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Full Length Research Paper

The effects of different sowing depth on grain yield and some grain yield components in wheat (*Triticum aestivum* L.) cultivars under dryland conditions

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The aim of the current study was to determine the effects of sowing depths (3, 5, 7, 9 cm) on grain yield and yield components for wheat cultivars during 2004-2006 at one site in Van Province in Eastern Turkey. Grain yield and yield components were found to positively correlate with coleoptile length, with marked declines observed in grain yield and yield components among varieties with shorter coleoptiles in deepest sowing. Wheat sown at 5 cm gave greater yields than wheat sown at 3, 7 and 9 cm by 19.9, 22.3 and 62.5%, respectively. The highest grain yield (2.98 T ha^{-1}) was obtained with the Alparslan cultivar sown at a depth of 5 cm. Grain yield of all varieties tested was drastically reduced when sown at depths of 9 cm, with the exception of the local Tir and Alparslan varieties, both of which, when compared to the other varieties tested, had longer coleoptiles.

Key words: Wheat (*Triticum aestivum* L.), sowing depth, grain yield.

INTRODUCTION

In dry environments such as Eastern Anatolia in Turkey, the amount of soil water found in the top soil layer is often limited at the optimum time for sowing. As a result, unless sowing is delayed until later rainfall, wheat stands may be poorly established, resulting in low yields. However, delaying sowing beyond the optimum time can also lead to reductions in yield (Mahdi et al., 1998). Increasing sowing depths can enhance wheat establishment because of the higher soil-water content in the seed zone, resulting in better germination and emergence of seedlings (Mahdi et al., 1998; Schillinger et al., 1998). Deeper sowing also reduces the number of seeds removed by birds and mice (Brown et al., 2003). With deeper sowing, the influential role of coleoptile length on plant emergence must be taken into account (Fick and Qualset, 1976; Whan, 1976; Rebetzke, 2007). Because coleoptile length varies by genotype and increases only slightly with increases in sowing depth, it is a limiting factor on sowing depth (Kirby, 1993). Many scientists (Schillinger et al., 1998; Takeda and Takahashi, 1999; Matsui et al., 2002, Rebetzke, 2007) have reported a positive association between coleoptile length and increases in plant numbers with deep sowing. At the same time, deep sowing can have adverse effects on seedling emergence (Hadjichristodoulou et al., 1977; Kirby, 1993) and subsequently on grain yields of cultivars not adapted to such conditions (Gill and Prihar, 1989; Loeppky et al., 1989). Placement of seeds at depths greater than 2.5 cm has been shown to result in slower emergence, less dry matter accumulation, deeper crown placement and reduced ability to withstand low temperatures (Loeppky et al., 1989). Photiades and Hadjichristodoulou (1984) have reported that shallow sowing (5 cm) always yields better results than deep sowing (10-20 cm). Not only were most of the agronomic traits they investigated adversely affected by deep sowing, the effects were more marked when deep sowing was combined with late sowing.

The present study aimed to shed more light on the subject by determining the effects of sowing depths on grain yield and yield components for 10 wheat cultivars in

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Table 1. Climatic data for Van Province from - 2004-2005, 2005-2006, long-term (LT) averages.

Month	Temperature (°C)			Rainfall (mm)			Relative humidity (%)		
	2004-05	2005-06	LT	2004-05	2005-06	LT	2004-05	2005-06	LT
September	18.0	17.2	16.3	-	9.2	15.4	48.7	55.4	55.2
October	12.0	11.2	10.3	48.1	35.4	49.6	64.1	56.9	63.2
November	4.6	4.6	4.3	102.4	29.3	47.5	75.1	69.1	67.0
December	-3.7	1.9	-1.1	41.0	34.3	32.1	73.8	69.0	69.0
January	-3.3	-3.1	-3.6	34.4	90.4	41.9	77.1	73.7	69.0
February	-4.0	-1.3	-3.5	27.2	47.7	35.4	73.7	74.2	64.0
March	2.5	3.0	0.5	59.1	45.7	46.2	70.9	77.5	57.0
April	8.9	9.8	7.0	55.9	39.6	57.5	64.1	66.5	50.0
May	13.3	14.6	13.0	35.8	35.4	40.5	62.5	54.0	44.0
June	18.7	21.5	17.8	13.0	0.1	16.8	55.4	41.9	41.0
July	24.1	22.3	22.0	0.3	22.4	5.5	51.3	47.5	43.0
Total				**417.2**	**389.5**	**323.4**			

dryland condition of Van region, Turkey.

MATERIAL AND METHODS

Ten different bread wheat cultivars were selected for this study (Tir, Süzen 97, Aytin 98, Kutluk 94, Altay 2000, Harmankaya 99, Bezostaya 1, Doğu-88, Nenehatun, Alparslan). Field experiments were conducted during the 2004-2005 and 2005-2006 winter growing seasons at one site in Van Province in Eastern Turkey (38°-55' N, 42 ° 05 ' E, 1725 m above sea level).

Soil and climatic description

Soil analysis has been described in detail by Kacar (1995). Soil samples were taken from the surface layer of the experimental area (0-20 cm). Analysis showed the soil to have a sandy-clay-loamy texture with low organic matter (1.15%) and nitrogen (0.15%) content, high potassium (185.6 kg da^{-1}) and lime (29.5%) content, medium phosphorus (5.48 mg kg^{-1}) content and slight alkalinity (pH: 7.35).

The region has a temperate climate. Table 1 shows the average temperatures, rainfall and humidity for both the 2004-2005 and 2006 growing seasons as well as long-term (1929-2006) averages for the region. Autumn and winter rainfall is important for recharging soil water. For both experimental years, rainfall during autumn and winter was significantly higher than the long-term average for the region. Rainfall during autumn and winter was slightly higher during the 2004-2005 growing season than during the 2005-2006 growing season. During both the 2004-2005 and 2005-2006 growing seasons, plants reached the flowering stage at the end of May and beginning of June. Rainfall at this time was lower than the long-term average for the region during both growing seasons (Anonymous, 2006).

Field management

In both years, land was prepared at the beginning of October using a disc plough and a power harrow. The experimental design consisted of 40 split plots with 3 replications for a total of 120 plots. Each plot contained 3 rows 1 m in length and spaced 0.20 m apart. Seeds were hand-drilled at depths of 3 cm (2-3 cm), 5 cm (4-5 cm), 7 cm (6-7 cm), or 9 cm (8-9 cm) and spaced approximately 1 cm apart along each row at a rate of 100 seeds (500 seeds m^{-2}).

Fertilizer was applied by hand and mixed into the top 1-5 cm of soil at planting time. Wheat was fertilized at planting with 150 kg DAP (Di-Ammonium Phosphate) ha^{-1} (N 18%-P 46%), and 200 kg AS (Ammonium Sulphate) ha^{-1} (N 21%) was applied as a top dressing before ear emergence.

Wheat was sown on 20 October, 2004 and 19 October, 2005. With the exception of those seeds sown at depths of 3 cm, all seeds were sown into a wet seedbed due to rain at the mid of October in both years.

All plots were weeded twice by hand during each growing season. No irrigation was provided at any time. No insects, pests, or disease infestations were observed.

Plant sampling and methods

Seedlings were excavated from a 1-m row during the early tilling stage (approximately eight weeks after emergence). Seedling numbers and coleoptile lengths were measured.

Plants were harvested at the end of June 2005 and 2006. Spike density was measured by hand cutting the above-ground portion of plants from the center of the middle row in each plot just prior to harvest and determining the number of spikes per meter. Harvested plants were then stored in a low-humidity room for seven days. Kernels were threshed by hand, and kernels $spike^{-1}$ and kernel weight $spike^{-1}$ were calculated based on spike m^{-2}. Grain yield (T ha^{-1}) was determined by harvesting grain in a paper bag, and weighing it on a digital scale accurate to 0.1 g.

Statistical analysis

Analysis of variance (ANOVA) was performed using the MSTATc statistical package to determine significant differences in grain yield and yield components in variety and sowing depth both growing

Table 2. Mean coleoptile lengths (CL) and seedling establishment (seedlings m^{-2}) (by variety and sowing depth).

Variety	Coleoptile lengths (cm)					Seedlings m^{-2}				
	3 cm*	5 cm	7 cm	9 cm	Mean	3 cm	5 cm	7 cm	9 cm	mean
1. Tir	2.58 p	5.08 ı	6.83 b	8.56 a	5.76 A	261.6 jk	275.8 ghıj	283.8 fgh	267.5 ıjk	272.2 B
2. Süzen 97	1.58 r	4.25 klm	4.63 j	5.50 gk	3.99 E	278.8 ghı	318.3 bc	300.6 de	181.0 tu	269.6 BC
3. Aytin 98	2.56 p	5.00 ı	6.00 ef	6.28 de	4.96 B	222.6 nop	315.8 bcd	312.3 cd	199.8 rs	262.5 C
4. Kutluk 94	2.50 p	4.00 m	4.58 jk	6.41 cd	4.41 D	217.8 opq	310.0 cd	277.8 ghı	209.5 pqr	253.7 DC
5. Altay 2000	2.00 q	3.50 n	4.23 lm	5.58 gh	3.82 E	268.5 hıjk	255.8 kl	231.5 no	160.1 v	229.0 E
6. Harmankaya 99	2.33 p	5.00 ı	6.00 ef	6.16 def	4.87BC	211.6 pqr	233.0 mn	291.6 efg	211.0 pqr	236.8 E
7. Bezostaya 1	2.50 p	5.00 ı	5.50 h	6.00ef	4.75 C	295.0 ef	246.5 lm	288.1 efg	173.8 uv	250.9 D
8. Doğu-88	2.00 q	4.50 jkl	5.00 ı	6.66 bc	4.54 D	268.3 hıjk	311.6 cd	319.6 bc	203.8 qr	275.8 B
9. Nenehatun	2.58 p	4.41 jkl	5.00 ı	6.0ef	4.50 D	268.6 hıjk	310.0 cd	286.0 efg	190.8 st	263.5 C
10. Alparslan	3.00 q	5.00 ı	6.53 c	8.58 a	5.77 A	330.6 b	348.8 a	351.6 a	291.3 efg	330.6 A
Mean	2.36 D	4.57 C	5.44 B	6.57 A		262.3 B	292.6 A	294.3 A	208.8 C	

*Sowing depth.

seasons. Duncan test comparison of mean differences were used.

RESULTS AND DISCUSSION

The calculated means for yield components and total yield by variety and sowing depth averaged over both growing seasons. Combined data for the two years showed highly significant differences in coleoptile length, seedling establishment, number of spikes m^{-2}, number of kernel per spike, kernel yield per spike and grain yield (T ha^{-1}) among the different wheat cultivars tested. Coleoptile length, seedling establishment (seedlings m^{-2}), number of spikes m^{-2}, number of kernels $spike^{-1}$, kernel yield $spike^{-1}$ and grain yield were also significantly affected by changes in sowing depth.

Coleoptile length

The coleoptile is a leaf sheath that surrounds and protects the first true leaf as it grows from the seed towards the surface. If the length of the coleoptile is less than the depth of planting, emergence will become difficult. When varieties were compared, Tir and Alparslan were found to have the longest coleoptiles and Süzen 97 and Altay 2000 to have the shortest coleoptiles (Table 2).

Coleoptile lengths were also found to increase with sowing depth. Coleoptile length was greatest in the Alparslan and Tir varieties at the deepest sowing. The interaction between sowing depth and variety was found to be highly significant. Whereas coleoptile lengths of Tir and Alparslan cultivars increased with sowing depth, coleoptile lengths of the other eight cultivars did not. Thus, while Alparslan and Tir may be sown at depths of 9 cm, the other eight varieties were not suitable for deep sowing, but may be favorably sown at depths of 5 cm.

Coleoptile length is basically an inheritable characteristic controlled by several genes (Chowdhry and Allan, 1963). Studies have shown significant differences in coleoptile length among different wheat genotypes (Matsui et al., 2002; Rebetzke et al., 2007). An earlier study found the local Tir variety to have the longest coleoptile length among varieties studied (Kaydan and Yağmur, 2005).

Seedling establishment (seedlings m^{-2})

Among those varieties tested, Tir and Alparslan were found to establish the greatest number of seedlings m^{-2} and Harmankaya 99 and Altay 2000 to establish the fewest. Seedling establishment was also found to be greatest among plants sown at 5 and 7 cm (Table 2). While 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. The effects of the interaction between sowing depth and variety were highly significant. Whereas seedling numbers were sharply reduced at deepest sowing among varieties with short coleoptiles, reduction in seedling numbers of varieties with long coleoptiles were minimal. In the current study, the highest number of seedlings was obtained from the Alparslan variety sown at a depth of 5 and 7 cm (348.8 and 351.6 seedlings per m^2, respectively) and the lowest number from the Altay 2000 variety sown at 9 cm. (Table 2). Sowing wheat seeds with shorter coleoptile at 9 and 7 cm, the deepest sowing led to reduced seedling vigor, giving longer and thinner shoots than those at 3, and 5 cm depths. Sowing wheat with longer coleoptile at 9 cm led to reduced seedling vigor, but this reduction was a minimal. The coleoptile length of eight high yielding varieties is about 5 centimetre. Therefore, seeds of these varieties should be

Table 3. Mean spikes m^{-2} and kernel spike^{-1}, (by variety and sowing depth).

Variety	Spikes m^{-2}					Kernels spike^{-1}				
	3 cm*	5 cm	7 cm	9 cm	Mean	3 cm	5 cm	7 cm	9 cm	mean
1. Tir	309.5 jk	324.1 ıj	357.5 gh	355.1 gh	336.5 B	18.08 f-j	18.35 fgh	21.63 c	24.70 b	20.6 B
2. Süzen 97	354.1 gh	408.1 bc	349.6 h	154.8 p	316.7 C	15.75 lm	16.53 kl	15.53 mn	21.23 cd	17.2 E
3. Aytin 98	286.3 lm	406.6 bc	353.5 gh	173.5 o	305.4 DE	18.06 f-j	17.28 ıjk	20.38 d	18.16 f-ı	18.4 D
4. Kutluk 94	278.5 m	415.5 ab	358.5 gh	180.3 no	308.2 D	14.46 opq	18.16 f-ı	18.56 efg	14.50 op	16.4 FG
5. Altay 2000	304.3 k	323.0 ıj	280.5 m	136.0 q	260.9 G	17.13 jk	16.66 kl	19.36 e	13.55 pqr	16.7 F
6. Harmankaya 99	282.1 m	284.3 m	369.0 fg	175.1 o	277.6 F	17.93 f-j	20.38 d	14.76 no	13.91 o-r	16.6 FG
7. Bezostaya 1	355.6 gh	364.5 fgh	325.0 ı	158.1 p	300.2 E	13.83 o-r	17.43 h-k	17.85 g-j	13.20 r	15.5 H
8. Doğu-88	351.5 h	408.6 bc	378.1 ef	190.0 n	332.5 B	13.65 pqr	18.90 ef	18.61 efg	13.66 pqr	16.2 G
9. Nenehatun	299.0 kl	394.0 cd	349.0 h	174.0 o	304.2 DE	13.50 qr	17.35 ıjk	24.75 b	21.18 cd	19.1 C
10. Alparslan	391.2 de	405.0 bcd	426.0 a	321.6 ıj	386.0 A	16.50kl	21.86 c	27.20 a	21.30 cd	21.6 A
Mean	321.3 B	373.4 A	354.7 B	201.8 C		15.88 D	18.29 B	19.86 A	17.54 C	

*Sowing depth.

covered not by more than 5 centimetre soil to ensure uniform and good germination.

Genotypic differences in coleoptile length have been strongly positively correlated with numbers of seedlings with deep sowing (Rebetzke et al., 2007). Seedling establishment is one of the major constraints to wheat production and can be assessed in terms of numbers of plants during early growth (Mahdi et al., 1998). As the coleoptile emerges from the soil, its growth stops and the first true leaf pushes through the tip. When wheat with shorter coleoptiles is sown deeply, the first true leaf forms deep in the soil and seedlings may be weak and easily damaged (Mahdi et al., 1998). Longer coleoptiles improve the plant's ability to emerge from greater depths (Schillinger et al., 1998; Rebetzke et al., 2007). Many researchers (Schillinger et al., 1998; Takeda and Takahashi, 1999; Matsui et al., 2002; Rebetzke, 2007) have demonstrated a positive association between coleoptile length and increased plant numbers with deep sowing. The positive correlation between coleoptile length and seedling emergence is more remarkable at greater depths (Sunderman, 1964).

Number of spikes m^{-2}

Number of spikes per m^2 is an important character in agronomic programmes. Among the varieties examined in the current study, Alparslan produced the greatest number of spikes m^{-2} and Harmankaya 99 the fewest. Numbers of spikes m^{-2} were found to increase with sowing depths up to 5 cm; however, the number of spikes m^{-2} tended to show significant decreases when wheat was sown at depths greater than 5 cm (Table 3). The interaction of variety and sowing depth had a significant effect on numbers of spikes m^{-2}. The Alparslan cultivar sown at 7 cm produced the greatest numbers of spikes (426 seedlings). Sowing wheat seeds with shorter coleoptile at 9 and 7 cm, the deepest sowing led to reduced seedling vigor, giving longer and thinner shoots than those at 3, and 5 cm depths. Number of spikes was lower than number of seedling among wheat varieties having shorter coleoptile at deepest sowing, because plants with thinner shoots was injuired by cold stress. In general, deep sowing has been shown to result in fewer spikes per area cultivated due to reduced seedling establishment (Rebetzke et al., 2007).

Number of kernels spike^{-1}

Among those cultivars studied, Tir and Alparslan produced the greatests per spike. Kernels also increased with sowing depths up to 7 cm; however, numbers of kernels spike^{-1} tended to show significant decreases when wheat was sown at depths greater than 7 cm. The greatest numbers of kernels spike^{-1} were produced at sowing depths of 7 cm, followed by depths of 5, 9 and 3 cm.

When the effects of the interaction between sowing depth and variety were examined, the Nenehatun and Alparslan wheat varieties sown at 7 cm were found to have the most kernels spike^{-1}, whereas Bezostaya 1 sown at 9 cm yielded the fewest kernels spike^{-1} (13.2) (Table 3). This study found reductions in numbers of kernels spike^{-1} with shallower as well as with deepest sowing. According to Mahdi et al. (1998), reductions at deepest sowing are related to weak seedlings and low leaf area indexes during the early growing stage due to shorter coleoptiles. Similar results have been found in other studies as well (Photiades and Hadjichristodoulou, 1984). With regard to reductions at shallower sowing, this

Table 4. Mean kernel yield spike^{-1} and grain yields (by variety and sowing depth).

Variety	Kernel yield spike^{-1}					Grain Yield (T ha^{-1})				
	3 cm	5 cm	7 cm	9 cm	Mean	3 cm	5 cm	7 cm	9 cm	mean
1. Tir	0.88 de	0.93 d	1.13 b	1.23 a	1.04 A	1.60 mno	2.72 b	2.43 cde	1.88 jkl	2.16 B
2. Süzen 97	0.61 nop	0.61 nop	0.58 opq	0.58 opq	0.63 G	1.85 jklm	2.39 de	1.41 o	0.51 s	1.54 F
3. Aytin 98	0.68 klmn	0.73 hıjk	0.78 ghı	0.76 ghıj	0.74 D	1.85 jklm	2.37 def	2.17 e-ı	0.80 pqr	1.80 CD
4. Kutluk 94	0.68 klmn	0.78 ghı	0.80 fgh	0.76 ghıj	0.75 D	1.86 jkl	2.55 bcd	2.00 ıjkl	0.85 pq	1.81 CD
5. Altay 2000	0.66 klmn	0.65 lmno	0.78 ghı	0.66 klmn	0.69 EF	2.21 e-ı	2.30 d-h	1.55 no	0.55 rs	1.65 EF
6. Harmankaya 99	0.71 ıjkl	0.88 de	0.63 mno	0.55 pq	0.70 E	1.98 ıjkl	2.11 f-j	2.32 defg	0.79 pqr	1.80 CD
7. Bezostaya 1	0.51 q	0.86 def	0.70 jklm	0.51 q	0.65 F	2.21 e-ı	2.28 efgh	1.78 lmn	0.70 qrs	1.74 DE
8. Doğu-88	0.51 q	0.65 lmno	0.80 fgh	0.68 klmn	0.66 EF	2.09 ghıj	2.73 b	1.80 klmn	1.02p	1.91 C
9. Nenehatun	0.68 klmn	0.71 jkl	1.18 ab	0.66 klmn	0.81 C	2.05 hıjk	2.65 bc	1.55 no	0.77 pqr	1.75 DE
10. Alparslan	0.81 efg	1.01 c	1.20 ab	0.86 def	0.97 B	2.35 defg	2.98 a	2.56 bcd	1.56 no	2.36 A
Mean	0.67 D	0.78 B	0.86 A	0.73 C		2.01 B	2.51 A	1.95 B	0.94 C	

may be related to low humidity in the top soil layer during the flowering stage.

Kernel yield spike^{-1}

When cultivars were compared, the local Tir variety was found to have the highest kernel yield spike^{-1} (1.04 g) and the Süzen 97 variety to have the lowest. The highest kernel yield was obtained when seeds were sown at 7 cm when compared to other sowing depths. Sowing beyond a depth of 7 cm was related with significant reductions in kernel yield spike^{-1} (Table 4).

When the effects of the interaction between sowing depth and variety were examined, the local Tir variety sown at 9 cm was found to have the greatest kernel yield spike^{-1}. This contrasted with all other varieties tested, whose kernel yield spike^{-1} was found to decrease when sown at 9 cm (Table 4). This study found that wheat with longer coleoptiles had higher kernel yield spike^{-1} at deeper sowing than wheat with shorter coleoptiles because, short drought duration affected kernel yield per spike of wheat having longer coleoptile at deepest sowing in minimal level due to deeper crown establishment (data not shown). Rainfall was less at wheat grain filling stage in both of two seasons in Van region compared to long term periods (Table 1). Grain filling period was taken place between the end of May and the end of June (data not shown).

Grain yield

Among those varieties tested, those with the longest coleoptiles, Tir and Alparslan, had the highest grain yields (2.16 T ha^{-1} and 2.36 T ha^{-1}, respectively). Süzen 97 and Altay 2000 and were found to have the lowest grain yield. Grain yields increased with sowing depths up to 7 cm (Table 4). In general, sowing beyond a depth of 7 cm was associated with significant reductions in grain yield. Overall, wheat sown at 5 cm gave greater yields than wheat sown at 3, 7 and 9 cm by 19.9, 22.3 and 62.5%, respectively.

When the effects of sowing depth and variety on grain yield are examined together, the Alparslan cultivar sown at 5 cm was found to have the greatest yield (2.98 T ha^{-1}). Grain yields for all varieties decreased drastically with sowing depths of 9 cm, with the exception of Alparslan, which exhibited only slight decreases in yield, and Tir, which had an increase in yield. Both these cultivars have long coleoptiles that help 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 deep sowing at 9 cm was unfavorable for varieties with shorter coleoptiles, sowing at 3 cm also resulted in consistently poorer establishment and lower yields than sowing at 5 and 7 cm. It is thought that roots of plants sown at 3 cm sought out moisture deeper in the soil profile because the top soil layer is assumed to have dried out very quickly. Similar results have also been reported by Photiades and Hadjichristodoulou (1984), Mahdi et al. (1998) and Rebetzke et al. (2007).

Conclusion

Results showed that wheat varieties with longer coleoptile lengths (Tir and Alparslan) performed favorably when sown at greater depths in terms of seedling establishment, grain yield components and grain yield. In order to obtain higher grain yields with these cultivars, a sowing depth of 6 or 7 cm may be preferable. The remaining eight cultivars tested had shorter coleoptiles and performed better when sown at shallower depths. In order to obtain higher grain yields with these cultivars, they may be sown at depths of 4 or 5 cm without risk. Moreover, sowing time with sowing depth should be examined for these wheat cultivars.

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