Effect of variations in seed size and planting depth on emergence, infertile plants, and grain yield of spring wheat

Y. Gan[1] and E. H. Stobbe

Department of Plant Science, The University of Manitoba, Winnipeg, Manitoba, Canada R3T 2N2.
Received 29 June 1994, accepted 3 January 1995.

Gan, Y. and Stobbe, E. H. 1995. **Effect of variations in seed size and planting depth on emergence, infertile plants, and grain yield of spring wheat.** Can. J. Plant Sci. **75**: 565–570. Crop yield can be improved by minimizing plant-to-plant variability in seedling emergence. A study was conducted to determine the effect of variations in seed size and planting depth within a plot on emergence, proportion of infertile plants and grain yield in hard red spring wheat (*Triticum aestivum* L.). Large seed (40.8 mg kernel^{-1}) was hand planted at 25-, 50- and 75-mm depths, creating three uniform seed size - planting depth treatments. Three other treatments consisted of repeating patterns within the same row: three large seeds and one small seed (23.4 mg kernel^{-1}) at each of 25-, 50- and 75-mm depths. Two additional treatments consisted of 1) three seeds planted 25 mm deep and one seed planted 50 mm deep and 2) three seeds planted 25 mm deep and one seed planted 75 mm deep within the same row. Variation in seed size or planting depth within a row had no impact on percentage emergence, but nonuniform planting depth increased the proportion of infertile plants, mainly as a result of late-emerging plants. On a single-plant basis, mainstem grain yields were relatively uniform, but tiller grain yields were highly variable. When small and large seeds were planted 75 mm deep within a plot, the small-seeded plants produced 34% lower tiller grain yield than neighbouring large-seeded plants, while the large-seeded plants produced 10% higher tiller grain yield than plants from a treatment in which only large seeds were planted. Thus, the variation in seed size within a plot had no impact on total grain yield per plot. When seed was planted at variable depths within a plot, grain yield per plant produced by deep-seeded (75 mm) plants was only 20% of that produced by neighbouring shallow-seeded (25 mm) plants and was only 26% of that produced by plants where all seeds were planted deep (75 mm). Within-plot variation in planting depth increased the proportion of infertile plants (up to 158%) and decreased the grain yield. To maximize grain yield in hard red spring wheat, seed should be planted at uniform, shallow planting depth.

Key words: Seed size, planting depth, emergence, fertile plants, interplant variation

Gan, Y. et Stobbe, E. H. 1995. **Effet des variations de grosseur du grain et de profondeur de semis sur la levée, sur le nombre de plantes stériles et sur le rendement en grain du blé de printemps.** Can. J. Plant Sci. **75**: 565–570. Il est possible d'améliorer les rendements des cultures en réduisant le plus possible la variabilité interplante à l'égard de la levée. Des recherches ont été menées pour déterminer l'effet des variations de grosseur des grains et de profondeur de semis dans une même parcelle sur la levée, sur la proportion de plantes stériles et sur le rendement grainier du blé roux vitreux de printemps (*Triticum aestivum* L.). Des gros grains (40,8 mg par grain) ont été semés à la main à des profondeurs de 25, 50 et 70 mm, donnant ainsi trois traitements grosseur uniforme-profondeur de semis. Trois autres traitements consistaient à répéter les mêmes dispositifs dans une même ligne, soit trois gros grains et un petit grain (23,4 mg par grain) à 25, 50 et 70 mm de profondeur. Dans deux autres traitements on semait dans la même ligne trois grains à 25 mm et un à 50 mm de profondeur et trois grains à 25 et un à 75 mm de profondeur. Le fait de varier la grosseur des grains ou la profondeur des semis dans une même ligne n'avait pas d'effet sur le pourcentage de levée, mais le semis à diverses profondeurs accroissait la proportion de plantes stériles surtout à cause de la levée tardive de certaines plantes. Plante par plante, le rendement en grain du maître-brin était relativement uniforme, mais celui des talles affichait une forte variabilité. Lorsqu'on semait en mélange des gros et des petits grains à 75 mm de profondeur dans une même parcelle, les plantes issues des petits grains produisaient 34% moins de grain sur les talles que les plantes voisines issues de gros grains. Par ailleurs, les plantes issues de gros grains produisaient 10% de plus de grains sur les talles que celles d'un traitement où l'on ne semait que des gros grains. Le fait de varier la grosseur des grains dans une même parcelle n'avait donc pas d'effet sur le rendement grainier total par talle. Lorsqu'on semait à diverses profondeurs dans une même parcelle, le rendement grainier des plantes semées profondément (75 mm) n'était que de 20% que celui des plantes voisines semées peu profondément (25 mm) et que de 26% des plantes issues de gros tous semés à 75 mm. La variation de la profondeur de semis dans une même parcelle accroissait jusqu'à 158% la proportion de plantes infertiles et abaissait le rendement grainier. Il ressort de ces recherches que, pour maximiser le rendement du blé roux vitreux de printemps, les grains devraient être semés uniformément à faible profondeur.

Mots clés: Grosseur des grains, profondeur des semis, levée, plantes fertiles, variation inter-plantes

[1]*Current address: Research Centre, Research Branch, Agriculture and Agri-Food Canada, P.O. Box 1030, Swift Current, Saskatchewan, Canada S9H 3X2.*

Abbreviations: **CV**, coefficient of variation; **U-D**, uniform large seed planted deep; **U-M**, uniform large seed planted at medium depth; **U-Sh**, uniform large seed planted at a shallow depth

For many crops, yield potential can be improved by minimizing the interplant variation in plant size (Glenn and Daynard 1974; Edmeades and Daynard 1979; Counce et al. 1989; Bonan 1991). A crop with uniform plant size has few nonproductive plants (Counce et al. 1989), while variability in plant size is usually associated with a large proportion of suppressed plants (Bonan 1991). These suppressed plants are small and contribute little to total grain yield (Gan et al. 1992).

Emergence date of seedlings within a plot affects plant size and grain yield. Soetono and Donald (1980) observed that late-emerging barley seedlings produced smaller plants than those that emerged early. Knight (1983) found that spring wheat seedlings that emerged late accumulated less dry matter than those that emerged early. In a hand-planted field trial, we found that delayed emergence reduced grain yield per plant by 29 g d^{-1} (Gan et al. 1992).

Seed size and planting depth have been shown to influence seedling emergence, plant growth, and grain yield in wheat. In general, plants produced from large seed grew faster, accumulated more above-ground biomass, and produced higher grain yields than those from small seed (Lafond and Baker 1986; Peterson et al. 1989; Spilde 1989; Gan et al. 1992). Plants grown from shallow-planted seeds exhibited advantages in emergence (de Jong and Best 1979; Loeppky et al. 1989), tiller and spike production (Loeppky et al. 1989), and grain yield (Gan et al. 1992) over plants from deep-planted seeds.

Briggs (1991) found that for Canadian prairie spring wheat, 10–15% of the seeds within a seedlot were small-sized seeds. We found that a commercial hard red spring wheat seedlot used on the Canadian prairie consisted of seeds 2.2–3.2 mm wide when the seedlot was screened with regular seed-cleaning–grading processes (Y. Gan and E. H. Stobbe, unpublished observation). Non-uniform seed placement, which occurs routinely in commercial wheat fields because of seeding equipment and soil conditions, results in large variations in seedling emergence among individual seeds (Knight 1983). There is still the question of how much grain yield these small- or deep-seeded plants can produce. If plants grown from the small- or deep-planted seeds contribute little or nothing to overall grain yield of the crop community, then these plants can be regarded as weeds since they compete for growth resources with their neighbouring productive plants. Knowledge of the relative grain yield contribution of individual plants within a plant population is needed to quantify the importance of seed size and seed placement.

The objectives of this study were 1) to determine the relative grain yield contribution of individual wheat plants grown from different seed sizes and at different planting depths within a population and 2) to determine the influence of variations in seed size and planting depth on seedling emergence, proportion of infertile plants, and grain yield of the crop community.

MATERIALS AND METHODS

Field experiments were conducted on a Newdale clay loam soil at Portage-la-Prairie, Manitoba, in 1989 and 1990. Seedbed preparation, fertilizer rate and application, and weed control practices were the same as those described by Gan et al. (1992).

Seed of hard red spring wheat (cultivar Roblin) was used. Large seed was obtained by using 3.0 mm × 19 mm lower and 3.2 mm × 19 mm upper sieves. Small seed was obtained by using 2.2 mm × 19 mm lower and 2.4 mm × 19 mm upper sieves. The average weight of large seed was 40.8 ± 4.2 mg $kernel^{-1}$, while small seed was 23.4 ± 3.9 mg $kernel^{-1}$, based on a sample of 150 individual seeds.

Seed was hand planted on 11 May 1989 and 14 May 1990. Seventy-two seeds were evenly spaced in plots consisting of three rows, 15 cm apart and 56 cm in length, using a template (300 seeds m^{-2}). Seeds were pushed into the soil through the individual holes of the template to the desired depths using a plunger. Seeds were covered by filling the holes made by the plonger with soil of similar moisture content, to avoid any difference in surface compaction between treatments. Each plot was surrounded by a border area of Roblin wheat, machine planted at 300 viable seeds m^{-2}.

The experiment was arranged as a randomized complete-block design, with five replicates. Three of the eight treatments consisted of the unifoirm large seed planted at each of the three planting depths: shallow (25 mm), medium (50 mm) and deep (75 mm) and designated as U-Sh, U-M and U-D, respectively. Three other treatments consisted of repeating patterns of within-row seed size: three large seeds and one small seed (3L:1S) planted in the same row at each of the 25-, 50- and 75-mm depths. The ratio of three large to one small seed was determined according to the seed size proportions most likely encountered in commercial seedlots (Y. Gan and E. H. Stobbe, unpublished observation). Two additional treatments were included to simulate within-row depth variation, using large seed only: 1) three seeds planted at 25 mm and one seed planted at 50 mm (3Sh:1M) and 2) three seeds planted at 25 mm and one seed planted at 75 mm (3Sh:1D) within the same row. Previous studies using commercial seeding equipment had established similar variations in planting depth (E. H. Stobbe, unpublished observation).

Emerging seedlings were tagged with a coloured wire loop, using a different colour each day. After seedling emergence was complete, the seedlings were identified according to the seed sequences in the row and double tagged with another wire loop. Double tagging not only identified a particular seed size or planting depth within the plot but also identified the emergence date of a plant.

At maturity all plants were individually hand harvested. Grain yield was determined for each plant. The CV among individual plant yields was calculated. CV were used to describe interplant variability within a plot (Counce et al. 1989) and to compare the degree of variation among plots (Bonan 1991). For each plot, total grain yield was determined by adding individual-plant grain yields. Proportion of infertile plants was calculated according to the number of emerged and fertile plants.

Data were subjected to analysis of variance using SAS (SAS Institute, Inc. 1990). When significant treatment effects were detected, mean differences were determined using LSD ($P < 0.05$). When year × treatment interactions were not significant, data were combined over years, and means were presented. Regression analysis was performed to determine the relationship between time of plant emergence and the proportion of infertile plants.

Table 1. Mean percentage emergence, proportion of infertile plants, grain yield, and CV of individual plant grain yields for wheat grown from different planting patterns

Treatment[z]	Percentage emergence (%)	Infertile plants (%)	Grain yield (g m^{-2})	CV of grain yields (%) Mainstem	CV of grain yields (%) Tillers
U-Sh	83.3*ab*	1.1*cd*	497.4*ab*	3.07*a*	92.4*cd*
U-M	84.1*ab*	2.3*bc*	455.3*ab*	34.8*a*	108.4*cd*
U-D	80.5*c*	5.6*a*	379.1*d*	23.5*a*	120.1*bcd*
(3L:1S)-Sh	85.9*a*	2.0*bc*	520.4*a*	34.1*a*	78.5*d*
(3L:1S)-M	85.1*ab*	2.2*bc*	476.9*ab*	29.2*a*	128.9*bc*
(3L:1S)-D	78.3*c*	5.8*a*	368.9*d*	23.7*a*	160.9*a*
3Sh:1M	81.7*ab*	1.8*cd*	448.7*bc*	34.5*a*	121.0*bc*
3Sh:1D	81.2*ab*	3.9*ab*	403.5*cd*	35.1*a*	170.5*a*

[z]U-Sh, U-M and U-D, uniform large seed planted at shallow depth (25 mm), medium depth (50 mm) and deep (75 mm), respectively; (3L:1S)-Sh, three large seeds and one small seed planted at shallow depth in the same row; 3Sh:1M, three seeds planted at shallow depth and one seed planted at medium depth in the same row; and 3Sh:1D, three seeds planted at shallow depth and one seed planted deep in the same row.
*a–c*Means followed by the same letter in a column are not significantly different at $LSD_{0.05}$.

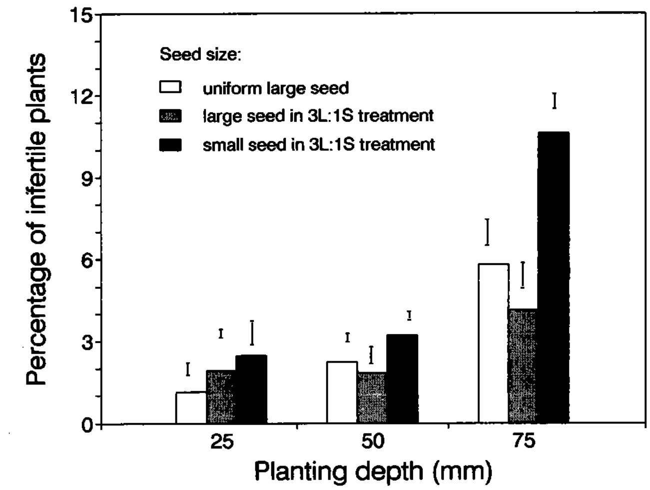

Fig. 1. Percentage infertile plants for wheat grown from large and small seeds planted in the same row, at each of the three planting depths. Bars are standard errors.

For the treatments that included two components within a treatment (i.e., treatments 3L:1S, 3Sh:1M and 3Sh:1D), mean proportion of infertile plants and mean grain yield per plant were determined for each of the two components. Since the two components in each treatment had unequal sample-size, analyses were performed using weighted means to estimate standard error. Comparisons were made between the two components to determine the relative yield contribution. Significant differences in grain yield between the two components were determined using a paired *t*-test (Giles 1990).

RESULTS AND DISCUSSION

Percentage emergence and plot grain yield were significantly higher in 1990 than in 1989. Overall emergence was 78.6 and 86.4% in 1989 and 1990, respectively. The grain yield was 575 g m^{-2} in 1989 and 629 g m^{-2} in 1990. Better soil moisture at planting and longer growing season in 1990 resulted in the higher percentage emergence and grain yield relative to 1989. The effects due to the variations in seed size and planting depth were similar between the 2 yr. As no significant year × treatment interactions were detected for emergence, infertile plants, or grain yield (data not shown), data were combined and presented as 2-yr means.

Emergence

Seeds planted 75 mm deep produced the lowest percentage emergence, regardless of the uniformity in seed size (Table 1). The U-D treatment had a significantly lower percentage of emergence than U-Sh or U-M. Similarly, (3L:1S)-D treatment had a significantly lower percentage of emergence than (3L:1S)-Sh or (3L:1S)-M. This result concurs with observations in other related experiments (Gan et al. 1992). Lafond and Fowler (1989) also reported that deep planting reduced the percentage of emergence in winter wheat.

Variation in the size of seeds planted in the same row did not affect percentage of emergence (Table 1). Regardless of planting depth, 3L:1S treatments had percentages of emergence similar to those of treatments where only uniform large seeds were planted. A small proportion of small seeds within a seedlot did not reduce the total percentage emergence.

Variation in planting depth in the same row did not affect percentage of emergence (Table 1). Seeds planted using the configurations 3Sh:1M or 3Sh:1D in the same row had percentages of emergence similar to that of the U-Sh treatment. A small proportion of deep-seeded plants within a plot did not cause a reduction in total percentage emergence.

Proportion of Infertile Plants

Among the three uniform-depth treatments, the U-D treatment had the largest proportion of infertile plants (Table 1). To minimize the number of infertile plants in a spring wheat population, seeds should be planted no more than 50 mm deep.

Variation in seed size within a seedlot had no impact on the proportion of infertile plants (Table 1). For each of the three planting depths, a similar proportion of infertile plants was obtained between the 3L:1S treatments and the uniform-seed-size treatments. At the 25- or 50-mm planting depths, the large seeds produced a proportion of infertile plants similar to that of their neighbouring small seeds (Fig. 1). Although the small seeds at the 75-mm depth produced more infertile plants than their neighbouring large seeds, the large seeds in the 3L:1S treatment compensated by producting fewer infertile plants than those produced by the large seeds planted alone. These observations suggest that the removal of small seeds from a seedlot is not necessary, since excluding the small seeds from the seedlot does not cause an increase in the number of fertile plants.

Variation in planting depth within a plot had a significant impact on the proportion of infertile plants (Table 1). The nonuniform-depth treatment, 3Sh:1D, resulted in 3.9% infertile plants, which was not different from the 5.6% infertile plants observed in the U-D treatment. This observation indicates that if as few as one fourth of the total number of seeds are planted deep within a plot, a significant increase in

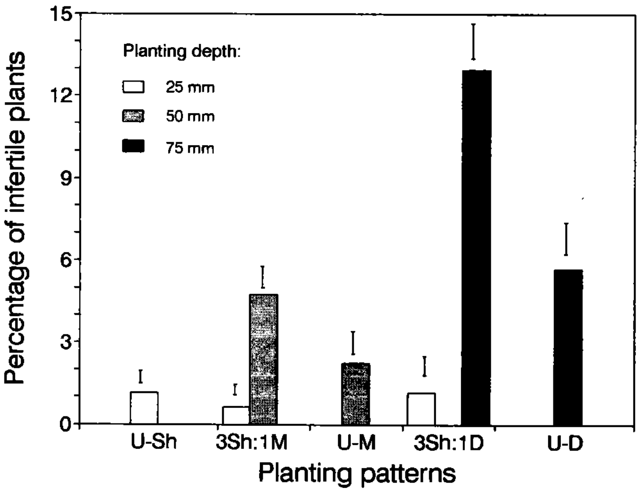

Fig. 2. Percentage infertile plants for wheat grown from different planting patterns. U-Sh, U-M and U-D, uniform-size seeds planted at shallow (25 mm), medium (50 mm) and deep (75 mm) depths, respectively. 3Sh:1M, three seeds planted at shallow depth and one seed planted at medium depth in the same row. 3Sh:1D, three seeds planted at shallow depth and one seed planted deep in the same row. Bars are standard errors.

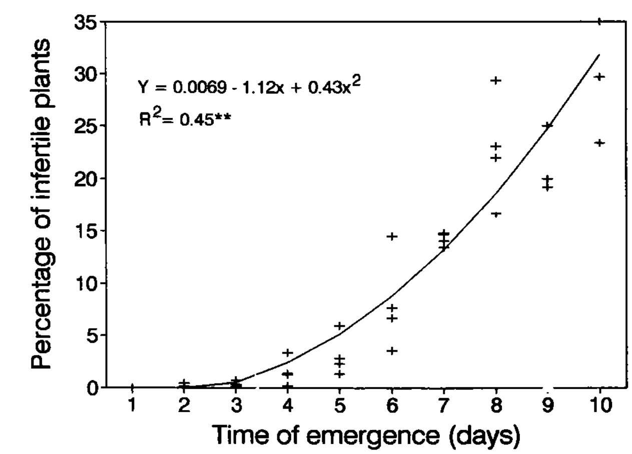

Fig. 3. Percentage infertile plants for wheat that emerged on different days within a plot.

number of infertile plants can result. The reason for the large proportion of infertile plants with the nonuniform-depth treatment is unknown, but it could be partially explained by interplant competition occurring between shallow- and deep-seeded plants.

When seeds were planted using the configuration 3Sh:1D, the deep-seeded plants (D plants) were poor competitors with their neighbouring shallow-seeded plants (Sh plants). Thirteen percent of the D plants were infertile, while just 1.2% of the Sh plants were infertile (Fig. 2). The proportion of infertile plants among the D plants was even greater than the 5.6% infertile plants observed in the U-D treatment in which all seeds were planted deep.

When seeds were planted using the configuration 3Sh:1M, the M plants produced more infertile plants

Table 2. Mean grain yield per plant for wheat grown from large (L) and small (S) seeds planted within the same plot (comparison between the two components of each treatment)

Treatment	Planting depth[y]	Seed size	Grain yields ($g\ plant^{-1}$) Mainstem	Tillers
3L:1S[z]	Deep	L	0.96	0.79
		S	0.91	0.52
		Difference	*	**
3L:1S	Deep	L	0.96	0.79
Uniform L	Deep	L	0.94	0.72
		Difference	NS	**
3L1S	Medium	L	0.93	1.01
		S	0.90	0.97
		Difference	NS	NS
3L:1S	Shallow	L	0.97	1.10
		S	0.96	1.08
		Difference	NS	NS

[z]3L:1S, three large seeds and one small seed were repeatedly planted within the same row.
[y]Deep, 75 mm; medium, 50 mm; shallow, 25 mm.
*,**, Significant at $P < 0.05$ and $P < 0.01$ levels of probability, respectively, in a paired t test; NS, not significant.

than their neighbouring Sh plants (Fig. 2), but the 3Sh:1M planting did not increase the total number of infertile plants per plot compared with the U-Sh treatment (Table 1). From these observations on planting depth ratios, we can conclude that plants from variable depths perform as well as those from uniform depth only when planting depths are not >50 mm.

Emergence date of individual seedlings within a plot had a significant effect on plant fertility (Fig. 3). The proportion of infertile plants was significantly higher for the late-emerging than for the early-emerging seedlings ($P < 0.01$). Emergence began 8–11 d after planting and continued for a 10-d period. Most plants that emerged within the first 3 d after initial emergence were productive, but 15–30% of the plants that emerged after the eighth day were infertile. Deep-seeded plants resulted in the large porportion of infertile plants (Fig. 2), which may be accounted for by the proportion of late-emerging plants (Fig. 3).

Grain Yield by Plot and Single Plant

Variation in seed size within a plot (3L:1S) had no impact on grain yield per plot (Table 1). At a same planting depth, the grain yield with the 3L:1S treatment was not significantly different from that of treatments where only large seeds were planted. For the 3L:1S treatments, relative grain yield between plants grown from large and small seeds was significantly influenced by planting depth (Table 2). Only at the 75-mm planting depth did plants from small seed have 5% less mainstem grain yield and 34% less tiller grain yield than neighbouring plants from large seed. Plants from large seed in the 3L:1S treatment produced 10% higher tiller grain yield than plants from the uniform-large-seed treatments. The increased grian yields of plants from large seeds compensated for the lowered grain yields of neighbouring plants from small seeds. Thus, the variation in seed size did not influence total grain

Table 3. Mean grain yield per plant for wheat grown from shallow-, medium- or deep-planted seeds

Treatment	Planting depth	Grain yields (g plant^{-1})	
		Mainstem	Tillers
3Sh:1M[z]	Shallow	0.95	1.11
	Medium	0.93	0.37
	Difference	NS	**
3Sh:1D	Shallow	0.96	0.94
	Deep	0.92	0.19
	Difference	*	**
3Sh:1M	Medium	0.93	0.37
U-M	Medium	0.93	0.87
	Difference	NS	**
3Sh:1D	Deep	0.92	0.19
U-D	Deep	0.94	0.72
	Difference	NS	**
3Sh:1D/1M	Shallow	0.96	1.03
U-Sh	Shallow	0.93	1.09
	Difference	NS	*

[z]3Sh:1M, three seeds planted at shallow depth (25 mm) and one seed planted at medium depth (50 mm) in the same row; and 3Sh:1D, three seeds planted at shallow depth and one seed planted deep (75 mm)in the same row; U-Sh, U-M and U-D, uniform large seed planted at shallow, medium and deep depths, respectively.
*,**, Significant at $P < 0.05$ and $P < 0.01$ levels of probability, respectively, in a paired *t*-test; NS, not significant.

yield per plot (Table 1). When seed was planted 25 or 50 mm deep, there were no significant differences in mainstem or tiller grain yields between plants from large and small seeds (Table 2).

The effect of variation in planting depth on grain yield per plot was dependent on planting patterns (Table 1). The grain yield with the 3Sh:1M treatment was similar to that of the uniform-depth treatment, U-Sh, while the 3Sh-1D treatment had a significantly lower grain yield than the U-Sh. The grain yield with the 3Sh:1D treatment did not differ from that with the U-D treatment, indicating that if one in four seeds are planted deep (75 mm), yield reductions are similar to those that occur if all seeds are planted deep. The reduced grain yield with the 3Sh:1D planting can be explained partially by the large proportion of infertile plants (Table 1) and the lowered tiller grain yield with the D plants (Table 3).

In the 3Sh:1D treatment, the D plants were poor competitors with neighbouring Sh plants because of their having low tiller grain productivity (Table 3). The tiller grain yield produced by D plants was only 20% of that produced by neighbouring Sh plants and only 26% of that produced by plants from the U-D treatment where all seeds were deeply planted. The consequence of the neighbouring-plant competition due to nonuniform depth was the decrease in total grain yield per plot (Table 1). Single-plant grain yields produced by medium-depth (M) plants from the 3Sh:1M treatment were 43% of those from the U-M treatment (Table 3), but the 3Sh:1M planting did not significantly reduce total grain yield per plot compared with the U-Sh treatment (Table 1).

There were considerable variations among single plant grain yields within a wheat population (Table 1). Analysis of variance for CV of individual plant yields showed that mainstem grain yields were relatively uniform (CV < 36%), but tiller grain yields were highly variable (CV > 79%). Similarly, Counce et al. (1989) found a CV of 58% for individual-plant grain yields in a rice plant population, and Benjamin and Hardwick (1986) noted a CV of individual plant weights as high as 200% in some dense crops.

Bonan (1991) reported that high planting density (400 viable seeds m^{-2}) caused large interplant competition, resulting in substantial variation in plant size. The degree of interplant competition increased with the decreased growing space available to the plant. In the present study, an optimum planting density was used, and seeds were spaced evenly within the rows. The space available to a plant was assumed to be the same, although it might have been altered slightly, as seedling emergence was less than 100%.

CONCLUSIONS

Variation in seed size within a seedlot affected neither seedling emergence, plant fertility, nor grain yield per plot. Although the small-seeded plants produced 2–44% less tiller grain yield than neighbouring large-seeded plants, the large-seeded plants compensated for the yield loss by producing a 10% higher tiller grain than plants grown from the uniform-large-seed treatment. Nonuniform seed placement had no impact on final percentage emergence but significantly increased the proportion of infertile plants and reduced final grain yield. When as few as one in four seeds were planted deep (> 50mm) within a plot, the proportion of infertile plants increased by 152%, but grain yield was reduced by 19%, compared with uniform shallow (25 mm) planting. The deep-seeded plants produced only 20% of the grain yield per plant of neighbouring shallow-seeded plants. The decreased yield with the deep-seeded plants was due to their having few grain-bearing tillers. Relative contribution of individual plants to total grain yield of the crop community was influenced more by planting depth than seed size in this study. To maximize grain yield in hard red spring wheat, attention must be given to uniform, shallow seed placement (not more than 50 mm) to minimize the proportion of infertile plants and to promote high single-plant grain yield.

ACKNOWLEDGMENTS

We are grateful to Alvin Iverson, Michael Czubath and Ken Ferris for their technical assistance and to Dr. Guy Lafond for his critical review of the manuscript. The study was conducted with partial funding provided by the Western Grains Research Fund and the Canadian and Manitoba Seed Growers Associations.

Benjamin, L. R. and Hardwick, R. C. 1986. Sources of variation and measures of variability in even-aged stands of plants. Ann. Bot. **58**: 757–778.

Bonan, G. B. 1991. Density effect on size structure of annual plant populations: an indication of neighbourhood competition. Ann. Bot. **68**: 341–347.

Briggs, K. G. 1991. Spatial variation in seed size and seed set on spikes of some Canadian wheat cultivars. Can. J. Plant Sci. **72**: 247–249.

Counce, P. A., Moldenhauer, K. A. K. and Marx, D. B. 1989. Rice yield and plant yield variability responses to equidistant spacing. Crop Sci. **29**: 175–179.

de Jong, R. and Best, K. F. 1979. The effect of soil water potential, temperature and seeding depth on seedling emergence of wheat. Can. J. Soil Sci. **59**: 259–264.

Edmeades, G. O. and Daynard, T. B. 1979. The development of plant to plant variability in maize at different planting densities. Can. J. Plant Sci. **59**: 561–576.

Gan, Y., Stobbe, E. H. and Moes, J. 1992. Relative date of wheat seedling emergence and its impact on grain yield. Crop Sci. **32**: 1275–1281.

Giles, B. E. 1990. The effect of variation of seed size on growth and reproduction in the wild barley *Hordeum vulgare* ssp. Heredity **64**: 239–250.

Glenn, F. B. and Daynard, T. B. 1974. Effects of genotype, planting pattern, and plant density on plant-to-plant variability and grain yield of corn. Can. J. Plant Sci. **54**: 323–330.

Knight, R. 1983. Some factors causing variation in the yield of individual plants of wheat. Aust. J. Agric. Res. **34**: 219–229.

Lafond, G. P. and Baker, R. J. 1986. Effects of genotype and seed size on speed of emergence and seedling vigour in nine spring wheat cultivars. Crop Sci. **26**: 341–346.

Lafond, G. P. and Flowler, B. D. 1989. Soil temperature and water content, seeding depth, and simulated rainfall effect on winter wheat emergence. Agron. J. **81**: 609–614.

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

Peterson, C. M., Klepper, B. and Rickman, R. W. 1989. Seed reserves and seedling development in winter wheat. Agron. J. **81**: 245–251.

SAS Institute, Inc. 1990. SAS user's guide: Statistics. SAS Institute, Cary, NC.

Soetono and Donald, C. M. 1980. Emergence, growth, and dominance in drilled and square-planted barley crops. Aust. J. Agric. Res. **31**: 455–470.

Spilde, L. A. 1989. Influence of seed size and test weight on several agronomic traits of barley and hard red spring wheat. J. Prod. Agric. **2**: 169–172.

This article has been cited by:

1. Sefa Altikat, Ahmet Celik, Zinnur Gozubuyuk. 2013. Effects of various no-till seeders and stubble conditions on sowing performance and seed emergence of common vetch. *Soil and Tillage Research* **126**, 72-77. [CrossRef]
2. Rajaâ Jebbouj, Brahim Yousfi. 2009. Barley yield losses due to defoliation of upper three leaves either healthy or infected at boot stage by Pyrenophora teres f. teres. *European Journal of Plant Pathology* **125**, 303-315. [CrossRef]
3. S. G. WILLIS, P. E. HULME. 2004. Environmental severity and variation in the reproductive traits of Impatiens glandulifera. *Functional Ecology* **18**:10.1111/fec.2004.18.issue-6, 887-898. [CrossRef]
4. J.A Pascual, A.D.M Hart, P.J Saunders, H.V McKay, J Kilpatrick, P Prosser. 1999. Agricultural methods to reduce the risk to birds from cereal seed treatments on fenlands in eastern England. I. Sowing depth manipulation. *Agriculture, Ecosystems & Environment* **72**, 59-73. [CrossRef]
5. Ghazi N. Al-Karaki. 1998. Seed Size and Water Potential Effects on Water Uptake, Germination and Growth of Lentil. *Journal of Agronomy and Crop Science* **181**, 237-242. [CrossRef]
6. L. A. Metho, P. S. Hammes, E. A. Beyers. 1998. The effect of soil fertility on the contribution of main stem, tillers and kernel position to grain yield and grain protein content of wheat. *South African Journal of Plant and Soil* **15**, 53-60. [CrossRef]
7. Jim W. Derrick, Megan H. Ryan. 1998. Influence of Seed Phosphorus Content on Seedling Growth in Wheat: Implications for Organic and Conventional Farm Management in South East Australia. *Biological Agriculture & Horticulture* **16**, 223-237. [CrossRef]