillers plant^{-1} (6.53, 6.73, 7.00, 6.87 and 5.69, respectively). On the other hand, the minimum number of tillers plant^{-1} at 42, 52, 62, 72 DAS and at harvest (4.13, 4.00, 3.73, 3.27 and 3.29, respectively) were obtained from 8 cm sowing depth and 15 cm row spacing combination.

Table 12. Interaction effect of sowing depth and row spacing on no. of tillers plant^{-1} of wheat

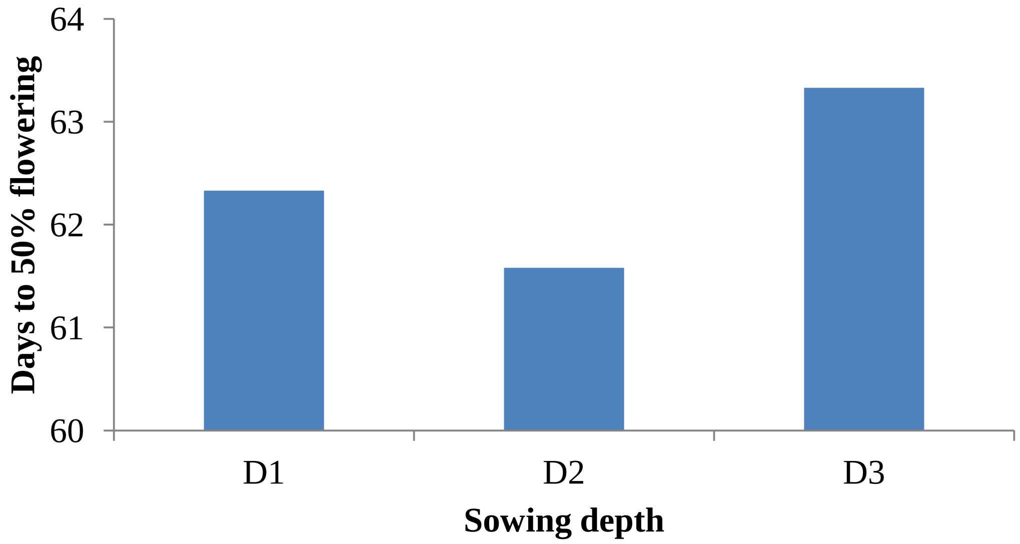
Treatment combination	Number of tillers plant^{-1} at					
	32 DAS	42 DAS	52 DAS	62 DAS	72 DAS	Harvest
D_1S_1	4.13 a-c	5.00 bc	4.93 c-e	4.73 c-e	4.10 ef	3.52 de
D_1S_2	3.27 d	5.47 b	5.93 ab	6.40 a	5.87 b	4.57 bc
D_1S_3	4.47 a	5.33 b	5.34 b-d	5.07 b-d	4.80 c-e	4.17 b-d
D_1S_4	4.60 a	5.22 b	5.57 b-d	5.20 b-d	5.20 b-d	4.33 bc
D_2S_1	3.40 cd	5.07 bc	4.87 c-e	4.00 ef	4.33 de	4.54 bc
D_2S_2	4.40 ab	6.53 a	6.73 a	7.00 a	6.87 a	5.69 a
D_2S_3	4.27 ab	5.33 b	5.73 bc	5.47 bc	5.47 bc	4.33 bc
D_2S_4	4.27 ab	5.67 ab	5.93 ab	5.53 b	5.33 bc	4.77 b
D_3S_1	3.40 cd	4.13 c	4.00 e	3.73 f	3.27 f	3.29 e
D_3S_2	4.27 ab	4.93 bc	4.93 cde	4.93 b-d	4.80 c-e	4.04 cd
D_3S_3	4.27 ab	4.73 bc	4.33 e	4.67 de	4.07 ef	3.62 de
D_3S_4	3.67 b-d	4.73 bc	4.60 de	5.00 b-d	4.27 e	3.63 de
LSD $_{(0.05)}$	0.80	1.00	0.97	0.75	0.90	0.69
CV (%)	11.71	11.36	10.91	8.6	10.96	9.61

D_1=2 cm; D_2=4 cm; D_3=8 cm
S_1=15 cm; S_2=20 cm; S_3=25cm; S_4=30 cm

4.9 Days to 50% flowering

4.9.1 Effect of sowing depth

Result showed that (Figure 14) among the sowing depths 2 cm and 4 cm required minimum days to 50 % flowering (62.33 and 61.58 days, respectively). On the other hand, 8 cm took more days to 50 % flowering (63.33 days).

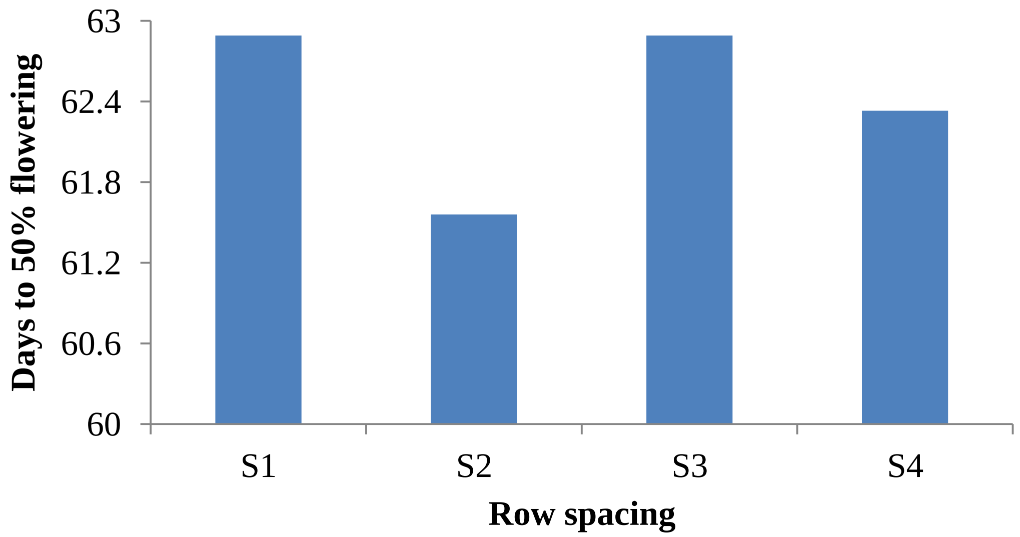


D_1=2 cm; D_2=4 cm; D_3=8 cm

Figure 14. Effect of sowing depth on days to 50% flowering of wheat (LSD $_{(0.05)}$ = 0.91)

4.9.2 Effect of row spacing

Among the row spacings 20 cm showed earlier flowering (61.56 days) which was statistically similar with 30 cm row spacing whereas, 15 and 25 cm row spacing showed delayed flowering (62.89 days) which was statistically similar with 30 cm row spacing (Figure 15).



S_1=15 cm; S_2=20 cm; S_3=25cm; S_4=30 cm

Figure 15. Effect of row spacing on days to 50% flowering of wheat (LSD $_{(0.05)}$ = 1.05)

4.9.3 Interaction effect of sowing depth and row spacing

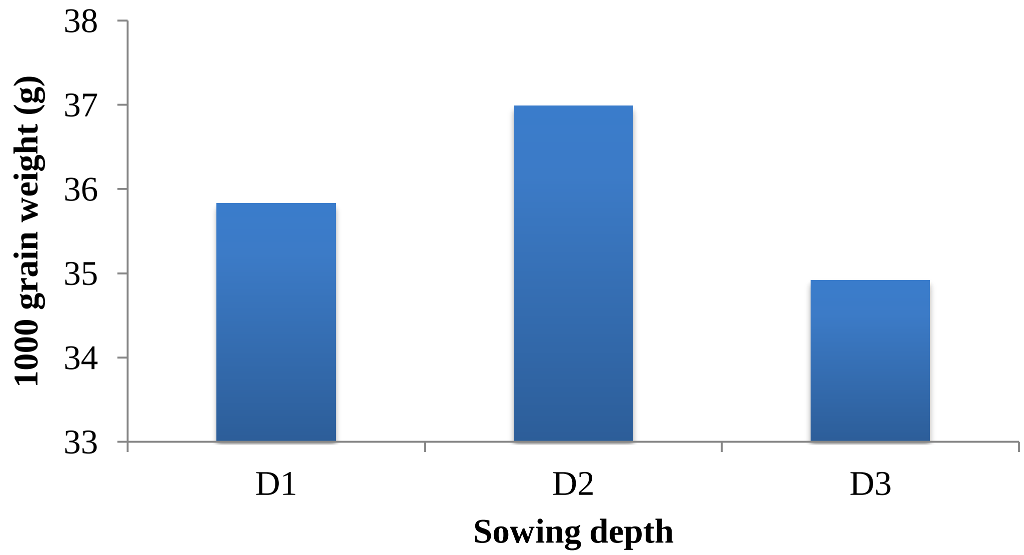
Among the interactions 4 cm sowing depth and 20 cm row spacing showed minimum days to 50 % flowering (60.33 days) (Table 13). On the other hand, 8 cm sowing depth and 15 cm row spacing took more days to 50 % flowering (64.00 days).

4.10 1000 grain weight (g)

4.10.1 Effect of sowing depth

Sowing depth showed significant influence on weight of 1000 seeds of wheat (Figure 16 and Appendix V). The maximum weight (36.99 g) of 1000 grain was recorded in 4 cm depth of sowing which was statistically similar with 2 cm sowing depth. The minimum weight (34.92 g) was obtained in 8 cm depth of sowing which was statistically similar with 2 cm sowing depth. This result was disagreed with Azad (1999). Azad (1999) reported that depth of seeding did not produce any significant variation in 1000 grain weight. The highest value of 1000 grain weight was obtained from 4.5 cm seeding depth and the lowest from 2.5 cm seeding depth. But Alam *et al*. (2014) observed that the highest 1000-

grain weight (51.18 g) was resulted from 4 cm sowing depth and it was the lowest (49.10 g) when sowing was done in 8 cm depth.

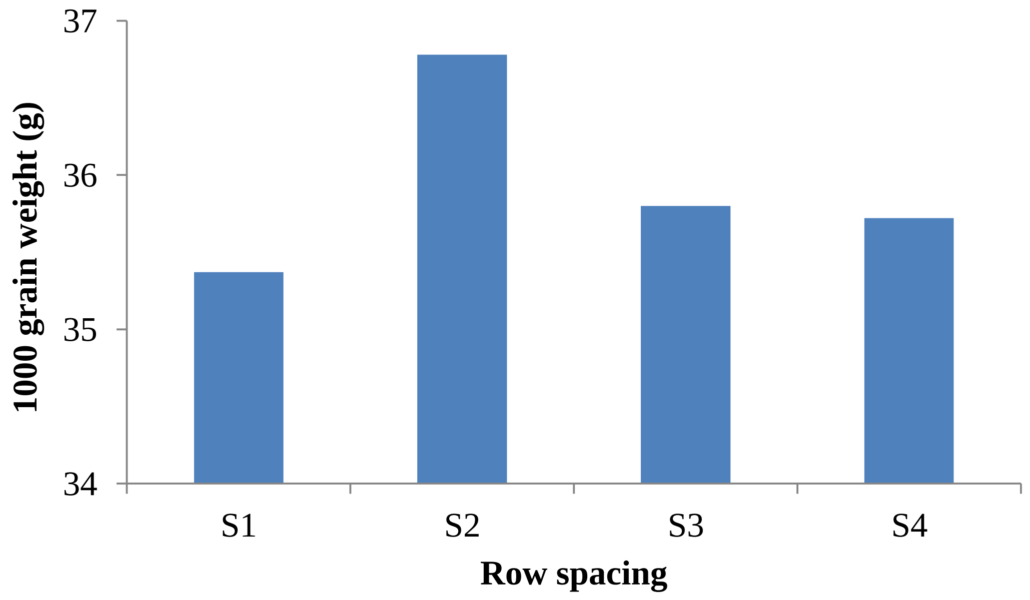


D_1=2 cm; D_2=4 cm; D_3=8 cm

Figure 16. Effect of sowing depth on the 1000 grain weight of wheat (LSD $_{(0.05)}$ = 2.05)

4.10.2 Effect of row spacing

Row spacing did not show any significant influence on weight of 1000 seeds of wheat (Figure 17 and Appendix V). The maximum weight (36.78 g) of 1000 grain was recorded in 20 cm row spacing. The minimum weight (35.57 g) was obtained in 15 cm row spacing. This result disagreed with Hussain *et al.* (2003) who reported that row spacing had significant effects on 1000-grain weight.



S_1=15 cm; S_2=20 cm; S_3=25cm; S_4=30 cm

Figure 17. Effect of row spacing on the 1000 grain weight of wheat (LSD $_{(0.05)}$ = NS)

4.10.3 Interaction effect of sowing depth and row spacing

There was significant interaction of sowing depth and row spacing on weight of 1000 seeds (Table 13). The highest weight of 1000 seeds (38.00 g) was observed with 4 cm sowing depth and 20 cm row spacing. The interaction of 8 cm sowing depth and 15 cm row spacing had the lowest weight of 1000 seeds (33.83 g).

Table 13. Interaction effect of sowing depth and row spacing on 1000 grain weight, spike length, no. of spikelet spike^{-1}, no. of grains plant^{-1}, grain yield, straw yield, biological yield and harvest index of wheat

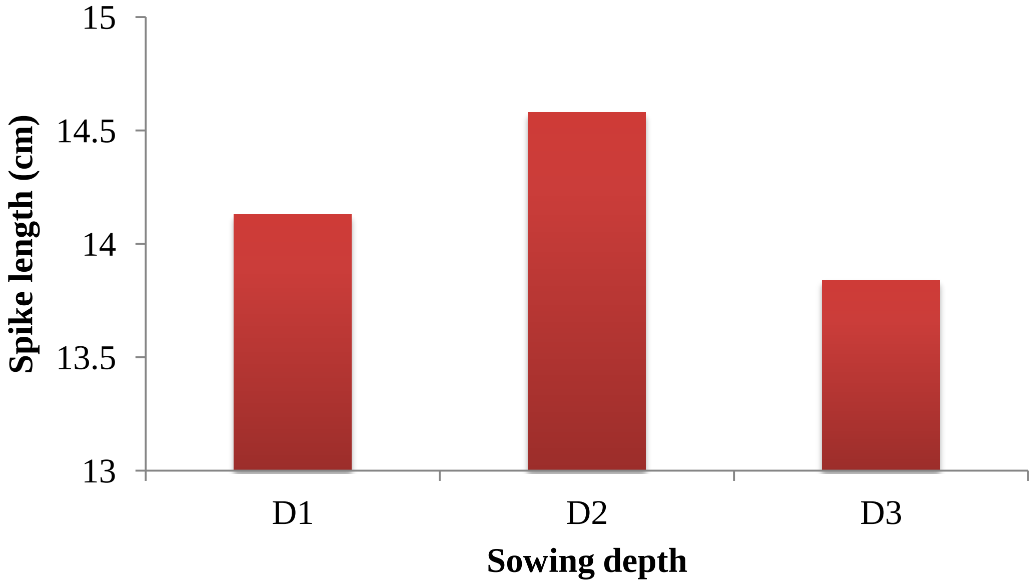
Treatment combination	Days to 50% flowering	1000 grain wt. (g)	Spike length (cm)	No. of spikelet spike^{-1} (No.)	No. of grains plant^{-1} (No.)	Grain yield (t ha^{-1})	Straw yield (t ha^{-1})	Biological yield (t ha^{-1})	Harvest Index (%)
D_1S_1	62.33 a-c	35.90 ab	13.57 ab	17.53 bc	51.73 ab	3.19 e-g	4.34 a-d	7.527 de	42.56
D_1S_2	61.67 cd	36.57 ab	14.51 ab	18.67 a-c	55.47 ab	3.62 b-e	4.87 a-c	8.487 b-d	42.56
D_1S_3	63.00 a-c	35.27 ab	13.97 ab	18.00 a-c	53.13 ab	3.25 ef	4.62 a-d	7.877 c-e	41.51
D_1S_4	62.33 a-c	35.60 ab	14.45 ab	18.53 a-c	53.80 ab	3.32 c-f	4.67 a-c	7.990 b-e	41.66
D_2S_1	62.33 a-c	36.37 ab	14.27 ab	17.53 bc	51.20 ab	3.71 bc	4.82 a-c	8.533 b-d	43.67
D_2S_2	60.33 d	38.00 a	15.11 a	19.47 a	58.53 a	4.53 a	5.42 a	9.950 a	45.67
D_2S_3	62.00 b-d	37.10 ab	14.39 ab	19.00 ab	56.93 ab	3.70 b-d	5.00 a-c	8.703 bc	43.30
D_2S_4	61.67 cd	36.50 ab	14.57 ab	19.07 ab	56.33 ab	3.96 b	5.12 ab	9.067 ab	43.79
D_3S_1	64.00 a	33.83 b	13.43 b	17.20 c	49.47 b	2.80 g	3.57 d	6.373 f	43.91
D_3S_2	62.67 a-c	35.77 ab	14.44 ab	18.33 a-c	53.40 ab	3.27 d-f	4.28 b-d	7.550 de	43.27
D_3S_3	63.67 ab	35.03 ab	13.65 ab	18.27 a-c	56.60 ab	3.12 fg	4.01 cd	7.130 ef	43.73
D_3S_4	63.00 a-c	35.07 ab	13.85 ab	18.67 a-c	52.97 ab	3.19 e-g	4.30 b-d	7.483 d-f	42.80
LSD $_{(0.05)}$	1.81	4.10	1.54	1.65	7.62	0.44	1.09	1.15	NS
CV (%)	1.71	6.75	6.39	5.3	8.31	7.5	14.07	8.4	9.1

D_1=2 cm; D_2=4 cm; D_3=8 cm, S_1=15 cm; S_2=20 cm; S_3=25cm; S_4=30 cm

4.11 Spike length (cm)

4.11.1 Effect of sowing depth

Sowing depth did not show any significant influence on length of spike (Figure 18). The highest length of spike (14.58 cm) was recorded with 4 cm depth. The shortest spike (13.84 cm) was recorded with 8 cm depth. Azad (1999) reported that spike length was not affected significantly by seeding depth and highest spike length was obtained for 2.5 cm seeding depth whereas the lowest at 4.5 cm seeding depth. This finding corroborated with Alam *et al.* (2014) who observed that spike length did not show significant variation due to different sowing depth. The longest spike was obtained from 4 cm sowing depth and the shortest one was found at 8 cm sowing depth.

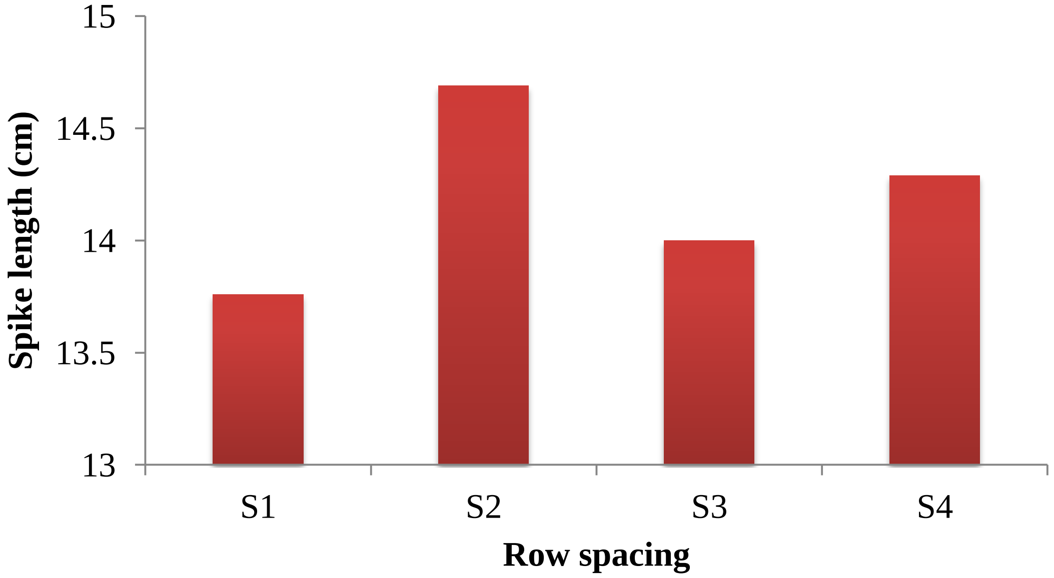


D_1=2 cm; D_2=4 cm; D_3=8 cm

Figure 18. Effect of sowing depth on the spike length of wheat (LSD $_{(0.05)}$ = NS)

4.11.2 Effect of row spacing

Row spacing showed significant influence on length of spike of wheat (Figure 19). The highest length of spike (14.69 cm) was recorded with 20 cm row spacing which was statistically similar with 25 cm and 30 cm row spacing. The shortest spike (13.76 cm) was recorded with 15 cm row spacing which was statistically similar with 25 cm and row spacing.



S_1=15 cm; S_2=20 cm; S_3=25cm; S_4=30 cm

Figure 19. Effect of row spacing on the spike length of wheat ($LSD_{(0.05)}$ = 0.89)

4.11.3 Interaction effect of sowing depth and row spacing

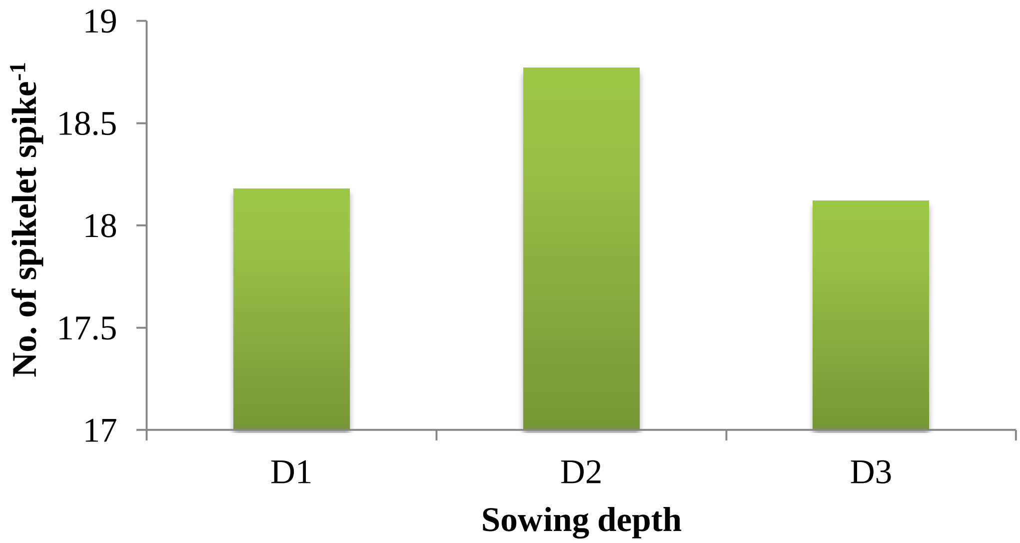
Spike length showed significant variation due to the interaction between sowing depth and row spacing (Table 13). The longest spike (15.11 cm) was obtained from the interaction of 4 cm sowing depth and 20 cm row spacing. The shortest length of spike (13.43 cm) was recorded with 8 cm sowing depth and 15 cm row spacing.

4.12 Number of spikelet spike^{-1}

4.12.1 Effect of sowing depth

Sowing depth did not show any significant influence on spikelet spike^{-1} of wheat (Figure 20). The maximum number of spikelets spike^{-1} (18.77) was obtained with 4 cm depth of sowing. The minimum number of spikelet spike^{-1} (18.12) was recorded with 8 cm depth. Similar result observed by Alam *et al.*

(2014) who reported that the highest number of spikelet spike^{-1} were obtained from 4 cm sowing depth and the lowest number were obtained from 8 cm sowing depth.

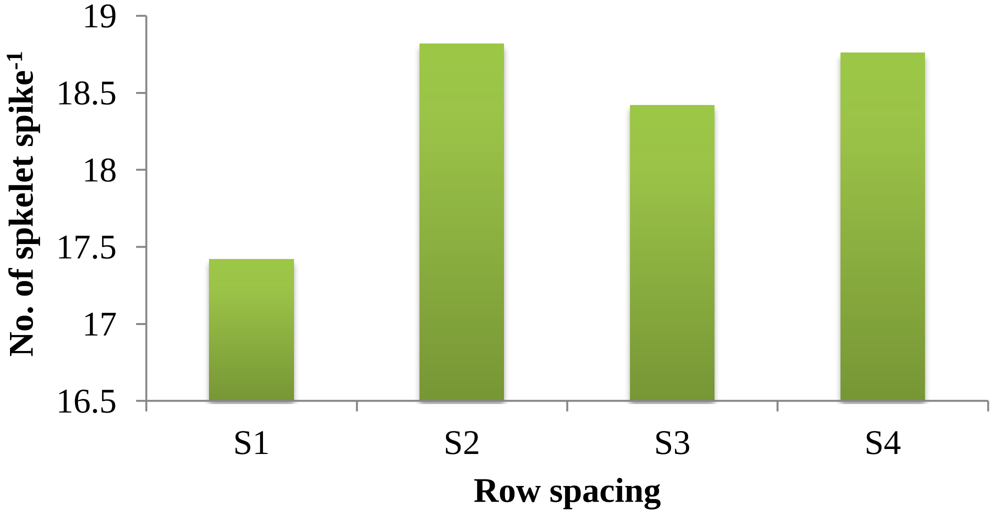


D_1=2 cm; D_2=4 cm; D_3=8 cm

Figure 20. Effect of sowing depth on the no. of spikelet spike^{-1} of wheat (LSD $_{(0.05)}$ = NS)

4.12.2 Effect of row spacing

Row spacing showed significant influence on spikelet spike^{-1} of wheat (Figure 21). The maximum number (18.82) of spikelet spike^{-1} was obtained with 20 cm row spacing which was statistically similar with 25 cm and 30 cm row spacing. The minimum number of spikelet spike^{-1} (17.42) was recorded with 15 cm row spacing 6). This result is similar with Pandey *et al.* (2013) who said that narrow row distance (15 cm) had the lowest number of florets spike^{-1}.



S_1=15 cm; S_2=20 cm; S_3=25cm; S_4=30 cm

Figure 21. Effect of row spacing on the no. of spikelet spike^{-1} of wheat (LSD $_{(0.05)}$ = 0.95)

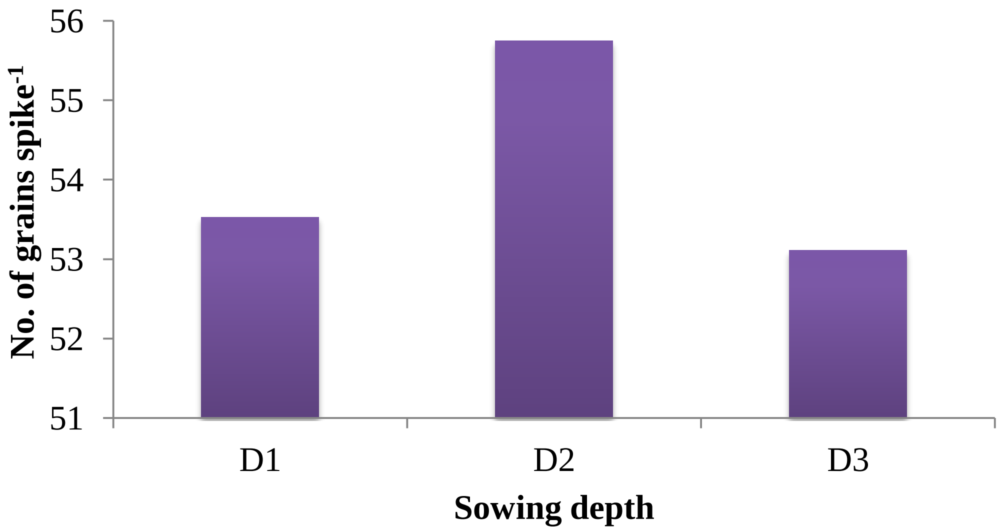
4.12.3 Interaction effect of sowing depth and row spacing

Number of spikelet spike^{-1} showed significant variation due to the interaction between sowing depth and row spacing (Table 13). The highest number of spikelet spike^{-1} (19.47) was obtained from the interaction of 4 cm sowing depth and 20 cm row spacing. The lowest number of spikelet spike^{-1} (17.20) was recorded with 8 cm sowing depth and 15 cm row spacing.

4.13 Number of grains spike^{-1}

4.13.1 Effect of sowing depth

Sowing depth didn't show any significant influence on number of grains spike^{-1} of wheat (Figure 22). The maximum number (55.75) of grains spike^{-1} was obtained with 4 cm depth of sowing. The minimum number of grains spike^{-1} (53.11) was recorded with 8 cm depth (Table 13). Similar result was obtained by Amin *et al.* (2004) who observed that maximum number of grains spike^{-1} were obtained from 4 cm sowing depth and the minimum were observed at 8 cm sowing depth.

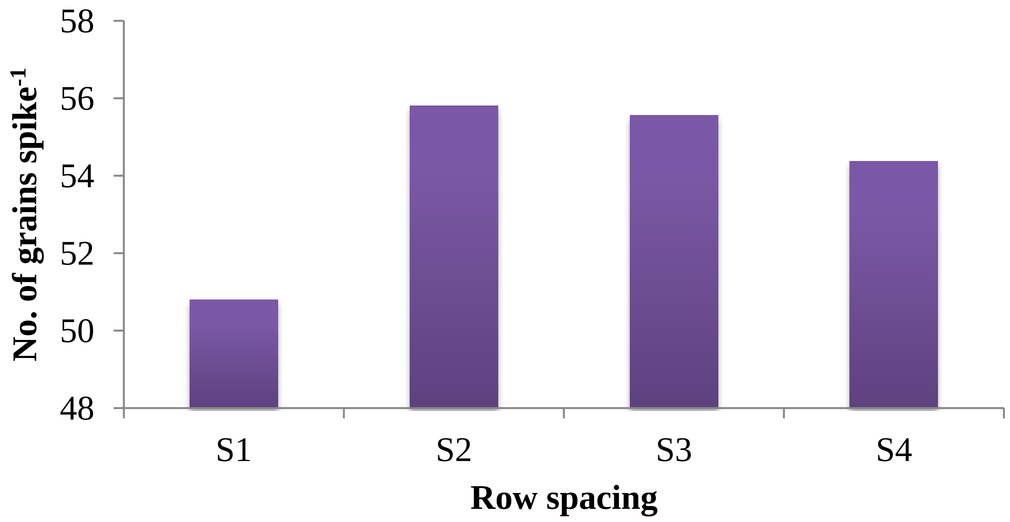


D_1=2 cm; D_2=4 cm; D_3=8 cm

Figure 22. Effect of sowing depth on the no. of grains spike^{-1} of wheat (LSD $_{(0.05)}$ = NS)

4.13.2 Effect of row spacing

Row spacing showed significant influence on number of grains spike^{-1} of wheat (Figure 23). Maximum number (55.80) of grains spike^{-1} was obtained with 20 cm row spacing which was statistically similar with 25 cm and 30 cm row spacing. Minimum number of grains spike^{-1} (50.80) was recorded with 15 cm row spacing which was statistically similar with 30 cm row spacing. Similar result was found by Donaldson *et al.* (2001) and Josep *et al.* (1985) who showed that increasing plant density caused to reducing grains spike^{-1} of wheat. Researchers contributed the reducing grains per ear in thicker densities to low light penetrating into, reducing plant growth rate and reducing photosynthesis (Andrade *et al.*, 1993; Tollenaar *et al.*, 1992).



S_1=15 cm; S_2=20 cm; S_3=25cm; S_4=30 cm

Figure 23. Effect of row spacing on the no. of grains spike^{-1} of wheat (LSD $_{(0.05)}$ = 4.40)

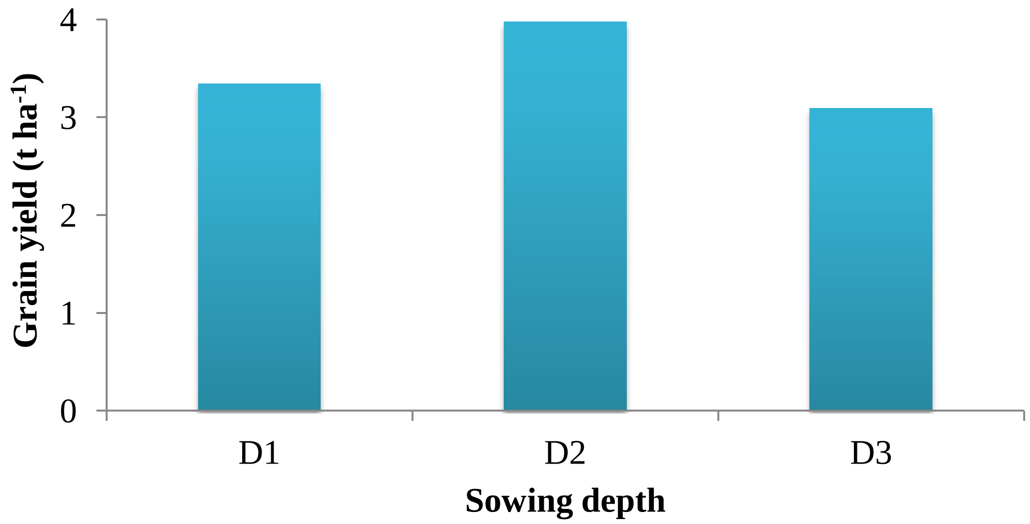
4.13.3 Interaction effect of sowing depth and row spacing

Number of grains spike^{-1} showed significant variation due to the interaction between sowing depth and row spacing (Table 13). The highest number of grains spike^{-1} (58.53) was obtained from the interaction of 4 cm sowing depth and 20 cm row spacing. The lowest number of grains spike^{-1} (49.47) was recorded with 8 cm sowing depth and 15 cm row spacing.

4.14 Grain yield (t ha^{-1})

4.14.1 Effect of sowing depth

Grain yield of wheat was significantly influenced by sowing depth (Figure 24 and Appendix V). The highest grain yield (3.97 t ha^{-1}) was obtained with 4 cm sowing depth. The lowest amount of grain yield (3.09 t ha^{-1}) was obtained with 8 cm sowing depth (Table 13). This was rather expected because lesser number of seedlings emerged from deeper sown seeds and sparsely populated plants had better growth. The result was conformity with the findings of Alam *et al*. (2014); Amin (2004) and Al-Amin *et al.* (1994). Al-Amin *et al.* (1994) reported that sowing deeper than 4 cm greatly reduced grain yield whereas, Alam *et al.* (2014) reported that significantly highest grain yield was obtained with 4 cm sowing and lowest from 8 cm depth.

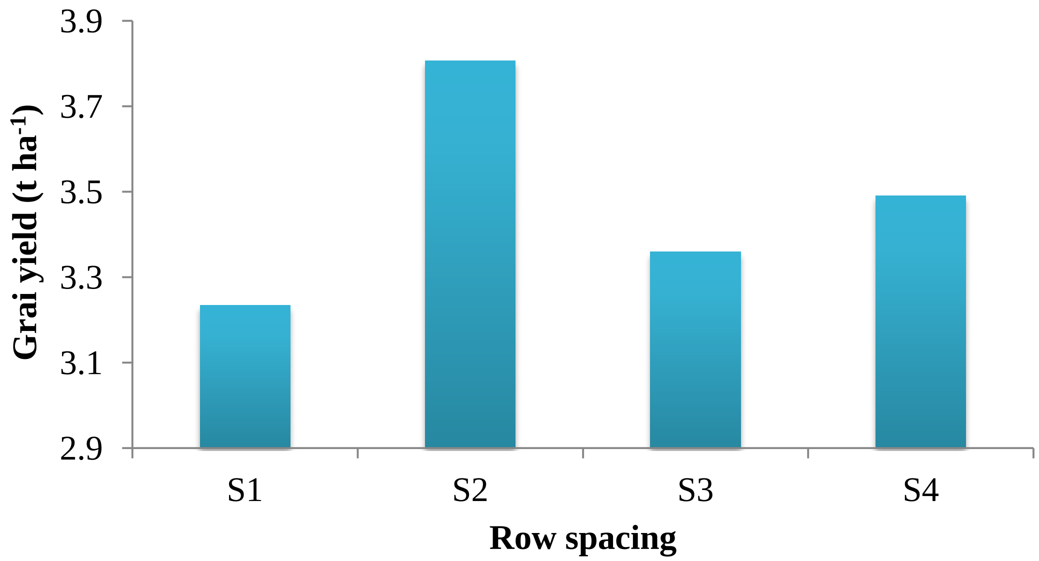


D_1=2 cm; D_2=4 cm; D_3=8 cm

Figure 24. Effect of sowing depth on the grain yield of wheat (LSD $_{(0.05)}$ = 0.22)

4.14.2 Effect of row spacing

Grain yield was significantly influenced by different row spacings (Figure 25 and Appendix V). The highest amount of grain yield (3.80 t ha^{-1}) was obtained with 20 cm row spacing. The lowest amount of grain yield (3.23 t ha^{-1}) was obtained with 15 cm row spacing. The results corroborated with the findings of Hussain *et al.* (2003) concluded that row spacing had significant effects on the grain yield. On the other hand, Fonts *et al.* (1997) reported that grain yield decreased with increase in row spacing.



S_1=15 cm; S_2=20 cm; S_3=25cm; S_4=30 cm

Figure 25. Effect of row spacing on the grain yield of wheat (LSD $_{(0.05)}$ = 0.25)

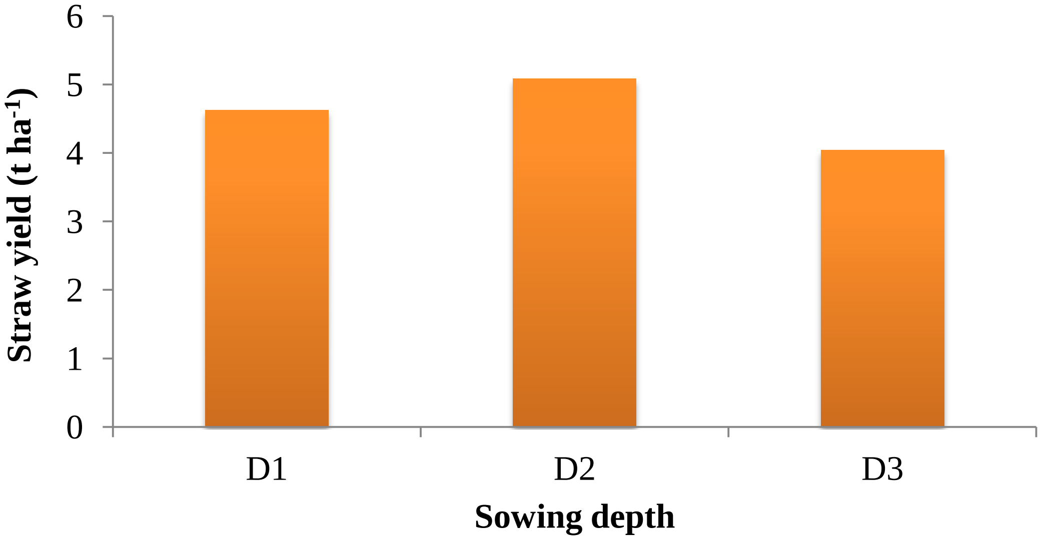
4.14.3 Interaction effect of sowing depth and row spacing

Grain yield showed significant variation due to the interaction between sowing depth and row spacing (Table 13). The highest grain yield (4.53 t ha^{-1}) was obtained from the interaction of 4 cm sowing depth and 20 cm row spacing. The lowest amount of grain yield (2.80 t ha^{-1}) was obtained with 8 cm sowing depth and 15 cm row spacing.

4.15 Straw yield (t ha^{-1})

4.15.1 Effect of sowing depth

Straw yield of wheat was significantly influenced by sowing depth (Figure 26 and Appendix V). The highest straw yield (5.09 t ha^{-1}) was obtained with 4 cm sowing depth which was statistically similar with 2 cm sowing depth. The lowest amount of straw yield (4.04 t ha^{-1}) was obtained with 8 cm sowing depth (Table 13). Amin *et al.* (2004) found the highest straw yield in 4 cm depth and lowest in 6 cm depth. This result uphold the findings of Alam *et al*. (2014) who observed the maximum straw yield at 4 cm sowing depth and lowest one at 8 cm sowing depth.

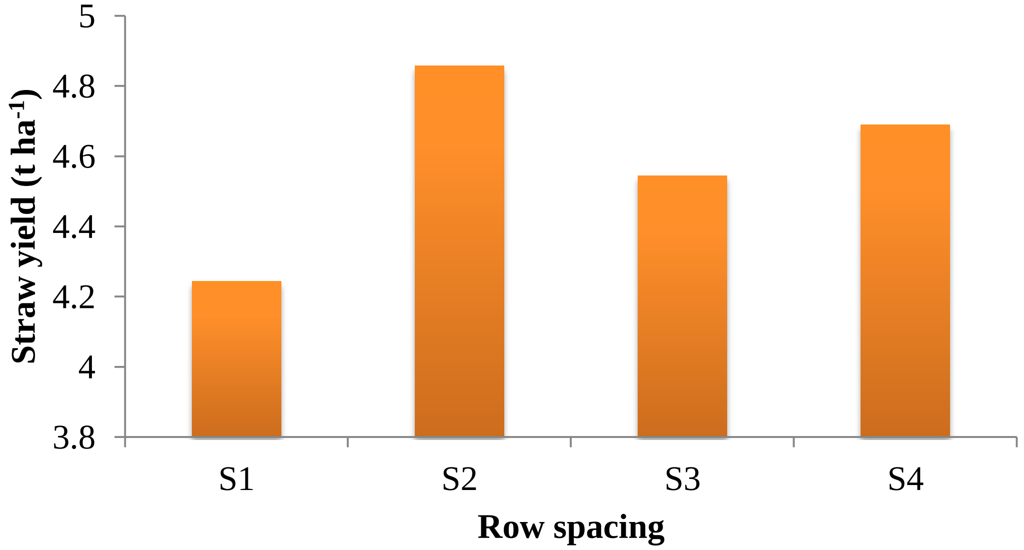


D_1=2 cm; D_2=4 cm; D_3=8 cm

Figure 26. Effect of sowing depth on the straw yield of wheat (LSD $_{(0.05)}$ = 0.55)

4.15.2 Effect of row spacing

Row spacing did not show any significant influence on straw yield (Figure 27 and Appendix V). The highest straw yield (4.86 t ha^{-1}) was obtained with 20 cm row spacing. The lowest straw yield (4.24 t ha^{-1}) was obtained with 15 cm row spacing.



S_1=15 cm; S_2=20 cm; S_3=25cm; S_4=30 cm

Figure 27. Effect of row spacing on the straw yield of wheat (LSD $_{(0.05)}$ = NS)

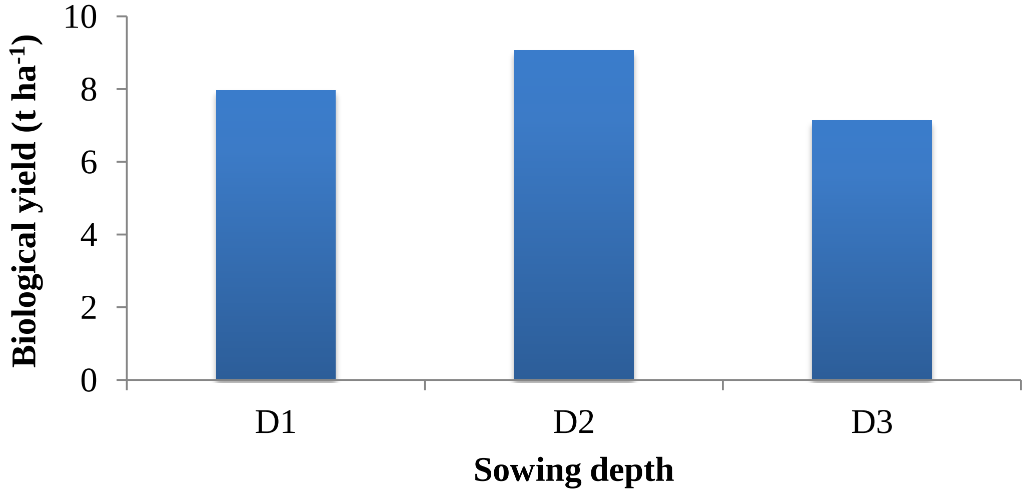
4.15.3 Interaction effect of sowing depth and row spacing

The interaction effect of sowing depth and row spacing significantly influenced the straw yield (Table 13). The highest straw yield (5.42 t ha^{-1}) was obtained from the interaction of 4 cm sowing depth and 20 cm row spacing. The lowest straw yield (3.57 t ha^{-1}) was obtained with 8 cm sowing depth and 15 cm row spacing.

4.16 Biological yield (t ha^{-1})

4.16.1 Effect of sowing depth

Biological yield of wheat was significantly influenced by sowing depth (Figure 28 and Appendix V). The highest biological yield (9.06 t ha^{-1}) was obtained with 4 cm sowing depth. The lowest biological yield (7.13 t ha^{-1}) was obtained with 8 cm sowing depth.

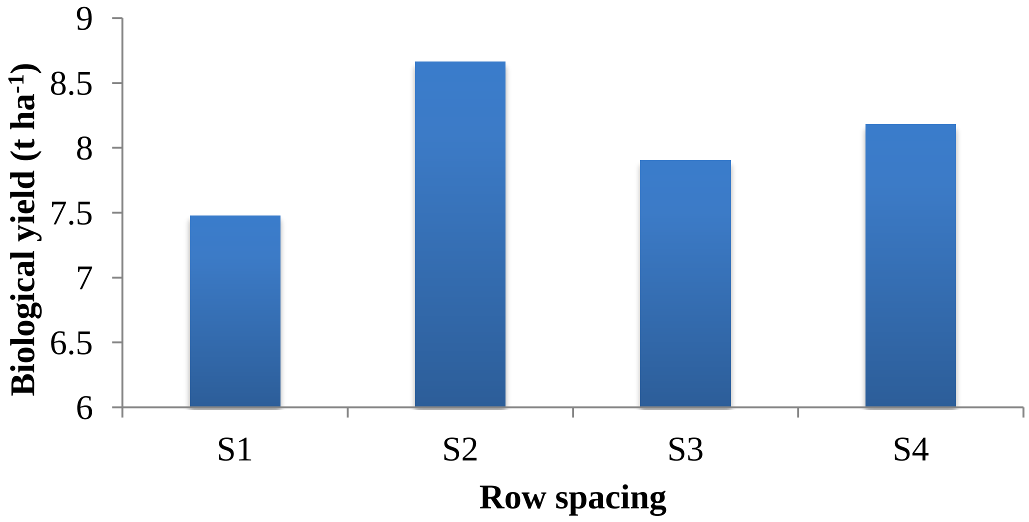


D_1=2 cm; D_2=4 cm; D_3=8 cm

Figure 28. Effect of sowing depth on the biological yield of wheat (LSD $_{(0.05)}$ = 0.57)

4.16.2 Effect of row spacing

Row spacing significantly influenced the biological yield (Figure 29 and Appendix V). The highest biological yield (8.66 t ha^{-1}) was obtained with 20 cm row spacing which was statistically similar with 30 cm row spacing. The lowest biological yield (7.47 t ha^{-1}) was obtained with 15 cm row spacing which was statistically similar with 25 cm row spacing.



S_1=15 cm; S_2=20 cm; S_3=25cm; S_4=30 cm

Figure 29. Effect of row spacing on the biological yield of wheat (LSD $_{(0.05)}$ = 0.66)

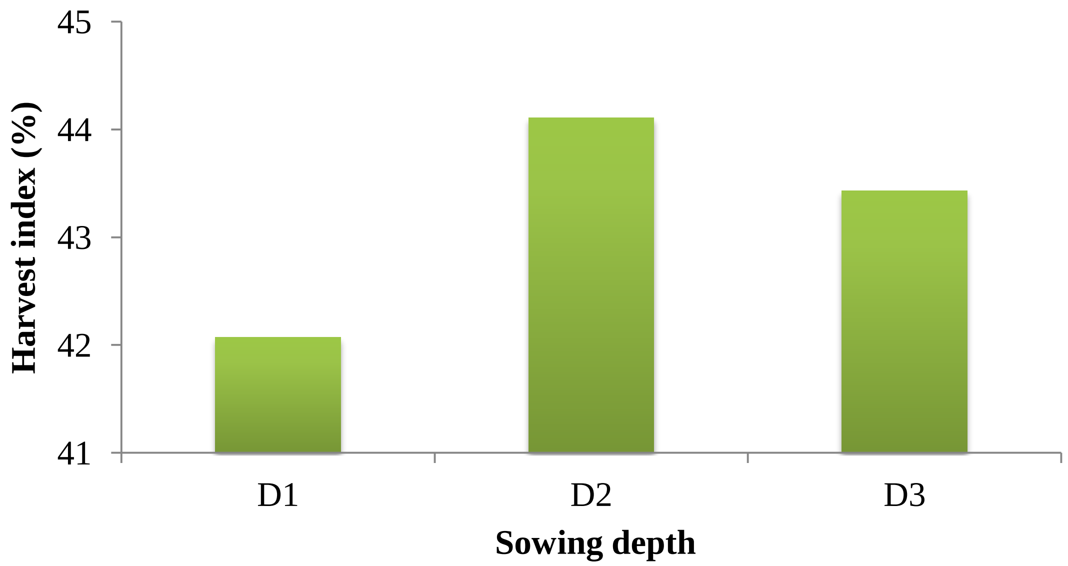
4.16.3 Interaction effect of sowing depth and row spacing

The interaction effect of sowing depth and row spacing significantly influenced the biological yield (Table 13). The highest biological yield (9.95 t ha^{-1}) was obtained from the interaction of 4 cm sowing depth and 20 cm row spacing. The lowest biological yield (6.37 t ha^{-1}) was obtained with 8 cm sowing depth and 15 cm row spacing.

4.17 Harvest index (%)

4.17.1 Effect of sowing depth

Sowing depth did not show any significant influence on harvest index (Figure 30 and Appendix V). The highest harvest index (43.43 %) was obtained with 8 cm sowing depth. The lowest harvest index (42.07 %) was obtained with 2 cm sowing depth.

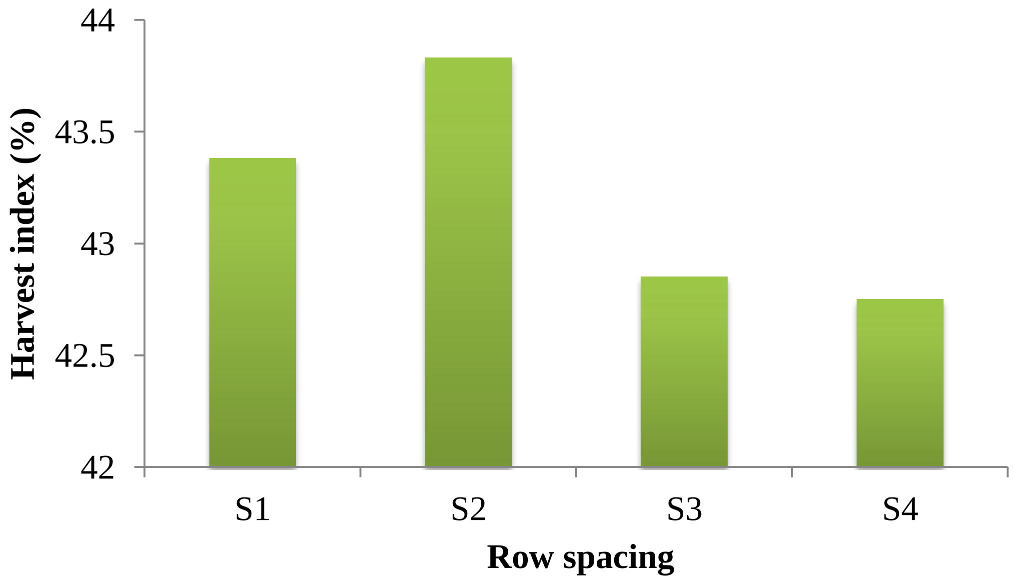


D_1=2 cm; D_2=4 cm; D_3=8 cm

Figure 30. Effect of sowing depth on the harvest index of wheat (LSD $_{(0.05)}$ = NS)

4.17.2 Effect of row spacing

The ability of a variety to convert the total dry matter into economic yield is indicated by its harvest index value. Row spacing did not show any significant influence on harvest index (Figure 31 and Appendix V). The highest harvest index (43.83%) was obtained with 20 cm row spacing. The lowest harvest index (42.75 %) was obtained with 30 cm row spacing. The result obtained is in conformity with the findings of Hussain *et al. (*2003).



S_1=15 cm; S_2=20 cm; S_3=25cm; S_4=30 cm

Figure 31. Effect of row spacing on the harvest index of wheat (LSD $_{(0.05)}$ = NS)

4.17.3 Interaction effect of sowing depth and row spacing

Interaction effect of sowing depth and row spacing did not show any significant variation on harvest index (Table 13). The highest harvest index (45.67 %) was obtained from the interaction of 4 cm sowing depth and 20 cm row spacing. The lowest harvest index (41.51 %) was obtained with 2 cm sowing depth and 20 cm row spacing.

Chapter 5

Summary and Conclusion

Chapter 5

SUMMARY AND CONCLUSIONS

The experiment was conducted at the Agronomy field of central research farm of Sher-e-Bangla Agricultural University, Dhaka, during Rabi season, November 2013 to March 2014 to evaluate the germination, stand establishment and yield of wheat as influenced by sowing depth and row spacing.

The experiment comprised of three sowing depth D_1=2 cm, D_2=4 cm, D_3=8 cm and four row spacing S_1=15 cm, S_2=20 cm, S_3=25 cm, S_4=30 cm. The experiment was laid out in a RCBD design with three replications. The size of the individual plot was 2.5 m and 2 m total numbers of plot were 36. There were 12 treatment combinations. Fertilizers in the form of urea, triple super phosphate, murate of potash, gypsum as a source of N, P, K, S, respectively were applied.

Significant variation was recorded among the treatments in respect to majority of the observed parameters. The analysis was performed using the MSTAT–C (Version 2.10) computer package program. The mean differences among the treatments were compared by least significant difference test (LSD) at 5 % level of significance.

The effect of sowing depth revealed that, maximum number of emerged seedlings m^{-2} (171.4, 182.9, 210.4 at 8, 11, 14 DAS, respectively) were obtained with 4 cm and at 5 DAS, maximum (136.2) with 2 cm sowing depth. On the other hand, minimum was obtained with 8 cm sowing depth. The highest seedling length (19.02 and 21.43 cm) was recorded with 4 cm at 11, 14 DAS, respectively and lowest with 8 cm sowing depth. The highest root length of seedling (5.32 and 10.96 cm) was recorded with 4 cm at 11, 17 DAS, respectively and lowest with 8 cm sowing depth. The maximum number of roots $plant^{-1}$ (5.97) at 17 DAS was counted from 4 cm and lowest from 8 cm sowing depth. Highest dry matter weight plant^{-1} (4.18, 5.02 and 7.44 g at 62, 72 DAS and at harvest, respectively) was obtained from 4 cm and lowest with 8 cm sowing depth. The maximum number of tillers plant^{-1}(5.50, 5.50 and 4.83 at 62, 72 DAS and at harvest, respectively) were recorded with 4 cm and lowest with 8 cm sowing depth. Minimum days (61.58) were required to 50% flowering in 4 cm and maximum in 8 cm sowing depth. Sowing depth showed non significant result on spike length, number of spikelet spike^{-1}, number of grain spike^{-1} and harvest index. Among the sowing depths, 4 cm showed it's superiority in producing 1000 grain weight, grain yield, straw yield and biological yield (36.99 g, 3.98 t ha^{-1}, 5.09 t ha^{-1} and 9.06 t ha^{-1}, respectively) whereas; the lowest were obtained from 8 cm sowing depth.

The effect of row spacing revealed that, maximum number of emerged seedlings m^{-2} (144.3, 176.2, 228.9 at 5, 8, 14 DAS. respectively) were obtained with 15 cm and minimum with 30 cm row spacing. The highest seedling length (19.54 and 22.31 cm) was recorded with 20 cm at 11, 14 DAS, respectively and the lowest with 15 cm row spacing. The highest root length of seedling (5.44, 8.36 and 10.94 cm) was recorded with 20 cm at 11, 14 and 17 DAS, respectively and the lowest with 15 cm row spacing. The maximum number of roots plant^{-1} (5.07 and 6.00 at 14 and 17 DAS, respectively) were counted from 20 cm and the lowest from 15 cm row spacing. The highest dry matter weight plant^{-1} (4.10, 4.96 and 7.17 g at 62, 72 DAS and at harvest, respectively) was obtained from 20 cm and the lowest from 15 cm. The maximum number of tillers plant^{-1} (6.11, 5.84 and 4.77 at 62, 72 DAS and at harvest, respectively) were recorded with 20 cm and the lowest with 15 cm row spacing. Minimum days (61.56) were required to 50% flowering in 20 cm and maximum in 15 cm and 25 cm row spacing. Row spacing showed non significant result on 1000 grain weight, straw yield and harvest index. Among the row spacing, 20 cm row spacing showed it's superiority in producing, spike length, number of spikelet spike^{-1}, number of grain spike^{-1}, grain yield and biological yield (14.69

cm, 18.82, 55.80, 3.81 t ha^{-1} and 8.66 t ha^{-1}, respectively) whereas; the lowest were obtained from 15 cm row spacing.

The combinations of sowing depth and row spacing had significant effect on almost all parameters. Maximum number of emerged seedlings m^{-2}(217.2, and 235.7 at 8 and 11 DAS, respectively) were obtained with D_2S_2 treatment combination. The highest seedling length (20.69 and 23.47 cm) was found in D_2S_2 treatment combination. The highest root length of seedling (8.71 and 11.83 cm at 14, 17 DAS, respectively)) observed from D_2S_2 treatment combination. The maximum number of roots $plant^{-1}$ (5.47 and 6.00 at 14 and 17 DAS, respectively) were counted from D_2S_2 treatment combination. The highest dry matter weight $plant^{-1}$ (4.67, 5.93 and 8.38 g at 62, 72 DAS and at harvest, respectively) was found in D_2S_2 treatment combination. The maximum number of tillers $plant^{-1}$ (7.00 and 6.86 at 62, 72 DAS, respectively) observed from D_2S_2 treatment combination. Minimum days (60.33) were required to 50% flowering in D_2S_2 treatment combination. Among the interaction D_2S_2 showed it's superiority in terms of 1000 grain weight, spike length, number of spikelet $spike^{-1}$, number of grain $spike^{-1}$, grain yield, straw yield and biological yield (38.00, 15.11 cm, 19.47, 58.53, 4.53 t ha^{-1}, 5.42 t ha^{-1} and 9.95 t ha^{-1}, respectively).

In this experiment, 4 cm sowing depth was found more effective than other treatment in respect to germination, stand establishment, growth and yield, and yield contributing characters. In row spacing, 20 cm gave best result in respect of yield contributing characters than treatment. For combined effect 4 cm sowing depth with 20 cm row spacing showed better performance in respect to germination, stand establishment, growth, yield and yield contributing characters.

References

REFERENCES

Ahmed, J., Marwat, M.I. and Ahmed, H.K. (2003). Effect of herbicides and row spacing on different traits of wheat (*Triticum aestivum* L.). *Pakistan J. Weed Sci. Res.* **9**(1-2): 33-40.

Ahmed, S. (2003). Effect of plant density on growth and yield of wheat cv Shourav. M.S. Thesis, Dept. Agron., Bangladesh Agri. Univ. Mymensingh, Bangladesh.

Ahmad, S., Ahmad, I., Banars, M. and Gill, M.A. (1984). Effect of row spacing and weed control on growth and yield of wheat. *J. Agric. Res. Pakistan.* **22**(2): 113-117.

Aikins, S.H.M., Afuakwa, J.J. and Baidoo, D. (2006). Effect of planting depth on maize stand establishment. Ghana Institute of Engineers. **4**(2): 20-25.

Alam, M.S., Sultana, M.S., Hossain, M.B., Salahin, M. and Roy, U.K. (2014). Effect of sowing depth on the yield of spring wheat. *J. Environ. Sci. Nat. Resour.* **7**(1): 277-280.

Al-Amin, A., Hamid, A. Islam, T. and Chand, T. (1994). Effect of seed size and seeding depth on the yield performance of wheat (*Triticum aestivum* L.). *Ann. Bangladesh Agric*. **4**(1): 1-5.

Ali, M., Ali, L., Sattar, M. and Ali, M.A. (2010). Improvement in wheat (*Triticum aestivum* L.) yield By manipulating seed rate and row spacing in Vehari zone. *J. Anim. Plant Sci.* **20**(4).

Ali, Y., Ahsanul, H.M.. Tahir, G.R. and Ahmad, N. (1999). Effect of inter and intra row spacing on the yield and yield components of chickpea. *Pakistan J. Biol. Sci*. **2**: 305-307.

Ali, M.A., Rehman, R., Siddique, M. and Rashid, M. (1996). Effect of seed rate and row spacing on wheat yield. *J. Agric. Res.* **34**(6): 351-357.

Amin, M., Hamid, A., Islam, A., Maniruzzaman, A.F.M. and Siddique, S.B. (2004). Effect of sowing depth and phosphorus fertilizer on stand establishment, root growth and yield of wheat. *Bangladesh Agro. J.* **10**(1 & 2): 93-98.

Amjad, M. and Anderson, W.K. (2006). Managing yield reductions from wide row spacing in wheat. *Australian J. Agric.* **46**(10): 1313-1321.

Anderson, W. and Garlinge, J. (2000). The Wheat Book: Principles and Practices. Department of Agriculture, Western Australia. Bulletin No. 4443.

Andrade, F.H., Uhart, S.A. and Frugone, M.I. (1993). Intercepted radiation at flowering and kernel number in maize: shade versus plant density effects. *Crop Sci.* **33**: 482-485.

Andrews, M., Scott, W.A. and Mckenzie, B.A. (1991). Nitrate effects on preemergence growth and emergence percentage of wheat (*Triticum aestivum* L.) from different sowing depths. *J. Exp. Bot.* **42**(11): 1449-1454.

Assenheimer, C., Metzger, B., Papworth, L. and Ragan, G. (1999). Agriculture and Agri-Food Canada Bulletin. The Alberta Farm Machinery Research Centre.

Ayaz, S., Shah, P., Sharif, H.M. and Ali, I. (1999). Yield, yield components and other important agronomic traits of wheat as affected by seed rate and planting geometry. *Sarhad J. Agric.* **15**: 255-261.

Azad, M.A.K. (1999). Effect of seeding depth and mulching on the yield of wheat. M. Sc. Thesis, Dept of Agronomy, Bangladesh Agricultural University, Mymensingh, Bangladesh.

Bakht, J., Qamer, Z., Shafi, M., Akber, H., Rahman, M., Ahmad, N. and Khan, M.J. (2007). Response of different wheat variety to various row spacing *Sarhad J. Agric*. **23**(4).

BARI (Bangladesh Agricultural Research Institute) (2008). Krishi Projukti Hatboi(Handbook on Agrotechnology). Bangladesh Agril. Res. Inst., Gazipur-1701, Bangladesh.

BARI (Bangladesh Agricultural Research Institute) (1989-90). The Effect of sowing depth and irrigation on wheat. Bangladesh Agri. Res. Ins. Annual Report Research. **17**: 211-219.

BBS (Bangladesh Bureau of Statistics) (2011). Statistical Year book of Bangladesh. Bangladesh Bur. Stat., Div., Min. Plan., Govt. Peoples Repub. Bangladesh, p. 37.

Borse, C.D. and Mahajan, V.K. (1980). Studies on the effects of sowing depth, seeding rate and nitrogen levels on growth and yield of wheat variety, ‘Sonalika’. *Indian J. Agron.* **25**(1): 45-60.

Bouaziz, A., Souty, N. and Hicks (1990). Emergence force exerted by wheat Seedlings. *Soil & Tillage Research*. **17**: 211-219.

Burch, R.N. (1986). Effects of changing row spacing on wheat yields. Final report: Wheat Industry Research Council Project No. 498/0051 and Western Australian State Wheat Research Committee Project No. 355/0067, Western Australian Department of Agriculture, Perth.

Campbell, C.A., Selles, F., Zentner, R.P., Mcleod, J.G. and Dyck, F.B. (1991). Effect of seeding date, rate and depth on winter wheat grown on conventional fallow in S.W. Saskatchewan. *Plant Sci.* **71**: 51-61.

Chata, M.S. and Nazir, M.S. (1984). Effect of plant population and geometry of plant on the yield and growth behaviour of wheat. *Pakistan J. Agril. Res.* **5**(2): 138-140.

Chen, C. and Neill, K. (2006). Response of Spring Wheat Yield and Protein to Row Spacing, Plant Density and Nitrogen Application in Central Montana. Fertilizer Fact: No. 37. Montana State University, Agricultural Experiment Station and Extension Service.

Darwinkel, A. (1978). Patterns of tillering & grain production of winter wheat at wide range of plant densities. *Netherland J. Agric. Sci.* **26**: 383-398.

Dawood, R.A. (1996). Effect of row spacings and timing of nitrogen application on the yield, yield components and some technological properties of wheat grains (*Triticum aestivum L.*). *Australian J. Agril. Sci.* **25**(1): 319-340.

Desbiolles, J. (2002). Optimising Seedling depth in the paddock. Internet: http://www.unisa.edu.au/amrdc/Areas/Proj/SeedTrials/Seedingdeptharti cle Kerribee.pdf

Donaldson, E., Schillinger, W.E. and Dofing, S.M. (2001). Strwa production and grain yield relationships in winter wheat. *Crop Sci.* **41**: 100-106.

Ercoli, L. and Masoni, A. (1995). Effects of row spacing and orientation on yield and yield components of winter wheat. *Agril. Mediterranea.* **125**(3): 215-221.

Ehsanullah, Chatha, A.A., Ghaffar, A. and Randhawa, M.A. (1999). Dry matter partitioning into root and seedling of wheat genotypes sown at different depths and dates under rainfed conditions. *Int. J. Agri. Biol.* **1**(4): 250-253.

Evers, J.B., Huth, N.I. and Renton, M. (2009). Light extinction in spring wheat canopies in relation to crop configuration and solar angle. IEEE Third International Symposium on Plant Growth Modeling, Simulation, Visualization and Applications (PMA), Beijing, 9-13 November 2009, 107-110.

Fatyga, J. (1991). Effect of different nitrogen fertilizer application rates and row spacing on the quantity and quality of buckwheat yields. *Roczniki Nauk Rolniczych. Seria A Produkcja Roslinna*. **109**: 87-94.

Fonts, J.R.M., de Souza, M.A., Cardosa, A.A., Cruz, C.D. and M.A.de Souza, M.A. (1997). Effect of spacing and sowing rate on yield and other agronomic characteristics of wheat (*Triticum aestivum* L.). *Revista Ceres*. **44**: 249-262.

Harbir, S., Singh, T., Singh S. M., Rao, D. S. R. M. Faroda, A. S., Panwar, K. S. and Singh, H. (1991). Effect of seeding depth in relation to germination, seedling establishment and yield of dwarf wheat (*Triticum aestivun*). *Indian J. Agron. Sci.* **61**(8): 546-550.

HongYong, S., ChangMing, L., XiYing, Z. and Dong, P. (2006). Effect of different row spacing on soil evaporation,evapotranspiration and yield of winter wheat. *Transactions Chinese Soc. Agric. Engg*. **22**(3): 22-26.

Hussain, M., Mehmood, Z., Khan, M.B., Farooq, S., Lee, D.J. and Farooq, M. (2012). Narrow row spacing ensures higher productivity of low tillering wheat cultivars. *Int. J. Agric. Biol*. **14**: 413-418

Hussain, I., Khan, M.A. and Ahmad, K. (2003). Effect of row spacing on the grain yield and the yield component of wheat *(Triticum aestivum* L.) *Pakistan. J. Agron.* **2**(3): 153-159.

Jepsen, H.M. (1985). Sowing depth and sowing methods. *Nordisk Jordbrugs forskning.* **67**(2): 194. [*Field Crop Abst*. (1987), 4(8): 608].

Josep, K.D.S., Alley, M.M., Bran, D.F. and Gravelle, W.D. (1985). Row spacing and seedling rate defects on yield and yield components of soft red winter. *Agron. J.* **77**: 211-214.

Keshtkar, E., Kordbacheh, F., Mesgaran, M.B., Mashhadi, R.H. and Alizadeh, M.H. (2009). Effects of the sowing depth and temperature on the seedling emergence and early growth of wild barley (*Hordeum spontaneum*) and wheat. *Weed Biol. Management.* **9**: 10-19.

Khan, M.S. and Mukhadum, M.I. (1988). Maximizing wheat grain yield by adopting seed rate in the southern Punjab. *Pakistan J. Agril. Res.* **9**(1): 16-18.

Kirkland, K.J.F. (1993). Weed management in spring barley (*Hordeum vulgare*) in the absence of herbicides. *J. Sust. Agric.* **3**: 95-l04.

Kumar, A., Sinha, A.K., Sinha, B.P., Singh, K.M.P. and Thakur, S.S. (1991). Response of wheat genotypes to seed rates and row spacing. *Indian J. Agron.* **36**: 78-82.

Lafond, G.P. (1994). Effects of row spacing, seeding rate, and nitrogen on yield of barley and wheat under zero-till management. *Canadian J. Plant Sci*. **74**(4): 703-711.

Loeppky, H., Lafond, G.P. and Flower, D.B. (1989). Seeding depth in relation to plant development, winter survival and yield of no–till winter wheat. *Agro. J.* **81**(1): 125-129.

Mallik, M.A., Haroon-ur-Rashid, M. and Razzaq, A. (1996). Row spacing on two wheat varieties under rainfed conditions. *Sarhad J. Agic.* **12**(1):31-36.

Marko, F. (1994). Effects of row spacing and seed rates on grain yield and properties of winter wheat seed. *Rostlinna Vyroba*. **40**: 431-438.

McLeod, J.G., Campbell, C.A., Gan, Y. Dyck, F.B., and Vera, C.L. (1996). Seeding depth, rate and row spacing for winter wheat grown on stubble and chemical fallow in the semiarid prairies. *Canadian J. Plant Sci.* **76**: 207-214.

Mostafa, M.G., Sarker, A., Islam, M.A. Chowdhury, F.A. and Chowdhury, A.K.M.S.H. (1990). Study on the effect of spacing and seeding depth on the yield of wheat. *Bangladesh J. Agril. Sci.* **17**(l): 27-30.

Nemeth, I. and Korosa, T. (1987). Yield response to plant spacing in wheat. *Novenytermcles*. **36**(5): 373-376.

Ogunlela, V.B., Chude, V.O. and Negedu, S. (2000). Response of two irrigated wheat (*Triticum aestivum* L.) varieties to row spacing and nitrogen supply: yield, yield components and N uptake. *Tropenlandwirt*. **101**: 165-180.

Patel, J.C., Vays, M.M., Malviya, D.D. and Khanpara, V.D. (1986). Response of wheat to different planting patterns and seed rates. *Indian J. Agron*. **31**(3): 256-258.

Pandey, B.P., Basnet, K.B., Bhatta, M.R., Sah, S.K., Thapa, R.B. and Kandel, T.P. (2013). Effect of row spacing and direction of sowing on yield and yield attributing characters of wheat cultivated in Western Chitwan, Nepal. *Agric. Sci*. **4**(7): 309-316.

Percival, J. (1985). The effect of depth of sowing under dry tropical condition. Division of soil report No 12, CSIRO, Australia.

Peterson, R.F. (1965). Wheat. *Int. Sci. Pub. Inc.*, New York. p. 258.

Porter, P.M. and Khalilian, A. (1995). Wheat response to row spacing in relay intercropping systems. *Agron. J*. **87**(5): 999-1003.

Raj, S., Diwan, S., Rao, V.U., Singh, R. and Singh, D. (1992). Effect of date of sowing and row spacing on the yield of wheat (*Triticum aestivum* L.). *Crop Res. Hisar.* **5**: 199-206.

Rajput, F.K.M., Arain, A.S., Rajput, M.J., Alam, S.M. and Baloch, A.W. (1989). The growth and yield of wheat as affected by different seed rates and row spacing. *Sarhad J. Agric*. **5**: 479-482.

Seeiso, T.M., and Materechera, S.A. (2011). Effects of seed sowing depth on emergence and early seedling development of two African indigenous leavesy legetables. *Life Sci. J*. **8**(S2): 12-17.

Shahbaz, A., Yasmin, S., Hashmi, N.I. and Qayyum, A. (1988). Influence of seed size and seeding depth on performance of tall and semidwarf wheat under limited soil moisture. *Pakistan J. Agri. Res.* **9**: 300-304.

Shaner, D.L. Isom, W.H. and Lyon, J.L. (1978). Effect of seeding rate and seeding depths on yield and competition with weeds of tow wheat varieties. *Proc. West. Soc. Weed Sci.* **31**: 89-95.

Sharma, R.R. and Thakur. R.C. (1990). Effects of seed rates, row spacing and soil moisture conservation practices on rainfed wheat (*Triticum aestivum* L.). *Himachal J. Agric. Res.* **16**: 1-5.

Silva, D.B.D.A. (1991). Effect of sowing depth on irrigated wheat in the Cerrado region. Pesquisa Agropecuaria Brasileira. **26**(5): 769-733. [Wheat, Barley and Triticali Abst. 1993, **10** (5): 531].

Singh, G., Singh, O.P., Yadav, R.A. Singh, R.S. and Singh. B.B. (1994). Effect of seeding methods, seed rates and fertility levels on yield and economics of late sown wheat after rice in flood prone area. *Ann. Agril. Res*. **15**: 448-451.

Singh, R.B. and Srivastava, R.K. (1991). Influence of different spacing on the yield of wheat *(Titticum aestivum* L.). *New Agriculturist*. **1**(2): 147.

Singh, R.V., Saran, R.N., Nema, D.P., Singh, P.P. and Singh, S. (1985). Response of dwarf wheat to irrigation schedules. *Indian J. Agric.* **32**(1): 124-126

Singh, B. P. (1970). Influence of seed size and depth of sowing on early growth and yield dwarf wheat. *Madras Agric. J*. **57**(8): 449-452.

Solie, J.B., Solomon, S.G., Nlijself, K.P., Peeper, T.F. and Koscalny, L.A. (1991). Reduced row spacing for improved wheat yields in weed free and weed infested fields. Transactions of tile ASAE (USA). **34**(4): 1654-1660.

Spaldon, E. and Derco, M. (1969). Influence of sowing factors on the yield of winter wheat. Pal Noliospodursilv **15**(4). 281-294. [*Field Crop Abst*. 1970, **23**(3): 279].

Srivastava, U.S.L., Paltoo, R., Om, P., Ram, P. and Prakash, O. (1996). Response of wheat (*Triticum aestivum* L.) to row spacing, seed rate and fertilizer. *Indian J. Agron.* **41**: 558-561.

Stickler, F.C. (1962). Seeding depth and use of press wheels as factors affecting winter barley and winter wheat yields in Kansas. *Agron. J.* **54**: 492-494.

Thorsted, M.D., Olesen, J.E. and Weiner, J. (2006). Width of clover strips and wheat rows influence grain yield in winter wheat/white clover intercropping. *Field Crop Res*. **95**: 280-290.

Tollenaar, M.L., Dwyer, M. and Stewart, D.W. (1992). Ear and kernel formation in maize hybrids representing three decades of grain yield improvement in Ontario. *Crop Sci.* **32**: 432-438.

Tompkins, D.K., Hultgjreen, G.E. Wright, A.T. and Fowler, D.B. (1991). Seed rate and row spacing of no-till winter wheat. *Agron. J.* **83**: 684-688.

Vedrov, N.G. and Frolov, I.N. (1990). The role of sowing depth in the formation of spring wheat yield. Sibirskii vest sel skokhozyaistvennoi Nsuki. **1**: 3-6[*Wheat, Barley, Triticale Abst.*1992. (2):672].

Wajid, A., Ali, H. and Shaukat, A. (1997). Some important agronomic parameters of wheat varieties affected by seeding depth at different locations. *Sarhad J. Agric.* **13**: 23-29.

Yagmur, M. and Kaydan, M. (2009). The effects of different sowing depth on grain yield and some grain yield components in wheat (*Triticum aestivum* L.) cultivars under dryland conditions. *African. J. Biotec.* **8**: 196-200.

Yoon, E.B., Yoon, Y.H., Kwon, Y.U., Youn, K.B and Shin, M.G. (1991). Studies on fertilizer level, row spacing and sowing rate using the plot drill seeder in winter wheat. Res. Reports of the Rural Dev. Administration. *Upland Indus. Crops*. **33**: 65-71.

Younas, M. (1993). Effect of different planting patterns on the seed yield and quality of mashbean (*Vigna mungo* L.). M.Sc. Thesis, Deptt. Agron., Univ. Agric., Faisalabad.

Yunusa, J.A.M., Belford, R.K, Tennant, D. and Sedgley, R.H. (1993) Row spacing fails to modify soil evaporation and grain yield in spring wheat in a dry Mediterranean environment. *Australian J. Agric. Res.* **44**, 661-676. doi:10.1071/AR9930661.

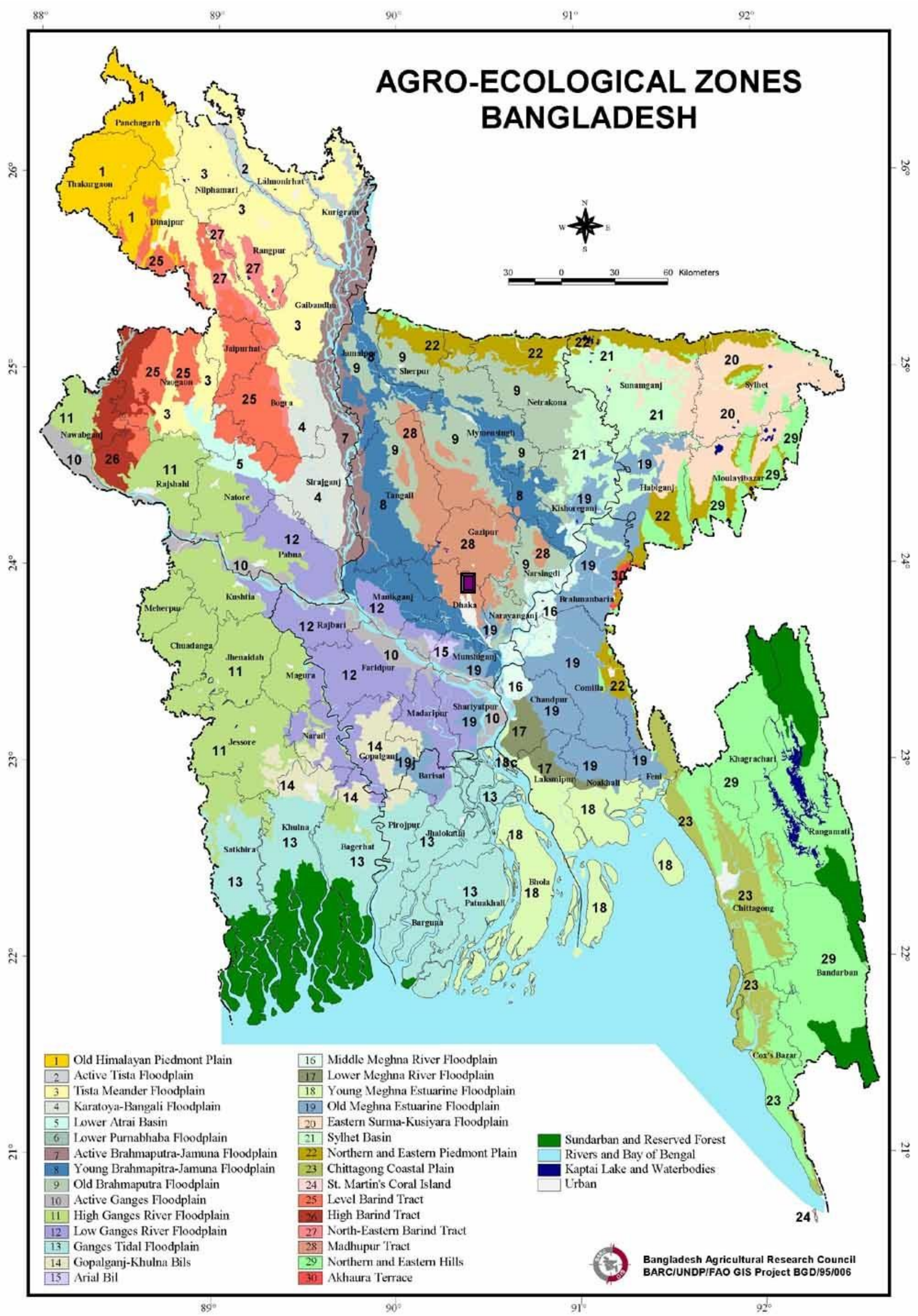
Zhenhua. I., Lua, I. and Yuyog, Z. (1995). A study on the physiological and ecological effects of late autumn sowing on the populations of large grain varieties of winter wheat. *Beijing Agril. Sci.* **13**(1): 35-39.

Zhou, X.B., Chen, Y.H. and Ouyang, Z. (2011). Effects of row spacing on soil water and water consumption of winter wheat under irrigated and rainfed conditions. *Plant Soil Environ*. **57**(3): 115-121.

Appendices

APPENDICES

Appendix I: Map showing the experimental sites under study



The experimental site under study

Appendix II: Characteristics of soil of experimental site is analyzed by Soil Resources Development Institute (SRDI), Khamarbari, Farmgate, Dhaka

A. Morphological characteristics of the experimental field

Morphological features	Characteristics
Location	Experimental field, SAU, Dhaka
AEZ	Madhupur Tract (28)
General Soil Type	Shallow red brown terrace soil
Land type	High land
Soil series	Tejgaon
Topography	Fairly leveled
Flood level	Above flood level
Drainage	Well drained

B. Physical and chemical properties of the initial soil

Characteristics	Value
%Sand	27.33
%Silt	42.45
%clay	30.22
Textural class	Silty Clay Loam
pH	5.7
Organic carbon (%)	0.82
Organic matter (%)	0.72
Total N (%)	0.071
Available P (ppm)	20.27
Exchangeable K (mel 1.00 g soil)	0.29
Available S (ppm)	16.65

Source: SRDI, 2013

Appendix III. Monthly record of air temperature, relative humidity and rainfall of the experimental site during the period of November, 2013 to March, 2014

Month	Air temperature (^0C)		Relative humidity (%)	Rainfall (mm) (total)
	Maximum	Minimum		
November, 2013	30.10	18.50	66	0.00
December, 2013	26.20	15.60	72	4.00
January, 2014	24.20	13.60	72	0.00
February, 2014	27.10	15.70	62	12.00
March, 2014	32.4	20.50	52	10.00

Source: Bangladesh Meteorological Department (Climate division), Agargaon, Dhaka-1212.

Appendix IV. Analysis of variance of the data on seedling m^{-2} of wheat as influenced by different sowing depth and row spacing

Source of variation	df	Mean square of seedling m^{-2}		
		5 DAS	8 DAS	11 DAS
Replication	2	1257.937	452.758	795.210
Factor A (D)	2	7869.568*	9271.719*	6607.496*
Factor B (S)	3	4048.151*	6077.996*	7640.037*
D X S	6	1248.083*	1398.585*	1705.152*
Error	22	245.461	241.349	368.553

*Significant at 5% level of significance

^{NS} Non significant

Appendix V. Analysis of variance of the data on 1000 grain weight (g), seed yield (t ha^{-1}), straw yield (t ha^{-1}), biological yield (t ha^{-1}) and harvest index (%) of wheat as influenced by different sowing depth and row spacing

Source of variation	Df	Mean square				
		1000 grain weight (g)	Seed yield (t ha^{-1})	Straw yield (t ha^{-1})	Biological yield (t ha^{-1})	Harvest index (%)
Replication	2	1.532	0.049	0.898	1.326	10.410
Factor A (D)	2	12.876*	2.489*	3.291*	11.231*	12.882 ^{NS}
Factor B (S)	3	3.286 ^{NS}	0.542*	0.610 ^{NS}	2.222*	2.277 ^{NS}
D X S	6	0.612*	0.072*	0.033*	0.161*	1.399 ^{NS}
Error	22	5.871	0.068	0.416	0.458	15.449

*Significant at 5% level of significance

^{NS} Non significant