SOYBEAN (*GLYCINE MAX* (L.) Merr.) SEED NUMBER, SIZE AND YIELD RESPONSE TO PARTIAL POD REMOVAL

By

Trust Themba Chigwada

A THESIS

Submitted to

Michigan State University
in partial fulfillment of the requirements
for the degree of

MASTER OF SCIENCE

Department of Crop and Soil Sciences

1985

ABSTRACT

SOYBEAN (GLYCINE MAX (L.) Merr.) SEED NUMBER, SIZE AND YIELD RESPONSE TO PARTIAL POD REMOVAL

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Information available on soybean (Glycine max (L.) Merrill) response to partial pod removal is inconsistent. This study was undertaken to examine soybean seed number, size and yield to partial pod removal (PPR) treatments applied at mid pod filling stage. Six cultivars and three degrees of pod removal (0, 25 and 50%) at upper and lower half canopy nodes were examined.

PPR delayed plant senescence as judged by green color loss. Dry weight, seed yield and seed number were linearly reduced 8-16%, 8-24% and 12-40% respectively, but not significantly so with no depodding on lower nodes. PPR at lower nodes was negatively correlated with seed number (r=-0.47) and yield (r=-0.33). Seed size increased 4-14%. PPR effects expressed as percent of untreated plants were similar for all cultivars. Twenty five percent PPR on upper nodes was established as optimum pod removal degree increasing seed size enough to compensate for pods removed such that yields were maintained.

TO THE CHIGWADA FAMILY

AKNOWLEDGEMENTS

Special recognition and appreciation is given to my major adviser, Dr. Thomas G. Isleib, for his unselfish interest and dedication in the guidance, encouragement, and constructive criticism throughout this project, and for the opportunity of association and involvement with soybean production in Michigan.

Special appreciation is also made to Dr. J.J. Kells and Dr. A.W. Saettler for their invaluable assistance as guidance committee members, and Mr. D.E. Wolfe for his technical assistance in the field work.

Gratitude is extende to: The Government of Zimbabwe, for financing this study; Michigan State University, for providing research facilities; and friends within and outside academic circles, who made my stay abroad, a memorable experience.

Finally, I want to thank my parents and family, for their endless love, understanding, support, and particularly for looking after my daughter Tendayi, who was born just after I left for this study. It is to them that I dedicate this thesis.

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INTRODUCTION

The soybean (Glycine max (L.) Merrill), contais high levels of protein (40%) and oil (20%) and offer one of the best answers to the world wide shortages of protein and oil in human diets (40). Soybeans have a wide range of uses including human consumption, livestock feed, and industrial processes. The oil is 85% unsaturated and is cholesterol free, making the dietary value of soybean substantially better than other common vegetables (40).

Soybeans are grown world wide. Increased production has been achieved by increased acreage, genetic improvement and cultural practices. However, yields have tended to plateau over the last years, and to meet increasing demands, yields must be increased faster than in the past. Soybean yield is influenced by various factors that include nutrient and moisture levels (2), diseases and insect pests like Heliothis Zea (Boddie) (44 48), hail injury, and promotion of floral and seed abortion by cool nights. These factors are all linked to the source-sink relationships of the plant.

Source-sink relationships determine seed size, number and ultimate yields. Manipulating the various relationships may increase plant yields (30). one such manipulation is partial pod removal (PPR).

The extent to which soybean plants can compensate for pod loss has not been fully determined (48), and results published are inconsistent. This study was conducted to:

-1 Examine the effects of partial pod removal on seed number, size and yield.

-2 Examine the effects of pod removal treatments applied on different sections of the soybean canopy.

-3 Determine combinations of the degree of pod removal and the canopy site of pod removal that best utilize the phenomenon of compensatory growth.

Degree of pod removal, canopy site of pod removal, and cultivars were tested as sources of variation.

REVIEW OF LITERATURE

PHOTOSYNTHESIS

Leaf photosynthesis is the primary source ultimately delimiting crop yields (8), and varietal differences are due to differences in net photosynthesis (20). These differences are attributed to differences in the various biochemical processes (20), and to resistance of the plant tissue to carbon dioxide diffusion to the site of fixation (15). Most of these factors are influnced by manipulating the various sorce-sink relationships of the plant.

Causal relationships between reproductive development and senescence in plants have been postulated for many years. Soybeans in particular, show a marked senescence during seed development under field conditions (42,43). Removal of young pods delays or prevents senescence as judged by loss of plant green color (21, 34, 38). Removing all pods causes leaves to remain green and active until killed by frost (55).

Senescence or yellowing of leaves has been attributed to various factors: (a) a decline in nutritional and moisture levels during flowering and seed development (47), (b) degradation of leaf protein to provide amino acids to the developing seeds (42), and to various hormonal signals associated with the reproductive sink (34), where there is competition by the growing pods, or a possible production of inhibitors by the developing pods .

Leaf senscence lowers photosynthetic activities of the canopy and subsequently reduces seed yields and quality (2, 42, 55). The sole source of carbohydrates for grain filling during pod fill is photosynthesis (4, 56). Fader and Koller (10) report that soybean growth is almost entirely dependent on assimilates exported from the leaves, and that only 4% of the carbon imported by the seed is accounted for by fixation of atmospheric carbon dioxide by the pods. This finding was supported by Hume and Criswell (23), who observed that the carbon-14 assimilated during development is recovered in the seeds at maturity. Net photosynthesis of most varieties begins to increase at the approximate beginning of seed filling (4). Therefore, a delay in leaf senescence following pod removal would be expected to increase seed yields.

Contrarily, Mondal et al.(38) observed that although contually depodded plants had dark green leaves, their photosynthetic rates declined significantly, starting at the same time and rate as in the control plants.

Phillips et al. (42) report that certain genetic lines of soybean produce mature seed, but show a delayed leaf senescence (DLS) phenotype in which leaves remain green until killed by frost.

Inhibition of photosynthesis by pod removal is reported elsewhere (28, 38). Koller and Thorne (28) reported that inhibition of photosynthesis resulting from removal of rapidly growing pods was due to partial closure of stomata and changes in leaf orientaion that led to a marked reduction in gas exchange. Mondal *et al*.(38) observed a decline in photosynthesis in desinked plants irrespective of the presence of dark green leaves. These workers found that the presence of pods stimulates photosynthesis. Three mechanisms may explain this effect:

1- sink alleviation of the end product inhibition by soluble carbohydrates,

2- sink promoted reduction of starch accumulation in the chloroplasts, an example being an increased phosphorylase starch degradation proposed by Koller and Thorne (28),

3- sink mediated hormonal signals (34).

Measurements of gas exchange in soybeans indicated that pod removal increased stomatal diffusion resistance (4, 28), and changed leaflet orientation (28). Dornholf and Shibles (4) reported that varietal differences in net photosynthesis were mainly a result of differences in diffusive resistance to carbon dioxide diffusion. Huck *et al*.(22) observed that significant reductions net carbon fixation rate generally accompanied a decrease in stomatal closure on upper leaf surfaces than the lower surfaces, and that the degree of stomatal closure was proportional to the number of nodes depodded. The stomatal response occurred in a leaf even when pods at that particular node remained on the plant, or when pods were removed from the stem above or below the test leaf. The combined effects of stomatal closure and vertical leaflet orientation reduce gas exchange, and may serve to reduce photosynthate production to levels commensurate with the reduced assimilate demand of depodded plants.

Loveys and Kriedemann (35) reported that there was an increase in leaf abscisic acid (ABA) that was associated with the increased stomatal resistance. ABA influences several physiological processes in the plant including stomatal closure, abscission, senscence, dormancy, cell division, cellular elongation, nucleic acid and protein synthesis, water relations, photosynthesis and flowering(53). The mode of action of ABA on these traits is not presently well understood. It has been hypothesized that ABA acts by enhancing ribonuclease (RNase) activity, an effect that leads to lower levels of ribonucleic acid (RNA) and deoxyribonucleic acid (DNA), and a consequent decline in the rate of protein synthesis, cell division and growth. A decline in these rates may serve to explain why ABA inhibits traits like germination and flowering, while on the other hand it accelrates certain other traits like senescence, stomatal closure and abscission (53). Contrarily, Ciha <u>et al</u>. (3) found that ABA levels in the leaves were not affected by the presence or abscence of developing pods.

NITROGEN FIXATION.

Nelson _et al_.(41) cited Thibodeau and Jaworski's model explaining the role of nitrogen and its relationship to soybean seed development. The model consisted of several parts. Soybeans use nitrate exclusively during vegetative development. At or near flowering, plants fail to use nitrate, resulting in the initiation of dinitrogen fixation activity, which peaks at the beginning of seed development, but declines rapidly as pods develop because the nearness of the pods to the source makes them a better sink. Nitrogen fixation gradually declines and the plant derives the remainder of the season's nitrogen from redistribution.

Lawn and Brun (31) reported that the symbiotic nitrogen fixation, as measured by both nodule fresh weight per plant and specific nodule activity (SNA) (micro moles of ethylene released per plant per hour) (5) increased during the pre-flowering and flowering stages. However, SNA and total nodule activity (TNA) decline markedly in the early pod filling stage due to limitations on the supply of photosynthates from the shoot to the nodules (31, 32, 33). Such decline in activity may have serious impact on the ability of the soybean plant to meet the requirements for nitrogen in developing seeds. It would be more deleterious under low soil nitrogen levels, when the plant strongly relies on symbiotically fixed nitrogen, and may present a barrier to the attainment of high yields.

Lawn and Brun (31) reported that pod removal increased nodular activity. Such a response may increase yields. This is supported by Phillips _et al_.(42), who reported that leaf yellowing, an obvious visual characteristic of senescence, was associated with decreases in foliar nitrogen concentrations, symbiotic nitrogen fixation, and soil nitrate utilization. They proposed that senescence limits assimilation of carbon and nitrogen at a time when they are required for seed development.

The combined reports of Lawn and Brun (31, 32, 33), and Phillips _et al_.(42, 43) imply that there could be an association between an increase in biological nitrogen fixation following pod removal, and manifestation of delayed leaf senscence (DLS) phenotype that would result in a increase in photosynthesis, thereby increasing seed size and yields by better supporting the carbon and nitrogen requirements for developing seeds.

Distinct genotypic differences in the ability of soybean cultivars to support symbiotic fixation exist. Acetylene reduction assays indicated that symbiotic fixation for "Chippewa 64" was substantially lower than for "Clay" at similar stages of development (32, 33). However, in both cultivars, partial pod removal raised nitrogen fixing nodular activity well above controls.

SEED.

Under normal conditions, particular cultivars produce characteristic seed yields and fairly definite seed size, normally ranging from 12 to 18 grams per 100 seeds, although seed size ranges from 4 to 55 grams per 100 seeds exist within Glycine max (8). Various hypotheses have been proposed to explain the observed variation in seed size. They include: genetic control(5,7), differential seed growth rates and dry matter accumulation in the seed (ranging from 3.38 to 8.32 mg/seed/day) (7), and differences in the duration of the filling period.

Egli (5) observed no significant differences between rates of dry matter accumulation and grain yield, seed weight or final number. Hanway and Weber (17) observed that the rate of dry matter accumulation in seeds of cultivars tested was similar (99 kg/Ha/day) from 30 days after stage 5 (9 to 10 trifoliate leaves unrolled and plants in full bloom) to stage 10 (30 to 50% leaves yellow with many falling and the lower pods yellowing). However, if growing conditions were unusually favorable or adverse during the life cylce, or during a critical stage of development, both the number and the size of the seeds produced would be far from normal.

Results published on the effects of PPR on seed size, number and yield are inconsistent. Lawn and Brun (31) found that the total plant yield at maturity (seed + pod + stem) was relatively unaffected by depodding at the end of flowering, but that pod number/plant, seed/pod and seed size increased. McAllister and Krober (36) found that increases in seed weight and size compensated for 17 and 22% fewer pods in "Haweye" and "Lincoln" cultivars repectively so that total seed yield per plant was not reduced. Severe depodding (80%) reduced seed yield but increased seed size. Moderate depodding (40%), resulted in a 17% actual decrease in pod number. Seed size increased sufficiently to offset pod loss. In both cultivars, seed weight did not increase proportionately with the more severe PPR treatments. Treatments were applied when the plant had an occasional flower in the terminal inflorescences of the main axes or branches. Pods from the first open flowers at the sixth and eight nodes contained one third more fully formed seeds while pods at the upper nodes were still elongating and showed very little development of seeds. Smith and Bass (48) also observed nonsignificant yield reductions until 40% or more of the pods were removed. PPR treatments were applied at different stages of plant maturity beginning when pods were at maximum fullness and hardiness. The above findings suggest that the extent to which soybeans can compensate for poor pod set by increasing seed size depends both on cultivar and degree of pod removal.

Different cultivar responses are reported elsewhere (11, 36). Fehr _et al_.(11) found that determinate cultivars "Hill" and "Lee" had significantly greater yield reductions from altering source- sink ratios than indeterminate cultivars "Hark" and "Beeson".

Egli _et al_.(6, 8) reported a trend towards reduced seed yield and increased seed size following pod removal treatments applied at the end of the flowering period before there was substantial seed development. They observed that pod removal resulted in a decline at maturity in yield, pods/plant, and seeds/plant, while seed size, pod wall weight and stem weight increased. At 21 and 28 days after pod removal, seeds from depodded plants were significantly heavier than controls. Kincade _et al_.(26), in an experiment simulating bollworm (_Heliothis zea_ (Boddie)) injury on soybean pods, observed nonsignificant difference in the sizes of depodded and control plants. However, 100 seed weights were progressively higher, but not significantly so in plots with higher injury levels.

The combined effects of defoliation and depodding vary in reducing seed yields depending on their severity and on the stage of plant growth at which the treatments are applied (52). Pod removal treatments have the most important effect in reducing seed yields (52).

Floral bud removal results in morphologiacl and chemical changes resembling the effect of depodding, but removal of floral buds early in their development had no effect on seed size or total seed yield per plant (21), Soybeans flower abundantly, but a large proportion of the flowers and young pods abscise rather than develop into mature pods (19). Thirty to 85% of the buds/flowers produced abort, with 20% of the abortion occurring during the early bud stage, and 75% during full bloom.(21). The cause of this abortion is unknown. It has been suggested that pod set is regulated by the supply of assimilates to developing flowers and pods. Because light penetration into the soybean canopy decreases from the top to the bottom, photosynthetic rates are lower for leaves deeper in the canopy. Heindl and Brun (19) propose that if assimilate supply regulates pod set, then pods/node, seeds/node, and seed weight/node would be expected to decrease at progressively lower levels.

Removal of flowers or young pods reduces seed abortion (21, 36, 48). The explanation proposed by McAllister and Krober (36) is that the naturally high floral abortion does not occur in depodded plants because excess flowers are removed mechanically by pod removal. Total pod number per plant was not affected by removal of up to sixty floral buds per plant randomly over all nodes.

Explanations for the different seed character responses observed following pod removal are inconsistent too. The vegetative tissue of the soybean plant serves as a reservoir for mineral nutrients during the vegetative growth of the plant and the minerals are translocated to the seed during pod filling. Losses from leaves, stems and pods account for the majority of the nitrogen, phosphorous and potassium in the mature seed (16, 29). Ninety-six percent of the carbon in the seed is imported from the leaves, and only 4% is fixed by the pod (10). Pod removal changes the pattern of photosynthate production and translocation resulting in seed weight increases to compensate for 19 to

22% pod loss such that yields are not significantly changed (36). Comparing C-14 accumulation in depodded and control plants, Egli and Leggett (7) observerd higher levels in labelled leaves and in the stem both above and below the node of the labelled leaf, following pod removal.

Kollman _et al_.(29) suggested that there was a positive relationship between sink size and photosynthetic rate, because the dry matter of the shoots increased with increasing sink size. Reductions in sink size by pod removal resulted in large increases in dry weights of stem and leaves. Major increases in individual seed size would therefore be expected as the number of fruits per plant was reduced. Yoshida (56) concluded that although the contribution of stored carbohydrates to grain yield may be as high as 50% for some species, the main source of carbohydrates for grain filling is photosynthesis. McAllister and Krober (36) indicated that there can be a limited amount of carbohydrate accumulation in soybean stems but the availability of this material for grain filling was questioned. They proposed that the most reasonable explanation for the apparent recovery of pods and seed yield in depodded plants is a result of reduced pod abortion. The normally high pod abortion in control plants is not observed in depodded plants. Abortion of pods in control plants is possibly a result of over-production of pods and the limited capacity of the plant to supply food for continued pod development.

The size of the seed has been recognized for many years as a factor influencing seedling vigor, subsequent plant growth and seed yield. Positive relationships between planted seed size and seed yield have been reported (49). Contrarily, Hartwig and Edwards (18) reported that lines selected for larger seed in programs of backcrossing produce yields similar to those of the recurrent parent, suggesting no close relationship between planted seed size and yield. However, many workers (4, 13, 49, 50) have reported greater plant growth and seed yield from progeny grown from large than from small seeds. In this context, because pod removal increases soybean seed size (6, 8, 11, 36, 52), it can be used as a technique to increase future soybean yields.

CANOPY SITE AND POD REMOVAL.

Different sections of the plant contribute differently to total seed yield (19). Heindl and Brun (19) reported that seed weight/node and seed weight/section were significantly greater in the middle section than the top or bottom section of cultivar "Evans", and that the middle section account for at least 75% of the main stem yield. There is only slight variation among sections in flowers produced, and therefore the primary cause of differences in pod number/node and ultimate seed yield for the various canopy sections is differential flower and pod abscission.

Other possible causes are differences in amount of light intercepted (45, 46), and in leaf area (27).

Koller (27) observed that the lower main stem produces the most leaf area, but due to abscission of lower leaves, the middle section has the most leaf area by the time of rapid seed development. This may explain why the middle section contributes the most to total yield. The seed's relative growth rate does not vary with position on the plant, an indication that supply of assimilates limits seed growth to no greater extent at lower nodes than at upper nodes. Koller (27) concluded that there was a downward translocation of assimilates to offset the potentially decreasing photosynthesis towards the bottom of the canopy. Seed growth rate therefore appears to be contolled primarily by regulatory mechanisms within the seed, rather than by external availability of assimilates.

Response to pod removal differs with canopy site of depodding (11, 12, 21). Hicks and Pendleton (21) reported that the section of the plant without pods following pod or floral bud removal remained green and vegetative until killed by frost, while the untreated sections senesced normally. They observed that pod number and yield per plant were unaffected by bud removal from any 1/3 section of the plant, but decreased when buds were removed from either the lower or upper 2/3 of the plant. Seed weights increased, but yields decreased. Because pod number was not reduced by PPR from any 1/3 section of the plant, Hicks et al. (21) proposed that the natural shedding of buds or flowers was reduced in other sections of the plant.

There is translocation of assimilates from leaves subtending the section of the plant whose buds are removed, and this explains the increase in seed size. An interaction exists between canopy levels and plant density during pod filling, and is due to an alteration in the pattern of translocation, and an inability of the lowest leaves to respond to increased light intensities following pod removal (24, 54, 56). The thinning treatments induced by PPR have greatest effct at the top of the canopy, with progessively diminishing effects towards the bottom (55).

Varietal differences also exist, with significantly greater yield reductions in determinate than indeterminate cultivars at any canopy site depodded (11, 12).

PROTEIN AND OIL

A number of investigations have examined the influence of pod removal on seed chemical composition, and results obtained are inconsistent. Lawn and Brun (31) observed nonsignificant, relatively small variation in seed protein content. McAllister and Krober (36) reported that pod removal increased protein content, lowered oil content and iodine number of the oil. Protein content increased proportionally with increase in pod removal extent. Hicks and Pendleton (21) observed that seed protein and oil content were not affected by floral bud removal. Weber (54), simulated hail injury to soybeans, to examine the effects of defoliation and topping and reported a 1%

reduction in oil content.

SUMMARY.

Total soybean seed yield is a function of the number and size of the seeds. Manipulating source- sink relationships of the soybean plant influences plant growth and subsequent seed yields. Effects of altering these relationships by partial pod removal have not been consistent.

Reported reductions in yields have been attributed to the actual reduction in pod number (which tends to have been severe), inhibition of photosynthesis, changes in translocation patterns, stomatal closure, and changes in leaflet orientation. Increases in seed size great enough to compensate entirely for reduced seed number and maintain total yields have been reported This has been explained by delays in senescence, higher nitrogen supplies to developing seed, better light penetration into the canopy, and a subsequent better plant performance.

Increasing the size of the seed to be planted increases yields to be harvested. PPR increases seed size, and attains a more or less uniform seed size. This has potential to increase soybean yields, especially in view of the relative ease of grading soybean seeds. Also a more precise spacing in the row, and better plant uniformity obtained by planting uniform seed size, may be basic in achieving higher total yields.

Partial pod removal has been shown to increase seed size (6, 8, 11, 36, 52). Response has varied with cultivars, sites of depodding, and the extent of depodding. Research is required to determine the best combination of these factors that will fully utilize the potential for increased seed size.

METHODS AND MATERIALS

Experiments to investigate the effects of partial pod removal (PPR) on soybeans were conducted at the Crop Science Research Farm on the campus of Michigan State University at East Lansing, Michigan., during the growing seasons of 1983 and 1984. Both experiments were conducted on Capac loam 2.5b (fine loamy, mixed, mesic Aeric Ochraqualfs) soils previously planted to small grain.

In 1983, seventeen cultivars of soybean (Table 1) were planted in an unreplicated nursery. Each plot comprised of four rows, 5m long and spaced 50cm apart. Ten plants were selected at random in each plot. Five were treated and five used as controls. Treatments consisted of 50% depodding of all nodes. When pods at any node reached mid pod filling stage, determined visually when seeds in the pods at that particular node half filled the available seed space, 50% pod removal treatments were applied mechanically by hand removal of one in every two pods. Treatment was applied at all nodes.

At maturity, the height of control plants was measured. All plants were harvested by hand, dried and threshed individually. Seed yield (g/plant) and number of seeds per plant were determined. Seeds from similarly labelled plants from each plot were mixed thoroughly, and two samples, each comprised of 100 randomly drawn seeds,

TABLE 1. Cultivars tested for seed size response to 50% partial pod removal, 1983.

Cultivar	Average 100 seed weight (grams)
Agate	25.30
Altona	18.69
Beeson	19.69
Corsoy 79	21.40
Harcor	17.92
Hodgson 78	16.68
Lakota	18.01
Manchuria	20.94
Mandarin	20.82
Maple Arrow	18.80
McCall	20.53
Morsoy	21.78
Mukden	20.54
Norman	21.30
Renville	20.30
Weber	16.20
Wirth	17.65

were made. The samples were weighed and the 100 seed weights were used to calculate seed size response for each cultivar, using the formular:

$$\% \text{ seed size increase} = 100 \times \frac{(A-B)}{B}$$

where A = Average weight in grams of 100 seeds from depodded plants in a plot

B = Average weight in grams of 100 seeds from untreated plants in the same plot.

The seed size response (Table 6) were used to select six cultivars: two exhibiting large response of seed size to pod removal, two exhibiting medium response, and two exhibiting low seed size response to pod removal. The cultivars selected were used in the 1984 study.

Sources of variation examined in 1984 (Table 2) were six cultivars and three degrees of pod removal (0, 25 and 50%) at two sites of pod removal (upper versus lower half canopy nodes). The factorial set of 54 treatments were arranged in a split-plot design with cultivars occupying whole plots. Each whole plot consisted of 12 rows 50cm apart and 18.3m long, arranged in a randomized block design with two replications. Subplots were 2m sections of single rows, and treatments were applied randomly to subplots within whole plots. Figure 1 shows a block of the plot layout.

The six cultivars were planted on June 05, at a depth of 3.8-5.0 cm. Planting rates (Table 3) were adjusted for each cultivar to produce a plant population of 370,000 per

TABLE 2. 1984 Treatments.

Partial Pod Removal Treatments

Treatment number	%pods removed at upper (top ½ canopy) nodes	% pods removed at lower (lower ½ canopy) nodes
1	0	0
2	0	25
3	0	50
4	25	0
5	25	25
6	25	50
7	50	0
8	50	25
9	50	50

25% PPR- One in every four pods removed.
50% PPR- One in every two pods removed.

Cultivar Treatments

Cultivar	Name	Maturity group	1983 response
A	Corsoy 79	II	Medium
B	Hodgson 78	I	Medium
C	Lakota	I	Low
D	Maple Arrow	0	High
E	Weber	I	High
F	Wirth	I	Low

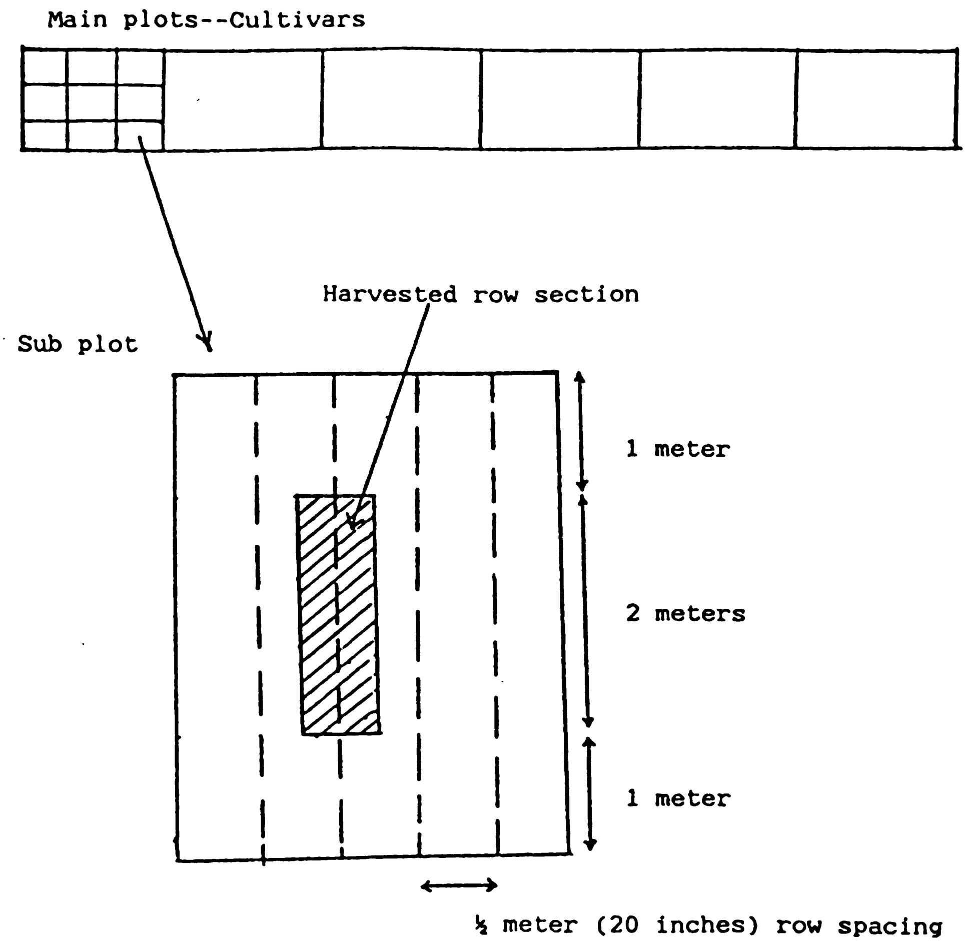


Figure 1. Plot plan. Cultivars and Partial Pod Removal (PPR) treatments were applied randomly to whole plots and sub plots respectively.

TABLE 3. Cultivar planting rates adjusted to produce 370,000 plants/Ha 1984.

Cultivars	Mean 100 seed weight (g)	500 seed weight required/plot (g)	Actual seed (g) planted/plot
Corsoy 79	16.60c	83.00	83.00
Hodgson 78	18.80	94.00	92.60*
Lakota	17.50b	87.50	87.50
Maple Arrow	19.10a	95.50	95.50
Weber	12.10c	60.50	60.50
Wirth	17.10bc	85.50	80.00*

*- limited seed supply

Means followed by the same letter are not significantly different from each other by the LSD test at P= 0.05

hectare assuming complete emergence of germinating seedlings. Two hundred twenty five Kg/ha of 6:24:24 fertilizer was incorporated in the soil prior to planting. Granular rhizobial inoculant was applied in the planting furrow.

Weeds were controlled by application of a combination of preplant incorporated (PPI) and postemergence herbicide treatments. The PPI treatment was 2lbs/A a.i. chloramben mixed with 1lb/A a.i. Trifluralin incorporated into the top 5 cm of the soil one day before planting. A tank-mix combination of bentazon (1lb/A a.i.) and fluazifop-butyl (¼lb/A a.i.) was applied at 2 and 5 weeks after planting. Plots were hand weeded to control weeds not killed by the herbicides.

A wooden stake was driven into the soil at each end of the treatment row, such that the height of the stake above the ground equalled half the plant height for the particular cultivar, as calculated from the previous year plant height measurements (Table 4). A string was tightly secured between the two stakes to indicate average half plant height (dividing the canopy into top and lower halves) along the row.

When pods began to form, they were examined visually on a daily basis to evaluate the mid pod filling stage. This was determined when seeds in the pods half filled the available seed space and could not be crushed under slight finger pressure. At this stage of pod development, pod removal treatments were applied to the respective canopy

TABLE 4. Half plant height calculated from 1983 height measurements.

Cultivar	Mean height (cm)	½ Plant height (cm)
Corsoy 79	120	60
Hodgson 78	130	65
Lakota	140	70
Maple Arrow	78	39
Weber	120	60
Wirth	100	50

sites. Treatments were applied progressively from the base to the top of the canopy, from August 04 to September 02.

At maturity, plants in the middle 2 meters of depodded and control rows were counted, harvested by hand, and their fresh weights measured. Plants of each treatment were bagged together, dried at 41°C for 48 hours, reweighed and threshed. Total seed yield and number were determined.

Three 100 seed samples were randomly drawn from each treatment plot and weighed. Average 100 seed weights and percent 100 seed weight changes were calculated and used as a measure to compare seed size response to partial pod removal within and among cultivars.

STATISTICAL ANALYSIS.

Lack of replication of treatments in the 1983 preliminary experiment did not allow statistical analysis of the data. Seed weight changes (Table 6) were used as a guide in selecting the six cultivars used in 1984, and in grouping the cultivars into high, medium and low seed size response (to PPR) cultivars.

The 1984 data were subjected to Analysis of Variance appropriate to a Split-plot design using MSTAT (39) and GENSTAT computer packages of statistical programs. Cultivar main effects were partitioned into among and within the high, medium and low response (to PPR) groups. The main effects of pod removal at upper and lower nodes were partitioned into linear and quadratic components and their interactions with the different cultivar groups. These components were included in the partitioning of the interactions between cultivar and depodding treatments. The form of the analysis of variance used is shown in Table 5.

When a significant "F" was obtained for treatment effects, treatment means were separated by the Least Significant Difference (LSD) test according to Steel and Torrie (51). Unless otherwise stated, the level of significance used was P=0.05.

Table 5. Form of analysis of variance

Source of variation	
Total	107
Replication	1
CULTIVARS	5
Among groups	2
high vs. low	1
medium vs. low	1
Within groups	3
within high	1
within medium	1
within low	1
Error (a)	5
UPPER NODES	2
Linear	1
Quadratic	1
Cultivar x upper nodes	10
Among groups x upper linear	2
Among groups x upper quadratic	2
Within groups x upper linear	3
Within groups x upper quadratic	3
high x upper linear	1
high x upper quadratic	1
medium x upper linear	1
medium x upper quadratic	1
low x upper linear	1
low x upper quadratic	1
LOWER NODES	2
Linear	1
Quadratic	1
Cultivar x lower nodes	10
Among groups x lower linear	2
Among groups x lower quadratic	2
Within groups x lower linear	3
Within groups x lower quadratic	3
high x lower linear	1
high x lower qudratic	1
medium x lower linear	1
medium x lower quadratic	1
low x lower linear	1
low x lower linear	1
Upper x lower	4
Linear x linear	1
Linear x quadratic	1
Quadratic x linear	1
Quadratic x quadratic	1
Cultivar x depodding treatments	40
Cultivar x upper nodes	10
Cultivar x lower nodes	10
Cultivar x upper x lower	20
Error (b)	48

RESULTS AND DISCUSSION

The choice of applying pod removal treatments at mid pod filling stage (determined visually when seeds in the pod half filled the available seed space) was influenced by attempts to maintain nearly equal time intervals between full pod (Stage R4) and full seed (Stage R6). This period takes as long as 46 days, and is very critical in changing yield production patterns, if a treatment influencing any of the various plant source-sink relationships is applied. It is important to know how yield production is changed during that time. Therefore to properly assess the effects of partial pod removal, it was decided to apply treatments within this critical growth stage, and mid pod filling stage appeared as near the middle as possible.

Just before harvesting in both 1983 and 1984, recognizable differences were observed among cultivars, and between depodded and untreated plants within a cultivar. The early maturing cultivars such as Maple Arrow were fully mature and completely dry two to three weeks before the late cultivars matured. Cultivar differences in both plant size and pod size were apparent. Within a cultivar, control plants senesced fully, showing a general yellowish-brown coloration over the entire plant canopy. Pods were dry and would crack under slight finger pressure. Depodded plants on the other hand had a complement of dark green leaves, thick green stems, and light green pods that would not crack under the same finger pressure. There was about 10-14 days' time difference between complete senescence and drying in control and depodded plants. Within the depodded plants, the sections without pods following pod removal were characteristically greener than the untreated sections.

Pods from depodded plants were visibly more plump than those from untreated plants. Pod plumpness was more pronounced in sections from which pods had been removed than in undepodded sections. Pod size and plumpness appeared to increase as degree of pod removal increased.

Lack of replication of treatments in the 1983 study did not allow statistical analysis of data, and seed weight changes were used as a guide in selecting the six cultivars used in the following year, and in grouping the cultivars into high, medium and low seed size response (to PPR) cultivars (Table 6). Seed size increases ranging from 1 to 24% were observed, with cultivars Mandarin, Mukden and Wirth giving the lowest response, and Agate and Altona being among the high seed size response cultivars. Seed size increases of 5% and below were considered low response, 5-15% considered medium response, and above 15% was high response. Table 6 shows that there were cultivars which should have been selected for further testing in 1984, but were not selected. This was due to limited supply of seed for planting in the 1984 study. Limited seed supplies reduced planting rates for cultivars Hodgson 78 and Wirth.

TABLE 6. 1983 Cultivars, mean 100 seed weights and % seed size increase response to 50% pod removal,

Cultivar	Mean 100 seed weight (grams) Control (B)	Depodded (A)	% Seed size Increase
Agate	25.30	31.35	23.91(*)
Altona	18.69	21.50	15.03(*)
Beeson	19.82	24.38	23.01(*)
Corsoy 79	21.40	24.06	12.43**
Harcor	17.92	19.40	8.26
Hodgson 78	16.68	18.90	13.31**
Lakota	18.01	18.90	4.94*
Manchuria	20.94	21.76	3.92
Maple Arrow	18.80	21.59	14.84***
McCall	20.53	22.71	10.62
Morsoy	21.78	22.81	4.73
Mukden	20.54	20.80	1.26
Norman	21.30	23.39	9.81
Renville	20.30	21.50	5.91
Weber	16.20	19.44	20.00***
Wirth	17.65	17.90	1.42*

$$\% \text{ seed size increase} = \frac{100 \times (A-B)}{B}$$

*,** and*** - respectively low, medium and large seed size response cultivars selected for 1984 study.

(*) - Limited seed supply prevented cultivar selection.

Despite the reduced planting rates for some cultivars, there were no significant differences among cultivars in the number of plants harvested from 2m row sections of sub-plots (Table 7), an indication that any differences observed in other traits was not due to non-uniform experimental plots, but due to the cultivar and pod removal treatments themselves. No significant changes in fresh weight (pods + stem + leaves) were observed among cultivars.

Mean square values (Table 8) from the analysis of variance indicates that there were no differences in total dry weight (pods + stem + leaves) yields among cultivars, but significant linear dry weight reductions following pod removal at both the upper and lower nodes. An interaction between the linear response to pod removal at upper nodes and dry weight yields within the high and low seed size response cultivars was apparent. Pod removal treatments reduced dry weight yields by as much as 16% (Tables 9 and 10, and Figure 2).

In cultivars Maple Arrow, Weber and Wirth, the dry matter reductions were not significant. Similar responses were observed in Corsoy 79 and Hodgson 78, except for significant reductions in treatment 6 (25:50 depodding ratio on upper:lower nodes) for both cultivars and treatment 4 (25:0) in Hodgson 78. However, these reductions are unlikely to be related to pod removal, since the more severe pod removal treatments maintained dry weight yields.

The overall mean column in Table 10 indicates that

TABLE 7. Number* of plants harvested from 2 meter row section subplots.

Treatment number	A@	B#	Corsoy 79	Hodgson 78	Lakota	Maple Arrow	Weber	Wirth	Mean*
			(# plants in 2 m subplot sections)						
1	0	0	35.5	37.0	39.0	52.0	30.5	35.0	38.25a
2	0	25	34.0	36.0	42.5	45.0	32.0	33.5	37.17a
3	0	50	39.5	40.0	41.0	54.5	28.0	44.5	41.25a
4	25	0	45.0	40.0	44.0	44.0	38.0	29.5	40.08a
5	25	25	34.5	24.5	33.0	40.5	35.0	29.0	32.75a
6	25	50	31.5	34.5	48.0	42.0	36.0	27.5	36.58a
7	50	0	48.0	36.5	27.0	39.5	40.0	32.5	37.08a
8	50	25	37.5	41.0	44.5	35.5	25.5	36.0	36.65a
9	50	50	32.0	46.0	42.0	51.0	43.0	27.0	40.17a
Mean			37.49a	37.17a	40.06a	44.89a	34.22a	32.78a	

* average of two replications.

LSD (0.05)= 7.54
Means sharing the same letter are not significantly different from each other by the LSD test at P= 0.05.

Table 8. Mean square values and level of significance.

Source of variation	df	Dry weight	Seed number	Seed yield	Seed size	Dry weight as % of control	Seed number as % of control	Seed yield % of control	Seed size as % of Control
Total	107								
Replication	1								
Cultivars	5	23082	318211*	18096*	91.69**	638.30	1432.70	880.5	482.51
Amoung groups of cultivars	2	13311.11	164902	294525*	29.89**	1226.50	1307.50	1307.50	697.33
High vs. others	1	26622	329004*	55370**	59.78**	496	1724	1169	53.65
Medium vs. low	1	0.22	800	3535	0.19	1957	743	1446	1341*
Within groups of cultivars	3	29596	420416*	10525	1328033**	246.08	1565.31	595.33	339.41
within high cultivar groups	1	2304	571284*	10235	320**	79.25	4165	856	43.24
within medium cultivar groups	1	68034	605284*	365	9.82*	142.0	513.0	642	417
within low cultivar groups	1	18451	84681	20977*	62.59**	517	17.94	288	558
Error (a)	5	12261	44558	2228	1.39	361.3	1269.3	292.5	151.07
Upper nodes	2	30995*	784235**	6641*	15.93**	650.7*	2819.9**	644.2*	641.72**
Linear	1	55889*	1528043**	13111*	31.84**	1180.57*	5536**	1286**	1283**
Within cultivar groups x upper linear	3	187715**	46753	1544	1.56	413.76	234.95	185.85	58.55
Low groups x upper linear	1	53110*	72270	3815	4.11*	1190*	472.8	506.18	130.80*
Lower nodes	2	31148*	1325813**	21343**	8.05**	504.9	4149.1**	1794.5**	297.09**
Linear	1	43218*	2473088**	36788**	14.12**	733.5	7710.7**	3038.5**	510.7**
Among cultivar groups x lower linear	2	13991	207384*	5486	0.09	253	785*	418.3	1.78
Error (b)	48	9653	61719	1996	0.67	189.8	231.6	169.5	24.93

* significant at P= 0.05.
** significant at P= 0.01.

TABLE 9. Dry weight response to pod removal.

Treatment number	A@	B#	Corsoy 79	Hodgson 78	Lakota	Maple Arrow	Weber	Wirth	Means
			-------------Dry weight	in grams/2m	subplot row	section)-----------			
1	0	0	789.5a	721.5a	638.5ab	693.0a	735.0a	669.0a	715.25a
2	0	25	669.5ab	614.0ab	754.0ab	663.5a	589.0a	626.5a	652.75ab
3	0	50	675.0ab	599.5ab	633.5abc	648.0a	630.0a	702.5a	648.08ab
4	25	0	758.5ab	526.0b	613.5abc	687.5a	732.5a	629.5a	657.92ab
5	25	25	596.0ab	534.5ab	610.0abc	594.0a	694.0a	593.5a	603.67b
6	25	50	586.0b	484.5b	688.5ab	668.0a	633.5a	678.0a	623.08b
7	50	0	701.5ab	619.0ab	519.5bc	609.0a	718.5a	703.0a	645.08b
8	50	25	645.0ab	626.5ab	482.0c	623.5a	592.0a	653.5a	603.75b
9	50	50	620.5ab	535.5ab	641.0c	691.0a	697.0a	597.5a	600.08b

C.V.% Cultivars = 12.26
C.V.% Pod removal treatments= 15.38
LSD (0.05) Means within a cultivar= 197.69
LSD (0.05) means across cultivars and replications= 80.71
Means within a column sharing the same letter are not significantly different from each other by the LSD test at P= 0.05.
@ - % partial pod removal at upper ½ canopy nodes.
# - % partial pod removal at lower ½ canopy nodes.

TABLE 10. Pod removal effect on dry weight expressed as percent of untreated plants.

Treatment number	A[@]	B[#]	Mean* dry weight	Actual dry weight decrease
			(grams/2m row)	(%)
1	0	0	715.25	8.38
2	0	25	91.62	9.08
3	0	50	90.92	8.05
4	25	0	91.95	8.05
5	25	25	84.61	15.39
6	25	50	87.72	12.28
7	50	0	90.23	9.77
8	50	25	84.54	15.46
9	50	50	84.02	15.98

* - Mean dry weight added across cultivars and replications.

@ - % partial pod removal at upper ½ canopy nodes.

- % partial pod removal at lower ½ canopy nodes.

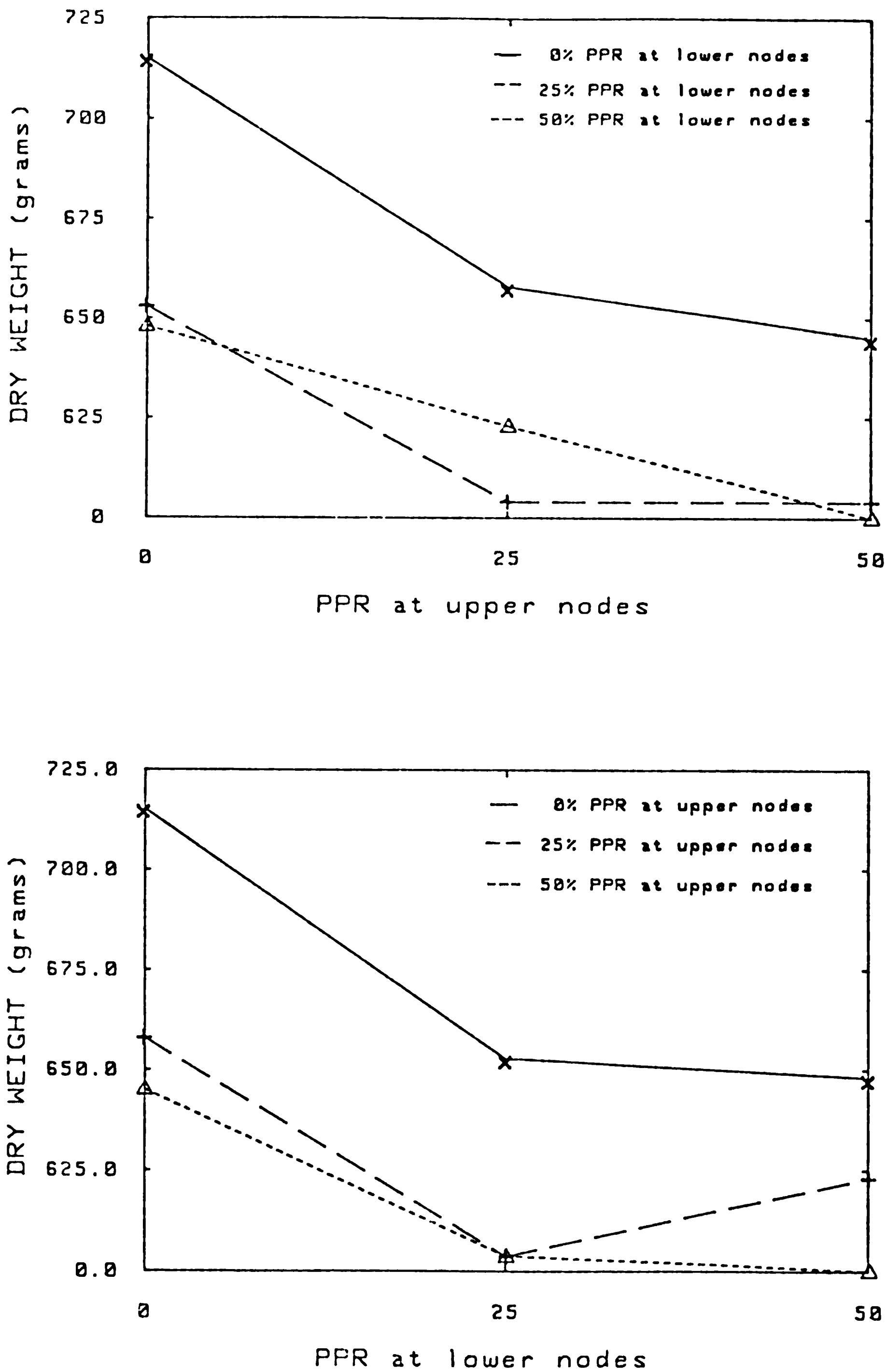


Figure 2. Response of dry matter yield (g/2m subplot row section) to pod removal at upper nodes (top) and lower nodes (bottom).

although there were 8 to 16% decreases in dry matter production between the two extremes of pod removal, up to 10% dry weight reductions were not significant in plants not depodded on one canopy site. The data suggests that a minimum of 25% of the pods on both the upper and lower nodes have to be removed for dry matter yields to be significantly reduced.

SEED YIELD RESPONSE TO POD REMOVAL.

The analysis of variance for seed yield (Table 8) was significant for cultivar differences and pod removal effects at both canopy nodes, with PPR at the lower nodes significant at the 1% level, and negatively correlated with seed yield (r = 0.47). Differences in cultivar seed yields resulted from differences within the low response cultivars (Lakota and Wirth) and among the high response group of cultivars when compared to the rest.

There was a trend for linear yield reductions following pod removal at both the upper and lower nodes, with a more pronounced linearlity and significance with pod removal at the lower nodes (Figure 3, Table 11). In Maple Arrow and Wirth, pod removal did not reduce seed yield. In Lakota, the more severe pod removal treatments 8 (50:25) and 9 (50:50) reduced seed yield 33 to 44%. Treatments 3 (0:25), 5 (25:25) and 9 (50:50) in Corsoy 79 reduced seed yield by an overall 32%. In Weber, all treatments except 2 (0:25) and 6 (25:50) maintained seed yield. Although the yield reductions in Corsoy 79 and Weber were significant at P=0.05 it is unlikely that they were due to pod removal, since the more severe pod removal treatments within the cultivars maintained seed yield.

When seed yield was expressed as a percentage of untreated plants (Tables 8 and 12), cultivar differences were nonsignificant, while pod removal effects at both the upper and lower nodes remained significant. The linear components

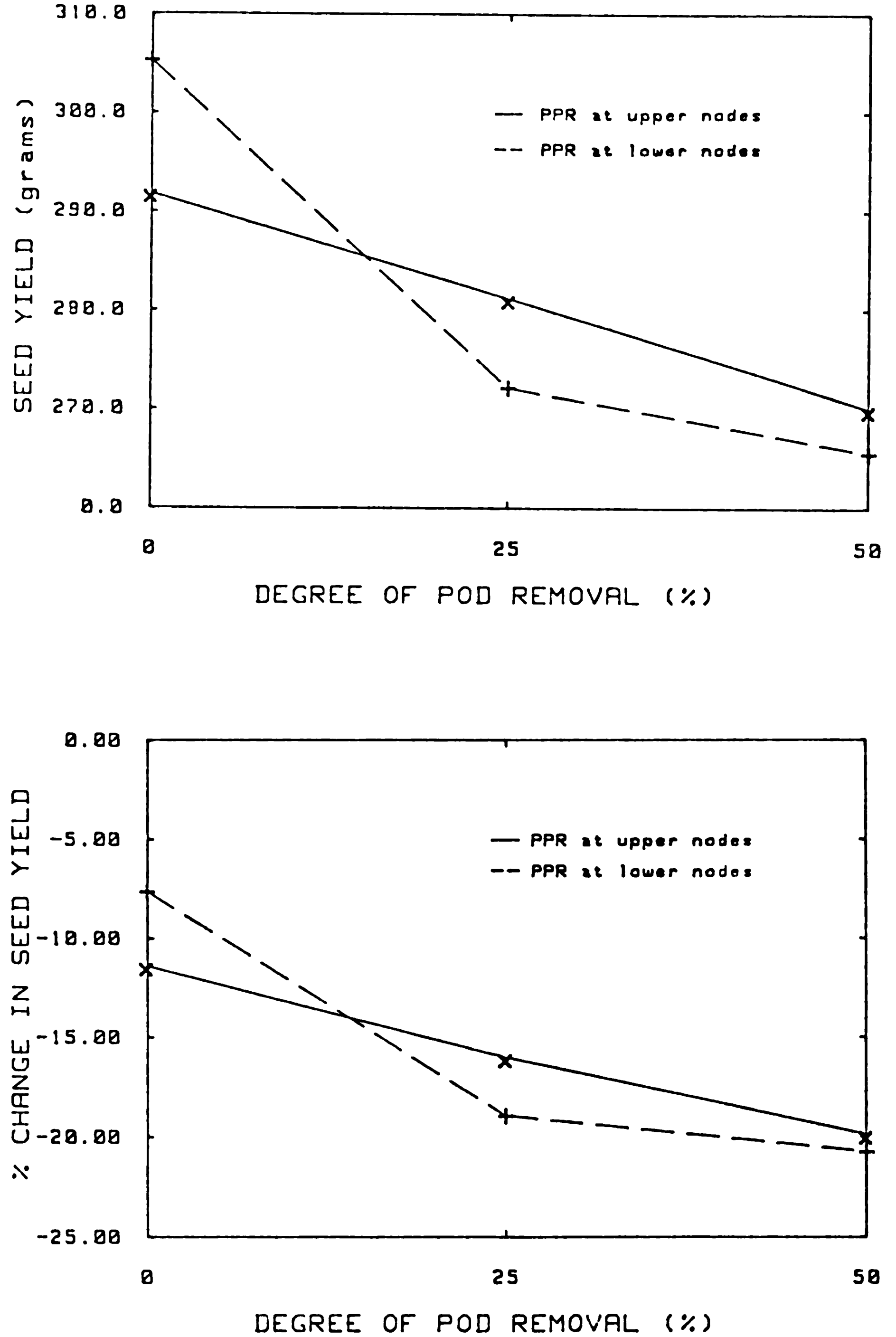


Figure 3. Effects of pod removal on seed yield (g/2m row section of subplot) and the percent change in seed yield.

TABLE 11. Seed yield response to pod removal.

Treatment number	A@	B#	Corsoy 79	Hodgson 78	Lakota	Maple Arrow	Weber	Wirth	Mean
			---(yield in grams / 2m subplot row section)---						
1	0	0	341.0a	317.5a	289.5a	355.0a	258.7a	321.0a	322.8a
2	0	25	284.0ab	288.9ab	253.6ab	341.8a	244.7b	282.4a	282.6bc
3	0	50	247.2b	225.3b	241.5abc	330.8a	289.2ab	285.7a	269.9bc
4	25	0	339.0a	252.4b	260.7ab	352.2a	338.2a	286.1a	304.7ab
5	25	25	229.4b	254.7b	244.9ab	298.0a	313.2ab	267.4a	267.9c
6	25	50	251.5ab	209.9b	275.7ab	341.0a	247.1b	301.9a	271.1bc
7	50	0	310.7ab	271.1b	222.6abc	317.5a	300.5ab	308.4a	288.5abc
8	50	25	269.0ab	269.9b	190.3bc	320.9a	280.1ab	264.5a	265.8c
9	50	50	231.7b	238.4b	153.5c	339.6a	321.4ab	249.4a	255.6c

C.V.% Cultivars= 11.86
C.V.% POd removal treatments= 15.90
LSD (0.05) Means within a cultivar= 89.88
LSD (0.05) Means across cultivars and replications= 36.70
Means within a column sharing the same letter are not significantly different from each other bt the LSD test at P= 0.05.
@ - % partial pod removal at upper ½ canopy nodes.
# - % partial pod removal at lower ½ canopy nodes.

TABLE 12. Pod removal effects on seed yield expressed as percent of control plants.

Treatment number	A[@]	B[#]	Corsoy 79	Hodgson 78	Lakota	Maple Arrow	Weber	Wirth	Mean % decrease
1	0	0	100.00a	100.00a	100.00a	100.00a	100.00a	100.00a	0.00a
2	0	25	83.98abc	77.17ab	89.18ab	95,94a	68.82b	88.33a	16.10bc
3	0	50	72.18c	66.34b	87.92ab	93.06a	81.95ab	89.46a	18.18bc
4	25	0	99.78ab	72.90b	93.44a	99.34a	94,46ab	90.00a	8.35ab
5	25	25	67.46c	69.20b	85.66ab	83.79a	88.20ab	83.40a	20.38c
6	25	50	73.38bc	54.75b	94.42a	96.27a	69.51b	94.51a	19.36c
7	50	0	91.10abc	72.19b	79.06abc	89.68a	84.45ab	95.84a	14.61bc
8	50	25	78.95abc	80.36b	66.25bc	90.04a	78.69ab	83.64a	20.34c
9	50	50	67.20c	64.53b	56.27c	95.92a	90.17ab	77.93a	24.65c

C.V.% Cultivars= 6.72
C.V.% Pod removal treatments= 15.44
LSD (0.05) Means within a cultivar= 26.17
LSD (0.05) Means across cultivars and replications = 10.68
Means within a column sharing the same letter are not significantly different from each other by the LSD test at P= 0.05.
@ - % partial pod removal at upper ½ canopy nodes.
# - % partial pod removal at lower ½ canopy nodes.

also remained significant. This may serve to indicate that the degree to which pod removal influences soybeans is independent of cultivar differences. Such differences have been attributed to differences in genetic make-up, seed size (as evident from differences in planted seed sizes, Table 3.), and other physiological and morphological differences.

Overall, Table 11 means (obtained by averaging across replications and cultivars) indicate that seed yield was maintained only in treatments 4 (25:0) and 7 (50:0), both having 0% depodding at the lower canopy nodes, suggesting that soybeans are highly sensitive to pod removal at lower nodes. When seed yields of depodded plants were expressed as percent of untreated plants (Table 12 and Figure 4), treatment 4 (25:0) was the only one not significantly different from the control, even though it had an 8.35% yield reduction.

The data is interpretted to suggest that 25 and 0% pod removal at upper and lower nodes respectively may be the maximum degree of pod removal soybeans withstand before seed yield is significantly reduced.

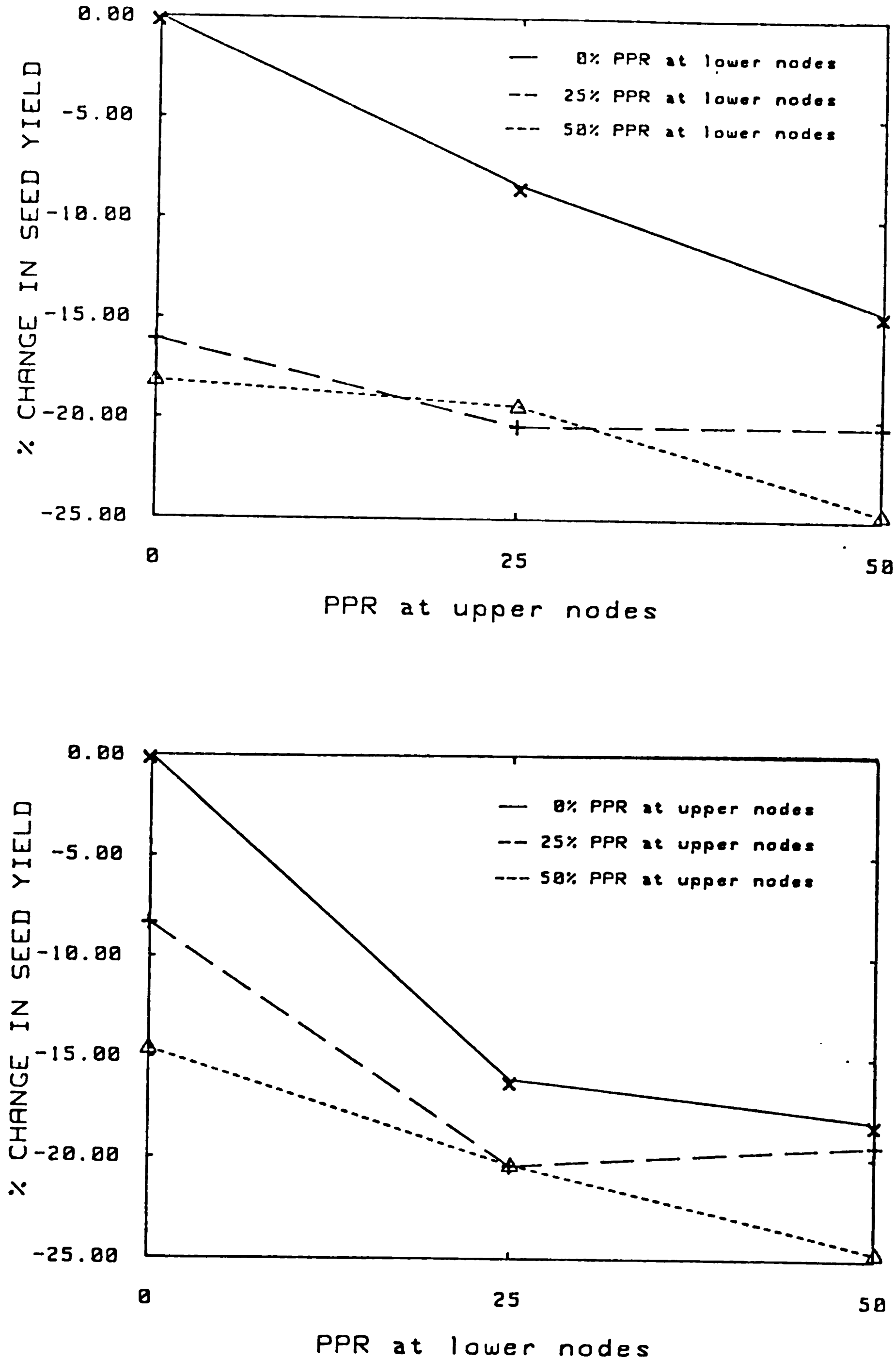


Figure 4. Seed yield (g/2m subplot section) response to pod removal at upper nodes (top) and lower nodes (bottom) expressed as a percentage of untreated plants.

SEED NUMBER RESPONSE TO POD REMOVAL.

The analysis of variance for seed number for the harvested 2m row sections of subplots showed significant cultivar differences and significant seed number reductions following pod removal (Tables 8 and 13). Differences in seed number were observed within the high response cultivars Maple Arrow and Weber, and between these two and the rest of the cultivars. Significant differences in seed number were also obtained within the low response cultivars (Lakota and Wirth) and the medium response cultivars (Corsoy 79 and Hodgson 78).

When seed number was expressed as percent of control, cultivar differences were not expressed, while pod removal effects remained significant at the 1% level (Tables 8 and 14), again indicating that the proportional effect of PPR was similar in all cultivars. However, the interactions among the groups of cultivars and the linear effects of pod removal at the lower nodes remained significant(Figure 5).

Tables 13 and 14 show that between the extremes of pod removal, seed number was reduced 16 to 39%, but that only Treatment 4 (25:0) maintained seed number. Highly significant linear components for seed number reduction at both canopy sites were obtained, and a significant interaction was obtained between cultivar groups and pod removal.

Response within individual cultivars was variable. In Corsoy 79, seed number was reduced by all pod removal treatments except 2 (0:25), 4 (25:0) and 7(50:0). As much

TABLE 13. The effects of pod removal on total seed number harvested from 2 meter row sections of subplot.

Treatment number	A[@]	B[#]	Corsoy 79	Hodgson 78	Lakota	Maple Arrow	Weber	Wirth	Mean
			------(# seeds from 2m row section of subplots)------						
1	0	0	1831a	1646a	1544a	1343a	2104a	1717a	1698a
2	0	25	1392abc	1375ab	1505a	1335a	1278bc	1334ab	1370bc
3	0	50	1131bc	962bc	1300ab	1253a	1413bc	1392ab	1240b-e
4	25	0	1781a	1280ab	1289ab	1287a	1651ab	1385ab	1445ab
5	25	25	1115bc	1045bc	1216ab	1040a	1578bc	1165b	1193b-e
6	25	50	1177bc	743c	1215ab	1223a	1106c	1196b	1110c-e
7	50	0	1614ab	1133bc	1153abc	1224a	1465bc	1392ab	1330b-d
8	50	25	1221bc	1008bc	846bc	1160a	1303bc	1034b	1095de
9	50	50	1017c	752c	667c	1196a	1430bc	993b	1009e

C.V.% Cultivars= 11.67
C.V.% Pod removal treatments= 19.46
LSD (0.05) Means within a cultivar= 499.78
LSD (0.05) Means across cultivars and replications= 204.04
Means within a column sharing the same letter are not significantly different from each other by LSD test at P= 0.05.
@ - % partial pod removal at upper ½ canopy nodes.
# - % partial pod removal at lower ½ canopy nodes.

TABLE 14. Effects of pod removal on seed number expressed as percent of control plants.

Treatment number	A@	B#	Mean* seed number	Actual decrease
			(total seeds/2m subplot)	(%)
1	0	0	100.00a	-
2	0	25	83.46a-c	16.54
3	0	50	75.80b-e	24.20
4	25	0	87.08ab	12.92
5	25	25	71.63b-e	28.37
6	25	50	62.02c-e	31.98
7	50	0	79.79b-d	20.21
8	50	25	65.90de	34.10
9	50	50	60.96e	39.04

LSD (0.01)= 16.80

* - obtained by averaging across cultivars and replications.

Means followed by the same letter are not significantly different from each other by the LSD test at P= 0.01

@ - % partial pod removal at upper ½ canopy nodes.
# - % partial pod removal at lower ½ canopy nodes.

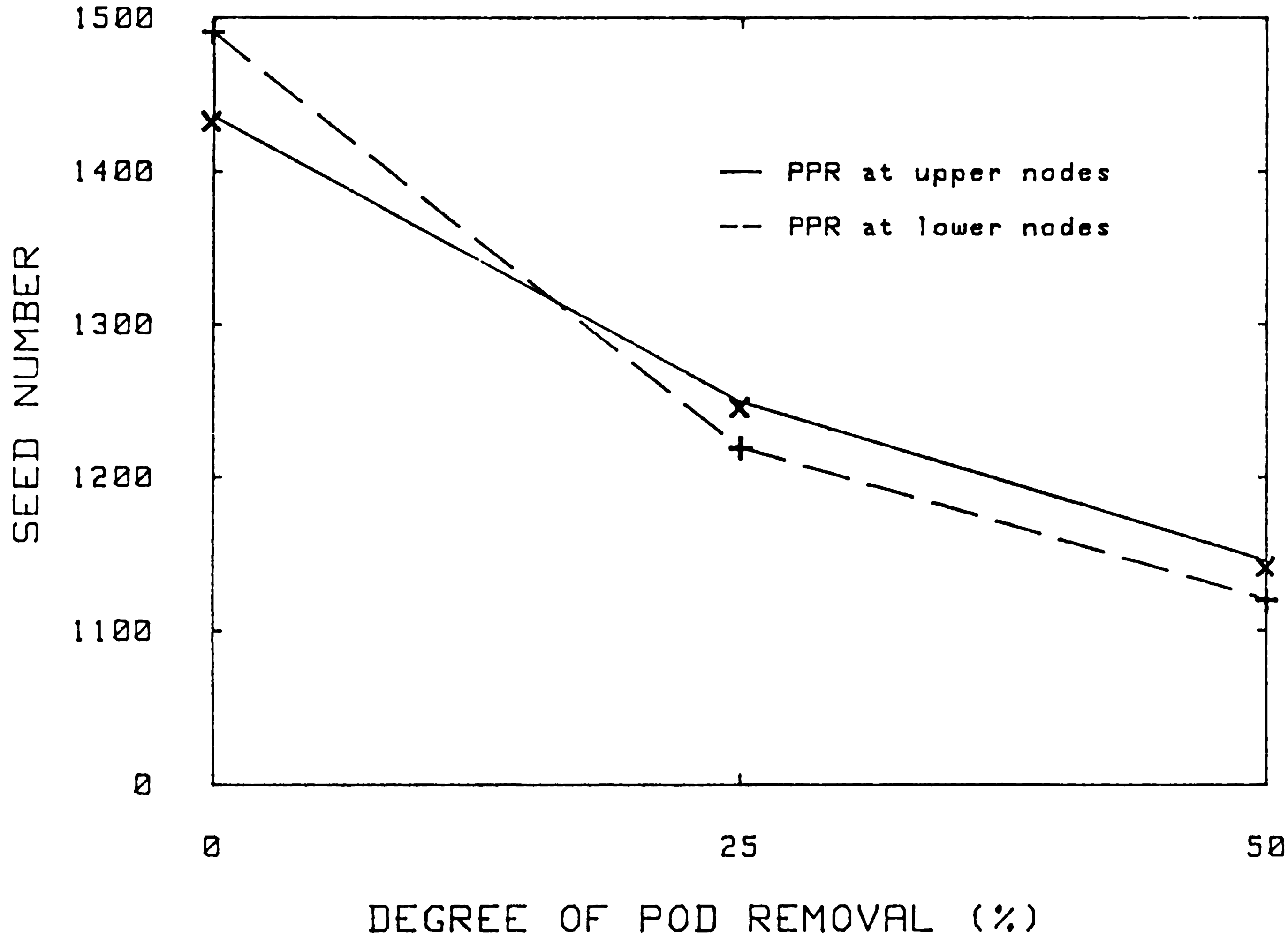
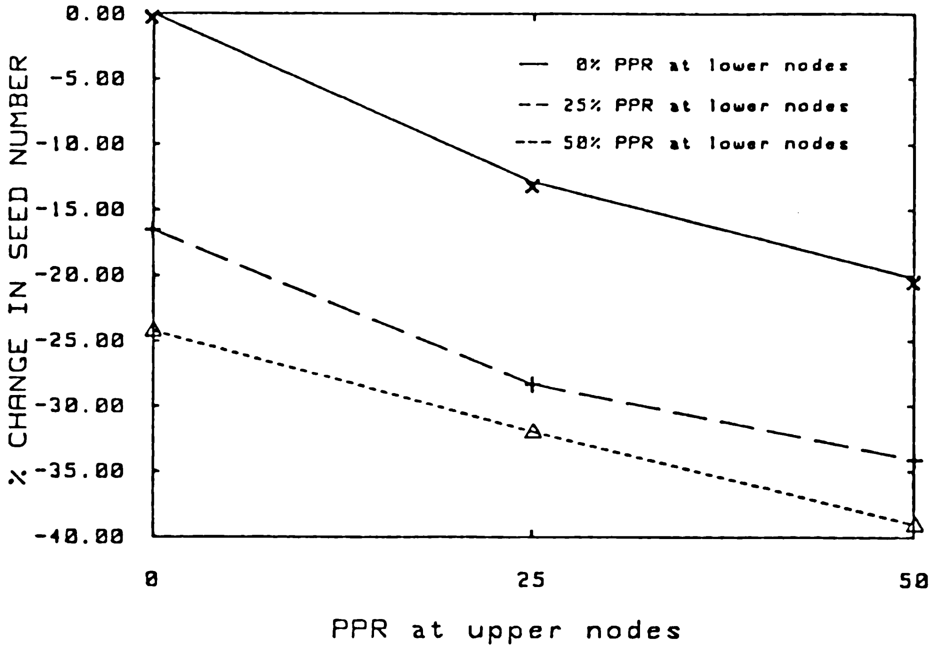


Figure 5. Effects of partial pod removal on the number of seeds harvested from 2 meter row sections of subplots.



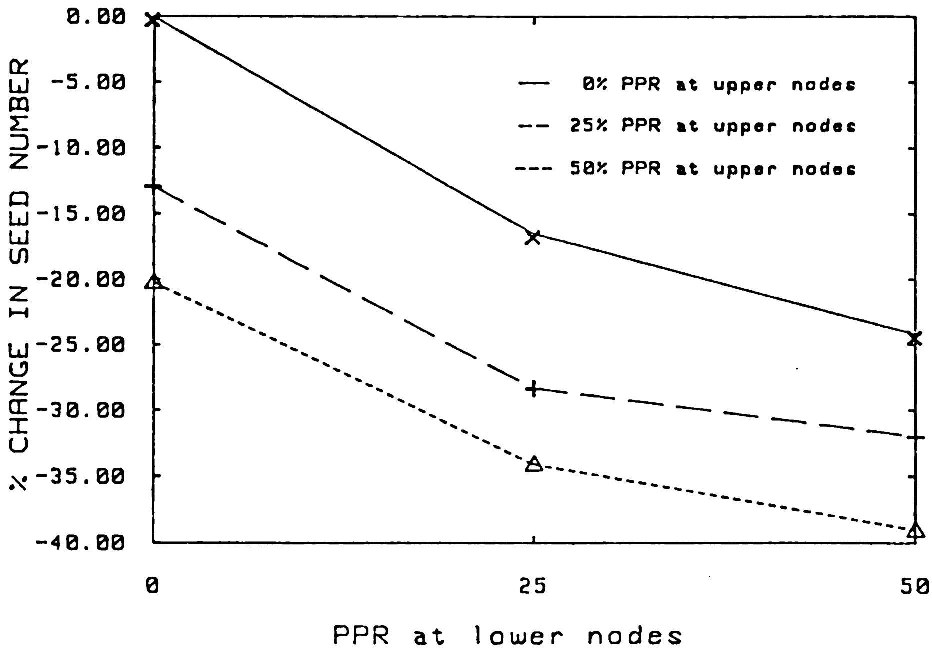


Figure 5 cont.
Partial pod removal effects on seed number expressed as percent of untreated plants.

as 45% reduction in seed number was observed in treatment 9 (50:50). In Hodgson 78 and Wirth, treatments 2,3,4 and 7 maintained seed number. The more severe depodding levels reduced seed number by as much as 36 to 55%. In Lakota, seed number became significantly reduced past the 50:0 PPR treatment. Weber maintained seed number in treatment 4 (25:0) only, while in Maple Arrow, seed number was not reduced by pod removal.

There was essentially the same number of seeds per pod regardless of treatment within each cultivar.

SEED SIZE RESPONSE TO POD REMOVAL.

Seed weight expressed as grams per one hundred seeds was used as the most sensitive measurement of seed size response to partial pod removal. The analysis of variance obtained was significant for both cultivar differences and pod removal effects at the 1% level (Table8). Differences were significant for for both among and within groups of cultivars. Differences within cultivar groups serve to indicate that the grouping of cultivars which was based on results of the preliminary (1983) experiment was incorrect, or that the response to pod removal by the cultivars was inconsistent.

When 100 seed weights were expressed as percent of untreated plants,cultivar differences were nonsignificant, while pod removal effects remained significant, an indication that the effects of pod removal on seed size was proportionately the same in all cultivars, and was independent of cultivar differences.

Between the two extremes of pod removal, individual cultivars showed a wide range of seed size response (Tables 15, 16 and 17). In Corsoy 79 and Hodgson 78, 100 seed weight changes resulting from pod removal treatments were not different from controls at P=0.01. At P=0.05 however, all pod removal treatments in Corsoy 79 induced a significant seed size increase ranging from 3 to 11%, while in Hodgson 78 seed size remained the same except for an unexpected decrease in treatment 4 (25:0) which however was

TABLE 15. Seed size response to pod removal (P= 0.01)

Treatment number	A[@]	B[#]	Corsoy 79	Hodgson 78	Lakota	Maple Arrow	Weber	Wirth	Mean*
			--------------seed size expressed as weight in grams of 100 seeds-----						
1	0	0	15.43a	17.53a-c	14.63a	20.03a	14.15a	15.89a	16.28a
2	0	25	16.01a	15.95c	16.36ab	21.31ab	14.72ab	17.52ab	16.95ab
3	0	50	16.21a	17.48a-c	14.84ab	21.48ab	15.59ab	17.87a-c	17.23bc
4	25	0	16.25a	15.86c	14.72ab	22.03ab	15.71ab	17.55ab	17.02a-c
5	25	25	16.53a	17.44a-c	15.73ab	22.04ab	15.66ab	18.64b-d	17.02a-c
6	25	50	16.52a	17.90a-c	16.20ab	22.37b	15.65ab	18.48b-d	17.85cd
7	50	0	16.38a	16.82bc	16.84b	20.75ab	15.73ab	18.92b-d	17.57b-d
8	50	25	17.13a	19.16a	16.32ab	21.65ab	16.08ab	20.28cd	18.44d
9	50	50	17.10a	18.82a	15.68ab	22.51b	16.53b	19.98d	18.44d
Mean**			16.40cd	17.44bc	15.70d	21.55a	15.54d	18.34b	

C.V.% Cultivars= 4.77
C.V.% Pod removal treatment= 4.69
LSD (0.01) Pod removal treatment means* = 0.90
LSD (0.01) Means within cultivars= 2.20
LSD (0.01) Cultivar means**= 1.59
Means within a column sharing the same letter are not significantly different from each other by the LSD test at P= 0.01.

TABLE 16. Seed size response to pod removal (P= 0.05).

Treatment number	A@	B#	Corsoy 79	Hodgson 78	Lakota	Maple Arrow	Weber	Wirth	Mean*
			-----------Seed size expressed as weight in grams of 100 seeds-----------						
1	0	0	15.43a	17.53a-d	14.63a	20.03a	14.15a	15.89a	16.28a
2	0	25	16.01b	15.95de	16.36bc	21.13a-c	14.72ab	17.52ab	16.95b
3	0	50	16.61b	17.48b-e	14.84ab	21.48a-c	15.59a-c	17.80b	71.23b-d
4	25	0	16.25b	15.86e	14.74ab	22.03bc	15.71a-c	17.55b	17.02bc
5	25	25	16.53b	17.44b-e	15.73a-c	22.04bc	15.66a-c	18.64b-d	17.67cd
6	25	50	16.52b	17.90a-c	16.20a-c	22.37bc	15.65a-c	18.48bc	17.85de
7	50	0	16.38b	16.82c-e	16.84c	20.75ab	15.73a-c	18.92b-d	17.57b-d
8	50	25	17.13b	19.16a	16.32bc	21.65a-c	16.08bc	20.28d	18.44e
9	50	50	17.10b	18.82ab	15.68a-c	22.51c	16.53c	19.98cd	18.84e
Mean**			16.40d	17.44bc	15.70d	21.55a	15.54d	18.34b	

C.V.% Cultivars= 4.77
C.V.% Pod removal treatments= 4.69
LSD (0.05) Pod removal treatment means*= 0.67
LSD (0.05) Means within cultivars= 1.65
LSD (0.05) Cultivar means**= 1.01
Means within a column sharing the same letter are not significantly different from each other by the LSD test at P= 0.05
@ - % partial pod removal at upper ½ canopy nodes.
# - % partial pod removal at lower ½ canopy nodes.

TABLE 17. Pod removal effect on seed size expressed as percent of untreated plants.

Treatment number	A[@]	B[#]	Corsoy 79	Hodgson 78	Lakota	Maple Arrow	Weber	Wirth	Average seed size increase(%)
Control	0	0	15.43a	17.53abc	14.63a	20.03a	14.15a	15.89a	00.00a
			(One hundred seed weight % increase(+) or decrease(-))						
2	0	25	+3.80ab	-9.07c	+12.00c	+5.49ab	+4.07ab	+10.36ab	4.44b
3	0	50	+5.07ab	-0.28abc	+1.33ab	+7.23ab	+10.15bc	+12.10b	5.93bcd
4	25	0	+5.32ab	-9.57c	+0.91a	+9.98b	+11.03b	+10.39b	4.68bc
5	25	25	+7.20ab	-0.44abc	+7.72abc	+10.03b	+10.64bc	+17.42bc	8.76d
6	25	50	+7.13ab	+2.16ab	+10.95bc	+11.69b	+10.59bc	+16.38bc	9.82de
7	50	0	+6.19ab	-4.10bc	+15.49c	+3.60ab	+11.16bc	+19.12bcd	8.58cd
8	50	25	+11.04b	+9.50a	+12.10c	+8.05ab	+13.67bc	+27.67d	13.67e
9	50	50	+10.88b	+7.38a	+7.75abc	+12.37b	+16.87c	+25.69cd	13.49e

C.V.% Cultivars= 8.09
C.V.% Pod removal treatments= 4.61
LSD (0.05) Means within cultivars= 10.0
LSD (0.05) Means across cultivars and replications= 4.08
Means within a column sharing the same letter are not significantly different from each other by the LSD test at P= 0.05.
@ - % partial pod removal at upper ½ canopy nodes.
# - % partial pod removal at lower ½ canopy nodes.

not significant when expressed as a percent of untreated plants. In Lakota, Maple Arrow and Weber, seed size was increased after the 25:50 pod removal treatment. In Wirth, treatment 3 (0:50) to 9 (50:50) showed significant seed size increases, and as much as 25% increase in seed size was observed.

There was a significant linear increase in seed size following pod removal (Table 8). Seed size increased as intensity of pod removal increased (Figures 6 and 7), but not proportionally so, ranging from 16.28 to 18.44 grams per 100 seeds (Tables 15 to 17). This represents a 4 to 13% seed size increase induced by partial pod removal across cultivars and replications.

A comparison of seed yield, seed number and seed size (Figures 3 to 7) indicates that soybean seed size was increased enough to compensate for 25 to 50% pod removal on the upper half canopy nodes, such that total seed yield was maintained.

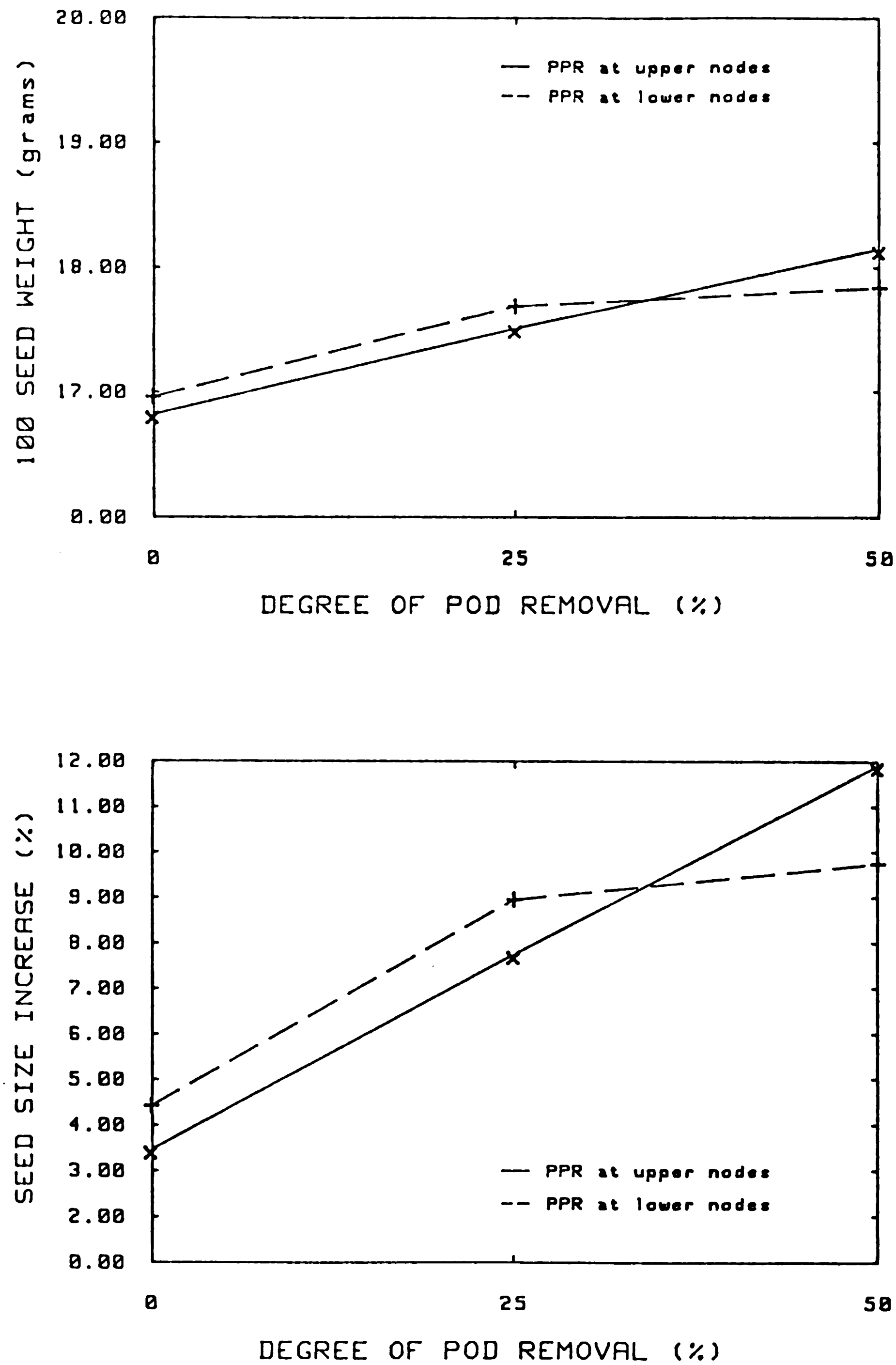
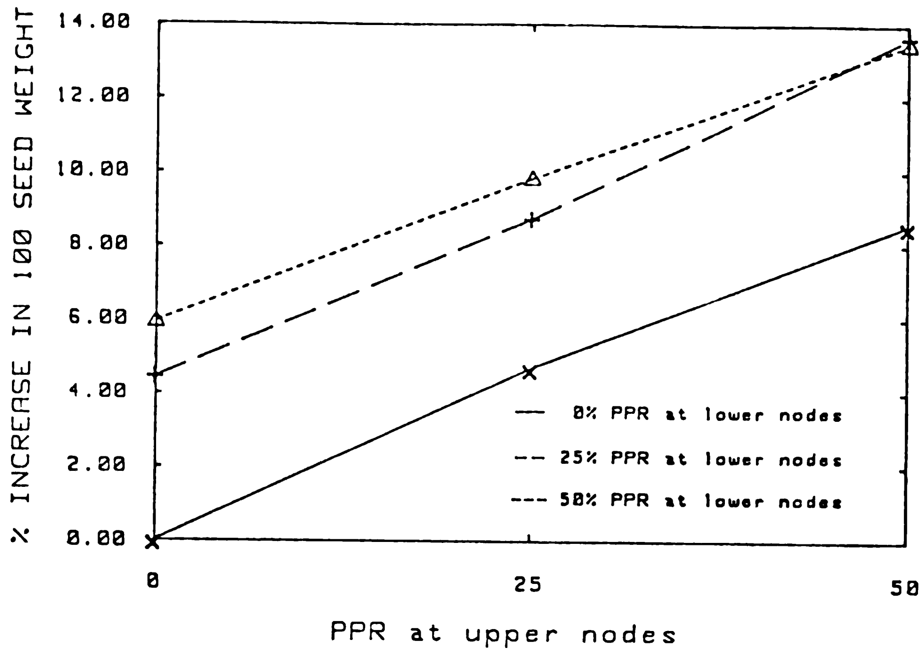


Figure 6. Seed size (expresssed as weight in grams of 100 seeds) response to pod removal.



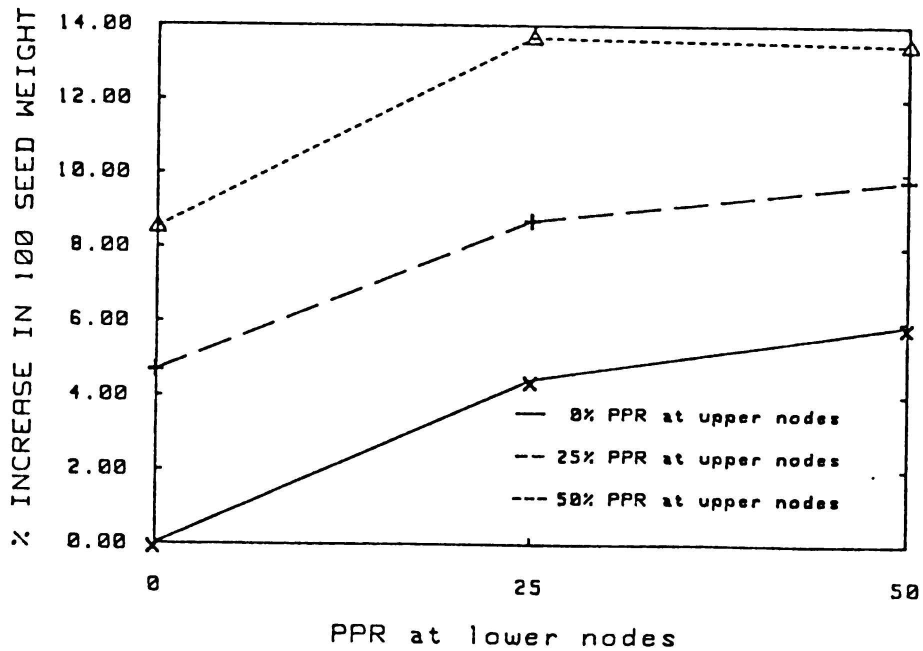


Figure 7. Partial pod removal effects on seed size (weight in grams of 100 seeds) expressed as a percentage of untreated plants.

The apparent recovery of seed yield in the treatments not depodded on lower half canopy nodes may be explained by changes pod removal induces in the patterns of light interception, seed or pod abortion and assimilate redistribution.

About 90% of the light interception in soybeans occurs primarily at the periphery of the canopy, and when the space within and between rows is closed, light interception is restricted to the very top of the canopy (54). Thus the lower leaves function in relatively low light intensities. Removing 25 to 50% of the pods on the upper half canopy nodes could have increased light interception and distibution in the canopies, both which have been long recognized to contribute dominant roles to crop productivity (24,46,54). In this study, no measurements of light levels were made, and the hypothesis that pod removal at upper nodes changes canopy light regimes may require further substantiation.

Soybeans produce many more flowers than mature pods. As much as 85% of the flowers may abort, with 75% abortion occuring during the full bloom stage (21). Pod removal has been shown to reduce pod and floral abortion (21,36,48). All cultivars used in this study were indeterminate types (types that continue vegetative growth during flowering), and their upper half canopy nodes would be producing flower buds long after the lower nodes would have stopped. Because pod set is genetically controlled, if the lower half canopy fails to contribute its full share of pods, they may be compensated for by an increased pod set in the upper half nodes. The maintainance of seed yield and number in plants receiving no depodding at lower nodes (Traetments 4 (25:0) and 7 (50:0)) would be expected, because the normally high pod abortion in the entire plant canopy is not duplicated in those partially depodded. However, Treatment 7 (50:0) significantly lost seed number and seed yield, and this is possibly because 50% PPR was just too severe to be fully compensated for.

The 4 to 14% increase in seed weights of depodded plants (Tables 15 to 17) has been reported by other investigators (6,8,11,36,52), and is most likely a reflection of a larger leaf area supplying assimilates to a smaller number of seeds. Begum and Eden (2) have reported significant yield reductions following defoliation treatments applied when beans were half grown in the pods, an indication that at this stage, soybean seed growth was rapid and highly dependent on assimilate supply from the leaves. Removal of pods at mid pod filling stage would therefore be expected to reduce competition for assimilates in the remaining seeds, resulting in seed size increases that compensate for part or all of the pods removed. The yield reduction observed in all PPR treatments except number 4 (25:0) could be a result of failure of the remaining seeds to fully utilize the increased assimilate supply, or because pod removal past the 25:0 mark becomes severe for plants to withstand.

According to Metz _et al_. (37), plants that produce high seed yields should possess characters believed to influence photosynthetic efficiency, partitioning of dry matter to seed production, and prevent seed yield losses through lodging resistance. Among such characters are vertical leaf orientation, high leaf area duration, thick stout stems, and minimum intraplant competition. In this study, pod removal achieved most of these characters. Depodded plants had thicker greener stems compared to untreated plants. Removal of pods reduced the sink size thereby reducing intraplant competition in the remaining seeds. Pod removal extended the leaf area duration as is evident from the visually observed delay in the onset of senescence and leaf abscission. Thus depodded plants would be expected to yield comparably to controls, but in this study, all pod removal treatments except number 4 (25:0) had significant yield reductions, an indication that 25 and 0% pod removal on upper and lower nodes respectively was the maximum pod removal degree increasing seed size enough to compensate for pods removed, such that yields were maintained.

SUMMARY AND CONCLUSION

Field experiments were conducted at Michigan State University, East Lansing, during the 1983 and 1984 growing seasons, to study the effects of partial pod removal (PPR) on soybean (Glycine max (L.) Merrill) seed number, size and yield. Sources of variation examined were cultivars, degree of pod removal (0, 25 and 50%), and site of pod removal (upper versus lower half canopy nodes).

The factorial set of treatments was arranged in a split plot design with whole plots in randomized complete blocks. Six cultivars occupied whole plots and pod removal treatments were applied to subplots. Pod removal treatments were applied when beans in the pods were half grown. At maturity, plants were harvested and dried. Dry matter yield (pod + stem + leaves), seed number, size and yield were determined. Seed size was expressed as weight in grams of 100 seeds.

Pod removal delayed soybean leaf senescence (visually judged by loss of green color) and leaf abscission (visually determined by the amount of leafage at harvest).

Cultivars were significantly different in dry weights, seed numbers, seed sizes, and seed yields. Differences were significant for both within and among cultivar groups, grouped on the bases of their response to 50% pod removal in the 1983 study. Differences within cultivar groups serve to indicate that the criteria used to group them was incorrect, or that the cultivar response to pod removal was not consistent over the two years of this study. When PPR effects were expressed as percent of untreated plants, cultivar differences were nonsignificant for all seed characters examined, indicating that pod removal affected all cultivars similarly. Overall means obtained by averaging across replications and cultivars showed general trends for linear dry weight, seed number, and seed yield reduction following pod removal.

Between the extremes of pod removal, dry weight decreased 8 to 16%, but decreases up to 10% were not significant in plants not depodded on one site of the canopy, suggesting that at least 25% PPR was required on both the upper and lower canopy nodes to significantly reduce dry matter production.

Up to 25% reduction in seed yield was observed with 50% pod removal on both canopy sites. Seed yield was maintained in plants not depodded on the lower canopy nodes. There was greater seed yield reduction as intensity of pod removal at lower nodes increased ($r = 0.47$ at $P=0.01$).

Seed number was reduced by pod removal, except in the 25:0 (25 and 0% PPR at upper and lower nodes respectively) treatment. 30 to 40% seed number reductions were observed in the more severely depodded plants.

Seed size (expressed as weight in grams of one hundred seeds) increased by as much as 13%, from 16.28 in untreated plants, to 18.44 in plants receiving 50% pod removal on both canopy nodes.

The following conclusions were drawn from the results of this study:

1 Soybean plants were more sensitive to partial pod removal in terms of dry matter yield, seed yield, and seed number, compared to pod removal at the upper nodes.

2 Pod removal effects (on the seed characters) expressed as percent of untreated plants were similar in all cultivars, an indication that the effect of pod removal was proportionally the same in all cultivars, and was independent of cultivar differences.

3 Dry weight, seed number, size and yield response to pod removal was linear.

4 Much of the capacity of the soybean plants to compensate for pod loss was by increasing seed size rather than by increasing or maintaining seed number.

5 25% PPR at upper nodes and 0% PPR at lower nodes was the highest pod removal combination inducing the least seed number and seed yield reductions (13 and 8.5% respectively), such that a 5% increase in seed size obtained was enough to compensate for pods removed, thereby maintaining total seed yield.

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