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# Effect of Plant Density on Modern Soybean Cultivars Released from Ohio and Liaoning

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**Abstract:** Seeding rate is an important management practice for soybean production. Chinese and U.S. soybean growers use different seeding rates, and breeders in the two countries have developed cultivars adapted to respective plant densities. The objective of this study was to compare the effect of plant density on cultivars recently released in different breeding programs, using four cultivars developed in Liaoning, China and four in Ohio, USA. We used 3 plant density treatments (7.5, 15.0, 22.5 x $10^4$ plants/$hm^2$) and assessed yield and agronomic traits from 2004 to 2006 in Liaoning. There was no significant effect of plant density on yield for either group of the cultivars. The average yield of Ohio cultivars was higher than that of Liaoning cultivars, and there was no significant interaction between plant density and cultivar for all the assessed traits. The plant height of Liaoning cultivars was significantly higher than that of Ohio cultivars, and there was a significant effect of plant density on plant height. The average branch number of Ohio cultivars was larger than that of Liaoning cultivars; higher plant density reduced the branch number per plant greatly. Plant density had a significant effect on the node number and internode length, Liaoning cultivars generally had longer internode length. Plant density had a significant effect on seed yield: stem ratio, as the plant density increased the seed yield: stem ratio decreased for both groups of cultivars. However, 100-seed weight was not affected by plant density.

**Key words:** Soybean [*Glycine max* (L.) Merr.]; breeding; planting density; agronomic trait

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## 1 Introduction

Planting soybean [*Glycine max* (L.) Merr.] at the optimal plant population reduces seeding costs, avoids some diseases, and minimizes lodging (Boquet and Walker, 1980; Norsworthy and Frederick, 2002). Researches showed that optimal plant population varied from 30 000 to 500 000 plants/$hm^2$ (Lehman and Lambert, 1960; Lueschen and Hicks, 1977; Costa, et al, 1980; Egli, 1988; Wells, 1991). Similar yield across plant populations results from equilibration of crop growth rate by the early reproductive period (Carpenter and Board, 1997a, b). Greater dry weight partitioning into branches is partly responsible for crop growth rate equilibration between low vs normal plant populations (Board, 2000). Rigsby et al. (2003) demonstrated

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that genotypic differences in low optimal plant population exist and are influenced by dry matter partitioning into branches. Some seeding population × cultivar interactions have been identified in cooler regions. In Nebraska, Elmore (1998) found that yield of a determinate cultivar increased as seeding population increased from 11 to 35 seeds/$m^2$ but the yield of an indeterminate cultivar was unaffected. Soil water availability throughout the soybean growth season directly influences the response of seed yields to seeding rates (Devlin et al., 1995). In drought-stressed environments, seed yields at low seeding rates are generally higher or equivalent to those at dense populations (Devlin et al., 1995; Elmore, 1998; Taylor, 1980). Heitholt et al. (2005) also demonstrated that management × genotype interactions within the range of experimental cultivars and management practices were not important in low-yielding environments and possibly were overwhelmed by the severity and timing of drought stress. Seed yield from irrigated and non-irrigated treatments increased as population density increased from 7 to 134 plants/$m^2$, except when lodging occurred (Ball et al., 2000a). As seed yields are closely tied to seed number per square meter (Ball et al., 2000b; Frederick et al., 1998, 2001), increased seed numbers on main stems and/or branches are essential for high yield at low plant densities. Cober et al. (2005) used the cultivars released from 1934 to 1996 to study the genetic improvement under different seeding rates, and concluded that new cultivars have more tolerant to plant population stress than older cultivars.

Soybean producers in Liaoning and Ohio use very different seeding rates. In Liaoning the plant density ranges from 120 000 to 150 000 plants/$hm^2$ for determinate cultivars and 150 000 to 195 000 plants/$hm^2$ for semideterminate cultivars (Zhang et al., 2006). The Ohio Agronomy Guide recommends final stands of 250 000 to 300 000 plants/$hm^2$ for the final stand, if planting in May. Breeders in Liaoning and Ohio have developed cultivars adapted to their respective plant densisties. Although many searches relevant to seeding rate have been reported, there was no document to compare the effect of seeding rate on the agronomic traits and seed yield of cultivars released from different breeding programs in two countries. It would be useful to understanding how several decades of selection for different seeding rates in the two countries resulted in specific adaptation. The objective of this study is to compare the effect of plant density on cultivars recently released in Liaoning, China and Ohio, USA.

## 2 Materials and methods

We compared 8 cultivars developed recently at Liaoning Province, China and Ohio State University under different plant densities (Table 1). The experiment was conducted in the field at latitude approximately 40°N (about the same as central Ohio) in Shenyang, Liaoning for 3 yr from 2004 to 2006. A split-plot design arranged in randomized complete blocks was used with three replications. Cultivars were the main-plot factor, and the split-plot factor consisted of three plant densities. As in Liaoning the recommended plant density is from 150 000 to 195 000 plants/ $hm^2$ for semideterminate cultivars, and in Ohio is from 250 000 to 300 000 plants/$hm^2$ for the final stand, if planting in May. For evaluating whether Ohio varieties yield best under high seeding rates and Liaoning varieties have a lower optimum seeding rate, they were planted under three plant densities(75 000, 150 000 and 225 000 plants/ $hm^2$ of final stands). The plant densities achieved by overplanting and thinning. The plots consisted of 5 rows, spaced 60 cm, and 5 m in length. Seeds were planted in late April or early May. Two days after planting, herbicides were applied for weed control. Before harvesting, 10 consecutive plants in a row were selected from each plot for the measurement of agronomic and morphological traits. Each sampled plant was measured for plant height from the node of cotyledon to the tip of stem, the nodes of the main stem and the number of branches was counted, Seed yield was divided by the total weight of straw and pod wall to determine the seed yield: stem ratio. After soybeans matured, the 3-m long middle part of the inside 3 rows ($3m$ per row $\times$ 3 rows $\times 0.6$ m $= 5.4$ $m^2$) was harvested for yield.

In the statistical analysis, time considered a random factor, so that effects and interactions were tested for significance against their respective interactions with year.

# 3 Results

## 3.1 Agronomic and morphological traits

The plant height of Liaoning cultivars was significantly higher than that of Ohio cultivars under different plant densities and in different years ( $F_{(7,14)} = 13.93^{**}$ ). There was a significant ( $P = 0.05$) effect of plant density on plant height: higher plant density was associated with greater plant height for both groups of cultivars ( $F_{(2,4)} = 9.96^{*}$ ). As the plant densities increased from 75 000 to 225 000 plants/hm$^2$, the average plant heights of Ohio and Liaoning cultivars increased by 6.2% and 4.7%, respectively (Table 2).

**Tab. 1 Origin of soybean cultivars for experiment**

| Cultivar | Representing | Origin |
|---|---|---|
| HS93 - 4118 | Ohio | Ohio State Univ. (St. Martin et al., 2001c) |
| Ohio FG1 | Ohio | Ohio State Univ. (St. Martin et al., 1996) |
| Darby | Ohio | Ohio State Univ. (St. Martin et al., 2001b) |
| Kottman | Ohio | Ohio State Univ. (St. Martin et al., 2001a) |
| Liaodou 11 | Liaoning | Liaoning Academy of Agric. Sciences, 1996 |
| Liaodou 12 | Liaoning | Liaoning Academy of Agric. Sciences, 1998 |
| Shennong 94 - 11 | Liaoning | Shenyang Agric. Univ., 1997 |
| Shendou 4 | Liaoning | Shenyang Academy of Agric. Sciences, 1997 |

The average branch number of Ohio cultivars was greater than that of Liaoning cultivars, averaged across plant densities. There was a significant difference in branches per plant between cultivars ( $F_{(7,14)} = 5.10^{*}$ ). Plant density affected the branch number per plant greatly ( $F_{(2,4)} = 65.00^{**}$ ), as the plant density increased from 75 000 to 225 000 plants/ hm$^2$, the average branch number would decrease by 65.2% and 73.5% for Ohio and Liaoning cultivars, respectively (Table2). There interaction of cultivar × density was not significant ( $F_{(14,28)} = 1.73$, $P = 0.11$).

Plant density had a significant effect on the node number ( $F_{(2,4)} = 8.98^{*}$ ). As the plant density increased from 75 000 to 225 000 plants/ hm$^2$, the average node number decreased by 6.5% and 8.6% for Ohio and Liaoning cultivars, respectively. There was a significant difference ( $F_{(7,14)} = 20.05^{**}$) between the node numbers of cultivars; Liaoning cultivars averaged about two more nodes than Ohio cultivars (Table 3). There interaction of cultivar × density was not significant ( $F_{(14,28)} = 0.81$, $P = 0.65$).

**Tab. 2 Effect of plant density on plant height and branch of soybean cultivars released from different breeding programs**

| Group | Cultivar | Plant density ( $\times 10^4$ plants/hm$^2$) | | | | | |
|---|---|---|---|---|---|---|---|
| | | 7.5 | 15.0 | 22.5 | 7.5 | 15.0 | 22.5 |
| | | Plant height/cm | | | Branc/No. | | |
| Modern Ohio | HS93 - 4118 | 95.1 | 96.3 | 101.5 | 5.0 | 2.5 | 1.7 |
| | Ohio FG1 | 91.2 | 98.7 | 97.1 | 4.9 | 2.6 | 1.8 |
| | Darby | 98.0 | 102.8 | 105.4 | 4.2 | 2.1 | 1.6 |
| | Kottman | 95.3 | 97.3 | 99.0 | 4.3 | 2.0 | 1.3 |
| | Mean | 94.9 | 98.8 | 100.8 | 4.6 | 2.3 | 1.6 |
| Modern Liaoning | Liaodou11 | 111.6 | 113.3 | 115.6 | 3.7 | 1.4 | 0.9 |
| | Liaodou12 | 104.2 | 105.3 | 109.3 | 4.2 | 1.4 | 0.8 |
| | Shennong94 - 11 | 113.4 | 118.3 | 119.1 | 3.1 | 0.7 | 0.9 |
| | Shendou4 | 125.6 | 134.9 | 132.3 | 2.7 | 1.1 | 0.9 |
| | Mean | 113.7 | 118.0 | 119.1 | 3.4 | 1.2 | 0.9 |
| | $LSD_{0.05}$ (for cultivar means) | | 5.12 | | | 0.67 | |

Plant density had a significant effect on the internode length ( $F_{(2,4)}$ = 23.40** ). As the plant density increased from 75 000 to 225 000 plants/hm$^2$, the average internode length increased by 12.8% and 14.0% for Ohio and Liaoning cultivars, respectively. There was a significant difference ( $F_{(7,14)}$ = 4.09* ) between the internode length of cultivars, Liaoning cultivars generally had longer internode length, which, combined with taller plants, resulted in greater susceptibility of Liaoning cultivars to lodging (Table 3). There interaction of cultivar × density was not significant ( $F_{(14,28)}$ = 1.34, $P$ = 0.25).

Plant density had a significant effect on seed yield: stem ratio ( $F_{(2,4)}$ = 17.25* ), as the plant density increased, the seed yield: stem ratio decreased for both groups of cultivars. Usually Ohio cultivars had a significantly higher seed yield: stem ratio than Liaoning cultivars ( $F_{(7,14)}$ = 15.52** ) (Table 4).

Cultivars showed marked differences for 100-seed weight. The average 100-seed weight of Liaoning cultivars was significantly higher than that of Ohio cultivars ( $F_{(7,14)}$ = 38.87** ). This difference reflects the effects of selection: Liaoning cultivars were developed for the tofu market, where large seed is advantageous as farmers sell soybean in free market. Of the Ohio cultivars, Ohio FG1 was developed for tofu use, but the other three were not subjected to selection for seed size. The plant density had no significant effect on 100-seed weight ( $F_{(2,4)}$ = 0.04). There was no interaction between plant density and cultivar ( $F_{(14,28)}$ = 0.67) (Table 4).

**Tab.3　Effect of plant density on node and internode length of soybean cultivars released from different breeding programs**

| Group | Cultivar | Plant density ( ×10$^4$ plants/hm$^2$) | | | | | |
|---|---|---|---|---|---|---|---|
| | | 7.5 | 15.0 | 22.5 | 7.5 | 15.0 | 22.5 |
| | | Node/No. | | | Internode length/cm | | |
| Modern Ohio | HS93 - 4118 | 24.7 | 23.0 | 23.3 | 3.9 | 4.2 | 4.4 |
| | Ohio FG1 | 22.3 | 20.9 | 21.0 | 4.1 | 4.7 | 4.6 |
| | Darby | 26.0 | 24.6 | 23.9 | 3.8 | 4.2 | 4.4 |
| | Kottman | 24.9 | 23.7 | 23.2 | 3.8 | 4.1 | 4.3 |
| | Mean | 24.5 | 23.1 | 22.9 | 3.9 | 4.3 | 4.4 |
| Modern Liaoning | Liaodou11 | 23.9 | 24.5 | 23.1 | 4.7 | 4.6 | 5.0 |
| | Liaodou12 | 25.7 | 24.6 | 22.3 | 4.1 | 4.3 | 4.9 |
| | Shennong94 - 11 | 28.0 | 26.7 | 25.4 | 4.1 | 4.4 | 4.7 |
| | Shendou4 | 29.0 | 27.1 | 26.7 | 4.3 | 5.0 | 5.0 |
| | Mean | 26.7 | 25.7 | 24.4 | 4.3 | 4.6 | 4.9 |
| | $LSD_{0.05}$ (for cultivar means) | | 1.78 | | | 0.34 | |

### 3.2　Yield

There was no significant effect of plant density on yield for both two groups of cultivars ( $F_{(2,4)}$ = 1.41) (Table 5). Soybean plants have a strong ability of self - adjustment under different plant densities, which result in the similar yield. However, the average yield of Ohio cultivars under different plant densities and in different years was higher than that of Liaoning cultivars. There was a significant yield difference between soybean cultivars ( $F_{(7,14)}$ = 4.51** ). There was no significant interaction between plant density and cultivar ( $F_{(14,28)}$ = 0.98).

## 4　Discussion

The current soybean breeders of Liaoning had a goal to develop semideterminate cultivar with a plant height about 110 - 130 cm, which provide a vigorous vegetative growth adapted to the unfertile soils in Liaoning,

**Tab. 4 Effect of plant density on seed yield: stem ratio and 100-grain weight of soybean cultivars released from different breeding programs**

| Group | Cultivar | Plant density ( $\times 10^4$ plants/hm$^2$) | | | | | |
|---|---|---|---|---|---|---|---|
| | | 7.5 | 15.0 | 22.5 | 7.5 | 15.0 | 22.5 |
| | | Seed yield: stem ratio | | | 100-grain weight/g | | |
| Modern Ohio | HS93 - 4118 | 1.05 | 1.00 | 0.97 | 15.2 | 15.8 | 15.8 |
| | Ohio FG1 | 0.95 | 0.85 | 0.86 | 21.3 | 21.7 | 20.7 |
| | Darby | 0.92 | 0.91 | 0.88 | 14.5 | 14.9 | 14.9 |
| | Kottman | 0.95 | 0.91 | 0.95 | 16.2 | 15.8 | 16.3 |
| | Mean | 0.97 | 0.92 | 0.92 | 16.8 | 17.1 | 16.9 |
| Modern Liaoning | Liaodou11 | 0.76 | 0.71 | 0.74 | 20.9 | 21.3 | 21.2 |
| | Liaodou12 | 0.90 | 0.88 | 0.80 | 23.4 | 23.1 | 23.3 |
| | Shennong94 - 11 | 0.77 | 0.71 | 0.67 | 20.5 | 19.9 | 20.5 |
| | Shendou4 | 0.76 | 0.70 | 0.72 | 18.0 | 17.0 | 16.9 |
| | Mean | 0.80 | 0.75 | 0.73 | 20.7 | 20.3 | 20.5 |
| | $LSD_{0.05}$ ( for cultivar means) | | 0.09 | | | 1.33 | |

**Tab. 5 Effect of plant density on seed yield of soybean cultivars released from different breeding programs**

| Group | Cultivar | Plant density ( $\times 10^4$ plants/hm$^2$) | | |
|---|---|---|---|---|
| | | 7.5 | 15.0 | 22.5 |
| Modern Ohio | HS93 - 4118 | 3 072 | 3 138 | 2 879 |
| | Ohio FG1/( kg • hm$^{-2}$) | 2 887 | 2 794 | 2 809 |
| | Darby/( kg • hm$^{-2}$) | 2 871 | 3 158 | 2 797 |
| | Kottman/( kg • hm$^{-2}$) | 3 276 | 3 242 | 3 210 |
| | Mean/( kg • hm$^{-2}$) | 3 026 | 3 083 | 2 924 |
| Modern Liaoning | Liaodou11 | 2 559 | 2 671 | 2 409 |
| | Liaodou12/( kg • hm$^{-2}$) | 2 776 | 2 968 | 2 570 |
| | Shennong94 - 11/( kg • hm$^{-2}$) | 2 654 | 2 717 | 2 430 |
| | Shendou4/( kg • hm$^{-2}$) | 2 741 | 2 537 | 2 697 |
| | Mean | 2 682 | 2 723 | 2 527 |
| | $LSD_{0.05}$ ( for cultivar means) | | 316 | |

China. In contrast the Ohio soybean breeders released cultivars with strong resistance to lodging, and a shorter plant height of indeterminate growth habit, which gives the cultivar a broad adaptability. Even though Ohio cultivars were planted in Liaoning environment, they still yielded well.

In the soybean breeding program of Ohio the early generations were planted in wide rows, Under these conditions, the best performing might be those with more branches. This may be why Ohio cultivars had more branches than Liaoning cultivars under low plant density. In contrast, soybean breeders in Liaoning try to stimulate the conditions of soybean production: soybeans were planted in 60 cm rows and 15 000 plants/hm$^2$ continually as most farmers plant soybeans. In selection of single plants, the breeders kept the best preforming plant with semideterminate habit, good vegetative growth, and proper branches (1 - 2 branches per plant). This resulted in cultivars with fewer branches even under low plant density.

The self-adjusting ability of soybean has not been altered by divergent selection in Ohio and Liaoning. Although there was no significant effect of plant density on seed yield, there was a significant seed yield difference between two groups of cultivars developed by different breeding programs, Ohio program in which breeder selected single plant with tolerance to lodging in wide rows will benefit to the cultivars with a better plant density adaptability, which will result in better seed yield and productivity under various plant densities . Of course, the Ohio breeder has the advantage of not needing to select for seed size, protein content, yellow hilum, etc, as US farmers sell soybean to processing factory directly, not in free market.

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