SOYBEAN SEED YIELD AND SIZE AS INFLUENCED BY ROW SPACING AND SEEDING RATE AND SEED-SIZE HERITABILITY

by

CHRISTOPHER MWANGI NDIRANGU

Dissertation submitted to the Faculty of the
Virginia Polytechnic Institute and State University
in partial fulfillment of the requirements for the degree of

DOCTOR OF PHILOSOPHY
in
Crop and Soil Environmental Sciences

Approved:

Glenn R. Buss
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ABSTRACT

Soybeans within a specific seed size range are often preferred for the manufacture of specialty soy products. This study examined the influence of row spacing and seeding rate on seed yield, average seed size, and seed size uniformity of Camp (small seeded) and V71-370 (large seeded) soybean cultivars [*Glycine max* (L.) Merr.]. Experiments were conducted in 1992 and 1993 at Kentland Farm near Blacksburg, Virginia. Row widths of 38 and 76 cm and seeding rates of 125, 250, 500, and 750 thousand seeds ha^{-1} were used.

Averaged over treatments, 38-cm row spacings yielded higher than 76-cm row spacing by 11.6%. Additionally, each increase in seeding rate resulted in increased yield up to 500,000 seeds ha^{-1} and then leveled off.

Yield of useful seed of Camp (total yield multiplied by the proportion of seed between 4.8 and 5.6 mm in diameter) was maximized at narrow row spacings and 500,000 seeds ha^{-1}. Neither row spacing nor seeding rate influenced V71-370 yield of usable seed (larger than 7.9 mm). Averaged over years and cultivars, soybean seed size was not influenced by row spacings or seeding rates. However, in 1993, smaller Camp seed was favored by narrow rows and low seeding rate. Seed size uniformity, as determined by analysis of variance of individual seed weights was, in general, not influenced by row spacing or seeding rates.

In a separate investigation in 1992, heritabilities were estimated by two methods using plot data from two replications of lines from crosses of Camp with Jizuka, MD87L-0198, and Stafford soybean cultivars. Heritabilities based on F_3 progeny means regressed on F_2 parental means ranged from 24% to 41% and were lower than the corresponding heritability estimates based on analysis of variance which ranged from 43% to 83%. Correlations of seed size with other agronomic traits were generally low. Although low in magnitude, significant positive correlations of seed size with yield in some crosses might hinder progress of breeders when selecting for small-seeded, high yielding cultivars.

This dissertation is dedicated to my parents

W. Nyamweru and E. Ndirangu.

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LITERATURE REVIEW

Introduction

Management factors such as row spacing, planting date, plant population, fertilizer application, weed control, and choice of cultivar have been shown to have an effect on soybean yield (Cooper, 1971a; Hicks et al., 1969). The effects of these factors on, seed size uniformity and composition are not clearly understood nor well documented. There is no doubt that as seeding rate is increased, intraplant and interplant competition occurs and reduction in the supply of plant growth requirements is likely to result. The average yield per plant will increase as plant population density decreases, but cannot be expected to increase beyond the point where population pressure is no longer the limiting factor to yield (Donald, 1963). The size and weight of seeds that a single plant can produce are then likely to be limited by genetic factors as the lower population density level is reached, and further reduction in the number of plants per unit area would have no effect on the yield per plant. It may, however, have an influence on seed distribution on the plant, and this might have a bearing on seed size and seed size uniformity.

Factors That Influence Seed Size

Soybean seed size, measured as mass per seed, is an important component of yield for this crop and it is influenced by genetic and environmental factors. According to Hartwig (1973), seed size for most cultivars used in agriculture ranges from 4 g to 55 g per hundred seeds. Seed from the same cultivar has been shown to vary in size even when grown under similar conditions (Burris et al., 1973; Johnson and Leudders, 1974). Variation in seed size may be attributed to differences in time of pod production, with early-developed pods producing larger seeds than later developed pods (Egli et al., 1978, 1985, 1987; Gbikpi and Crookston, 1981). Seeds produced on the lower nodes of the main stem may also be larger than those from the upper nodes (Fraser et al., 1982; Spaeth and Sinclair, 1984).

Griffin et al. (1988), working with Davis and Ransom cultivars of soybean, compared moisture supply at various stages in crop development and found that the largest seed size was obtained when irrigation was supplied throughout the season. However, Kadhem et al. (1985) found that irrigation during the R 4.7 to R 6.4 growth stages as described by Fehr et al. (1971), was more effective in increasing soybean seed size than either no irrigation or irrigation throughout the growing period. Herbert and Baggerman (1983), working with a different legume, found that seed size of cowpea [*Vigna unguiculata* (L.) Walpers] was not influenced by row spacing, seeding rate, or irrigation level, and the seed size was more or less uniform across treatments.

Fontes and Ohlrogge (1972) tested Wayne and Amsoy cultivars of soybean at 18, 30, and 42 plants m^{-2} and found that seeding rate had no influence on seed size. They also found that plants established from large and small seeds produced seeds that were similar in size. In a later experiment, Weil and Ohlrogge (1976) found that reducing plant competition by thinning at the beginning of pod filling stage significantly increased individual seed size particularly from the uppermost portion of the plant. The weight per seed from uppermost canopy level for the plants that had been thinned was 23.9% higher than from plants that had not been thinned. Wright et al. (1984) varied plant population density under no-tillage and conventional tillage systems and observed that an increase in plant population density resulted in a significant increase in seed size. On the other hand, Basnet et al. (1974) did not find any influence of plant population on seed weight of five soybean cultivars. In their study, plants in 46 and 92 cm row spacings produced similar seed sizes. Ramseur et al. (1984), using Braxton soybean cultivar, an inter-row spacing of 91 cm, and intra-row spacings of 4.3, 5.1, 6.1, 7.6, 10.2, 15.2, 30.2, and 45.7 cm that correspond to 25.6, 21.5, 18.0, 14.5, 10.5, 7.2, 3.6, and 2.4 plants per m^{-2}, found no differences in seed size in the first year. However, in the second year they found significant differences in seed size as influenced by seeding rate although the trends in these seed weights were not clear. When the lowest four seeding rates were compared with the highest four, there were no significant differences. Further pair-wise comparisons revealed significant differences between 2.4 and 3.6 seeds m^{-2} compared with 7.2 and 10.8 seeds m^{-2}. Hinson and Hanson (1962) found that seeds produced at higher seeding rates were larger than those produced at lower seeding rates for Jackson and D51-4871 soybean cultivars but no response was observed for the cultivars Lee and Yelnanda in the same investigation. Immer et al. (1977) working with dry beans (*Phaseolus vulgaris* L.) at different seeding rates found that the seed sizes at 28.8 plants m^{-2} were larger than those produced at either 3.2 or 7.2 plants m^{-2}.

Parker et al. (1981) planted four soybean cultivars in early April, late April, early May, late May, early June, late June, and early July, and found that in general, seed weights increased with a delay in planting date up to late May and early June. The heaviest seeds were obtained for late May and early June planting. Beech et al. (1988) also found increased seed size with delayed planting.

Other putative factors that affect seed size are temperature, nitrogen fertilizer application, defoliation, plant lodging, and seed inoculation with *Rhizobium*. Night temperature has been shown by Seddigh and Jolliff (1984) to influence seed size. Working with S 09-90 soybean cultivar of maturity group 0, they found that increasing night temperature resulted in production of larger seeds. Raising the night temperature from 10 to 16°C increased seed size by 16% and 26% in 1981 and 1982, respectively. Raising the night temperature from 10 to 24°C resulted in an increase in seed weight of 21% and 23% in 1981 and 1982, respectively. The observed differences were highly significant. In another study by Bullock (1990) involving the effect of nitrogen fertilizer application and defoliation at various levels, seed weight was not affected by rate of nitrogen applied but was reduced as the level of defoliation was increased. Shapiro et al. (1987) subjected soybeans to three levels of lodging at different stages of growth and found that pod initiation stage was the most critical stage at which seed size was significantly reduced by lodging.

Soybean seed size has been shown to be under genetic control (Hartwig, 1973). Little to no response of row spacing and plant population on seed size has been reported (Basnet et al., 1974; Fontes and Ohlrogge, 1972; Herbert and Baggerman, 1983). However, Immer et al. (1977) obtained larger dry bean seeds at higher plant population density than at lower ones. In addition, availability of moisture has been shown to increase seed size (Griffin et al., 1988; Kadhem et al., 1985).

Factors that Influence Soybean Yield

Literature reveals a lot of published reports on the influence of management practices on soybean seed yield and yield components, but, results have been inconsistent. Cooper (1971b) using seven soybean cultivars, two row spacings, and three plant populations found significant yield advantage for the 17 cm row spacing over the 50 cm particularly where lodging was not serious. Where lodging occurred, increase in seeding rate above the optimum rate resulted in yield reduction. Yield advantage for narrow rows has been attributed to increased leaf area index and increased efficiency in light interception by plants (Shibles and Weber, 1965, 1966; Weber et al., 1966). Row spacing and seeding rates (or plant population) have been shown to influence agronomic traits as some of the following published results show. Herbert and Litchfield (1982), using 25 and 50 cm row spacings and population densities ranging from 25 to 135 plants m^{-2}, found a 12% to 16% yield advantage for the narrow row over the wide row spacing in 1979. In 1980, a 75 cm row spacing was added as a treatment and a yield advantage of 31% for the 25 cm row spacing over the 75 cm row spacing was obtained. Averaged over treatments, an increase in plant population density from 25 to 80 plants m^{-2}, resulted in a yield increase between 13% and 27% while 80 and 135 plants m^{-2} had similar seed yields.

Parks et al. (1982), using Essex, Bragg, Davis, and Hutton soybean cultivars, varied row spacing and planting date and obtained higher yields with a 46 cm row spacing than with 92 cm, particularly at later planting dates.

However, Wells (1991, 1993) did not obtain significant differences using similar row spacings.

Hesterman and Isleib (1991) obtained yields of 3608, 4280, and 5174 kg ha^{-1} for 75, 50, and 25 cm row spacings, respectively, showing an increase in yield as the row spacing was reduced. Shroyer and Whigham (1981) who used 17, 34, and 69 cm row spacings and 33, 63, or 93 plants m^{-2} obtained higher seed yields for narrow-row versus wide-row spacings. Eckert (1987) used 18 and 76 cm row spacings and also found that soybeans in the narrow-row spacing yielded more than those in the wide-row spacing. However, Savoy et al. (1992) did not find a significant difference in yield for 36 and 102 cm row spacings.

Blumenthal et al. (1988) tested yield response as influenced by 50, 100, 200, and 400 thousand plants per hectare and found that yield increased with increasing seeding rates up to 200 thousand plants ha^{-1} and then declined. Ranjbar et al. (1988) also obtained higher yields from narrow-row than from wide-row spacings using Clark 63 and Williams soybean cultivars at 30 and 50 cm inter-row spacings and 20, 30, and 40 plants m^{-2}. Yield was higher at 20 and 40 plants m^{-2} for Clark 63 and Williams cultivars, respectively. Ranjbar et al. (1988) also found that yield was highly correlated with the seed size and with the number of seeds located on the middle portion of the plant.

Beaver and Johnson (1981) used two determinate and two indeterminate soybean cultivars at inter-row spacings of 20, 50, and 80 cm and found that the two closest row spacings yielded more than the widely-spaced rows. They also varied the seeding rate from 350 to 650 thousand seeds ha^{-1} and found no significant differences in yield among the seeding rates while row-spacing yield differences were significant.

Ablett et al. (1984) also tested the response of determinate, semi-determinate, and indeterminate soybean types using row spacings of 25, 50, and 75 cm and plant populations of 400, 600, and 800 thousand seeds ha^{-1} and obtained yield increases for the 25 cm row over the 75 cm row spacing of 14%, 20% and 23% for indeterminate, semi-determinate, and determinate forms of soybean, respectively. Further, Beuerlein (1988) tested determinate and indeterminate semi-dwarf soybean cultivars at row spacings of 15, 25, 35, and 50 cm and obtained increased seed yields as row spacing was reduced. Weaver et al. (1991), using determinate and indeterminate cultivars of soybean and 30 and 60 cm row spacings, on the other hand did not find any significant differences in yield between narrow-row and wide-row spacings for either the determinate or the indeterminate types.

Various studies involving differing moisture regimes showed different response of soybean yield to row spacings. Reicosky et al. (1981) using Evans soybean cultivar at inter-row spacings of 15, 46, and 76 cm obtained higher yields from narrow-row spacings than from wide-row spacings when the crop was irrigated, but this was reversed when the crop was not irrigated. Boquet (1989 and 1990) evaluated irrigated and non-irrigated soybean plots at 50 and 100 cm row spacings and obtained higher yields with the narrow-row spacing at all irrigation levels. Taylor (1980), Mason et al. (1980), and Taylor et al. (1982) used row spacings of 25, 50, 75, and 100 cm and found differences in yield between the narrowest and widest row spacing with narrow rows giving higher yields during the season when rainfall was abundant but little to no difference when moisture was limiting during the growing season. Doss and Thurlow (1974) on the other hand, tested two soybean cultivars at 60 and 90 cm inter-row spacings and obtained higher yields for the wide-row than the narrow-row spacing in an irrigated system.

Cooper (1989) using Williams and Sprite soybean cultivars at two locations obtained 800 to 941 kg ha^{-1} higher seed yields for a 17 cm row spacing compared to 50 cm when rainfall was abundant. However, in one of the locations, he found no advantage for narrow rows over the wide rows in three out of seven years and associated the results with drought in those three years.

Board et al. (1990) using row spacings of 50 and 100 cm, different plant populations and May or July planting dates obtained increased soybean yields for narrow-row compared to wide-row spacings at both early and late planting dates, but the yield advantage was higher for the late-planted crop. Yanusa and Ikwelle (1990) on the other hand, found that yield advantage for narrow rows was higher for an early-planted crop than for late planted ones when they tested one soybean cultivar at 40, 60, and 75 cm row spacings, different seeding rates, and planting dates of 26 June and 10 July.

Summary of Influence of Row Spacing and Seeding Rate on Soybean Yield

A number of studies have been done with regard to the influence of population density on soybean plants but the results have been contradictory. Buttery (1969) and Cooper (1977) reported an increase of seed yield with increasing seeding rates while Fontes and Ohlrogge (1972) and Nave and Cooper (1974) found a reduction in seed yield as the seeding rate increased. Other workers found no effect of seeding rate on yield (Fink et al., 1974; Johnson and Harris, 1967).

Yield increases with reduced row spacing has been reported in many published results though one needs to be cautious because the definition of narrow and wide varies among different studies. Reduction in yield from narrow rows and high seeding rates as a result of increased lodging has been reported (Buttery, 1969; Cooper, 1971a). Of the yield components, seed size is the least influenced by environment and management practices (Fontes and Ohlrogge, 1972; Probst, 1945). Little information regarding seed size uniformity is available and most of this mainly deals with stand establishment and subsequent plant development.

How seed size uniformity is influenced by management practices and the prevailing environmental conditions is not well documented.

Heritability of Seed Size

Estimation of heritability for various plant traits has been of interest over the years. The work of Johannsen (1903), quoted by Allard (1960) details an account of determining variability. Using dry beans *(Phaseolus vulgaris* L.), he demonstrated that within a particular class there was a range of seed sizes, but variability among various classes was greater than variability within a class. Fisher (1918) divided genetic variance, which he called genetic effect, into additive variance (the average effect of the gene), dominance variance (deviation from the additive scheme or allelic interactions), and epistatic interactions (non-allelic interactions).

Lush (1940), in his classic work on heritability, distinguished between broad sense and narrow sense types. He defined broad sense heritability as the fraction of the observed variance which was caused by differences in heredity. This definition is general enough to be applicable to both plants and animals. He defined narrow sense heritability as the fraction of the total genetic variance for segregating generations that is attributable to additive gene effects. Hanson (1963) gave an account of heritability particularly as it refers to plants and brought in the concept of prediction of genetic gain from selection. The phenotypic value of a selection unit according to Hanson (1963) was that of an individual, as in mass selection, or that of a mean, as in family selection.

Estimates of heritability can be calculated from measurements of individual plants within a plot or from plot totals and/or means. The estimates of environmental component can be obtained by various methods. Weber (1950) suggested that the best estimate of environmental variance for computing heritability was the cube root of the products of the variances of the non-segregating populations, P_1, P_2 and F_1. Mahmud and Kramer (1951) used the square root of the sum of variances for the two parental non-segregating populations. From a theoretical standpoint, broad sense heritability provides information on the relative magnitude of genetic and environmental variation in the plant population that one is dealing with. In general, the more environments used for estimating the different variances, the smaller are estimates of genetic variance because the genotype-environment interaction is removed from the estimate of genetic variance (Comstock and Moll, 1963).

Methods used in estimating heritability differ and so do the results obtained (Bartley and Weber, 1952). Cahaner and Hillel (1980) used three methods to estimate heritability and compared the results. They used the variance of non-segregating generations to estimate the environmental variance and then subtracted that value from the variances of a segregating population to get an estimate of total genetic variance. Dividing the total genetic variance by the phenotypic variance, they obtained broad-sense heritability. These workers also used the method of analysis of variance and covariance and obtained narrow sense heritabilities based on intra-class correlation. Finally, they used offspring on parent regression and got an estimate of broad sense heritability. The three methods gave similar results.

Smith and Kinman (1965) also used the parent-offspring regression method to estimate narrow sense heritability. The assumptions necessary for use of the Smith and Kinman heritability are similar to the assumptions of Dudley and Moll (1969) and are as follows:

1. Normal Mendelian diploid inheritance.
2. No environmental correlations with relatives.
3. No maternal effects.
4. Population in linkage equilibrium.
5. Negligible dominance and epistatic effects.

When analysis of variance and regression methods are used in estimating heritability of an F_2 plant population, results obtained are comparable only if gene action is additive (Johnson et al., 1955). The nature of evaluation units used (individual plants, plots means, or means of several plots) and the nature of sampling, influence the magnitude of the estimates of heritability obtained (Weber and Moorthy, 1952).

Heritability estimates for various traits have been determined for soybean by several workers giving different results depending on the method used and the genetic composition of the plant material used. Johnson et al. (1955) used F_3 lines and obtained heritability values of 92.1% and 68% for seed size, 80.9% and 61.4% for plant height, 89.3% and 84.4% for flowering date, and 25.2% and 39.5% for seed yield in two soybean crosses. These workers used F_3-derived lines in the F_4 and F_5 generations grown at two locations. Measurements were taken on 10 randomly selected plants and the mean was used as a plot value. Variance among the non-segregating populations was equated to environmental variance and subtracted from the variance among the segregating populations to obtain an estimate of genetic variances. Fehr and Weber (1968) also used analysis of variance method and obtained heritability values of 92% and 94% for seed weight in two soybean crosses.

Soybean yield, seed size, and other agronomic traits are influenced by both genetic and environmental factors as shown above. Chapter two of this dissertation deals with the effects of row spacing and seeding rate on agronomic characteristics of Camp and V71-370 soybeans, and chapter three deals with the genetic aspect of soybean seed size.

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Chapter Two

SOYBEAN YIELD, SEED SIZE, AND SEED SIZE UNIFORMITY AS INFLUENCED BY ROW SPACING AND SEEDING RATE

(ABSTRACT)

Seed size and uniformity of seed size are important factors in determining suitability of soybeans for food uses. The influence of management variables on soybean seed size and seed size uniformity is not clearly understood. Research was undertaken to determine the influence of cultural practices on seed production, seed size, and seed size uniformity of two soybean cultivars, Camp (small seeded) and V71-370 (large seeded). The investigation was carried out at Kentland Farm near Blacksburg, Virginia and at Eastern Virginia Agricultural Research and Extension Center, Warsaw, Virginia, in 1992 and 1993. Row spacings of 38 and 76 cm and seeding rates of 125, 250, 500, and 750 thousand seeds ha^{-1} were used throughout the study period.

Narrow rows yielded higher than wide rows by 13.9% and 9.3% for Camp and V71-370, respectively. When averaged over treatments, yield increased as seeding rate was increased up to 500,000 seeds ha^{-1} and then leveled off for the full season crop at Blacksburg and the double-crop at Warsaw.

Averaged over years and cultivars, seed size was not affected by row spacing or seeding rate. However, smaller seeds of Camp were favored by narrow row spacings and lower seeding rates in 1993. Seed size uniformity as determined by analysis of variance of individual weights of twenty randomly sampled seeds indicated V71-370 seed was significantly more uniform for the wide-row spacings than for the narrow-row spacings in 1992 but not in 1993 or in either year for Camp. Additionally, Camp seed size was more uniform at lower seeding rates than at higher seeding rates in 1992 but no significant influence was found in 1993 or in either year for V71-370. Yield of useful Camp seed, determined by multiplying the total yield (kg ha^{-1}) by the proportion of seed that was smaller than 5.6 mm but larger than 4.8 mm in diameter, was maximized at narrow row and 500,000 seeds ha^{-1}. Neither row spacing nor seeding rate had a significant influence on the yield of useful seed (larger than 7.9 mm) for V71-370.

Introduction

Soybean seed is used in the food industry for the manufacture of various products. For some of these products, specific seed sizes are required. Natto, for instance, requires a very small seed size with a diameter of less than 5.6 mm. Tofu on the other hand requires soybean types with larger seeds. Nearly 500,000 metric tons of soybeans are exported to Japan annually for the manufacture of tofu (Nakamura, 1979). Eighty to ninety percent of all the tofu made in Japan is from soybeans imported from the United States (Smith, 1989). In recent years, US global soybean market share has decreased markedly largely because of competition from Brazil and Argentina (McVey et al., 1995). There is a need to diversify soybean production to meet the specific market requirements because of the impending competition.

A major problem in meeting the demand for these specific requirements from various manufacturing firms is that of producing uniform seed sizes. Although seed uniformity is not usually considered as a component of yield, it plays a crucial role in the quality of seed and also influences stand establishment. Seed size is frequently measured as weight per seed or by screen size through which they will pass. Management variables such as cultivars, seeding rates and plant populations, fertilizer types and time of application, row spacing, time of planting, and disease and pest control can interact with other factors to influence the ability of plants to respond to their neighbors in the utilization of available resources and this might have an effect on yield and yield components.

Yield advantage of narrow rows over wide rows has been reported by Boerma and Ashley (1982), Boquet (1989, 1990), and Parks et al. (1982). Other workers however, reported no yield advantage using narrow rows (Caviness, 1966; Hartwig, 1973; Taylor, 1980). Yield advantage of narrow over wide rows is more pronounced when the prevailing conditions are not optimal. Late planting compared to optimal planting or non-irrigated compared to irrigated crops are examples in which crops in narrow row culture out-yielded those under wide rows (Taylor et al., 1982). In narrow rows, yield increase has also been associated with high population density (Cooper, 1977; Probst, 1945; Wiggans, 1939). However, reduction in yield for narrow rows and high plant population densities as a result of increased lodging has been reported (Buttery, 1969; Cooper, 1971a).

In studies evaluating the effects of seeding rate on *yield*, some workers obtained increased yields as seeding rates were increased (Beuerlein, 1988; Cooper, 1977; Herbert and Litchfield, 1982; Ranjbar et al., 1988; Shahidulla and Hossain, 1987; Shroyer and Whigham, 1981), but others found no effect (Beaver and Johnson, 1981; Fink et al., 1974; Johnson and Harris, 1967; Nave and Cooper, 1974). Lower yields at high seeding rates also have been reported (Buttery, 1969; Cooper, 1971a).

From the harvested crop, seed size and seed quality of soybean have shown little response to row spacing and seeding rate (Basnet et al., 1974; Fontes and Ohlrogge, 1972; Lehman and Lambert, 1960; Probst, 1945). Similarly, Herbert and Baggerman (1983) working with cowpea [*Vigna unguiculata* (L.) Walp.] at different row spacings, seeding rates and irrigation levels found that seed size of this crop was not influenced by any of the treatments imposed. Immer et al. (1977) working with dry bean (*Phaseolus vulgaris* L.) at different plant population densities found that seed sizes at 28.8 plants m^{-2} were larger than those produced at either 3.2 or 7.2 plants m^{-2}. Factors that have been shown to increase soybean seed size are moisture availability (Griffin et al., 1988; Kadhem et al., 1985) and some delay in planting time (Beech et al., 1988). How seed size uniformity is influenced by management practices and the prevailing environmental conditions has not been investigated thoroughly.

If certain management practices produce more uniformly sized seeds, then employment of these practices should increase the yield of desired seed sizes and reduce the amount of seed screening necessary to produce a uniform product. The objective of this study was to determine the effect of cultivar, row width, and seeding rate on yield, average seed size, and seed size uniformity.

MATERIALS AND METHODS

Experiments were conducted at Kentland Research Farm near Blacksburg, Virginia, and at the Eastern Virginia Agricultural Research and Extension Center at Warsaw, Virginia. All the seed used in the study were obtained from Dr. G.R. Buss of Blacksburg, VA. Camp and V71-370 soybean cultivars were used in all experiments. Camp is a small seeded cultivar (6 g/100 seeds) while V71-370 is a large seeded cultivar (24 g/100 seeds). Plots in both years at Blacksburg consisted of seven 6 m rows and four 6 m rows for the 38 and 76 cm row spacings, respectively. Initially, all plots were planted using a plot planter at a spacing of 76 cm between rows. The 38 cm rows were obtained by inter-seeding three additional rows per plot by hand immediately thereafter. Seeding rates of three, six, twelve and eighteen seeds m^{-1} of row for the narrow-row spacings and six, twelve, twenty-four, and thirty-six seeds m^{-1} of row for the wide-row spacings corresponded to 125, 250, 500, and 750 thousand seeds ha^{-1}, respectively. Trifluralin (trifluoro-2, 6-dinitro-N, N-dipropyl-p-toluidine) was applied as a pre-emergence herbicide at the rate of 0.75 kg active ingredient ha^{-1} and was incorporated into the soil before planting. The experimental design used was a split plot design with cultivars as the main plot. Row spacings and seeding rates were randomized within the main plots.

Three replications were planted at the Blacksburg location. The plots in Blacksburg were planted on 14 June, 1992 and 20 May, 1993.

In 1992, at Warsaw, a double crop planting of Camp and V71-370 was established on 9 July. An inter-row spacing of 60 cm and seeding rates of 125, 250, 500, and 750 thousand seeds ha^{-1} were used. Plots in this case consisted of four 5.4 m rows (two center rows harvested) and the treatments were replicated three times. A split plot design also was used at this location.

Data collected on a plot basis were seed yield; maturity, taken as the number of days after 31 August when approximately 95% of the pods had ripened; average plant height, taken on four random plants from the base to the stem apex in cm; total number of plants that set seed per plot, determined by counting the plants on the harvest area just before harvest; and lodging score on a 1 to 5 scale, where 1 indicated that all plants in a plot were upright and 5 all plants in a plot had lodged severely.

Before the crop was harvested, ten plants were randomly selected from each plot in the Blacksburg tests. Plant height, number of branches, number of pods and seed yield were determined for each plant. At the time of harvesting, plots were end-trimmed to a length of 4.9 m. A small plot combine was used to harvest two center rows from the plots with 76 cm row spacing and four center rows from the plots with 38 cm row spacing. Seeds were collected in paper bags, weighed, and moisture content determined. From the bulk seed of each plot harvested at Blacksburg in 1992 and 1993, 100 seeds were counted and weighed to determine the average seed weight. Twenty seeds also were randomly selected from the one hundred seed sample and weighed individually to estimate uniformity of seed size. Standard deviations were calculated from the weights of those twenty seeds. Seed uniformity was also determined by passing 200 g of seed through a graduated series of screens and weighing the seeds that stayed on each screen and that passed through the smallest screen. Camp was screened through 5.6, 5.2, 4.8, and 4.4 mm screens. The amount of seed suitable for the manufacture of natto was determined as the total percentage of seed that had a diameter of less than 5.6 and larger than 4.8 mm (14/64-12/64 inch). The classes of Camp seed obtained were categorized as very large (VL), large (L), medium (M), small (S), and very small (VS) for those that were retained on 5.6, 5.2, 4.8, 4.4, or < 4.4 mm respectively. V71-370 seed was screened using 8.7, 8.3, 7.9 and 7.5 mm screens. Similarly, classes of V71-370 were categorized as VL, L, M, S and VS if they were retained on 8.7, 8.3, 7.9, 7.5, or <7.5 mm screen hole diameters, respectively. The amount of V71-370 seed that was useful for the manufacture of soy products such as tofu and miso was determined by assessing the percentage of seed that was larger than 7.9 mm.

For individual cultivar response to treatments, analysis was done as if it were a randomized complete block design. Standard analysis of variance procedures were followed for a split-plot design to determine significant differences among the treatments over cultivars. Homogeneity of variances for 1992 and 1993 data was determined by computing the ratio of the largest to the smallest error mean square as proposed by Hartley (1950). Mean separation was done using Duncan's multiple range test. Regression analyses were conducted using inter-row spacing and plant population in the harvest area as independent variables and total seed yield or yield of useful seeds as dependent variables. Stand counts in the harvest area extrapolated to plants ha^{-1} was taken as plant population. Comparison of regression coefficients obtained in different years was done using the test of homogeneity of regressions by Sokal and Rohlf (1995). Unless otherwise stated, significant differences were at the 0.05 probability level.

RESULTS AND DISCUSSION

Response of Camp Soybean at Blacksburg in 1992 and 1993

Effects of row spacing and seeding rate on agronomic characteristics of Camp soybean at Blacksburg in 1992 are presented in Table 1. Narrow-row plots significantly out-yielded wide-row plots, while seed size, plant height and plant stands were not affected by row spacing. Significant yield increases were obtained with increases in seeding rate from 125,000 to 250,000 and 250,000 to 500,000 seeds ha^{-1}. Seeding rate had no influence on seed size, but plants produced at the two lowest seeding rates were shorter than those from the two highest seeding rates. Plant stands at harvest increased with each increase in seeding rate, and the observed differences were highly significant ($P<0.01$).

As observed in 1992, narrow-row plots significantly out-yielded wide-row plots in 1993 (Table 2). In addition, plants in wide-row plots produced larger seeds and were taller than those in narrow-row plots. Plant stands at maturity were higher in narrow- than in wide-row plots. No significant differences were observed between row spacings for maturity and lodging.

Seeding rate had significant effects on all agronomic traits except for maturity. Yields produced at the lowest seeding rate were significantly less than those at the other three seeding rates, which did not differ significantly from each other. In 1993, there was a trend for larger seed size as seeding rate was increased. Seed size at the lowest seeding rate was significantly smaller than at the two highest seeding rates. Plants at the lowest seeding rate were shorter than those at the two medium seeding rates and these in turn were significantly shorter than the plants at the highest seeding rate. Increases in seeding rate beyond 250,000 seeds ha^{-1} resulted in increased plant lodging.

Test for homogeneity of error variances for the 1992 and 1993 Blacksburg agronomic data using the method proposed by Hartley (1950) revealed that the Camp error variances for yield, seed size, and stands were homogeneous but those for plant height were not. Combined analyses for 1992 and 1993 data were done for yield, seed size, and stands but not for plant height. Yields of 1347 and 3131 kg ha^{-1} were obtained in 1992 and 1993, respectively, showing a tremendous year (seasonal) variation. The seed filling period in 1992 likely was shortened by frost that occurred in September resulting in lower yield and smaller seed size in 1992 than in 1993

(Table 3). Defoliation, particularly during the reproductive phase, has been shown to reduce both light interception and canopy photosynthesis (Board et al., 1990), the severe frost occurring in the 1992 test possibly had similar effects. This in part accounts for the observed differences in yield and seed size between the two years. Seed size values were generally higher when individual seeds were measured than when 100 seed weight was determined, probably because of the difference in methods of measurement (Tables 1, 2, and Table 7). However, the treatment differences observed were similar for both methods.

Overall, narrow-row plots produced higher yields and had smaller seed than wide-row plots. The regression model using row spacing and plant population as independent variables and yield as the dependent variable was significant in both 1992 and 1993 (Table 4). Plant population was a significant factor in the regression in both years, but row spacing was significant only in 1993. In 1992 and 1993, each increase of 1,000 plants ha^{-1} produced a yield increase of 1.5 and 1.2 kg ha^{-1}, respectively. The regression equations for 1992 and 1993 were significantly different from each other using a test of homogeneity of regressions (Sokal and Rohlf, 1995) so a combined analysis was not conducted.

Narrow-row plots had higher stands than wide-row plots in both years although the difference was not significant in 1992 (Tables 1 and 2). This difference in plant stands was unexpected, since seeding rates were the same for both row widths. It is possible that there was natural thinning out of weaker plants in the wide-row spacing but in the narrow rows, plants were spaced further apart in the row and there was less interplant competition allowing a greater proportion to survive to maturity. Averaged over years, stand count and seed yield increased with increases in seeding rate (Table 3). There was a trend toward increased seed size as seeding rate increased but the differences were not significant.

Camp Seed Size Distribution and Seed Size Uniformity

In 1992, plants grown in rows that were 76 cm apart had relatively more seed in seed size class L, and fewer in S and VS classes than plants grown in rows that were 38 cm apart (Table 5), suggesting that larger seeds were produced by plants grown in wide-row versus narrow-row spacings. It was also observed in 1992 that as seeding rate increased, the amount of VL seed decreased suggesting that more larger seeds were produced at lower seeding rates than at high seeding rates. This is supported by seed size data from individual plants in 1992 (appendix Table 5). However, seeding rate had no significant effect on the other seed size classes of Camp in 1992. There was a tendency for more M and S seeds to be produced at highest seeding rates, but it was not great enough to be of practical significance.

In 1993, plots with wide-row spacing had about 10% more of VL and about 10% less of the combined seed size classes M and S than plots with narrow-row spacing (Table 5). Differences were significant for the three seed size classes VL, M and S but not for L and VS.

In 1993, seeding rate had a significant effect on Camp seed size classes VL, M and S but not on L and VS (Tables 5 and 6). Contrary to what was observed in 1992, the percentage of VL increased as seeding rate increased suggesting that more large seeds were produced by plants grown at higher seeding rates. The reason for this apparent contradictory response for the Camp plants in the two years was not quite clear, but it has been reported that plants produce larger seeds as seeding rates are increased when growth conditions are not limiting (Hinson and Hanson 1962; Johnson and Leudders, 1974; Parvez et al., 1989; Ramseur et al., 1984; Wright et al., 1984). Growth conditions were better in 1993 than in 1992, as evidenced by the higher seed yields; thus the 1993 data appear to be in agreement with results obtained in previous reports.

In 1993, Camp seed trapped on the 5.2 mm screen (L class) exhibited an interaction between row spacing and seeding rate. More seeds were retained for the wide-row plots than for the narrow-row plots at the two lowest seeding rates, and the situation was reversed at the two highest seeding rates (Table 6). The differences were significant only at 250,000 and 750,000 seeds ha^{-1}. The percentage of seed in category L increased as seeding rate was increased from 125,000 to 500,000 seeds ha^{-1} and then stabilized for the narrow-row spacing. For the wide-row spacing, however, this category of seed was maximized at the medium seeding rates. This is a major component of Camp seed that is suitable for the manufacture of natto and thus the agronomic practices that would maximize this class would be the most desirable. The absolute highest proportion of class L seed was obtained in the narrow rows with the highest seeding rates. However, when the L and M seed classes, which are the components of useful seed are combined (Table 7), the greatest proportion of useful seed was obtained at the lower seeding rates in

1993. Seeding rate differences were not significant in 1992. The percentage of seed that was less than 4.4 mm in diameter in 1993 was very low and was not influenced by either row spacing or seeding rate.

Camp seed size uniformity as determined from weights of individual seeds was significantly influenced by seeding rate but not by row spacing in 1992 (Table 7). Seed from the two lowest seeding rates were more uniform than seed produced by plants at the two higher seeding rates. In 1993, neither row spacing nor seeding rate significantly influenced seed size uniformity. This is somewhat at odds with the seed size distribution data (Table 5) in which more significant differences were observed in 1993 than in 1992. However, individual seed data are measuring variability over all seed size classes while the seed screening data are measuring only differences among treatments within a given size class. The screening data make it possible to obtain a breakdown of the various seed size categories and, therefore, better determine the influence of the treatments, than is possible when the method of individual seeds is used. Seed size distribution data indicated that row spacing significantly affected the percent seed in three of the five seed classes in 1992 and 1993 (Table 5).

Variation in VL in both years, and M and S in 1993 resulted due to seeding rate, while significant variation was not observed for L, M, S and VS in 1992 or VS in 1993. The VL class decreased in 1992 but increased in 1993 as seeding rate was increased (Table 5). That kind of information was not readily available from the seed size uniformity data. The screening data obviously has greater application in determining the yield of useful product than can be expected from individual seed size data.

Even though a particular treatment may produce a high percentage of useful seed, if the overall yield is low, the yield of useful seed could also be low. The product of total yield and percent useful seed represents a more reliable estimate of the yield of useful product. Yield of seed suitable for the manufacture of natto was significantly influenced by seeding rate in both years and by row spacing in 1993 (Table 8).

The regression models using row spacing and plant population as independent variables and yield of useful seed as the dependent variable were significantly influenced by seeding rate in 1992 and by row spacing in 1993 (Table 9).

The regressions for the two years were significantly different. An increase in yield of useful seed of 1.1 kg ha^{-1} for each 1000 plants ha^{-1} increase in plant population was obtained in 1992.

In 1993, the plant population part of the regression model was almost significant ($P = 0.07$). Results of the analysis of variance show that the yield of useful seed peaked at 250,000 seeds ha^{-1} in 1993 and decreased at both lower and higher rates in 1993 (Table 8). Plant population on the other hand, increased for each increase in seeding rate as shown in Table 2. Thus, the regression analysis does not show a direct relationship with plant population as shown by non-significant seeding rate effect on the yield of useful seeds (Table 9). The analysis of variance is merely detecting whether or not there are significant differences among treatments. Yield of useful seed for the lowest seeding rate was significantly lower than for the other three seeding rates in 1992.

In 1993, narrow-row spacings had 581 kg ha^{-1} more useful seed than wide-row spacings and the difference was significant (Table 8). Based on two-year row width and seeding rate combination averages, yield of useful seed for Camp grown in narrow rows ranged from 1557 kg ha^{-1} at

125,000 seeds ha^{-1} to 1992 kg ha^{-1} at 500,000 seeds ha^{-1}. In wide-row spacings, the yields ranged from 1300 kg ha^{-1} at 125,000 seeds ha^{-1} to 1793 kg ha^{-1} at 500,000 seeds ha^{-1}. The fact that the highest yields of useful seed were produced at the 500,000 seeds ha^{-1} seeding rate suggests that this might be near the optimal seeding rate for producing seed for natto. Camp seed suitable for the manufacture of natto averaged 962 and 2524 kg ha^{-1} in 1992 and 1993, respectively, showing high seasonal variation in the yield of suitable seed as also was observed for total yield (Tables 3 and 8).

Total yield from narrow-row plots was significantly higher than from wide-row plots in both years (Tables 1 and 2). The percentage of useful seed from narrow-row plots was significantly lower than that from wide-row plots in 1992 and significantly higher than wide-row plots in 1993 (Table 7). Though not significant, 66 kg ha^{-1} more useful seed was obtained from narrow-row spacings than from wide-row spacings in 1992. Additionally, a significantly higher yield of seed suitable for the manufacture of natto was obtained in narrow-row culture over the two years and in 1993 (Table 8). Thus it would appear that the total seed yield is probably the most significant component of yield of useful seeds.

In 1993 when the influence of seeding rate on percent useful seed was significant (Table 7), there was a clear reduction in the proportion of useful seed at each increase in seeding rate. Again, yield of useful seed was heavily influenced by total grain yield, since both total yield and yield of useful seed were significantly reduced at the lowest seeding rate (Tables 2 and 8) even though that treatment had the highest percentage of useful seeds (Table 7).

Of most importance to soybean farmers is the information that the yield of useful seed was significantly lower for the lowest seeding rate than for the two highest seeding rates which did not differ from each other (Table 8). Based on the two year averages, it would appear that the optimal seeding rate for producing the greatest yield of useful seed for natto would be around 500,000 seeds ha^{-1} planted in narrow rows. An upper limit of 500,000 seeds ha^{-1} is also suggested by the lack of a linear relationship for plant stand and yield of useful seed in 1993, apparently due to the lower yield of useful seed at the 750,000 seeds ha^{-1} seeding rate. This is in good agreement with currently recommended seeding rates of 400,000 to 650,000 seeds ha^{-1} for best yields of short cultivars such as Camp, further reinforcing the hypothesis that total seed yield is the major factor determining yield of useful seed.

In summary, seasonal variation played an important role in the overall response to row spacing and seeding rates. Based on average Camp seed size, smaller seed sizes are favored by narrow row-spacing, although the difference was not significant in 1992 (Tables 1, 2 and 3).

Response of V71-370 soybean at Blacksburg in 1992-1993

The influence of row spacing and seeding rate on V71-370 agronomic traits at Blacksburg in 1992 is shown in Table 10. Row spacing significantly affected the number of plants that matured to produce seed, and narrow-row plots had nearly 10% more plants than wide-row plots. Yield, seed size, and plant height were not influenced by this treatment. Seeding rate on the other hand, had a significant effect on V71-370 yield, plant height, and the number of plants that matured to produce seed but not on seed size. Yields at the three highest seeding rates were significantly above the lowest seeding rate, but did not differ from each other. V71-370 plant height and stand counts increased with increases in seeding rate with the exception that plant heights were similar at the two lowest seeding rates.

In 1993, row spacing had a significant effect on V71-370 yield, stand counts and lodging but not on seed size, maturity, or plant height (Table 11). Yield, lodging, and plant stands were higher for narrow-row spacings than for wide-row spacings. Plant height and lodging at the lowest seeding rate were lower than at the other seeding rates. Stand counts increased as seeding rate increased. Yield, seed size, and maturity were not affected by seeding rate.

Plant stands were higher for narrow-row than for wide-row spacings in both years (Tables 10 and 11). This suggests that at the same seeding rate, fewer plants survived to maturity to produce seed at the wide-row spacings than at the narrow-row spacings. This could have resulted from natural thinning due to higher inter-plant competition in the wide rows where the number of plants per meter of row was twice as many as those for narrow rows. Similar response was found in Camp plots.

A test for homogeneity of error variances for 1992 and 1993 agronomic data showed that V71-370 yield, seed size, and plant height were homogeneous but plant stands were not. The combined two year V71-370 data show that the overall average yields were 2086 and 3003 kg ha^{-1} in 1992 and 1993, respectively, and the differences were highly significant (Table 12). Further, yield of narrow-row plots was higher than the yield of wide-row spacings. In addition, yield for the lowest seeding rate was significantly lower than for the other three seeding rates which did not differ significantly from each other (Table 12). The regression models using row spacing and plant population as independent variables and total yield as the dependent variable were significant in 1992 and 1993 (Table 13). The plant population part of the model was significant in 1992 but not in 1993. The regression coefficient between yield and the number of plants ha^{-1} was generally small but positive in both years showing that yield would be expected to increase as plant population was increased. Yield increase for an increase of one thousand plants ha^{-1} was 0.68 kg ha^{-1} in 1992. The row spacing part of the model was significant in 1993 but not in 1992. The regressions for the two years were significantly different from each other, and a combined regression was not undertaken.

Neither row spacing nor seeding rate had a significant effect on seed size over years (Table 12). Row spacing did not have a significant effect on V71-370 plant height in either year. Plant height increased as seeding rate was increased and plants at the lowest seeding rate were 17 cm shorter than plants at the highest seeding rate.

V71-370 Seed Size Uniformity and Seed Distribution

The proportion of each of the seed size classes of V71-370 in 1992 and 1993 is shown in Table 14. An overview of the distribution shows that seeds produced in 1993 were larger than in 1992. Row spacing had a significant effect on the distribution of the 1992 seed size classes designated as VL, L, M, and VS. In general, wide-row spacings had a higher proportion of the three large classes and less of the smaller category than narrow-row spacings (Table 14). Seeding rate had no effect on the proportion of the seed classes in that year. In 1993, neither row spacing nor seeding rate had a significant effect on the distribution of the various seed classes of V71-370. The proportion of the seed that was larger than 7.9 mm in diameter (useful seed) encompasses seed size classes VL, L and M and is shown in Table 15. Most of the seed produced in 1992 (nearly 76%) was less than 7.9 mm and, therefore, unsuitable for tofu (Table 15). This contrasts sharply with the seed produced in 1993 where more than 89% was larger than 7.9 mm.

V71-370 seeds from wide-row spacings were significantly more uniform than those from narrow-row spacings in 1992, but there was no difference in 1993 (Table 15). Seeding rate did not have a significant influence on seed uniformity in either year although there were trends of reduced uniformity (higher standard deviation units) as seeding rates were reduced.

Manufacture of soy products such as tofu and miso requires uniformly large seeds (Smith, 1989). In the current study, yield of V71-370 seed suitable for the manufacture of soy products was determined as the product of yield in kg ha^{-1}, and the percentage of seed that was larger than 7.9 mm in diameter. Most of the seed produced in 1992 was small and shrivelled and, therefore, unsuited for the manufacture of tofu. The average yield of useful V71-370 was very low in that year (Table 16). Though the effect of increasing row spacing had a negative effect on V71-370 total yield in 1992

(Table 10), wide-row plots had a higher percentage of useful seed than narrow-row plots (Table 15) resulting in significantly higher yield of useful V71-370 at the wide-row spacings than at the narrow-row spacings.

Most of the seed produced in 1993 was uniformly large and, averaged over seeding rates, plants in narrow-row spacings produced 237 kg ha^{-1} more useful seed than those in wide-row spacings (Table 16). Yield of useful seed was dependent upon total yield and percent of the seed that was larger than 7.9 mm in diameter. Averaged over row spacings and seeding rates, the yield of useful seed was 502 and 2687 kg ha^{-1} in 1992 and 1993, respectively, showing enormous seasonal differences in the yield of useful V71-370 seed.

The regression models using row spacing and plant population as independent variables and yield of useful seed as dependent variable were not significant in both years. The regression coefficient between yield of useful seed and row spacing was positive in 1992 but negative in 1993 (Table 17). In 1992 when conditions were unsuitable for production of large V71-370 seed, wide-row plots had more large seeds than narrow-row plots but this was reversed in 1993. Plant population part of the models was not significant in either year.

For the narrow-row spacings in 1992, total yield and yield of useful seed were maximized at 500,000 seeds ha^{-1}, although the proportion of useful seed was highest at the highest seeding rate (data not shown). In the wide-row spacings, total yield and yield of useful seed were maximized at 500,000 and 750,000 seeds ha^{-1}, respectively, whereas the percentage of useful seed was highest at 750,000 seeds ha^{-1}. In 1993 when the prevailing conditions in the field were more ideal for higher production, both the total yield and yield of useful seed were maximized at 250,000 seeds ha^{-1} (Tables 11 and 16). This was the same seeding rate where the highest proportion of useful seed was obtained for the narrow-row spacings in 1993 (data not shown). For the wide-row spacings in 1993, total yield and yield of useful seed were maximized at 500,000 seeds ha^{-1}. The two year average of yield of useful seed ranged from 1520 kg ha^{-1} at the lowest seeding rate to 1774 kg ha^{-1} at 250 thousand seeds ha^{-1} for the narrow rows and 1531 kg ha^{-1} for the lowest seeding rate to 1687 kg ha^{-1} at 500 thousand seeds ha^{-1} for the wide rows (data not shown). It was apparent that both yield and the proportion of useful seed were important factors in determining the yield of V71-370 useful seed.

In summary, narrow-row spacings out-yielded wide-row spacings by 9.3% (225 kg ha^{-1}). The difference in yield could mainly be attributed to lower interplant competition in narrow rows and consequently more plants surviving to maturity than in wide-row spacings (Tables 10 and 11). The two year data showed that row spacing did not have a significant effect on seed size and V71-370 plant height. Additionally, V71-370 yield was maximized at 500 thousand seeds ha^{-1} with a yield of 2696 kg ha^{-1}. The lowest seeding rate yielded significantly lower than the other three seeding rates which did not differ from each other. As was the case with row spacing, seeding rate had no influence on V71-370 seed size. Thus, the primary determinant of yield of useful seed was the total seed yield and percentage of useful seed. Plant height and stand counts increased as seeding rate was increased in both years.

Response of Camp and V71-370 in Double Crop Planting

The responses of Camp and V71-370 to seeding rate at uniform row spacing are shown in Tables 18 and 19. Cultivar differences in yield, seed size, maturity, plant height, and lodging were significant. V71-370 yielded more, was taller, lodged more, had larger seed size, and matured about four days earlier than Camp.

Seeding rate effects were significant for yield, plant height and lodging but not for seed size or maturity. Yield increased with increasing seeding rate up to 500,000 seeds ha^{-1} and then leveled off (Table 18). Similar response was observed for the full season crop at Blacksburg (Table 20). Plant height and lodging also increased as the seeding rates were increased. The cultivar x seeding rate interaction for lodging was significant. The interaction was due to the lodging scores of V71-370 increasing with seeding rate while Camp scores differed little among seeding rates (Table 19). Yield trends observed for the full season soybean crop at Blacksburg and the double crop at Warsaw were similar for the two cultivars (Tables 18 and 20). Camp yield was significantly lower than the yield of V71-370 for both the full season and for the double crop. On average yields for both cultivars were lower for the full season crop than for the double crop in 1992. Additionally, Camp was shorter than V71-370, lodged less, and matured later than V71-370 for the full season and the double crop (Tables 18, 19, and 22).

Comparison of Camp and V71-370 Agronomic Traits in 1992 and 1993

The means of yield and seed size for Camp and V71-370 are shown in Table 20. V71-370 yield was significantly higher than the yield of Camp in 1992 but varietal differences were not significant in 1993. When averaged over years, V71-370 yielded more than Camp. The overall cultivar yield differences could mainly be attributed to higher yields of V71-370 versus those of Camp at the two lower seeding rates, particularly in 1992. V71-370 also out-yielded Camp in both narrow- and wide-row spacings and at all four seeding rates. The yield advantage of V71-370 over that of Camp was 11.6% and 16.3% for narrow and wide-row spacings, respectively (Tables 3 and 12). Furthermore, V71-370 out-yielded Camp by 37.0, 19.6, 8.4, and 0.9 percent at 125, 250, 500, and 750 thousand seeds ha^{-1}, respectively, showing progressive decrease in V71-370 yield advantage over that of Camp as seeding rates were increased. This could have resulted from a number of factors such as the number of harvested Camp and V71-370 plants and the corresponding seed yields per plant at the various seeding rates. Camp and V71-370 had similar stand counts at the lower seeding rates but there were comparatively more Camp plants than V71-370 at the two highest seeding rates (Tables 1, and 10). Yield per plant differences between Camp and V71-370 on the other hand were high and significant at the low seeding rates, but decreased as the seeding rate increased and differences were not significant at the two highest seeding rates (Appendix Table 22). Comparative Camp and V71-370 two-year yield data show that V71-370 yield over that of Camp decreased from 552 kg ha^{-1} at the lowest seeding rate to 35 kg ha^{-1} at the highest seeding rate (Tables 3 and 12).

Though both cultivars showed tremendous compensatory ability over a range of seeding rates, V71-370 utilized the available resources more effectively than Camp as inter-plant competition was reduced at the lower seeding rates. This is probably because Camp is a short cultivar and thus cannot compensate for thin stands as well as larger and taller cultivars like V71-370. In 1993, yield of the two cultivars did not differ significantly (Table 20). However, cultivar x seeding rate interaction for yield was significant in 1993, largely because V71-370 yield differences among seeding rates were not significant, whereas, Camp yielded significantly less at the lowest seeding rate than at the three higher seeding rates (Tables 2 and 11).

Soybean yield increased as seeding rate increased from the lowest to the medium seeding rates and then stabilized in both years (Table 20). However, seasonal (year) variation in yield was observed and the differences were significant. The cultivar yield differences in 1992 appear to have played an important role in the overall varietal yield differences (Table 20). Cultivars were not significantly different in 1993 but when yield was averaged over years, V71-370 significantly out-yielded Camp. Averaged over treatments the yield of Camp at Blacksburg was 2382 and 2091 kg ha^{-1} for narrow and wide-row spacings, respectively compared with 2657 and 2432 kg ha^{-1} for V71-370 at the same row spacings, respectively (Tables 3 and 12).

Yield response to changes in row spacing was similar for the two soybean cultivars as evidenced by lack of a significant cultivar x row spacing interaction in 1992 and 1993. Narrow-row plots yielded higher than wide-row plots; although, the differences for V71-370 were not significant ($P = 0.05$) in 1992 (Table 10). Averaged over years, narrow-row spacings produced 261 kg ha^{-1} (11.5%) more than wide-row spacings (Table 20). The higher seed yields obtained from narrow-row spacings in this study could be attributed to the higher plant counts for the narrow versus wide-row spacings

(Table 22). The effect of row spacing on the yield of Camp and V71-370 confirmed the results of Beaver and Johnson (1981), Cooper (1970), Johnson and Harris (1967), Parks et al., (1982), Parvez et al., (1989), Probst (1945), and Wright et al., (1984) who found that soybeans in narrow rows yielded more than those grown in wide-row spacings.

Means of yield components for Camp and V71-370 are shown in appendix Tables 21 to 24 and except for individual seed size, there was an inverse relationship between seeding rates and yield components. At low seeding rates plants were shorter, produced more branches, and had higher seed yields than the plants in medium and high seeding rates. This in part explains why yield differences among seeding rates were not significant in some cases. Where differences between yields at the lowest seeding rate and yields of the other seeding rates were significant, the increased magnitude in yield components could not compensate for the low number of plants at the lowest seeding rate.

For the Camp and V71-370 combined yield analyses, each increase in seeding rate resulted in yield increases at the three lowest seeding rates and then the yield leveled off (Table 20). Besides the yield components discussed above, it is possible that yield at the higher seeding rates might have been reduced because of un-harvested crop due to increased lodging of the plants which was higher for V71-370 than for Camp (Table 22).

Components of regression analysis using row spacing and plant population as independent variables and combined yield of Camp and V71-370 as dependent variable are shown in Table 21. The average Camp and V71-370 yields increased by 1.1 and 0.8 kg ha^{-1} for every one thousand plants ha^{-1} increase in plant population in 1992 and 1993, respectively (Table 21). These yield increases were lower than the 1.5 and 1.2 kg ha^{-1} for Camp but higher than the 0.7 and 0.3 kg ha^{-1} for V71-370 in 1992 and 1993, respectively (Tables 4 and 13). As would be expected, cultivar differences in seed size were significant in both years and averaged over years, the weight of 100 seeds was 6.1 and 24.5 g for Camp and V71-370, respectively (Table 20). Results of the combined seed size data also showed that neither row spacing nor seeding rate had significant effect on soybean seed size (Table 20). Individual cultivar seed size response to variation in row spacing and seeding rate was significant for Camp in 1993, but not for either cultivar in 1992 or for V71-370 in 1993 (Tables 1, 2 , 10, and 11).

Cultivar differences in stand counts were not significant in either year (Table 22). Camp plants were shorter than V71-370 in both years. Not surprising, the latter had a higher plant lodging than the former. Cultivar differences in maturity date were also significant, and V71-370 matured three days earlier than Camp. It is possible that Camp was affected more adversely by the frost that occurred in 1992 than the slightly earlier maturing V71-370.

Row spacing and seeding rate had significant effects on stand counts. Narrow-row spacings had higher stand counts than wide-row spacings in both years. Row spacing did not have significant effect on plant height, plant lodging or maturity (Table 22). Other studies have shown that plant height is not affected by row spacing (Doss and Thurlow, 1974; Lehman and Lambert, 1960).

It was also observed that each increase in seeding rate resulted in increased stands and that observation was within the realm of expectation. In 1992, an increase in seeding rate after 250,000 seeds ha^{-1} seeding rate resulted in increases in plant height. In 1993, plants at the lowest seeding rate were significantly shorter than plants at the medium seeding rates, and these in turn were shorter than the plants at the highest seeding rate.

Tall plants have been shown to lodge more than short plants (Cooper, 1971a; Hicks et al., 1969; Lehman and Lambert, 1960; Probst, 1945). As would be expected, plant lodging for the two cultivars generally increased with increases in seeding rate (Tables 2, 11 and 22). Cultivar x spacing and cultivar x seeding rate interactions were significant for this trait. Lodging was significantly higher for V71-370 plants in narrow-row spacings than those in wide-row spacings but no effect of row spacing on lodging in Camp was observed (Tables 2 and 11). Higher lodging scores for Camp were found in wide-row spacings at high seeding rates (Table 2) while V71-370 plants in narrow row spacings lodged more than those in wide-row spacings (Table 11).

As was recognized by Cooper (1971a), lodging in a crop is a major factor that may contribute to the yield advantage or lack of it for narrow-row spacings over wide row spacings. If lodging occurred early for instance, Cooper (1971b) found that the overall yield advantage for narrow rows over wide rows was reduced or absent. The higher lodging score for V71-370 particularly at the two highest seeding rates might account for the lack of significant yield differences among seeding rates for that cultivar in 1993.

In summary, row spacing had a significant effect on yield and stand counts of the combined Camp and V71-370 agronomic characteristics. Plots with narrow-row spacings had higher yields than those with wide-row spacings. The differences could be attributed to higher stand counts for the narrow row versus wide-row spacings which together with yield plant^{-1} cumulatively contributed to the yield differences. Row spacing did not have significant effect on seed size, plant height, maturity or lodging.

Seeding rate significantly influenced yield, stand count, plant height and lodging, but had no effect on seed size and maturity (Tables 19 and 22). Soybean yield increments were obtained by increasing seeding rate from 125,000 to 250,000 and from 250,000 to 500,000 and then stabilized (Table 20). Plants were generally taller at the higher seeding rates than at the lower seeding rates. Stand counts and lodging increased as the seeding rate was increased.

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Table 1. Means for agronomic traits of Camp soybean grown at two row spacings and four seeding rates at Blacksburg, VA in 1992.

		Agronomic traits			
Treatment		Yield	Seed size	Plant height	Plant stand
		kg ha^{-1}	g 100^{-1}	cm	x1000 ha^{-1}
Row spacing	cm				
	38	1459a†	5.4a	56a	370a
	76	1235b	5.6a	52a	357a
Seeding rate	x 1000 ha^{-1}				
	125	848c	5.6a	47b	107d
	250	1160b	5.6a	48b	203c
	500	1630a	5.5a	59a	451b
	750	1748a	5.5a	61a	695a

† Means followed by the same letter in a treatment are not significantly different at 0.05 probability level.

Table 2. Means for agronomic traits of Camp soybean grown at two row spacings and four seeding rates at Blacksburg, VA in 1993.

Treatment		Yield	Seed size	Plant height	Plant stand	Maturity	Lodging
		kg ha^{-1}	g 100^{-1}	cm	x1000 ha^{-1}	days†	score‡
Row spacing	cm						
	38	3315a§	6.5b	72b	343a	44.7a	2.1a
	76	2946b	6.9a	75a	311b	44.5a	2.3a
Seeding rate	x 1000 ha^{-1}						
	125	2683b	6.3b	64c	117d	44.3a	1.5c
	250	3204a	6.6ab	74b	224c	44.5a	1.8c
	500	3347a	6.9a	76b	404b	44.8a	2.3b
	750	3289a	7.0a	81a	562a	44.7a	3.3a

† Days after August 31

‡ 1 = all erect, 5 = all prostrate

§ Means followed by the same letter in a treatment are not significantly different at 0.05 probability level.

Table 3. Means for agronomic characteristics of Camp soybean grown at two row spacings and four seeding rates at Blacksburg, VA in 1992 and 1993.

Treatment		Agronomic traits		
		Yield	Seed size	Plant stand
		kg ha^{-1}	g 100^{-1}	x 1000 ha^{-1}
Year	1992	1347b†	++	++
	1993	3131a	++	++
Row spacing	cm			
	38	2387a	6.0b	357a
	76	2091b	6.3a	334b
Seeding rate	x 1000 ha^{-1}			
	125	1766c	++	++
	250	2182b	++	++
	500	2488a	++	++
	750	2519a	++	++

† Means followed by the same letter in a treatment are not significantly different at 0.05 probability level.

++ Significant interaction - data presented separately.

Table 3a. Means of seed size and stand counts for Camp soybean grown at two row spacings and four seeding rates at Blacksburg, VA in 1992 and 1993.

	Seeding rate (x1000 ha^{-1})				
Year	125	250	500	750	Avg.
	Seed size g 100^{-1}				
1992	5.6c†	5.6c	5.5c	5.5c	5.5q
1993	6.3b	6.6ab	6.9a	7.0a	6.7p
Avg	6.0x	6.1x	6.2x	6.3x	
	Stand count (x1000 ha^{-1})				
1992	107e	203d	451c	695a	364p
1993	117e	224d	404c	562b	327q
Avg	112z	213y	427x	629w	

† Means followed by different letter in a treatment are significantly different at 0.05 probability level.

Table 4. Components of regression analysis of yield for Camp soybean grown at two row spacings and four seeding rates at Blacksburg, VA in 1992 and 1993.

Treatment	P	Intercept	Beta	r^2
Total yield				
1992				
Overall model	***	1100		0.70
Independent variable				
Row spacing	ns		-5.4	
Plant population	***		1.5	
1993				
Overall model	**	3276		0.42
Independent variable				
Row spacing	*		-9.0	
Plant population	**		1.2	

*, **, *** Significant regressions at the 0.05, 0.01, and 0.001 probability levels, respectively.

ns = not significant.

Table 5. Seed distribution by several seed size classes of Camp soybean grown at two row spacings and four seeding rates at Blacksburg, VA in 1992 and 1993.

		Seed size classes (mm diameter)				
		<4.4	4.4-4.8	4.8-5.2	5.2-5.6	>5.6
Treatment		VS	S	M	L	VL
		-------Percentage in a seed class----------				
1992						
Row spacing	cm					
	38	6.4a†	23.0a	48.9a	19.3b	2.7a
	76	4.5b	17.5b	50.0a	25.2a	3.0a
Seeding rate	x1000 ha^{-1}					
	125	5.1a	16.7a	46.4a	27.1a	5.1a
	250	6.1a	20.1a	47.5a	23.3a	3.3a
	500	5.5a	22.1a	52.2a	19.0a	1.5b
	750	5.3a	22.2a	51.7a	19.6a	1.5b
1993						
Row spacing	cm					
	38	0.4a	2.4a	29.8a	‡	12.7b
	76	0.3a	1.4b	20.7b	‡	22.4a
Seeding rate	x1000 ha^{-1}					
	125	0.4a	2.9a	33.5a	‡	10.5c
	250	0.3a	2.1b	28.4a	‡	14.4bc
	500	0.2a	1.5c	21.6b	‡	19.5b
	750	0.3a	1.2c	18.9b	‡	24.5a

† Means followed by same letter in a treatment are not different at the 0.05 probability level.

‡ Significant interaction - data presented separately.

Table 6. Percentages of seed size class 5.2 to 5.6 mm for Camp soybean grown at two row spacings and four seeding rates at Blacksburg, VA in 1993.

		Seeding rate (x1000 ha^{-1})			
		125	250	500	750
		percentages			
Row spacing	cm				
	38	51.2b†	52.3b	58.6a	58.1a
	76	55.0ab	57.9a	56.3ab	52.9b

† Means followed by the same letter are not different at the 0.05 probability level.

Table 7. Mean standard deviations of twenty individual seed weights, percentage of seed with diameter between 4.8 and 5.6 mm, and mean individual seed size for Camp soybean grown at two row spacings and four seeding rates at Blacksburg, VA in 1992, and 1993.

Treatment		Year					
		1992	1993	1992	1993	1992	1993
		standard deviation		% seed 4.8 to 5.6		Seed size (mg seed^{-1})	
Row spacing	cm						
	38	16.9a†	21.0a	68.2b	84.9a	64a	67b
	76	17.6a	20.5a	75.2a	76.3b	61a	72a
Seeding rate	x 1000 ha^{-1}						
	125	15.9b	20.8a	73.4a	86.6a	65a	67b
	250	16.4b	20.7a	70.8a	83.5b	62a	67b
	500	18.4a	21.1a	71.3a	79.1c	62a	71a
	750	18.3a	20.4a	71.3a	74.4d	61a	73a

† Means followed by different letter in a treatment are significantly different at 0.05 probability level.

Table 8. Means of yield of useful seed for Camp soybean grown at two row spacings and four seeding rates at Blacksburg, VA in 1992 and 1993.

Treatment		Year	
		1992	1993
		--------- kg ha^{-1}	-------
Row spacing	cm		
	38	995a†	2814a
	76	929a	2233b
Seeding rate	x 1000 ha^{-1}		
	125	623c	2323b
	250	821b	2675a
	500	1162a	2647a
	750	1246a	2449ab

† Means followed by different letter in a treatment are significantly different at 0.05 probability level.

Table 9. Components of regression for yield of useful seed of Camp soybean grown at two row spacings and four seeding rates at Blacksburg, VA in 1992 and 1993.

Treatment	P	Intercept	Beta	r^2
1992				
Overall model	***	643		0.56
Independent variable				
Row spacing	ns		-1.00	
Plant population	***		1.10	
1993				
Overall model	**	3409		0.51
Independent variable				
Row spacing	***		-15.30	
Plant population	ns		0.05	

, * Significant differences at the 0.01, and 0.001 probability levels, respectively.

ns = not significant.

Table 10. Means for agronomic traits of V71-370 soybean grown at two row spacings and four seeding rates at Blacksburg, VA in 1992.

Treatment		Agronomic traits			
		Yield	Seed size	Plant height	Plant stand
		kg ha^{-1}	g 100^{-1}	cm	x1000 ha^{-1}
Row spacing	cm				
	38	2181a†	21.9a	62a	367a
	76	1990a	22.2a	64a	333b
Seeding rate	x1000 ha^{-1}				
	125	1733b	21.9a	54c	101d
	250	2132a	22.1a	55c	221c
	500	2326a	22.1a	66b	432b
	750	2151a	22.1a	75a	647a

† Means followed by the same letter in a treatment are not significantly different at 0.05 probability level.

Table 11. Means for agronomic traits of V71-370 soybean grown at two row spacings and four seeding rates at Blacksburg, VA in 1993.

Treatment		Agronomic traits					
		Yield	Seed size	Plant height	Plant stand	Maturity	Lodging
		kg ha^{-1}	g 100^{-1}	cm	x1000 ha^{-1}	days†	score‡
Row spacing	cm						
	38	3132a§	26.8a	96a	331a	42.1a	3.4a
	76	2874b	26.9a	97a	268b	42.0a	3.0b
Seeding rate	x 1000 ha^{-1}						
	125	2903a	26.8a	88b	124d	42.0a	2.5b
	250	3086a	26.8a	98a	202c	42.0a	3.3a
	500	3066a	26.9a	100a	361b	42.0a	3.5a
	750	2957a	26.8a	101a	513a	42.1a	3.6a

† Days after August 31

‡ 1 = erect, 5 = prostrate

§ Means followed by the same letter in a treatment are not significantly different at $p = 0.05$.

Table 12. Means for agronomic traits of V71-370 soybean grown at two row spacings and four seeding rates at Blacksburg, VA in 1992 and 1993.

Treatment		Agronomic traits Yield	 Seed size	 Plant height
		kg ha^{-1}	g 100^{-1}	cm
Year	1992	2086b[†]	22.0b	63b
	1993	3003a	26.8a	97a
Row spacing	cm			
	38	2657a	24.4a	79a
	76	2432b	24.5a	81a
Seeding rate	x 1000 ha^{-1}			
	125	2318b	24.4a	71d
	250	2609a	24.5a	77c
	500	2696a	24.5a	83b
	750	2554a	24.5a	88a

[†] Means followed by different letter in a treatment are significantly different at 0.05 probability level.

Table 13. Components of regression of yield for V71-370 soybean grown at two row spacings and four seeding rates at Blacksburg, VA in 1992 and 1993.

Treatment	P	Intercept	Beta	r^2
1992				
Overall model	*	2098		0.23
Independent variable				
Row spacing	ns		-4.4	
Plant population	*		0.7	
1993				
Overall model	*	3290		0.26
Independent variable				
Row spacing	*		-6.4	
Plant population	ns		0.3	

*, **, *** Significant differences at the 0.05, 0.01, and 0.001 probability levels, respectively.
ns = not significant.

Table 14. Seed distribution by several seed size classes of V71-370 soybean grown at two row spacings and four seeding rates at Blacksburg, VA in 1992 and 1993.

Treatment		Seed size classes (mm)				
		<7.5 VS	7.5-7.9 S	7.9-8.3 M	8.3-8.7 L	>8.7 VL
		----------------		percentages		----------------
1992						
Row spacing	cm					
	38	44.9a†	35.6a	15.9b	3.4b	0.4b
	76	34.7b	36.9a	22.0a	6.0a	0.8a
Seeding rate	x 1000 ha^{-1}					
	125	41.7a	35.6a	18.3a	4.3a	0.4a
	250	39.6a	37.0a	18.7a	4.6a	0.4a
	500	38.7a	37.1a	19.1a	4.8a	0.6a
	750	40.0a	35.4a	18.8a	5.4a	0.9a
1993						
Row spacing	cm					
	38	2.4a	8.4a	22.7a	37.5a	29.4a
	76	2.3a	8.5a	22.9a	37.5a	29.0a
Seeding rate	x 1000 ha^{-1}					
	125	2.1a	9.0a	24.5a	37.9a	26.8a
	250	2.3a	7.5a	22.5a	36.8a	31.2a
	500	2.6a	8.6a	22.3a	37.4a	29.0a
	750	2.6a	8.6a	22.1a	37.9a	29.3a

† Means followed by same letter in a treatment are not different at 0.05 probability level.

Table 15. Standard deviations of individual seed weights, percentage of seed with diameter greater than 7.9 mm, and mean individual seed size for V71-370 soybeans grown at two row spacings and four seeding rates at Blacksburg, VA in 1992 and 1993.

Treatment		Year					
		1992	1993	1992	1993	1992	1993
		Standard deviation		% of seed >7.9 mm		Seed size (mg seed^{-1})	
Row spacing	cm						
	38	17.8a†	13.4a	19.7b	89.5a	235a	272a
	76	15.1b	13.2a	28.8a	89.4a	229a	270a
Seeding rate	x 1000 ha^{-1}						
	125	17.3a	13.4a	23.0a	89.2a	233a	279a
	250	16.4a	13.7a	23.7a	90.5a	240a	267a
	500	16.4a	13.0a	24.5a	89.1a	230a	270a
	750	15.8a	13.2a	25.1a	89.3a	225a	267a

† Means followed by different letter in a treatment are significantly different at 0.05 probability level.

Table 15. Standard deviations of individual seed weights, percentage of seed with diameter greater than 7.9 mm, and mean individual seed size for V71-370 soybeans grown at two row spacings and four seeding rates at Blacksburg, VA in 1992 and 1993.

Treatment		Year					
		1992	1993	1992	1993	1992	1993
		Standard deviation		% of seed >7.9 mm		Seed size (mg seed^{-1})	
Row spacing	cm						
	38	17.8a†	13.4a	19.7b	89.5a	235a	272a
	76	15.1b	13.2a	28.8a	89.4a	229a	270a
Seeding rate	x 1000 ha^{-1}						
	125	17.3a	13.4a	23.0a	89.2a	233a	279a
	250	16.4a	13.7a	23.7a	90.5a	240a	267a
	500	16.4a	13.0a	24.5a	89.1a	230a	270a
	750	15.8a	13.2a	25.1a	89.3a	225a	267a

† Means followed by different letter in a treatment are significantly different at 0.05 probability level.

Table 16. Means of yield of useful seed for V71-370 soybean grown at two row spacings and four seeding rates at Blacksburg, VA in 1992 and 1993.

Treatment		Year 1992	Year 1993
		---------- kg ha^{-1}	----------
Row spacing	cm		
	38	430b†	2802a
	76	573a	2569b
Seeding rate x1000 ha^{-1}			
	125	399a	2589a
	250	505a	2793a
	500	570a	2732a
	750	532a	2642a

† Means followed by different letter in a treatment are significantly different at 0.05 probability level.

Table 17. Components of regression for yield of useful seed of V71-370 soybean grown at two row spacings and four seeding rates at Blacksburg, VA in 1992 and 1993.

Treatment	P	Intercept	Beta	r^2
		kg ha^{-1}		
1992				
Overall model	ns	200		0.20
Independent variable				
Row spacing	*		4.5	
Plant population	ns		0.2	
1993				
Overall model	ns	3023		0.18
Independent variable				
Row spacing	ns		-6.1	
Plant population	ns		0.1	

* Significant differences at the 0.05 probability levels.

ns = not significant.

Table 19. Means of lodging score for Camp and V71-370 soybeans grown at one row spacing and four seeding rates at Warsaw, VA in 1992.

	Seeding rate (x1000 ha^{-1})			
Cultivar	125	250	500	750
	--------------	Lodging score†	--------------	
Camp	1.0c‡	1.0c	1.2bc	1.2bc
V71-370	1.0c	1.2bc	1.3b	1.7a

† Score 1 = all erect, and 5 = all prostrate

‡ Means followed by the same letter are not significantly different at $P = 0.05$

Table 20. Means of yield and seed size for Camp and V71-370 soybeans grown at two row spacings and four seeding rates at Blacksburg, VA in 1992 and 1993.

		Yield		Seed size		
		1992	1993	1992	1993	Avg.
		--- kg ha^{-1} ---		--------- g 100^{-1} ---------		
Cultivar	Camp	1347b†	++	5.5b	6.7b	6.1b
	V71-370	2086a	++	22.1a	26.8a	24.5a
Spacing	cm					
	38	1820a	3224a	13.7a	16.7a	15.2a
	76	1613b	2910b	13.9a	16.7a	15.4a
Seeding rate	x1000 ha^{-1}					
	125	1291c	++	13.8a	16.6a	15.2a
	250	1646b	++	13.9a	16.7a	15.3a
	500	1978a	++	13.8a	16.9a	15.4a
	750	1950a	++	13.8a	16.9a	15.4a

† Means followed by the same letter in a treatment are not significantly different at 0.05 probability level.

++ Significant interaction, data presented elsewhere.

Table 20 cont. Means of yield and seed size for Camp and V71-370 soybeans grown at two row spacings and four seeding rates at Blacksburg, VA in 1992 and 1993 .

	Seeding rate (x1000 ha^{-1})				
Cultivar	125	250	500	750	Avg.
	kg ha^{-1}				
Camp	2683c†	3204a	3347a	3312a	3137p
V71-370	2903ab	3086a	3067a	2956ab	3003p
Avg	2793y	3145x	3207x	3134x	

† Means followed by the same letter are not significantly different at P = 0.05

Table 21. Components of regression for yield of Camp and V71-370 soybeans grown at two row spacings and four seeding rates at Blacksburg, VA in 1992 and 1993.

Treatment	P	Intercept	Beta	r^2
		kg ha^{-1}		
1992				
Overall model	***	1602		0.23
Independent variable				
Row spacing	ns		-4.8	
Plant population	**		1.1	
1993				
Overall model	***	3251		0.32
Independent variable				
Row spacing	**		-7.4	
Plant population	**		0.8	

*, **, *** Significant differences at the 0.05, 0.01, and 0.001 probability levels, respectively.

ns = not significant.

Table 22. Means of agronomic traits for Camp and V71-370 soybeans grown at two row spacings and four seeding rates at Blacksburg, VA in 1992 and 1993.

		Year					
		1992	1993	1992	1993	1993	1993
		Plant height		Stand count		Maturity	Lodging
		----- cm -----		-- x1000 ha^{-1} --		days†	score‡
Cultivar	Camp	54b§	82b	364a	327a	45a	++
	V71-370	63a	97a	350a	300a	42b	++
Row spacing	cm						
	38	59a	84a	369a	337a	43a	2.8a
	76	58a	86a	345b	290b	43a	2.7a
Seeding rate	x1000 ha^{-1}						
	125	51c	76c	104d	121d	43a	++
	250	52c	86b	212c	216c	43a	++
	500	63b	88b	442b	383b	43a	++
	750	68a	91a	671a	537a	43a	++

† Days after August 31

‡ Scale 1 = erect, 5 = prostrate.

§ Means followed by the same letter in a treatment are not significantly different at 0.05 probability level.

++ Significant interaction - data presented elsewhere.

Table 22 cont. Means of agronomic traits for Camp and V71-370 soybeans grown at two row spacings and four seeding rates at Blacksburg, VA in 1992 and 1993.

	Row spacing (cm)		Seeding rate (x1000 ha^{-1})				
Cultivar	38	76	125	250	500	750	Avg.
			lodging score†				
Camp	2.1u‡	2.3u	1.5c	1.8c	2.3b	3.3a	2.2q
V71-370	3.4s	3.0t	2.5b	3.3a	3.5a	3.6a	3.0p
Avg.	2.8r	2.7r	2.0z	2.6y	2.9x	3.4w	

† Score 1 = all erect, and 5 = all prostrate

‡ Means followed by the same letter are not significantly different at P = 0.05

Chapter Three

HERITABILITY ESTIMATES OF SEED SIZE IN SOYBEAN

ABSTRACT

The manufacture of some soybean products such as natto require specific seed sizes. "Camp" soybean [*Glycine max* (L.) Merr.] is suited for that purpose but has limitations such as low sugar content and hard seed during processing. Recently, this cultivar has been crossed with other soybean cultivars to overcome some of these shortcomings. The objective of this investigation was to determine heritability of seed size in these Camp crosses. Plot data for traits of a number of lines derived from crosses involving Camp and three soybean cultivars Jizuka (small-seed), MD87L-0198, and Stafford (both medium-seeded) were used in determining heritability of seed size. Heritability estimates were made using two methods: analysis of variance of the segregating populations and regression of F_3 progeny means on F_2 parents. Estimates of genotypic and phenotypic variance were computed from analysis of variance and residual variances of each population were taken as estimates of environmental variance. Based on analysis of variance, heritability estimates ranged from 43% to 83%. Heritabilities based on regression of F_3 progeny means on F_2

parents ranged from 24% for the small x small seeded crosses to 41% for small x medium seeded crosses and were lower than the corresponding heritability estimates based on analysis of variance.

Correlation of seed size with other agronomic traits also was determined. The correlation was low and negative for flowering date and maturity. The correlation was negative for four populations but positive for five other populations for plant height. There was little to no correlation between seed size and lodging score. The correlation of seed size and yield was positive, particularly in the crosses between the smallest and the largest seeded parents, suggesting that it might be difficult to select for high yield and small seed size simultaneously. Based on heritability values, and the range of seed sizes obtained, and that seeds smaller than 5.6 mm are preferred for the manufacture of natto, successful selection of small seed was more feasible for the Camp x Jizuka cross than for small x medium seed crosses.

Introduction

Genetic improvement of soybean for food uses has increased in recent years. The manufacture of soybean products requires a wide range of seed sizes. Some manufacturers are not specific in their requirements but others are quite specific and are even prepared to pay a premium for specific seed sizes. One such product is natto for which seeds that are less than 5.6 mm in diameter are preferred. Camp is a small-seeded cultivar which is used in the manufacture of natto. This cultivar has desirable seed size but is deficient in certain desirable quality characteristics such as high sugar content and soft seed after processing. Crosses between Camp and other cultivars have been made to overcome these shortcomings. Knowledge of the heritability and genetic correlation of seed size and its interrelated characteristics would aid selection among progenies from these crosses.

Heritability for various plant traits has been of interest over the years. Estimates of heritability for a particular trait differ depending on the method and the genetic composition of the plant material used. Johnson et al. (1955) used F_3 lines and obtained heritability values of

92.1% and 68% for seed size in two soybean crosses. They also found a positive association between seed yield and large seed. In another study, Fehr and Weber (1968) showed that seed size was highly heritable when they obtained broad sense heritability values of 92% and 94% for seed size of two crosses of soybean. Variation among lines and potential for selection within a line has been demonstrated for dry beans (Johanssen, 1903). The purpose of the present study is to estimate the heritability of seed size and to evaluate the association between seed size and other agronomic traits using crosses between Camp and three other cultivars; Jizuka, MD87L-0198, and Stafford.

MATERIALS AND METHODS

Inheritance of seed size was evaluated in crosses of Camp (6.7 g/100 seed) x Jizuka (9.0 g/100 seed), Camp x MD87L-0198 (13.7 g/100 seed), and Stafford (11.8 g/100 seed) x Camp soybean cultivars as shown in Table 23. All source populations shown in the table were grown at the Eastern Virginia Research and Extension Center at Warsaw in 1991. Each F_2 population was derived from a separate F_1 plant. F_2 plants were chosen at random and then threshed individually. No selection for any trait was practiced. Seeds harvested from each plant were counted, weighed, and average seed size was obtained by dividing the total weight by the number of seeds for each of the F_2 populations. Those plants with less than forty seeds were discarded.

F_3 populations 8, 9, and 10 were derived from a single F_2 Camp x Jizuka population. The seeds, harvested in bulk from the F_2 population, were screened into three sizes as shown in Table 23 and planted in 1991. F_3 plants were randomly selected from each sub-population. F_3 populations 3 and 4 were derived from seed harvested from a single F_2 population of Camp x Stafford that was screened with a 5.6 mm screen.

F_4 populations 48 and 49 were derived from three Camp x Jizuka F_1 plants that were grown in the greenhouse in 1989. F_2 progeny were grown in separate plots in 1990 at Warsaw. Single pods were picked from each plant in the plots and all seeds were bulked. Seed was screened through 5.6 and 4.8 mm round hole screens. Seed that passed through the 4.8 mm diameter screen and seed between 4.8 and 5.6 mm were grown as separate F_3 populations in the greenhouse. Seeds were bulk harvested from each population and planted in 1991 as F_4's 48 and 49, respectively. F_4 population 46 was handled similarly except that there was no selection for seed size. At the end of the 1991 growing season, mature plants were randomly picked from the field.

A replicated field trial consisting of fifty entries for each of the F_3 populations, F_4-48, and F_4-49, 79 entries for F_2-21, 74 entries for F_2-22, 61 entries for F_2-102, 58 entries for F_2-104, 43 entries for F_2-105, and 81 entries for F_4-46 was established on 17 June, 1992 at the Eastern Virginia Research and Extension Center at Warsaw. Each plot consisted of 20 to 25 seeds planted in a one meter row with one meter between tiers of plots. Rows were spaced 76 cm apart. Two replications were arranged in a modified randomized block design in which entries were blocked according to cross and generation. Data obtained from each plot included plant height (the average height of four plants from the base to the apex of the stem in centimeters), maturity (the number of days after 31 August when 95% of the pods on the plants were mature), lodging on a scale of 1 (all the plants in the plot were upright) to 5 (all the plants in the plot had lodged), seed yield in grams per plot, and seed size estimated by weighing 100 randomly selected seeds. Rows were harvested without trimming to a uniform length. Estimates of the components of variance on a plot data basis were obtained from the analyses of variance. Heritabilities were estimated by using the analysis of variance method or by regression of F_3 progeny means on F_2 parents.

The statistical models used for the estimation of broad sense heritability are those of Hanson (1963) as modified by Uhr and Murphy (1992). The models are adjusted for fixed effects and give unbiased estimates of the components of variance. Analyses of variance which included replication, genotype (entry), and residual variances were computed using Agrobase software. Variance components were estimated by computing appropriate linear functions of the mean squares.

Heritability also was estimated by regressing F_3 offspring mean seed sizes on the F_2 parental values proposed by Smith and Kinman (1965) and modified by Fehr (1987). Using this method, heritability estimate is given by the following:

$$h^2 = \frac{b}{2r_{xy}}$$

Where

h^2 = heritability

b = regression coefficient of the F_3 mean seed weight on the F_2 parent seed weight

r_{xy} = probability that a random gene from x is identical by descent to a random gene from y

x, y = parent and offspring, respectively

The regression coefficient was estimated from the mean seed size of the progeny and parents by using standard regression procedure (Steel and Torrie, 1980) as shown below.

$$Y_i = a + bx_i + e$$

Where

X_i = measurement of the ith parent

Y_i = measurement of the offspring of the ith parent

a = mean seed size of the parents

b = regression coefficient of y on x

e = random error

RESULTS AND DISCUSSION

Heritability estimates were made by evaluating genotypes of crosses involving Camp and three lines, Jizuka, Stafford, and MD87L-0198 as shown in Table 24. Heritabilities based on analysis of variance and regression methods for F_2 populations were 75% and 24% for F_2-21, 61% and 25% for F_2-22 (a Camp x Jizuka cross), 61% and 39% for F_2-102, 57% and 41% for F_2-104, and 79% and 30% for F_2-105 (Camp x MD87L-0198 cross), respectively (Table 24). Heritabilities based on regression were lower than those based on analysis of variance. Heritability estimates for F_3 and F_4 populations ranged between 66% and 83% except F_4-48 which was 43%. The coefficient of variation for this particular population was relatively high and that probably is primary cause of the low heritability for this population compared with the other populations.

Table 24 also shows ranges, means, and coefficients of variation for seed size of the various populations. Seed size varied substantially and analyses of variance showed that the differences among genotypes in each population were highly significant (Table 25).

The range between the smallest and the largest seed within a population was lowest for the lines derived from the F_3-9 Camp x Jizuka cross and highest for the line derived from F_2-104 Camp x MD87L-0198 cross. In general, and as would be expected, the lowest ranges in seed size occurred in Camp x Jizuka that had been screened for seed size while the widest ranges were in the unselected populations from parents with the widest range in seed size (Camp x MD87L-0198 and Stafford x Camp).

The observed seed size differences among the F_3 lines from Camp x Jizuka cross were significantly different using t-test. Using a similar test, the difference between the seed size of F_4-48 and F_4-49 were also significantly different. The mean seed sizes for F_3-3 and F_3-4 were 8.9 and 8.0 g per 100 seed, respectively, and these were also significantly different. Seed size differences between lines derived from small and large seed size selections were significantly different for both small x small and small x medium seeded crosses showing that selection for seed size was effective. F_2-104 and F_2-105 had similar seed size, but the mean seed size of F_2-102 was at least 1.1 g per one hundred seed heavier than the other two populations of Camp x MD87L-0198 cross and the differences were significant.

The seed size data in Table 24 show a very clear response to selection for seed size. In the Camp x Jizuka lines derived from F_3's 8 and 10 there was a 1.1 gram per 100 seeds average difference between the lines selected from the smallest compared to the largest seeds in the original F_2 population. In other words, the seeds from plants grown from seeds that were smaller than 4.8 mm were 15% smaller than seeds on plants grown from seeds larger than 5.6 mm. In the Stafford x Camp populations, the difference of 0.9 gram per 100 seed between the lines from large and small F_2 seeds was similar, but smaller, as might be expected, since the selection differential was not as great. A smaller difference was observed between the lines from F_4's 48 and 49. However, the difference is very similar to that observed in the F_3-derived lines from the same cross that were grown from seeds of comparable size. Populations F_3-10 and F_4-48 were both derived from seeds less than 4.8 mm in diameter and had very similar average sizes. A comparison of lines F_3-9 and F_4-49 shows a similar result. The F_3- and F_4-derived lines both originated from populations in which selection was performed on seeds from F_2 plants. The major difference is that the F_4-derived populations were advanced one generation after selection but the F_3-derived population was not. The similarity of seed size in the F_4-derived populations compared to the F_3-derived populations with similar treatments is a good indicator that selection for seed size in bulk seed from an F_2 population is very effective and that the selected differences are retained through advancing generations. This indicates that heritability for seed size is fairly high.

It is also interesting to note that the F_4 populations had wider ranges than F_3 populations, which is evidence that the extra generation after selection allowed additional segregation of more extreme genotypes. Seed sizes within all populations were very variable, as shown by highly significant differences among genotypes within populations (Table 25). However, it is clear that seed size of the parents is more important in determining seed size of the progeny than is the size of seed selected in a previous generation. For example F_3-9 and F_3-4 were derived from seeds of very similar size, but seed size of the resulting populations were very different. The mean seed size for lines derived from F_3-9 (Camp x Jizuka) was 1.0 gram less per one hundred seeds than for lines derived from F_3-4 (Stafford x Camp). The success rate is likely to be higher if selection is practiced in the Camp x Jizuka cross than in the crosses involving Camp x medium sized seed cultivars, regardless of how hard they are screened in the F_2. Also, the lower end of the range for all of the Camp x Jizuka F_3's was lower than any of the Stafford x Camp F_3's indicating a much greater likelihood of isolating smaller-seeded lines in the Camp x Jizuka cross.

Means for the six agronomic traits that were evaluated in each population are presented in Table 25. High levels of variation among genotypes were obtained for seed size and other traits. The F_3 populations that were selected for different seed sizes showed some trends of correlated responses in other traits. The Camp x Jizuka lines derived from smaller seeds (F_3-10) flowered four days later and matured three days later and were six cm taller than the lines derived from large sized seeds (F_3 -8) as shown in Table 25. Similar trends were observed for the Stafford x Camp F_3 derived lines but not for the Camp x Jizuka F_4 derived lines. The lack of maturity differences in the latter could be due to inadvertent elimination of maturity extremes in the F_2 and/or F_3 generations.

It is useful to the breeder to know whether or not seed size is correlated with other traits. Selection for one trait may result in change of a correlated trait depending on the magnitude of correlation coefficient (Anand and Torrie, 1963; Fehr, 1987; Vogel et al., 1980; Weber and

Moorthy, 1952). Weber and Moorthy (1952), for instance, showed that selection for high oil content was correlated with reduced protein content.

The correlations between seed size and the plant traits for each population are shown in Table 26. Seed size generally was correlated negatively with flowering date suggesting that selection for small seed also may increase selection for later maturity. The magnitude of these correlations were small but they were significant for five populations. The correlation between seed size and maturity was generally similar to that for flowering date with values for F_2-21, F_4-48 and F_4-46 being negative and significant. However, F_3-9 had a significant positive correlation between seed size and maturity. The reason for this response being contrary to the trend is not known.

The correlation between seed size and plant height was negative and significant for three of the Camp x Jizuka populations. This is in agreement with the negative correlation between seed size and maturity, since later maturing plants are usually taller plants. However, this association was positive and significant for F_3-10, F_4-46, and all three F_2 populations from the Camp x MD87L-0198 cross. It appears that Jizuka and MD87L-0198 have different alleles regulating plant height and, possibly, maturity.

The three populations that had significant correlations of seed weight with lodging all showed positive correlations, suggesting that plants with smaller seeds tended to lodge less. Relatively low correlation between seed size and lodging is probably related to the generally low level of lodging in the whole experiment.

The correlation of seed size with yield was generally positive and was significant for F_3-10 and for all three populations involving Camp x MD87L-0198, which suggests that it would be difficult to select high yielding genotypes with small seed size from these populations. However, the highest r value was only 0.40 and the correlations in most of the populations were small and non-significant, so this should not be an insurmountable problem.

The correlations obtained in this study, though significant in some populations, were generally too small to warrant a major concern that selection for small seed size would result in undesirable changes for the other agronomic traits. Correlations were not consistent in sign or significance when all the populations of a particular cross were compared further indicating that selection for small seed size need not result in major undesirable changes.

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Table 23. The plant materials used for heritability study of seed size.

Source population	Pedigree	Description	# Lines
F_2 - 21	Camp x Jizuka	small x small	79
F_2 - 22	Camp x Jizuka	small x small	74
F_2 - 102	Camp x MD87L-0198	small x medium	61
F_2 - 104	Camp x MD87L-0198	small x medium	58
F_2 - 105	Camp x MD87L-0198	small x medium	43
F_3 - 8	Camp x Jizuka (>5.6mm)	small x small	50
F_3 - 9	Camp x Jizuka (4.8 to 5.6mm)	small x small	50
F_3 - 10	Camp x Jizuka (<4.8mm)	small x small	50
F_3 - 3	Stafford x Camp (>5.6mm)	medium x small	50
F_3 - 4	Stafford x Camp (<5.6mm)	medium x small	50
F_4 - 46	Stafford x Camp	medium x small	81
F_4 - 48	Camp x Jizuka (<4.8mm)	small x small	50
F_4 - 49	Camp x Jizuka (4.8 to 5.6mm)	small x small	50

Table 24. Ranges, means, F values, coefficient of variation (CV), and heritability estimates of seed size for various Camp crosses.

Source population	Pedigree	Seed size range	Seed size mean	CV	h^2(a)†	h^2(b)
		------ g 100^{-1} ------				
F_2 - 21	Camp x Jizuka	5.85-10.15	7.65**	5.63	0.75	0.24(0.07)‡
F_2 - 22	Camp x Jizuka	5.55-9.20	7.45**	7.72	0.61	0.25(0.07)
F_2 - 102	Camp x MD87L-0198	8.35-13.05	10.18**	6.21	0.61	0.39(0.08)
F_2 - 104	Camp x MD87L-0198	7.00-11.90	9.09**	8.45	0.57	0.41(0.11)
F_2 - 105	Camp x MD87L-0198	7.20-11.20	8.77**	6.10	0.79	0.30(0.07)
F_3 - 8	Camp x Jizuka (>5.6mm)	6.00-9.40	7.54**	6.21	0.73	
F_3 - 9	Camp x Jizuka (4.8 to 5.6mm)	5.45-8.50	7.02**	6.69	0.68	
F_3 - 10	Camp x Jizuka (<4.8mm)	4.65-7.80	6.44**	6.54	0.73	
F_3 - 3	Stafford x Camp (>5.6mm)	7.00-11.25	8.91**	6.60	0.66	
F_3 - 4	Stafford x Camp (<5.6mm)	7.00-10.50	8.00**	4.94	0.80	
F_4 - 46	Stafford x Camp	5.80-10.15	8.17**	5.81	0.77	
F_4 - 48	Camp x Jizuka (<4.8mm)	5.00-8.85	6.58**	1.92	0.43	
F_4 - 49	Camp x Jizuka (4.8 to 5.6mm)	5.35-9.15	7.06**	4.98	0.83	

** Genotypic differences within a cross were significant at 0.01 probability level.

† h^2 (a) and h^2 (b) are heritabilities based on analysis of variance and regression methods, respectively.

‡ Values in parentheses are standard errors.

Table 25. Means of agronomic traits of Camp crosses grown at Warsaw, VA. in 1992.

Source population	Pedigree	Flowering date	Maturity date†	Plant height	Lodging score‡	Yield	Seed size
		days	days	cm		g plot^{-1}	g 100^{-1}
F_2 - 21	Camp x Jizuka	36**	51**	43*	1.1	235*	7.7***
F_2 - 22	Camp x Jizuka	36*	52**	41*	1.1	224*	7.5***
F_2 - 102	Camp x MD87L-0198	34**	41**	36**	1.1**	310**	10.2***
F_2 - 104	Camp x MD87L-0198	35**	44**	34*	1.1	194	9.1***
F_2 - 105	Camp x MD87L-0198	35	41**	30	1.1	167	8.8***
F_3 - 8	Camp x Jizuka (>5.6mm)	41**	51**	39**	1.1	209	7.5***
F_3 - 9	Camp x Jizuka (4.8 to 5.6mm)	42**	51**	42*	1.2**	217*	7.0***
F_3 - 10	Camp x Jizuka (<4.8mm)	45**	54**	45	1.2*	220	6.4***
F_3 - 3	Stafford x Camp (>5.6mm)	33**	46**	36*	1.1	233*	8.9***
F_3 - 4	Stafford x Camp (<5.6mm)	35**	49**	38	1.0	249	8.0***
F_4 - 46	Stafford x Camp	34**	46**	36**	1.1	241**	8.2***
F_4 - 48	Camp x Jizuka (<4.8mm)	39**	50	42**	1.1	215**	6.5***
F_4 - 49	Camp x Jizuka (4.8 to 5.6mm)	39**	49**	40**	1.1	217*	7.1***

*, **, *** Genotypic differences within a cross were significant at 0.05, 0.01, and 0.001 probability levels, respectively.

† Days after August 31.

‡ 1 = all erect; 5 = all prostrate.

Table 26. Correlation of seed size with other agronomic traits for Camp crosses grown at Warsaw, Virginia in 1992.

Source population	Pedigree	df	Flowering date	Maturity	Plant height	Lodging	Yield
F_2 - 21	Camp x Jizuka	78	-0.23**	-0.22**	-0.40***	-0.04	-0.19*
F_2 - 22	Camp x Jizuka	73	-0.30*	-0.08	-0.24**	0.05	-0.11
F_2 - 102	Camp x MD87L-0198	60	-0.05	0.07	0.37***	0.30***	0.38***
F_2 - 104	Camp x MD87L-0198	57	-0.04	0.08	0.31***	0.05	0.35***
F_2 - 105	Camp x MD87L-0198	42	0.16	0.15	0.37***	0.24*	0.35***
F_3 - 8	Camp x Jizuka (>5.6mm)	49	-0.08	-0.12	-0.39***	-0.02	0.10
F_3 - 9	Camp x Jizuka (4.8 to 5.6mm)	49	-0.06	0.25**	0.05	0.03	0.08
F_3 - 10	Camp x Jizuka (<4.8mm)	49	-0.04	-0.07	0.27**	0.11	0.40***
F_3 - 3	Stafford x Camp(>5.6m)	49	-0.20*	-0.09	0.14	0.05	0.12
F_3 - 4	Stafford x Camp(<5.6)	49	-0.16	-0.15	-0.24*	0.07	0.09
F_4 - 46	Stafford x Camp	80	-0.17*	-0.17*	0.17*	0.09	0.07
F_4 - 48	Camp x Jizuka (<4.8mm)	49	0.23*	0.41***	0.04	0.37***	0.16
F_4 - 49	Camp x Jizuka (4.8 to 5.6mm)	49	-0.16	-0.15	-0.15	-0.04	0.07

*, **, *** significant at the 0.05, 0.01, and 0.001 probability levels, respectively.

Chapter Four

SUMMARY AND CONCLUSIONS

Field experiments were conducted in 1992 and 1993 to evaluate the effect of row spacing and seeding rate on agronomic traits and seed size distribution. Treatments included one small seeded and one large seeded soybean cultivar, 38 and 76 cm row spacings, and 125, 250, 500, and 750 thousand seeds ha^{-1} seeding rates in three replications arranged in a split-plot experimental design. Plots in both years were seven 6 m rows (four harvested) and four 6 m rows (two harvested) for the 38 and 76 cm row-spacings, respectively. The experiments were undertaken at Kentland Farm near Blacksburg, Virginia and at Eastern Virginia Agricultural Research and Extension Center, Warsaw, Virginia.

Soybean yield is a function of cultivar, number of branches, number of pods, number of seeds, and seed size. Factors that reduce potential yield are not fully understood. Part of the variation is genetic in that some cultivars have the genetic potential to produce more yield components than others. Soybean genotypes interact with the environment in which they are grown and thereby express their yield potential. Camp and V71-370 were grown under similar cultural practices and environmental conditions, but the yield for V71-370 was significantly higher than that of Camp in 1992 at Blacksburg (Table 20) and for the double-crop test at Warsaw (Table 18). However, the yields of the two cultivars were not significantly different in 1993. Yields of 1347 and 3131 kg ha^{-1} for Camp and 2086 and 3003 kg ha^{-1} for V71-370 were obtained at Blacksburg in 1992 and 1993, respectively.

Comparison of 38 and 76 cm row spacings show that the narrow-row spacings produced higher yields than wide-row spacings at all seeding rates for both Camp and V71-370. These data indicate that substantial yield benefit could be derived from reducing row spacing from 76 cm to 38 cm. The results of this study also show that low yields were obtained at the low seeding rate because the yield components, though higher on a per plant basis did not completely compensate for the low number of plants. Averaged over years, Camp yielded 1766, 2182, 2488, and 2519 kg ha^{-1} while V71-370 yielded 2318, 2609, 2696, and 2554 kg ha^{-1} at 125, 250, 500, and 750 thousand seeds ha^{-1} seeding rates, respectively. Camp yields at the three lowest seeding rates were significantly different from each other but the yields at the two highest seeding rates did not differ significantly. For V71-370, yield at the lowest seeding rate was significantly lower than for the other three seeding rates which did not differ from each other (Tables 3 and 12).

The implication this has for production practices is that low stand establishment might not to lead to reduction in yields, particularly for tall and branching cultivars such as V71-370. In this study, yields of V71-370 among seeding rates were not significantly different from each other in 1993. In contrast, Camp, a short cultivar, showed significant yield reductions at the lowest two seeding rates.

Of the yield components investigated, seed size was stable over the treatments imposed and a combined Camp and V71-370 analysis of variance for seed size did not reveal significant row spacing or seeding rate effects in either year (Table 20, appendix Tables 21, and 24). However, treatment effects were significant for Camp in 1993, and plants in narrow rows produced smaller seeds than plants in wide rows. Additionally, plants at the lowest seeding rate had smaller seeds than plants at the two higher seeding rates (Table 2).

Camp seed size distribution data show that seed size classes L, S, and VS in 1992 and VL, M, and S in 1993 were influenced by row spacing (Table 5). In 1992, wide-row spacings had more of L and less of S and VS than narrow-row-spacings. In 1993, wide-row spacings had more of VL but less of M and S suggesting that small seeds were favored by narrow-row spacings. Of special interest is the seed in the categories M and L because they fall into the group of seed suited for the manufacture of natto. In 1992, narrow-row spacings had a lower percentage of useful seed than wide-row spacings but this was reversed in 1993 (Table 7). However, the yield of useful seed was higher from the narrow-row spacings than from the wide-row spacings in both years though the difference was not significant in 1992 (Table 8).

Additionally, the percentage of useful seed was maximized at the lowest seeding rate in both years and the differences were significant in 1993 (Table 7). However, the yield of useful seed was significantly lower at the lowest seeding rate than at the other seeding rates in both years (Table 8). The yield of useful seed at a particular row spacing or seeding rate vis-a-vis the total yield and percentage of useful seed for the respective treatment indicates that total yield is a better determinant of yield of useful seed than was percentage of useful seed. The amount of Camp seed that was suitable for the manufacture of natto was 978 and 2554 kg ha^{-1} in 1992 and 1993, respectively (Table 8). Tremendous seasonal differences in the yield of useful seeds were also evident when total yields were considered (Tables 3 and 8).

In 1992, most of V71-370 seed was smaller than 7.9 mm in diameter and, therefore, unsuitable for the manufacture of soy products (Tables 15 and 16). This contrasted sharply 1993 when more than 89% of the seed was suitable for the manufacture of tofu. Though the average yield for narrow-row spacings was slightly higher than the average yield of wide row-spacings in 1992, (Table 10), the yield of useful seed was significantly lower from the narrow-row spacings than from the wide-row spacings (Table 16). In 1993, higher total yield and yield of useful seed were obtained at the narrow-row spacings than at the wide-row spacings although no differences in percentage of useful seed were found. The two year total yield and yield of useful seed averages show that total yield for narrow rows was significantly higher but percentage of useful seed was lower than for wide-row spacings. However, the yield of useful seed was not significantly different at the two row spacings. For this cultivar, both total yield and percent of seed that was larger than 7.9 mm were important determinants of useful seed. The amount of V71-370 seed that was suitable for the manufacture of tofu was 502 and 2718 kg ha^{-1} in 1992 and 1993, respectively. Again, seasonal variation in the yield of useful seed was observed.

Heritability of seed size and association of seed size with flowering date, maturity, plant height, lodging and yield were also investigated. Heritability values based on the analyses of variance ranged from 43% to 83% and they were invariably higher than heritability estimates based on the regression of F_3 progeny means on the F_2 parental means which ranged from 24% to 41%. Variation in seed size of the different genotypes within each of the populations was highly significant (Table 24). The mean seed sizes for F_3 lines of Camp x Jizuka cross selected for small, medium and large seeds were 6.4 g, 7.0 g, and 7.5 g per one hundred seeds, respectively. The mean seed size for the F_4 Camp x Jizuka lines selected for small and medium seeds were 6.5 and 7.1 g per 100 seed. The F_3 Stafford x Camp lines selected for medium and large seeds had mean seed sizes of 8.0 and 8.9 g per one hundred seed, respectively, and selection for small and large seeds was effective (Table

24). Heritability estimates for this trait were moderate to high, further suggesting that selection for small seed size was feasible.

It is however, important to know how this trait is associated with other traits. Seed size was negatively correlated with flowering date and maturity with significant r values ranging from -0.17 to -0.41 (Table 26). Significant correlation coefficients for seed size and plant height ranged from -0.40 to 0.37. Seed size was generally positively correlated with yield and four of the populations had highly significant r values ranging from 0.35 to 0.40. Breeders should take these associations of seed size with the other agronomic traits in to consideration particularly when selecting for high yielding small seeded lines. However the magnitude for most of the correlation coefficients does not appear to be large enough to pose serious problems to breeders.

Appendix Table 1. Mean squares from analysis of variance of agronomic traits for Camp soybean grown at two row spacings and four seeding rates at Blacksburg, VA in 1992.

		Agronomic traits			
Source	df	Yield	Seed size	Plant height	Plant stand
		-----------------mean squares-----------------			
Rep	2	107877	0.155	32.3	136
Row spacing (Sp)	1	300713*	0.220	114.8	580
Seeding rate (Ra)	3	1050135***	0.020	307.2	242264***
Sp x Ra	3	36596	0.047	107.2	127
Residual	14	61501	0.139	69.8	500

*, **, *** Significant at 0.05, 0.01 and 0.001 probability levels, respectively.

Appendix Table 2. Mean squares from analysis of variance of agronomic traits for Camp soybean grown at two row spacings and four seeding rates at Blacksburg, VA in 1993.

		Agronomic traits					
Source	df	Yield	Seed size	Plant height	Plant stand	Maturity	Lodging
		mean squares					
Rep	2	462152*	0.05	0.50	3817	0.042	0.385
Row spacing (Sp)	1	815343**	0.63*	7.04*	338	0.167	0.375
Seeding rate (Ra)	3	554873***	0.57**	44.38***	111402***	0.278	3.458***
Sp x Ra	3	19788	0.15	0.49	1023	0.722	0.236
Residual	14	60744	0.10	1.50	1565	0.189	0.124

*, **, *** Significant at 0.05, 0.01 and 0.001 probability levels, respectively.

Appendix Table 3. Mean squares from analysis of variance of agronomic traits for Camp soybean grown at two row spacings and four seeding rates at Blacksburg, VA in 1992 and 1993.

		Agronomic traits		
Source	df	Yield	Seed size	Plant stand
		-------------mean squares-------------		
Year (Yr)	1	38446175**	600.7*	16560
Rep within year	4	281555	23.3	1479
Row spacing (Sp)	1	1095532**	183.3*	5997*
Seeding rate (Ra)	3	1497959***	7.4	634726***
Sp x Ra	3	13430	10.0	1360
Yr x Sp	1	73527	13.9	1066
Yr x Ra	3	122829	54.4	15113***
Yr x Sp x Ra	3	38274	0.7	879
Residual	28	60876	20.5	913

*, **, *** Significant at 0.05, 0.01, and 0.001 probability levels, respectively.

Appendix Table 4. Mean squares from analysis of variance of yield components for Camp soybean grown at two row spacings and four seeding rates at Blacksburg, VA in 1992 and 1993.

Source	df	Yield components Branches plant^{-1}	 Pods plant^{-1}	 Yield plant^{-1}
		-----------------mean	squares-----------------	
1992				
Rep	2	2.1	1060	8.0
Row spacing (Sp)	1	4.3*	384	14.9
Seed rate (Ra)	3	19.4***	2559***	77.8***
Sp x Ra	3	0.8	378	4.5
Error a	28	0.6	186	4.8
1993				
Rep	2	0.5	2111	2.8
Row spacing (Sp)	1	0.4	287	0.1
Seed rate (Ra)	3	2.3	1598**	57.3
Sp x Ra	3	0.2	292	3.3
Error a	28	1.6	286	46.6

*, **, *** Significant at 0.05, 0.01 and 0.001 probability levels, respectively.

Appendix Table 5. Means of yield components for Camp soybean grown at two row spacings and four seeding rates at Blacksburg, VA in 1992 and 1993.

Treatment		Yield components		
		Branches plant^{-1}	Pods plant^{-1}	Yield
		-----number-----		g plant^{-1}
1992				
Row spacing	cm			
	38	2.8a†	35a	7.2a
	76	1.9b	33a	5.7a
Seeding rate	x1000 ha^{-1}			
	125	3.2a	41a	11.1a
	250	2.6b	36ab	7.5b
	500	1.4c	30b	4.0c
	750	0.5d	29b	3.3c
1993				
Row spacing	cm			
	38	1.3a	36a	9.2a
	76	1.1a	29a	9.1a
Seeding rate	x1000 ha^{-1}			
	125	2.1a	56a	13.2a
	250	1.1a	29a	9.7a
	500	0.9a	25a	7.3a
	750	0.7a	21a	6.2a

† Means followed by different letter in a treatment are significantly different at 0.05 probability level.

Appendix Table 6. Mean squares from analysis of variance of seed distribution for Camp soybean grown at two row spacings and four seeding rates at Blacksburg, VA in 1992 and 1993.

		Seed size classes				
		<4.4	4.4-4.8	4.8-5.2	5.2-5.6	>5.6
Source	df	VS	S	M	L	VL
		mean squares				
1992						
Rep	2	5.19	17.39	8.05	47.96	2.48
Row spacing (Sp)	1	21.85*	183.71*	6.83	215.40*	0.45
Seeding rate (Ra)	3	1.04	40.34	52.73	83.10	18.13*
Sp x Ra	3	3.64	39.00	13.98	43.87	2.51
Residual	14	4.52	26.13	19.28	44.98	4.28
1993						
Rep	2	0.03	0.06	3.82	2.34	6.25
Row spacing (Sp)	1	0.06	6.10**	492.32***	1.40	560.67***
Seeding rate (Ra)	3	0.02	3.41**	296.21***	19.36	238.34***
Sp x Ra	3	0.04	1.12	34.77	39.15*	1.21
Residual	14	0.01	0.44	23.86	0.44	20.10

*, **, *** Significant at 0.05, 0.01, and 0.001 probability levels, respectively.

Appendix Table 7. Mean squares from the analysis of variance of seed size uniformity, percentage of useful seed, and individual seed size for Camp soybean grown at two row spacings and four seeding rates at Blacksburg, VA in 1992 and 1993.

Source	df	Seed size uniformity 1992	Seed size uniformity 1993	Percent useful seed 1992	Percent useful seed 1993	Individual seed size 1992	Individual seed size 1993
		--------------------mean squares--------------------					
Rep	2	0.1	0.4	24.4	6.3	20	26
Row spacing (Sp)	1	2.5	1.1	299.6**	441.2***	48	149**
Seeding rate (Ra)	3	9.6*	0.4	8.1	202.4***	21	41*
Sp x Ra	3	1.5	1.0	55.8	1.0	4	7
Residual	14	1.6	0.4	33.8	15.2	31	10

*, **, *** Significant at 0.05, 0.01 and 0.001 probability levels, respectively.

Appendix Table 8. Mean squares from analysis of variance of yield of useful seed of Camp soybean grown at two row spacings and four seeding rates at Blacksburg, VA in 1992 and 1993.

Source	df	Year 1992	 1993
		--------mean	squares ---------
Rep (within yr)	2	89726	402703
Spacing(Sp)	1	14982	2029592***
Seed rate (Ra)	3	515481**	181172*
Sp x Ra	1	29741	7939
Error (b)	28	57263	41575

*, **, *** Significant at 0.05, 0.01, and 0.001 probability levels, respectively.

Appendix Table 9. Mean squares from analysis of variance of agronomic traits for V71-370 soybean grown at two row spacings and four seeding rates at Blacksburg, VA in 1992.

		Agronomic traits			
Source	df	Yield	Seed size	Plant height	Plant stand
		------------------mean squares------------------			
Rep	2	61522	0.97	78.4	461
Row spacing (Sp)	1	217467	0.63	31.5	3978*
Seeding rate (Ra)	3	376700*	0.08	594.0***	200949***
Sp x Ra	3	174	0.54	107.2*	784
Residual	14	112533	0.71	25.1	567

*, **, *** Significant at 0.05, 0.01 and 0.001 probability levels, respectively.

Appendix Table 10. Mean squares from analysis of variance of agronomic traits for V71-370 soybean grown at two row spacings and four seeding rates at Blacksburg, VA in 1993.

		Agronomic traits					
Source	df	Yield	Seed size	Plant height	Plant stand	Maturity	Lodging
		--------------------mean squares-------------------------					
Rep	2	738310	2.47	10.29	659	0.042	2.82
Row spacing (Sp)	1	400443***	0.01	0.38	13968	0.042	0.84*
Seeding rate (Ra)	3	46395	0.01	35.26	78431***	0.042	1.48**
Sp x Ra	3	54061	0.21	5.38	1026	0.042	0.01
Residual	14	45901	0.59	6.58	6369	0.042	0.18

*, **, *** Significant at 0.05, 0.01 and 0.001 probability levels, respectively.

Appendix Table 11. Mean squares from the analysis of variance of agronomic traits for V71-370 soybean grown at two row spacings and four seeding rates at Blacksburg, VA in 1992 and 1993.

Source	df	Agronomic traits		
		Yield	Seed size	Plant height
		---------------- mean squares ----------------		
Year (Yr)	1	10099969*	276.48**	17922.01***
Rep within year	4	119914	1.72	91.15
Row spacing (Sp)	1	603973**	0.40	1.17
Seeding rate (Ra)	3	314441*	0.04	884.51**
Sp x Ra	3	29683	0.43	69.23
Yr x Sp	1	13844	0.24	47.01
Yr x Ra	3	108648	0.05	107.42
Yr x Sp x Ra	3	73622	0.32	44.23
Residual	28	73928	0.65	62.57

*, **, *** Significant at 0.05, 0.01 and 0.001 probability levels, respectively.

Appendix Table 12. Mean squares from analysis of variance of yield components for V71-370 soybeans grown at two row spacings and four seeding rates at Blacksburg, VA in 1992 and 1993.

		Yield components		
Source	df	Branches plant^{-1}	Pods plant^{-1}	Yield plant^{-1}
		-----------mean squares-------------		
1992				
Rep	2	0.51	216	26.6
Spacing (Sp)	1	0.02	170	0.1
Seed rate (Ra)	3	14.94***	1016***	237.9***
Sp x Ra	3	0.60	48	1.0
Error a	28	0.18	95	11.2
1993				
Rep	2	0.04	4161	13.0
Spacing (Sp)	1	0.12	30	1.6
Seed rate (Ra)	3	2.48	2329	88.5
Sp x Ra	3	1.52	1779	32.0
Error a	28	2.02	1375	47.6

*, **, *** Significant at 0.05, 0.01 and 0.001 probability levels, respectively.

Appendix Table 13. Means of yield components for V71-370 soybean grown at two row spacings and four seeding rates at Blacksburg, VA in 1992 and 1993.

Treatment		Yield components Branches plant^{-1}	Pods plant^{-1}	Yield
		---- number	----	g plant^{-1}
1992	cm			
Row spacing	38	1.7a†	29a	10.2a
	76	1.7a	24a	10.4a
Seeding rate	x1000 ha^{-1}			
	125	3.8a	44a	16.8a
	250	1.9b	28b	14.2a
	500	0.8c	21bc	6.7b
	750	0.3d	14c	3.4b
1993				
Row spacing	cm			
	38	1.5a	51a	9.6a
	76	1.3a	48a	10.2a
Seeding rate	x1000 ha^{-1}			
	125	2.0a	68a	13.5a
	250	1.8a	57a	11.0a
	500	1.5a	52a	10.7a
	750	0.5a	22a	4.5a

† Means followed by different letter in a treatment are significantly different at 0.05 probability level.

Appendix Table 14. Mean squares from analysis of variance of seed distribution for V71-370 soybean grown at two row spacings and four seeding rates at Blacksburg, VA in 1992 and 1993.

		Seed size classes (mm diameter)				
Source	df	<7.5 VS	7.5-7.9 S	7.9-8.3 M	8.3-8.7 L	>8.7 VL
		--------------------	----------mean	squares----------	--------------------	
1992						
Rep	2	1385.62	123.01	633.80***	72.46	1.44
Row spacing (Sp)	1	2515.31***	41.08	978.75***	176.58*	3.76*
Seeding rate (Ra)	3	44.79	15.41	15.26	3.56	1.32
Sp x Ra	3	47.87	47.28	12.45	2.76	0.40
Residual	14	119.74	28.37	59.48	18.71	0.80
1993						
Rep	2	1.847	13.99	36.35	14.41	48.31
Row spacing (Sp)	1	0.004	0.08	0.18	0.06	1.17
Seeding rate (Ra)	3	0.692	2.35	8.82	1.53	19.77
Sp x Ra	3	0.152	1.21	4.17	0.76	8.25
Residual	14	0.477	2.82	16.08	5.10	42.06

*, **, *** Significant at 0.05, 0.01, and 0.001 probability levels, respectively.

Appendix Table 15. Mean squares from the analysis of variance of seed size uniformity, percentage of seed larger than 7.9 mm and individual seed size for V71-370 soybean grown at two row spacings and four seeding rates at Blacksburg, VA in 1992 and 1993.

		Year					
		1992	1993	1992	1993	1992	1993
Source	df	Seed size uniformity		Percent useful seed		Individual seed size	
		--------------------mean squares--------------------					
Rep	2	24.1**	8.3*	319.9**	24.4*	140	148
Row spacing (Sp)	1	42.4**	0.1	499.6**	0.1	7	74
Seeding rate (Ra)	3	2.3	0.4	11.3	3.3	228	9
Sp x Ra	3	0.5	1.2	4.1	1.5	33	172
Residual	14	3.2	1.5	35.6	5.2	161	134

*, ** Significant at 0.05 and 0.01 probability levels, respectively.

Appendix Table 16. Mean squares from analysis of variance of yield of useful seed for V71-370 soybeans grown at two row spacings and four seeding rates at Blacksburg, VA in 1992 and 1993.

Source	df	Year		
		1992	1993	1992-1993
		---------------mean squares ---------------		
Yr	1			57410588**
Rep (within yr)	2	402703	266443	209822
Spacing(Sp)	1	161137*	345518*	17371
Seed rate (Ra)	3	29222	55333	62318
Sp x Ra	1	2142	55920	29380
Yr x Sp	3			89284
Yr x Ra	3			22237
Yr x Sp x Ra	3			28733
Error (b)	28	35999	52947	44173

*, **, *** Significant at 0.05, 0.01, and 0.001 probability levels, respectively.

Appendix Table 17. Mean squares from analysis of variance for agronomic traits of Camp and V71-370 grown at four seeding rates at Warsaw, VA in 1992.

		Agronomic traits				
Source	df	Yield	Seed size	Plant height	Maturity	Lodging
		----------------------		mean squares	------------------	
Rep	2	4157	0.693	0.125	3.042	0.046
Cultivar (C)	1	685599*	1602.300***	92.042***	112.667***	0.327*
Error a	2	18258	0.895	1.542	0.542	0.013
Seeding rate (Ra)	3	2595306***	0.354	80.400***	0.556	0.230***
C x Ra	3	103620	0.535	0.264	0.556	0.086*
Error b	12	83914	0.551	3.333	1.847	0.016

*, **, *** Significant at 0.05, 0.01, and 0.001 probability levels, respectively.

Appendix Table 18. Mean squares from analysis of variance of yield and seed size of Camp and V71-370 soybeans grown at two row spacings and four seeding rates at Blacksburg, VA in 1993.

		Year			
		1992	1993	1992	1993
Source	df	Yield		Seed size	
		---------------------- mean squares ----------------------			
Rep	2	65240	549423	0.88	1.61
Cultivar (C)	1	6552410*	214078	3267.00***	4861.21***
Error (a)	2	104159	84218	0.24	0.92
Spacing (Sp)	1	514815*	1233960***	0.80	0.40
Seed rate (Ra)	3	1235899**	421031**	0.03	0.33
C x Sp	1	3365	44736	0.53	0.24
C x Ra	3	109936	196011*	0.07	0.26
Sp x Ra	3	18776	42786	0.21	0.12
C x Sp x Ra	3	17694	26672	0.37	0.24
Error b	56	87017	53079	0.42	0.35

*, **, *** Significant at 0.05, 0.01, and 0.001 probability levels, respectively.

Appendix Table 19. Mean squares from analysis of variance of agronomic traits for Camp and V71-370 soybeans grown at two row spacings and four seeding rates at Blacksburg, VA in 1992 and 1993.

		Year					
		1992	1993	1992	1993	1993	1993
Source	df	Plant height		Stand count		Maturity	Lodging
		----------------------		mean squares	------------------------		
Rep	2	78.5	6.8	547	4123	0.06	1.2
Cultivar (C)	1	963.5*	1045.3***	1292*	5334	77.52**	12.5
Error (a)	2	32.2	4.0	49	4232	0.02	2.0
Spacing (Sp)	1	13.0	5.3	3799**	4232	0.19	0.1
Seed rate (Ra)	3	864.6**	78.3***	441885***	2070770***	0.19	4.2
Sp x Ra	1	131.2	1.7	414	687	0.24	0.1
C x Sp	1	133.3	2.1	760	1587	0.02	1.2**
C x Ra	3	36.6	1.4	1328	379	0.13	0.8**
C x Sp x Ra	3	83.3	4.1	497	596	0.52	0.1
Error b	28	47.5	4.0	533	2503	0.11	0.2

*, **, *** Significant at 0.05, 0.01, and 0.001 probability levels, respectively.

Appendix Table 20. Mean squares from analysis of variance of yield components for Camp and V71-370 soybeans grown at two row spacings and four seeding rates at Blacksburg, VA in 1992.

		Yield components			
Source	df	Branches plant^{-1}	Pods plant^{-1}	Yield plant^{-1}	Individual seed size†
		--------------------mean squares-------------------			
Rep	2	2.62	180	3.31	482
Cultivar (c)	1	3.69	6092	151.94*	486663***
Error a	2	0.57	3468	8.23	25
Spacing (Sp)	1	3.47*	252	2.61	45
Seed rate (Ra)	3	34.45***	2311**	293.09***	79
Sp x Ra	3	0.31	65	3.64	6
C x Sp	1	1.17	1616	9.18	111
C x Ra	3	0.35	358	24.77*	190
C x Sp x Ra	3	0.79	1712	3.64	35
Error b	28	0.47	830	8.13	85

† Plot bulk seed used

*, **, *** Significant at 0.05, 0.01 and 0.001 probability levels, respectively.

Appendix Table 21. Means of yield components for Camp and V71-370 soybean grown at two row spacings and four seeding rates at Blacksburg, VA in 1992.

Treatment		Yield components			
		Branches plant^{-1}	Pods plant^{-1}	Yield	Seed size†
		---- number ----		g plant^{-1}	mg seed^{-1}
Cultivar	Camp	2.6a‡	55a	++	63b
	V71-370	1.5a	50a	++	232a
Row spacing	cm				
	38	2.2a	55a	8.4a	146a
	76	1.9b	50a	8.6a	149a
Seeding rate	x 1000 ha^{-1}				
	125	3.2a	73a	++	149a
	250	2.6b	62ab	++	147a
	500	1.4c	41ab	++	147a
	750	0.5d	24b	++	146a

† Plot bulk seed used

‡ Means followed by different letter in a treatment are significantly different at 0.05 probability level.

++ Significant interaction - data presented elsewhere.

Appendix Table 22. Means of yield per plant for Camp and V71-370 soybean grown at two row spacings and four seeding rates at Blacksburg, VA, in 1992.

	Seeding rate				
Treatment	125	250	500	750	Avg.
	-----------Yield g plant^{-1} -----------------				
Camp	11.1b†	7.5c	4.0d	3.3d	6.5q
V71-370	16.8a	14.2a	6.7d	3.4d	10.3p
Avg	13.9w	10.9x	5.4y	3.3y	

† Means followed by the same letter in a treatment or treatment interaction are not different at $p = 0.05$.

Appendix Table 23. Mean squares from analysis of variance of yield components for Camp and V71-370 soybeans grown at two row spacings and four seeding rates at Blacksburg, VA in 1993.

		Yield components			
Source	df	Branches plant^{-1}	Pods plant^{-1}	Yield plant^{-1}	Individual seed size†
		------------------------	mean squares	--------------------	
Rep	2	2.17	874	4.73	36
Cultivar (c)	1	4.94	5896	175.95	344187***
Error a	2	0.40	344	29.93	132
Spacing (Sp)	1	2.43	320	6.09	120
Seed rate (Ra)	3	33.54***	2851***	288.29***	28
Sp x Ra	3	0.52	118	1.36	70
C x Sp	1	1.92*	96	8.93	1
C x Ra	3	0.76	386	27.35	2
C x Sp x Ra	3	0.89	544	4.08	106
Error b	28	0.38	830	17.98	83

† Plot bulk seed used

*, **, *** Significant at 0.05, 0.01 and 0.001 probability levels, respectively.

Appendix Table 24. Means of yield components for Camp and V71-370 soybean grown at two row spacings and four seeding rates at Blacksburg, VA in 1993.

		Yield components			
		Branches	Pods		Seed
Treatment		plant^{-1}	plant^{-1}	Yield	size†
		---number---		g plant^{-1}	mg seed^{-1}
Cultivar	Camp	1.2a‡	33a	9.1a	70b
	V71-370	1.5a	50a	9.9a	271a
Row spacing	cm				
	38	1.4a	44a	9.4a	169a
	76	1.2a	39a	9.6a	171a
Seeding rate	x 1000 ha^{-1}				
	125	2.0a	57a	13.3a	174a
	250	1.3b	44a	9.0b	167a
	500	1.3b	40a	8.6b	170a
	750	0.7c	24b	7.1c	170a

† Plot bulk seed used

‡ Means followed by different letter in a treatment are significantly different at 0.05 probability level.

VITA

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