Research Article

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Growth, yield attributes and yield of irrigated spring wheat as influenced by sowing depth

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Abstract: In South Asia, including Bangladesh, most farmers sow wheat under residual soil moisture after rice is harvested, but the upper layer of soil dries quickly after soil has been prepared for wheat sowing. Crop seeds that are sown either deeply or shallowly can result in failed emergence, low dry matter accumulation, and reduced grain yield. Therefore, appropriate sowing depth is crucial for seedling emergence and successful crop establishment. Considering this, a two-year field experiment was conducted at the research field of the Agricultural Research Station of the Bangladesh Agricultural Research Institute at Dinajpur during the dry, *rabi* (winter) season of 2013-14 and 2014-15, at four sowing depths, i.e., 2, 4, 6 and 8 cm, to identify the most appropriate sowing depth for higher grain yield. Wheat seeds sown at a depth of 4 cm resulted in significantly highest number of seedlings and seminal roots, tallest plants as well as largest roots and plant biomass followed by sowing at a depth of 6, or 2 cm. Depth of sowing also significantly affected the yield and yield-related attributes, all performing best at a depth of 4 cm. The highest number of spikes m⁻², grain yield, straw yield and harvest index were observed when seeds were sown at depths of 4 or 6 cm, relative to 2 or 8 cm. Therefore, a sowing depth of 4 to 6 cm is recommended for wheat cultivation in South Asia, including Northern Bangladesh.

Keywords: depth of sowing; coleoptile; grain yield; seedling; seminal roots; wheat

1 Introduction

The growth cycle of wheat follows this sequence: germination, seedling establishment and leaf production, tillering and head differentiation, stem and head growth, head emergence and flowering, and grain filling and maturity (Batra 2014; Kong et al. 2016). When a kernel is sown, the process of germination begins, and the radicle and seminal roots first extend, followed by the coleoptile (Ali 2010). Roots can be initiated from several positions on the seedling, both at the level of the seed and at the crown, which is usually separated from the seed by a sub-crown internode (Gunston and Ali 2011). The length of the internode increases as the depth of planting increases (Kong et al. 2016).

The depth to which seeds are sown is an important factor that influences root length, diameter, density, fresh and dry weight, shoot to root weight ratio, secondary root and root hair number, root penetration, root architecture and growth rates during different plant growth stages (Taiz and Zeiger 2002; Akman and Topal 2013). The ability of plants to obtain water and mineral nutrients from the soil is related to their capacity to develop an extensive root system (Taiz and Zeiger 2002). Deep root systems can access greater soil profiles in order to absorb and accumulate more water and nutrients than a shallow/surface root system (Garnett et al. 2009). Optimum sowing depth is thus a desired goal for seedling emergence and establishment of all crops. If seeds are sown at too shallow a depth, then sowing results in poor germination due to inadequate soil moisture in the top soil layer (Desbiolles, 2002) while seeds sown at excessively deeper depths result in significantly reduced seedling emergence, crop establishment and yield (Aikins et al. 2006; Desbiolles 2002; Mohan et al. 2013).

Similar to a root system, coleoptile length in wheat is also positively correlated with growth and yield, and when seeds are sown too deep (9 cm), this can result in

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seedlings with a shorter coleoptile and a marked decline in yield (Yagmur and Kaydan 2009). Mohan et al. (2013) and Odeleye et al. (2007) noted that if seeds are placed deeper than the length of coleoptiles, then the shoot has to displace superficial mechanical obstacles. The sowing depth for wheat has a direct influence on the number of spikes m^{-2} , and finally on grain yield. With deeper sowing, the influential role of coleoptile length on plant emergence must be taken into account (Joshi et al. 2007; Rebetzke et al., 2007). Many researchers (Matsui et al. 2002, Rebetzke et al. 2007; Rebetzke et al. 2016) have reported a positive association between coleoptile length and plant number with deep sowing. Kirkegaard and Lilley (2007) as well as Thorup-Kristensen et al. (2009) observed that shallow sowing (5 cm) always resulted in better yield of wheat and barley than deep sowing (10–20 cm). At depths less than 2.54 cm, there is a higher risk of poor seed-soil contact and poor emergence, especially when the seed bed is rough and/or dry, and thus it is strongly suggested that spring wheat should never be planted at a depth of less than 2.54 cm or more than 7.5 cm (Hall 2012).

Wheat (*Triticum aestivum* L.) is the most important cereal in terms of production and acreage in the world (FAO 2015), including the countries in South Asia. In Bangladesh, it is the second most important cereal after rice for securing the food security of an ever increasing poor population (Timsina et al. 2016), although its average yield is low (3.08 t ha^{-1}) (BBS 2015) compared to the yield of other wheat-growing countries around the world (FAO 2015). However, according to the Bangladesh Agricultural Research Institute (BARI), the potential yield of wheat varieties is $4.0\text{--}4.5 \text{ t ha}^{-1}$ (BARI 2016); with climatic yield potential as high as 6.0 t ha^{-1} (Timsina et al. 2010, 2016). Such a wide gap between potential yield and actual yield needs to be reduced to improve Bangladesh's food security. One reason for low wheat yield in South Asia, and particularly in Bangladesh, may be the lack of awareness among farmers about the use of proper agronomic practices, including seeding depth (Anonymous 2015; Wajid et al. 2004; Guberac et al. 2005; Hall 2012; Schillinger 2005; Kristó et al. 2007; Maric et al. 2008; Otteson et al. 2008; Valério et al. 2009; Zecevic et al. 2014). Most farmers in South Asia, including Bangladesh, grow wheat in residual soil moisture after harvesting rice in the rainy (*aman*) season, a condition in which the upper soil layer dries quickly after land preparation for the subsequent dry, winter (*rabi*) season, in which wheat is also grown. As a result, seeds that are sown at a shallower depth are at risk of poor germination due to less imbibition and poor seed-soil contact. Therefore, an experiment was carried out in two consecutive years in

Northern Bangladesh to determine the optimum sowing depth for wheat that could be recommended for South Asia as a whole.

2 Materials and methods

2.1 Site description

2.1.1 Location of the experiment

The experiment was carried out at the Agricultural Research Station (ARS), BARI, Rajbari, Dinajpur during the 2013-14 and 2014-15 wheat seasons. The Agro Ecological Zone (AEZ) of the area is the Old Himalayan Piedmont Plain (AEZ-1) (FAO/UNDP 1988). The geographical position of the area is between $25^{\circ} 38' \text{ N}$ and $88^{\circ} 38' \text{ E}$, and 42 m above sea level.

2.1.2 Soil characteristics in the experimental field

Soil of the experimental field was analysed before sowing wheat in the first year. Organic carbon was determined by the Walkley and Black oxidation method (Walkley and Black 1934), total nitrogen (N) by the micro Kjeldhal method (Jackson 1958), calcium (Ca) and magnesium (Mg) by the extractable method (Hunter 1972), phosphorus (P), potassium (K), sulphur (S) and zinc (Zn) by a modified Hunter's method (BARC 1984), and boron (B) was determined colorimetrically by the Azomethine-H method (Sippola and Ervio 1977). Soil pH was measured in soil/water (1:2, w/v) using a glass electrode pH meter. The results of the soil analysis indicated that soil pH of the experimental site was 6.7 and organic matter content was 1.71% (Table 1). Total N was 0.09% which was below the critical level of 0.12%. Based on the critical levels of these nutrients, Ca, Mg, K, and Zn were low, S and B were just above critical levels, while P was high.

2.1.3 Meteorological information in 2013-14 and 2014-15

Daily maximum and minimum temperatures, humidity, sunshine hours and rainfall were recorded in both years, by the HOBO U12 Family of Data Loggers (MicroDAQ.com) at the meteorological observatory of the ARS, and are presented in Figure 1. The experimental site covers about 21% of the wheat-growing area of Bangladesh, due to a comparatively cooler and longer winter (Sarker et al. 2015).

Table 1: Soil analysis report of the experimental field before sowing

Items	pH	Organic matter	Total N	Ca	Mg	K	P	S	B	Zn
		%		Meq 100 g ⁻¹ soil			µg g ⁻¹ soil			
Pre-sowing status	6.66	1.71	0.09	0.90	0.60	0.21	24.19	24.04	0.84	1.31
Critical level	-	-	0.12	2.00	0.80	0.20	14.00	14.00	0.20	2.00

Figure 1: Weekly average temperature, rainfall and relative humidity for two wheat-growing seasons (November to April, 2013-14 and 2014-15) (Source: Meteorological station, Rajbari-Dinajpur, Bangladesh).

2.2 Experimental design and treatments

The experiment was conducted in a completely randomized block design with three replications. The treatments were four sowing depths: 2, 4, 6 and 8 cm. The unit plot size consisted of 15 rows, each 4 m long, and a row-to-row distance of 20 cm and a block-to-block distance of 1 m.

2.3 Experimental procedure and crop management

2.3.1 Variety, seed rate, sowing time and seed treatment

Wheat varieties ‘BARI Gom 28’ and ‘BARI Gom 26’ (Table 2) were sown in lines by hand on November 26 in 2013 and on November 30 in 2014, respectively. Seeds were sown at 120 kg ha⁻¹ at specified depths by making specific narrow

furrows with an iron rod and covering the holes with soil after sowing seeds. Before sowing, seeds were treated with Provax-200 WP (marketed by Hossain Enterprise CC Bangladesh Ltd., an agrochemical company, in association with Chemtura Corp., USA), which is a seed-treatment fungicide containing carboxin and thiram. Provax-200 WP is a perfect fungicide to control fungi in soil at the seedling stage (Hossain and Teixeira da Silva 2012).

2.3.2 Fertilizer and irrigation

Fertilizer was applied at recommended doses by the WRC: 100-27-40-20-1 kg ha⁻¹ of N, P, K, S, and B. Two-thirds of N and a full amount of the other fertilizers were applied as a basal amount during final land preparation. The remaining N fertilizer was applied immediately after the first irrigation (21 days after sowing (DAS)) while second and third irrigations were applied at booting (47 DAS) and grain-filling (78 DAS) stages.

Table 2: Characteristics of wheat varieties BARI Gom 26 and BARI Gom 28 used in the study. Source: BARI (2016)

Variety	Stress tolerance capacity	Life span (days)	1000-grain weight (g)	Yield (kg ha ⁻¹)	Suitable area for cultivation	Year of release	Sowing time	Harvest time	Major diseases and pests
BARI Gom 26	Tolerant to terminal heat stress in late seeding	104-110	45.0-49.0	3500-5000	Possible to grow throughout the country except in areas with salinity level >6 dS/m	2010	Nov.15-30	Mar.-Apr.	Tolerant to <i>bipolaris</i> leaf blight and resistant to leaf rust (stem rust) race Ug 99
BARI Gom 28	Tolerant to terminal heat stress in late seeding	102-108	43.0-48.0	4000-5500	All over the country except saline areas	2012	Nov.15-30	Mar.-Apr.	It is resistant to leaf rust and tolerant to <i>Bipolaris</i> leaf blight

2.3.3 Data collection

Data on seedling emergence m⁻² at different sowing depths were recorded up to 12 DAS, starting from 5 DAS. For measuring seminal roots, plant dry weight (DW) plant⁻¹ and root DW plant⁻¹, five randomly selected plants per treatment were uprooted and carefully washed with tap water. To determine the DW of roots and shoots, the samples were dried in an oven at 70°C for 72 h, and weighed on an electric balance to two decimal places. Plant height was measured at 10-day intervals up to 80 DAS, starting from 20 DAS. The crop was harvested, 3 m long by using 10 (3×2 m) middle rows to avoid border effects, for grain yield at full maturity. The harvested crop of each plot was bundled separately, tagged and manually threshed on a threshing floor. The bundles were thoroughly dried in bright sunshine before their weights were recorded. Data were recorded for plant height (cm), number of spikes m⁻², 1000-grain weight (g; TGW), grain yield (t ha⁻¹), straw yield (t ha⁻¹) and harvest index (HI) (%), all at harvest. Grain yield was recorded at 14 % moisture content while straw yield was measured on a sun-dry basis (approx. 3% moisture content). Grain yield and HI were calculated according to the following equations (Donald 1962; Hellevang 1995):

$$Y(M_2) = \frac{100 - M_1}{100 - M_2} \times Y(M_1)$$

where, $Y(M_2)$ = weight of grain at 14% moisture; $Y(M_1)$ = weight of grain at actual moisture %; M_1 = actual moisture %; M_2 = expected moisture %.

2.4 Data analysis

Data was statistically analyzed using the MSTAT statistical package of Michigan State University, USA (Anonymous 1986). The Least Significant Difference (LSD) test at $P < 0.05$

was used to test the differences between means (Hayter 1986).

Ethical approval: The conducted research is not related to either human or animals use.

3 Results

In two varieties of wheat growing in Northern Bangladesh, seeding depth significantly affected different developmental and growth parameters, as explained next.

3.1 Seedling emergence

The progression in seedling emergence was significantly influenced by sowing depth (Figure 2). Seedling emergence started at 5 DAS, increased significantly up to 9 DAS, and then levelled off. At 5 DAS, the highest seedling emergence was recorded at a depth of 4 cm, followed by 2 and 6 cm while no seedlings were observed when seeds were sown at a depth of 8 cm. However, after 7 DAS, seedling emergence of seeds sown at a depth of 8 cm was higher than at 2 cm while seeds sown at a depth of 4 cm formed most seedlings at 9 DAS followed by 6 cm. Lowest seedling emergence was observed at 2 cm, followed by 8 cm.

3.2 Plant height

Plants increased in height from 20 to 80 DAS (Figure 3). However, plant height increased up to 70 DAS for depths of 2, 4 and 6 cm, and up to 80 DAS for a depth of 8 cm. The tallest plants were observed when seeds were sown at 4 cm. After 60 DAS, no significant differences were observed between 2, 4 and 6 cm (Figure 3) and shortest plants formed when seeds were sown at a depth of 8 cm.

3.3 The initiation of seminal roots and root dry weight

The number of seminal roots plant⁻¹ (Figure 4) and root DW (Figure 5) at 10 DAS were significantly influenced by sowing depth, with maximum number of seminal roots and largest weight observed at a depth of 2 cm, followed by 4 or 6 cm (Figure 4).

3.4 Plant dry weight

Sowing depth significantly affected DW plant⁻¹ at 10 DAS. The highest DW plant⁻¹ was recorded at a depth of 4 cm, followed by 6 cm, and the lowest plant DW was found at a depth of 2 cm (Figure 6). The pattern of DW was different between the two years.

3.5 Plant height at harvest

Plant height at harvest varied significantly depending on the depth of sowing. The tallest plants were observed at a sowing depth of 4 cm, followed by 2 or 6 cm, while shortest plants formed when seeds were sown at a depth of 8 cm (Figure 7).

3.6 Number of spikes

Spikes m⁻² varied significantly at different sowing depths: the highest number of spikes was recorded at a depth of 4 cm followed by 6 cm, while fewest spikes formed when seeds were sown at a depth of 2 or 8 cm (Figure 8).

3.7 1000-grain weight

TGW was significantly affected by the depth of sowing in 2013-14, but not in 2014-15. The maximum TGW was recorded for a sowing depth of 2 or 8 cm, while the minimum weight was recorded for a sowing depth of 4 or 6 cm (Figure 9).

3.8 Grain yield

Grain yield was significantly affected by sowing depth: the maximum grain yield was observed for a depth of 4 or 6 cm, while the lowest yield was found for a depth of 2 or 8 cm (Figure 10).

Figure 2: Seedling emergence as affected by sowing depth at different days after sowing in wheat (average of 2 years). Mean ($\pm$ SD) was calculated from three replicates for each treatment and significantly different at $P \leq 0.05$ (LSD test).

Figure 3: Plant height as affected by sowing depth at different days after sowing of wheat (average of 2 years). Mean ($\pm$ SD) was calculated from three replicates for each treatment and significantly different at $P \leq 0.05$ (LSD test).

Figure 4: Number of seminal roots as affected by sowing depth of wheat recorded at 10 DAS. Mean ($\pm$ SD) was calculated from three replicates for each treatment and significantly different at $P \leq 0.05$ (LSD test).

Figure 5: Seminal roots' dry weight (mg plant⁻¹) as affected by sowing depth of wheat recorded at 10 DAS. Mean ($\pm$ SD) was calculated from three replicates for each treatment and significantly different at $P \leq 0.05$ (LSD test).

Figure 6: Plant dry weight as affected by sowing depth of wheat recorded at 10 DAS. Mean ($\pm$ SD) was calculated from three replicates for each treatment and significantly different at $P \leq 0.05$ (LSD test).

Figure 7: Plant height at harvest as affected by sowing depth of wheat. Mean ($\pm$ SD) was calculated from three replicates for each treatment and significantly different at $P \leq 0.05$ (LSD test).

Figure 8: Number of spikes as affected by depth of sowing depth of wheat. Mean ($\pm$ SD) was calculated from three replicates for each treatment and significantly different at $P \leq 0.05$ (LSD test).

Figure 9: 1000-grain weight of wheat as affected by sowing depth. Mean ($\pm$ SD) was calculated from three replicates for each treatment and significantly different at $P \leq 0.05$ (LSD test).

Figure 10: Grain yield of wheat as affected by sowing depth. Mean ($\pm$ SD) was calculated from three replicates for each treatment and significantly different at $P \leq 0.05$ (LSD test).

3.9 Straw yield

Straw yield was also significantly affected by the depth of sowing: the highest straw yield was recorded for a depth of 4 or 6 cm, while the lowest was observed for a depth of 2 or 8 cm (Figure 11).

3.10 Harvest index

HI% was also significantly affected by the depth of sowing: the maximum HI% was found for a depth of 4 or 6 cm while the lowest HI% was found for a depth of 2 or 8 cm (Figure 12).

4 Discussion

4.1 Weather conditions during the field experiment

The weather parameters such as maximum and minimum temperature, rainfall as well as relative humidity are the most important climatic factors for the growth and development of plants, and hence their daily fluctuations affect crop growth and development, and ultimately yield (Hossain et al. 2013). The ideal timing for sowing wheat is linked to favorable climatic conditions that prevail in November until mid-December. In this study, wheat seeds were sown in a line by hand on November 26 in 2013 and on November 30 in 2014. Hossain and Teixeira da Silva (2012), Hossain and Teixeira da Silva (2013) and Hossain et al. (2013) reported optimum sowing times for existing wheat varieties of Bangladesh as being from mid-November to the first week of December in the agro-ecological zone 1 (our experimental site) of Northern Bangladesh. Relative to those findings, the weather conditions in our experimental period were suitable for good wheat yield (Figure 1) because in the vegetative stage, the average temperature was below 25°C and at the grain-filling stage, it was below 20°C in both years.

4.2 Seedling emergence

In our study, seedling emergence was the highest and the quickest when seeds were sown at a depth of 4 and 6 cm (Figure 2). Seeds sown at a depth of 2 cm resulted in the lowest seedling emergence, possibly due to low moisture

Figure 11: Straw yield of wheat as affected by sowing depth. Mean ($\pm$ SD) was calculated from three replicates for each treatment and significantly different at $P \leq 0.05$ (LSD test).

Figure 12: Harvest index of wheat as affected by sowing depth. Mean ($\pm$ SD) was calculated from three replicates for each treatment and significantly different at $P \leq 0.05$ (LSD test).

content in the upper soil layer. Similarly, seeds sown at a depth of 8 cm also resulted in lower seedling emergence, possibly due to the limitation of coleoptile length. These assumptions are supported by Desbiolles (2002) and Wang et al. (2009), who noticed that when seeds are sown at too shallow a depth, they result in poor germination due to inadequate soil moisture in the top soil layer, while sowing excessively deeply can significantly reduce crop emergence and finally yield (Aikins et al. 2006; Desbiolles 2002). Rebetzke et al. (2004; 2007), also noticed that poor wheat stands were not due to the depletion of seed reserves, but probably due to other characteristics such as coleoptile length, soil surface mechanical resistance, soil moisture content or, in waterlogged soils, a lack of available oxygen for respiration, all of which are affected by seeding depth.

4.3 Plant height

In the present study, up to 60 DAS, the tallest plants were observed when seeds were sown at 4 cm, followed by 2 or 6 cm (Figure 3) and shortest plants at a sowing depth of 8 cm throughout the growing season. In contrast, tallest plants at harvest were observed for a sowing depth of 2 cm in 2013-14 and for 4 cm in 2014-15 (Figure 7). This discrepancy may be due to the genetic makeup of the wheat varieties used, 'BARI Gom 28' in 2013-14 and 'BARI Gom 26' in 2014-15, as well as the micro-environmental conditions at those depths, which ultimately affected coleoptile length and plant height. Most of the existing wheat varieties, including these two, in Bangladesh have short coleoptiles. As a result, when they are sown excessively deeply (i.e., at 8 cm), coleoptiles are unable to emerge properly or are sometimes damaged, ultimately affecting the plant height. Rebetzke et al. (2007) noted that genotypic differences in wheat coleoptile length were strongly and positively correlated with the number of seedlings as well as plant height when seeds were sown deeply. When wheat seeds with short coleoptiles are sown deeply, the first true leaf forms deeply in the soil and seedlings may be weak and easily damaged (Botwright et al. 2001; Rebetzke et al. 2005). Most modern wheat genotypes have short coleoptiles (Wheat Doctor 2016).

4.4 Seminal root initiation and root dry weight

The depth at which seeds are sown, both between and within rows, is a significant factor both in assessing crop development and for predicting crop phenological stages. When wheat seeds are sown too deeply, the length of elongation and primordial leaves are shorter, and the final DW of seminal roots is reduced (Anderson and Garlinge 2000; Shackley 2000). In the present research, the number of seminal roots plant⁻¹ (Figure 4) and maximum root DW (Figure 5) at 10 DAS were observed at 2 cm, followed by 4 or 6 cm (Figure 4). This is due to adequate soil moisture at those depths, which influences germination as well as the growth and development of seedlings through the initiation of seminal roots and coleoptile length. This assumption is supported by Hoad et al. (2001) and Fan et al. (2016), who observed that the embryo normally possesses five roots, a primary radicle and two pairs of lateral rootlets, and following imbibition, the coleorhiza (root sheath) expands, splitting the seed coat; at the same time, the primary radicle and the first pair of seminal rootlets break through the coleorhiza,

followed shortly after by a second pair. Wang et al. (2009) reported that optimum sowing depth is generally a desired goal for initial crop establishment characterized by the primary radicle, initiation of seminal roots and initiation of the coleoptile, all of which provide a suitable growth environment. Sowing seeds too shallowly results in poor germination due to inadequate soil moisture in the top soil layer while excessively deep sowing can limit growth and development (Acevedo et al. 2002).

4.5 Plant dry weight

In the present study, the greatest DW plant⁻¹ was recorded for a sowing depth of 4 cm, followed by 6 cm, while the smallest DW was found for a sowing depth of 2 cm (Figure 6). Aikins et al. (2006) and Mo et al. (2017) reported that inadequate soil moisture at a sowing depth of 2 cm, or excessively deep sowing at a depth of 8 cm significantly reduced crop emergence, biomass and finally yield. Rebetzke et al. (2007) and Murphy et al. (2008) reported that shorter coleoptiles of semi-dwarf wheat varieties do not adversely affect establishment when seeds are sown in favorable conditions, but short coleoptiles can reduce yield through poor seedling establishment when conditions are less favorable (Rebetzke et al. 2016).

4.6 Number of spikes

Productive tillers are an important part of a wheat plant and contribute to higher grain yield (Gulnaz et al. 2011). In cereals, most tillering occurs from the main axis of the plant, i.e., from main stem tillers. A second source of tillers is coleoptile tillers that arise from belowground from a node at the base of the coleoptile (Gulnaz et al. 2011). Sowing wheat seeds with a shorter coleoptile at a depth of 9 and 7 cm led to reduced seedling vigor, forming longer and thinner shoots. The number of spikes was also lower than the number of seedlings at deeper sowing, because plants with thinner shoots were injured by cold stress (Yagmur and Kaydan 2009). In general, deep sowing results in fewer spikes per cultivated area due to reduced seedling establishment (Rebetzke et al. 2007). In our study, the highest number of spikes was found in treatments where seeds were sown at a depth of 4 or 6 cm (Figure 8), while sowing at depths of 2 or 8 cm produced fewest spikes. Also in Bangladesh, Alam et al. (2014) observed highest number of spikes when seeds were sown at a depth of 4 cm, while fewest spikes were found at a depth of 8 cm. Yagmur and Kaydan (2009) found highest

number of spikes m^{-2} at a sowing depth up to 5 cm, that decreased significantly when wheat seed were sown at a depth greater than 5 cm.

4.7 1000-grain weight

The number of tillers, particularly fertile tillers, number of grains spike⁻¹ and TGW all contribute toward increasing yield (Eldakak et al. 2014). In our study, the TGW was higher when seedling emergence as well as spikes m^{-2} were lower, resulting in a lower plant population, receiving more moisture, nutrients, and sunlight (Figure 9). The planting density influences the quality and yield of wheat (Zecevic et al. 2014). Olaru et al. (2008) reported that in wheat, yield and quality parameters were influenced by the seed rate or plant density in which yield and wet gluten content increased with a reduction in the plant population per unit area.

4.8 Grain yield

Elongation of the internodes in wheat is related to the elongation of the associated leaf, so that in deeply sown seedlings, adjustment of crown depth might continue until the third leaf is fully grown; as a result, the shoot apex stage and culm elongation are affected by sowing depth, ultimately reducing the yield of deep-seeded wheat and barley (Chen et al. 2001; Jackson et al. 2006). In the present research, the highest grain yield was found in plots where seeds were sown at a depth of 4 or 6 cm while the lowest yield was recorded for depths of 2 and 8 cm (Figure 9). Highest grain yield for a depth of 4 or 6 cm may have been due to a suitable growing environment at these depths, influencing growth, development and formation of productive tillers, and ultimately yield. Yagmur and Kaydan (2009) reported from Turkey that for 10 wheat varieties sown at a depth of 3, 5, 7, or 9 cm, sowing deeper than 7 cm was associated with a significant reduction in grain yield while the seeds sown at 5 cm gave greater yield than when sown at 3, 7 and 9 cm. Only 'Tir' showed an increase in yield at a depth of 9 cm. This cultivar, as well as 'Alparslan', has a long coleoptile that helps to maintain seedling establishment, number of spikes m^{-2} , number of kernels spike⁻¹, kernel yield spike⁻¹ and grain yield with deeper sowing. While sowing the seeds deeply at 9 cm was unfavorable for varieties with shorter coleoptiles, sowing at 3 cm also resulted in consistently lower yield and poor establishment than sowing at 5 and 7 cm. The roots of plants sown at 3 cm may have sought moisture deeper in

the soil profile because the top soil layer is assumed to have dried out very quickly.

4.9 Straw yield

The highest straw yield was found in plots where seeds were sown at a depth of 4 cm while the lowest straw yield was observed when sown at depths of 2 and 8 cm (Figure 11), which may be due to a suitable growth environment at the depth (4–6 cm) that mostly influenced growth and development, and ultimately influencing biomass. This trend confirms earlier findings by Ehsanullah et al. (1999) in Pakistan, with three wheat genotypes ('Pak 81', 'Chakwal 86' and 'Barain 83') sown at two depths (5 and 10 cm). They reported that sowing depth had a real effect on the absolute growth rate of roots and shoots: when planted at a depth of 5 cm, highest number of roots and shoots resulted, ultimately increasing the biomass of all three genotypes while deep sowing (10 cm) resulted in lowest biomass yield of roots and shoots.

4.10 Harvest index

The HI was highest for a sowing depth of 4 cm in 2013-14, but for a depth of 6 cm in 2014-15. The lowest HI was found for a sowing depth of 2 cm in the first year and for 8 cm in the second year (Figure 12). Roy et al. (2011) reported that HI varied significantly for different sowing depths. Similar to our results, they also found highest HI (35.78%) for a sowing depth of 4 cm and lowest HI (34.8%) for a depth of 6 cm.

5 Conclusions, recommendations and suggestions

Wheat seeds sown at a depth of 4 cm gave the highest number of seedlings, seminal roots, tallest plants as well as highest root and plant biomass followed by 6, 2, or 8 cm depths. Similar to growth parameters, yield and yield-related attributes also differed significantly for different depths of sowing, and all performed best for a 4 cm sowing depth, followed by 6 cm. Greatest number of spikes m^{-2} , grain yield, straw yield and HI were found for a depth of 4 or 6 cm while the smallest values of all those parameters were recorded for depths of 2 or 8 cm. Therefore, a sowing depth of 4 to 6 cm is recommended for wheat cultivation in South Asia, including Northern Bangladesh.

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