Source and Sink Effects on Protein and Oil Accumulation in Soybean

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ABSTRACT

rrill) seed growth in field environments can be either source-limited or sink-limited, as the source-sink ratio during the seed filling period often depends on the environmental conditions present during seed fill relative to the conditions present during flower and pod set. Source-sink ratios can also be altered experimentally through the use of pod removal, shade, and defoliation treatments. Field experiments in multiple locations near St. Paul, amine relationships between yield, seed protein concentration, and seed oil concentration sink-limited conditions. Sink-limited conditions resulted in significant increases in seed size and seed protein concentration, as well as significant decreases in seed oil concentration. Source-limited conditions resulted in decreased seed weight with variable effects on seed composition. Shade treatments significantly increased seed ind decreased seed oil concentration, while defoliation treatments resulted in decreased seed vith minimal effect on seed oil concentration. Yield and seed protein concentration were negatively correlated under both source- and sink-limited conditions, except when plants were defoliated. In addition, seed protein concentration and seed oil concentration were negatively correlated under both source- and sink-limited conditions, except when plants were defoliated. Under defoliated conditions, there was no correlation between yield and ation, and decreases in seed protein concentration did not result in concomitant increases in seed oil concentration. Results suggest that factors at both the seed level and whole-plant level affect the relationships

MATERIALS AND METHODS

between yield, seed protein concentration, and seed oil concentration

Field trials were established at University of Minnesota sites near Becker, St. Paul, and Lamberton, MN in 2006 and at University of Minnesota sites near Becker and Rosemount, MN in 2007. Commercial cultivar Asgrow 2107 was grown in Lamberton, while commercial cultivar Pioneer 91M61 was grown in Becker, St. Paul, and Rosemount. Plots were four rows wide and 3 m long with 76 cm row spacing, and a 1 m length of the middle two plot rows was harvested. A seeding rate of 370,500 seeds ha⁻¹ was used. Treatments were arranged in a randomized complete block design and replicated four times.

POD REMOVAL TREATMENTS: Pod removal treatments were applied at R5, and were designed to reduce the sink capacity of treated plants to 80%, 60%, 40%, or 30% of the control. Treatments consisted of complete pod removal from all branch nodes and designated main stem nodes as outlined in the following table, with the bottom node defined as the first node above the unifoliate node:

| Treatment Name | Procedure |
|----------------|---|
| Depod 80% | Remove pods from bottom 5 nodes. |
| Depod 60% | Remove pods from bottom 5 nodes. For the rest of the main stem, alternate leave 1 node, remove pods from 1 node. |
| Depod 40% | Remove pods from bottom 5 nodes. For the rest of the main stem, alternate leave 1 node, remove pods from 2 nodes. |
| Depod 30% | Remove pods from bottom 5 nodes. For the rest of the main stem, alternate leave 1 node, remove pods from 3 nodes. |

SHADE TREATMENTS: Shade treatments were applied at R5, and commercial shade cloth with respective light reduction ratings of 50%, 60%, 70%, and 80% was used. The shade cloth was suspended over the plots at a height of 1.8 m, and the complete length of all four plot rows was effectively shaded.

DEFOLIATION TREATMENTS: Defoliation treatments consisted of upper half canopy defoliation or lower half canopy defoliation at soybean growth stage R5. A random sample of soybeans was first taken from the border areas to determine the average number of nodes per plant, and this number was then used to determine nodal locations for leaflet removal. All branch node leaflets were also removed.

Seed samples were analyzed for protein and oil content with NIR spectroscopy, and protein, oil, seed weight, and yield values are expressed on a 13% seed moisture basis. Categorical data was analyzed with the GLM procedure of SAS version 8.2, and regression analyses were performed with SigmaPlot version 10.0.

For this poster, the term "environment" refers to an individual location-year combination. When not indexed to the control, seed sizes are expressed on a mg seed⁻¹ basis.

RESULTS

TREATMENT EFFECTS WITHIN ENVIRONMENTS

S Figure 1 describes pod removal treatment effects on seed protein and oil concentrations within a single environment. S Pod removal treatments increase seed protein concentration and decrease seed oil concentration.

S Figure 2 describes shade and defoliation treatment effects on seed protein and oil concentrations within a single

- Shade treatments increase seed protein concentration and decrease seed oil concentration. Defoliation treatments either decrease or have minimal effect on seed protein concentration, and have minimal effect on seed oil concentration.
- S Figure 3 describes treatment effects on seed size within all environments.
 - Pod removal treatments increased seed size when compared to the control, indicating that seed growth was sink-limited within this treatment group.
 - Shade treatments and defoliation treatments decreased seed size when compared to the control, indicating that seed growth was source-limited within these treatment groups.
- S Table 1 describes treatment effects on protein, oil, yield, seed size, and seed number across the two 2007
 - Protein and oil responses are often significantly different among shade treatments of varying intensity, and are often similar among pod removal treatments of varying intensity.

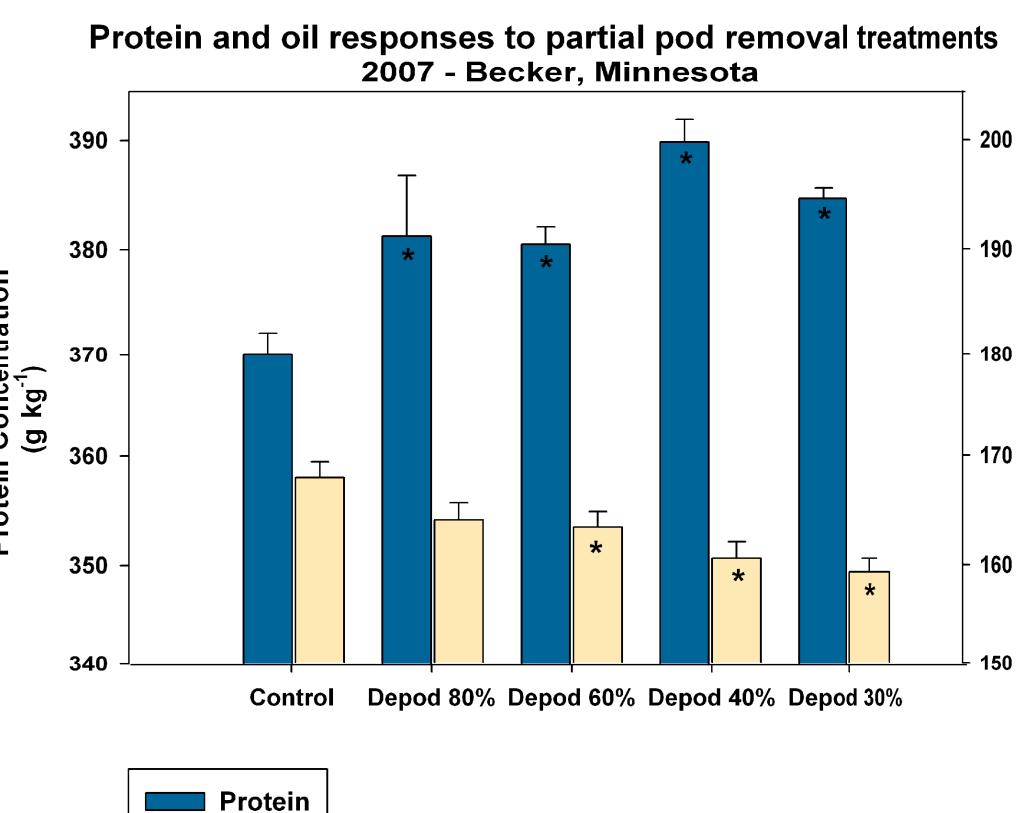
RELATIONSHIPS BETWEEN RESPONSE VARIABLES WITHIN TREATMENT GROUPS

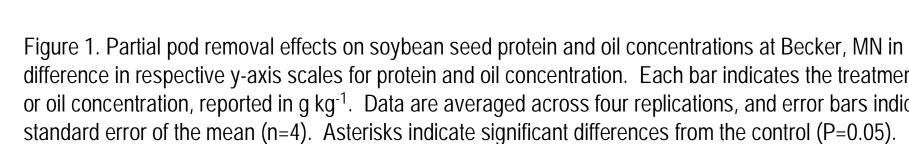
- S Relationships between response variables within treatment groups are complicated by variation between environments (Figures 4 and 5). Therefore, response variables were indexed to allow analysis of data across all environments (Figures 6 – 11).
- S Under sink-limited conditions, yield is correlated with seed number but not with seed size, although seed size is generally larger than the control (Figure 6).
- S Under source-limited conditions, yield is correlated with both seed number and seed size, and relationships are similar for both methods of source reduction (Figure 7).
- § Figure 8 describes the relationship between seed size and seed protein concentration under both sink- and sourcelimited conditions; Figure 9 describes the relationship between seed size and seed oil concentration.
 - Under sink-limited conditions, there is no correlation between seed size and seed protein concentration nor between seed size and seed oil concentration.
 - Under source-limited conditions created by shade, decreases in seed size are correlated with increases in seed protein concentration and decreases in seed oil concentration.
 - Under source-limited conditions created by defoliation, decreases in seed size are correlated with decreases in seed protein concentration with no correlation to seed oil concentration.

S Figure 10 describes the relationship between yield and seed protein concentration under both sink- and source-limited conditions; Figure 11 describes the relationship between yield and seed oil concentration.

- Reductions in yield under sink-limited conditions are correlated with increases in seed protein concentration and decreases in seed oil concentration.
- Reductions in yield under source-limited conditions created by shade are correlated with increases in seed
- protein concentration and decreases in seed oil concentration.
- Under source-limited conditions created by defoliation, there is no correlation between yield and seed protein concentration nor between yield and seed oil concentration.

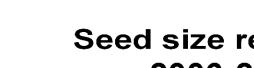
F1 and F2

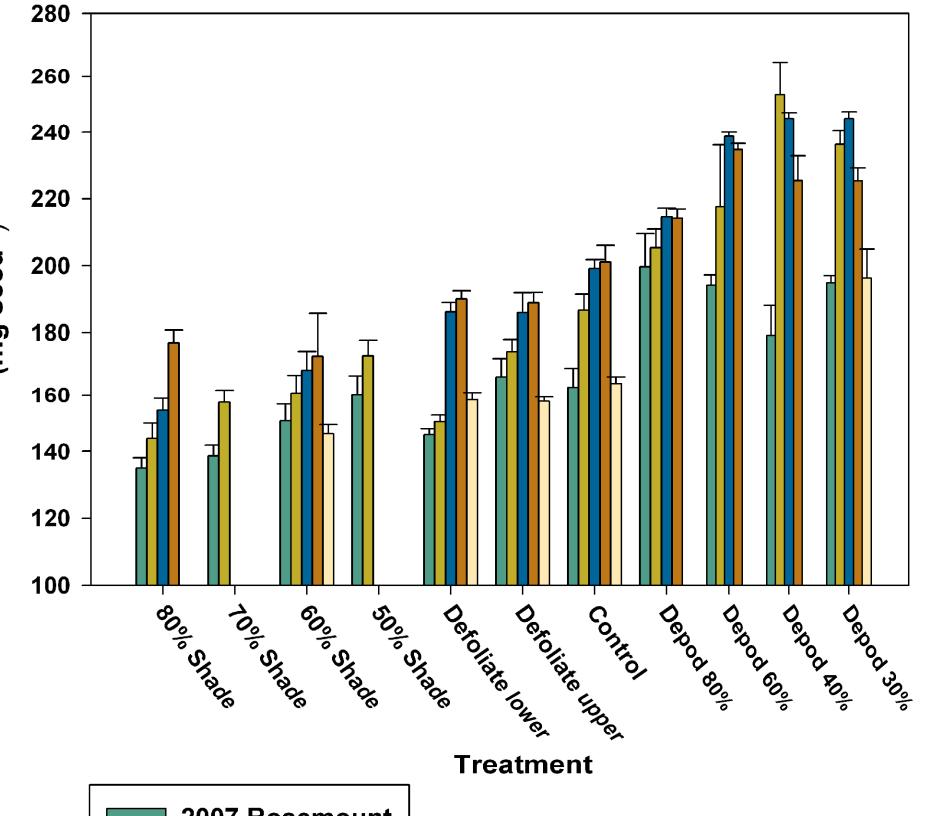




Oil 📃







2007 Rosemount 2007 Becker **2006 St. Paul 2006** Becker 2006 Lamberton

replications, and error bars indicate standard error of the mean (n=4).

across Becker and Rosemount in 2007

| | | | | | | Pr> | | | | | |
|---|------------|------------------------------------|-------------------|---|-----|---|-----|--|-----|---|-----|
| | | Protein (g · kg ⁻¹) | | Oil (g [·] kg ⁻¹) | | Yield (kg [·] ha ⁻¹) | | Seed Size (mg ⁻ seed ⁻¹) | | Seed Number (seeds [·] m ²) | |
| Source | df | | | | | | | | | | |
| Location | 1 | <.0001 | *** | <.0001 | *** | <.0001 | *** | <.0001 | *** | <.0001 | *** |
| Blocks (Location) | 6 | 0.0009 | *** | 0.0207 | * | 0.0209 | * | 0.2290 | NS | 0.1571 | NS |
| Treatment | 13 | <.0001 | *** | <.0001 | *** | <.0001 | *** | <.0001 | *** | <.0001 | *** |
| Location x Treatment | 13 | <.0001 | *** | 0.0048 | ** | <.0001 | *** | <.0001 | *** | <.0001 | *** |
| * indicates significance at P=0.05 ** indicates significance at P=0.01 | | | | | | | | | | | |
| *** indicates significance at P=0.001 | | | | | | | | | | | |
| NS indicates significance at P=0.05 | | | | | | | | | | | |
| | | Protein | | Oil | | Yield | | Seed Size | | Seed Number | |
| Treatment | (<u>ç</u> | | J ^{−1}) | (g | | (kg ha ⁻¹) | | $(mg^{-1}seed^{-1})$ | | (seeds · m ²) | |
| Control | | 376 | f | 171 | а | 3440 | а | 175 | С | 1910 | а |
| Defoliate upper canopy @R5 | | 357 | h | 171 | а | 2110 | cd | 148 | ef | 1420 | С |
| Defoliate lower canopy @R5 | | 366 | g | 172 | а | 2970 | b | 170 | С | 1730 | ab |
| 50% Shade beginning @ R5 | | 377 | f | 166 | b | 2930 | b | 166 | cd | 1750 | ab |
| 60% Shade beginning @ R5 | | 380 | ef | 163 | b | 2480 | С | 156 | de | 1580 | bc |
| 70% Shade beginning @ R5 | | 395 | ab | 154 | С | 2390 | С | 148 | ef | 1570 | bc |
| 80% Shade beginning @R5 | | 398 | а | 152 | С | 2250 | С | 140 | f | 1580 | bc |
| Depod 80% | | 388 | cd | 165 | b | 2980 | b | 203 | b | 1470 | С |
| Depod 60% | | 384 | de | 165 | b | 2350 | С | 206 | ab | 1150 | d |
| Depod 40% | | 391 | bc | 163 | b | 1770 | de | 216 | а | 790 | е |
| Depod 30% | | 387 | cd | 163 | b | 1720 | е | 216 | ab | 780 | е |
| LSD (0.05) | | 6 | | 4 | | 370 | | 13 | | 210 | |

Values followed by the same letter are not significantly different at P=0.05.

Figure 1. Partial pod removal effects on sovbean seed protein and oil concentrations at Becker, MN in 2007. Note the difference in respective y-axis scales for protein and oil concentration. Each bar indicates the treatment mean protein or oil concentration, reported in g kg⁻¹. Data are averaged across four replications, and error bars indicate the

Protein and oil responses to shade and defoliation treatments 2007 - Becker, Minnesota

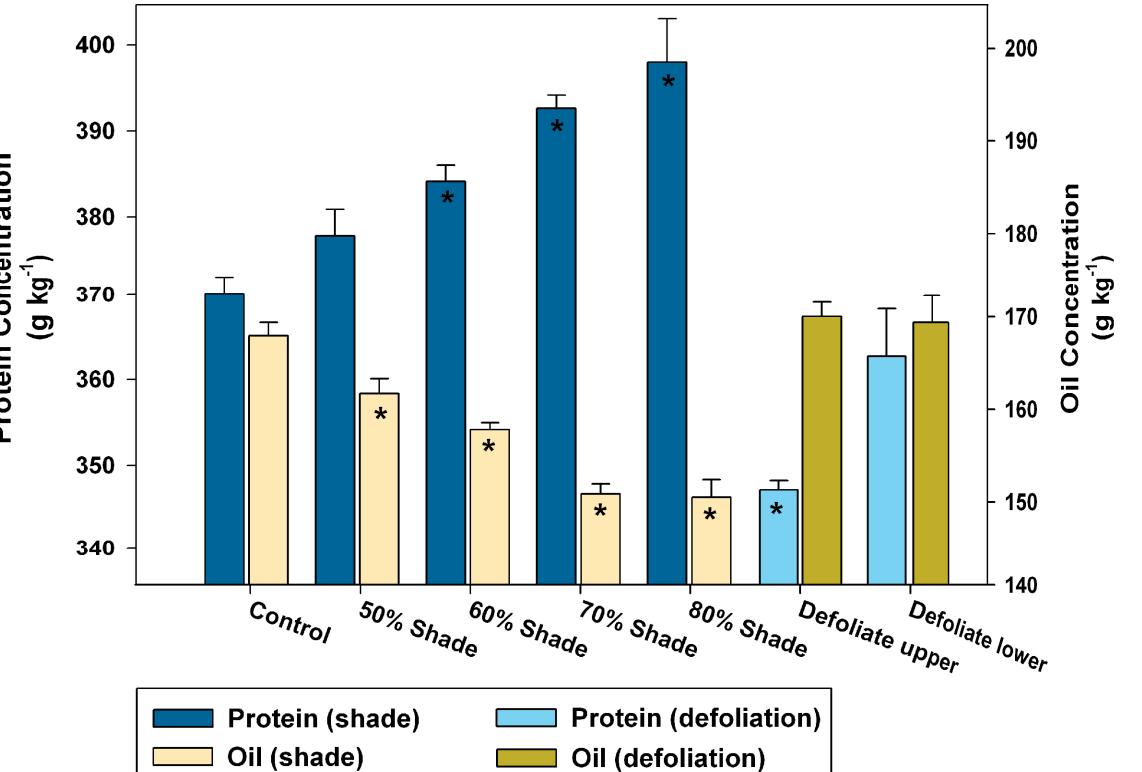
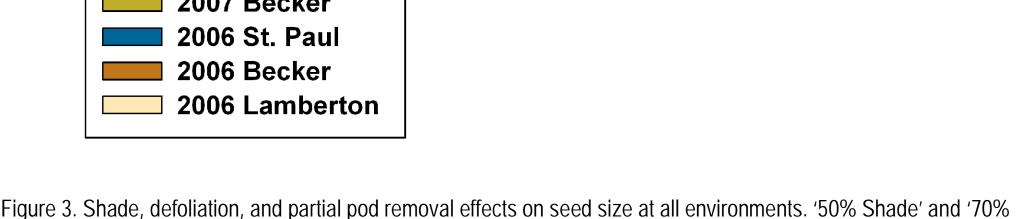


Figure 2. Shade and defoliation effects on sovbean seed protein and oil concentrations at Becker, MN in 2007. Note the difference in respective y-axis scales for protein and oil concentration. Each bar indicates the treatment mean protein or oil concentration, reported in g kg⁻¹. Data are averaged across four replications, and error bars indicate the standard error of the mean (n=4). Asterisks indicate significant differences from the control (P=0.05).

Seed size response by treatment 2006-2007 All locations



Shade' treatments were only applied in 2007, and only 5 of the 11 treatments were applied in the '2006 Lamberton' environment. Each bar indicates the treatment mean seed size, reported in mg seed⁻¹. Data are averaged across four

Analysis of variance table for protein, oil, yield, seed size, and seed number responses to treatments



Conclusions

q Under source-limited conditions, smaller seeds are produced, with protein concentrations dependent on source reduction method. When compared to the control, shaded pl produce seeds with higher seed protein concentration, while defoliated plants prod with lower seed protein concentration.

q For shaded plants:

- **q** Yield decreases are correlated with seed size decreases.
- **Q** Seed size decreases are correlated with increases in seed protein concentration.
- **Q** As yield decreases, seed protein concentration increases.
- **q** For defoliated plants
 - **Q** Yield decreases are correlated with seed size decreases.
 - **Q** Seed size decreases are correlated with decreases in seed protein concentration.
 - **Q** As yield decreases, there is no relationship with seed protein concentration.

F4 and F5

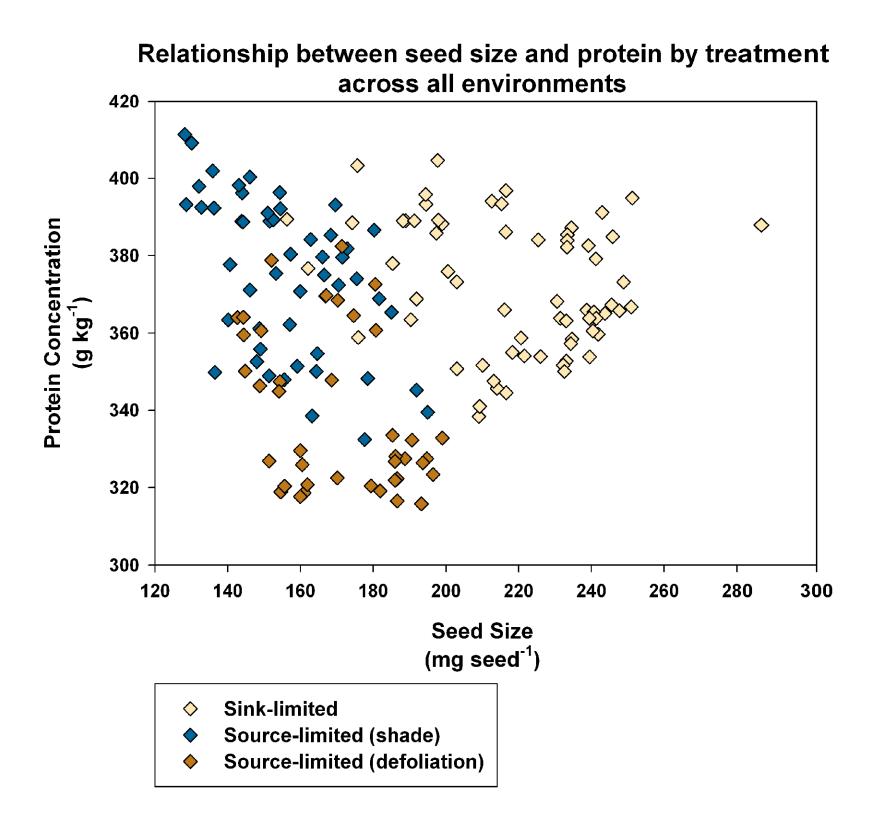


Figure 4. Relationship between seed size and seed protein concentration for soybeans treated with partial pod removal, shade, and defoliation. Sink-limited conditions correspond to pod removal treatments, and source-limited conditions correspond to both shade and defoliation treatments. Data from all five environments is shown, and each data point represents one plot at one environment.

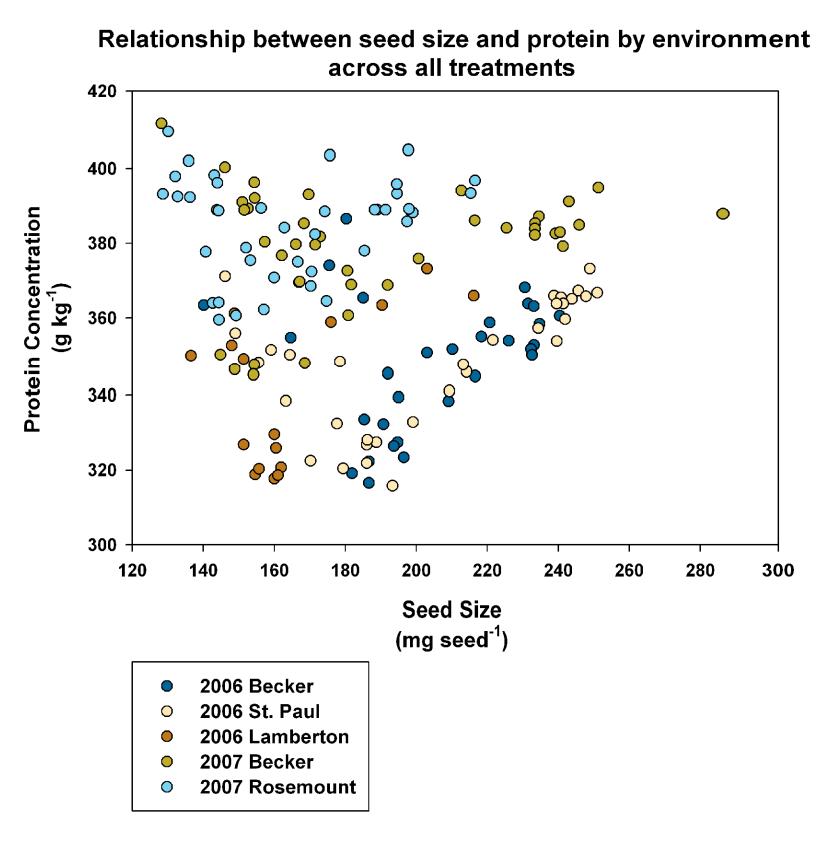
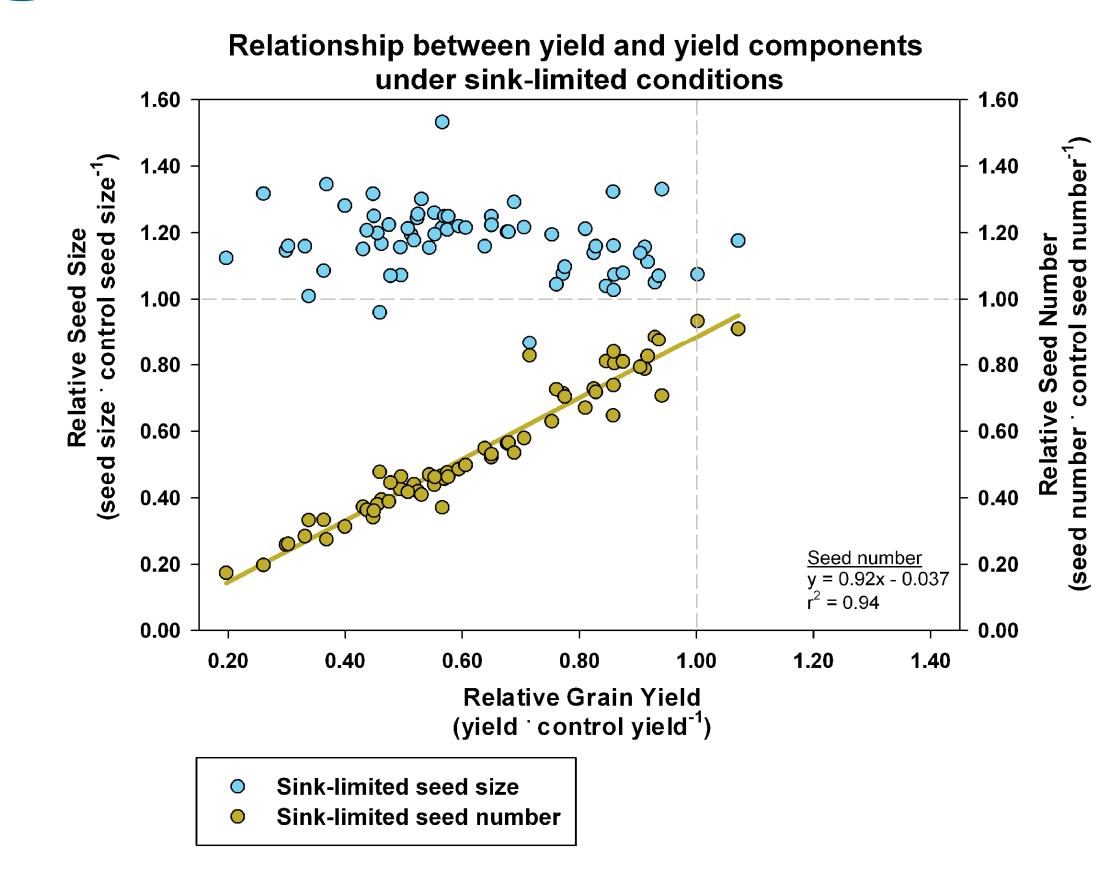


Figure 5. Relationship between soybean seed size and seed protein concentration at each environment. Data from partial pod removal, shade, and defoliation treatments is shown. Each data point represents one plot at one environment.











environmer

F10 and F11

| icentration protein ⁻¹) | 1.10 |
|--|------|
| elative Protein Concentration (protein [·] control protein ⁻¹) | 1.00 |
| Relative P (protein | 0.90 |

environment.

| ntrations plants | Q Under sink-limited conditions, bigger seeds are produced, with higher protein concentrations than control seeds. |
|---------------------|---|
| oduce seeds | q Yield is independent of seed size. |
| | q Seed size is independent of seed protein concentration. |
| | q As yield decreases, seed protein concentration increases. |
| oncontration | q Implications for relationships between protein, oil, and yield: |

- **q** Factors at the seed level appear to affect the relationship between yield and seed protein concentration.
- **Q** Seed load at the plant level also appears to play a role in the relationship between yield and seed protein concentration.
- **Q** Leaf protein reserves are important for seed protein accumulation, and are apparently more important than leaf photosynthetic output.
- **Q** Under both source- and sink-limited conditions, increases in seed protein concentration were associated with decreases in seed oil concentration.
- **q** It is difficult to achieve higher seed oil concentrations, even when seed protein concentrations are reduced.

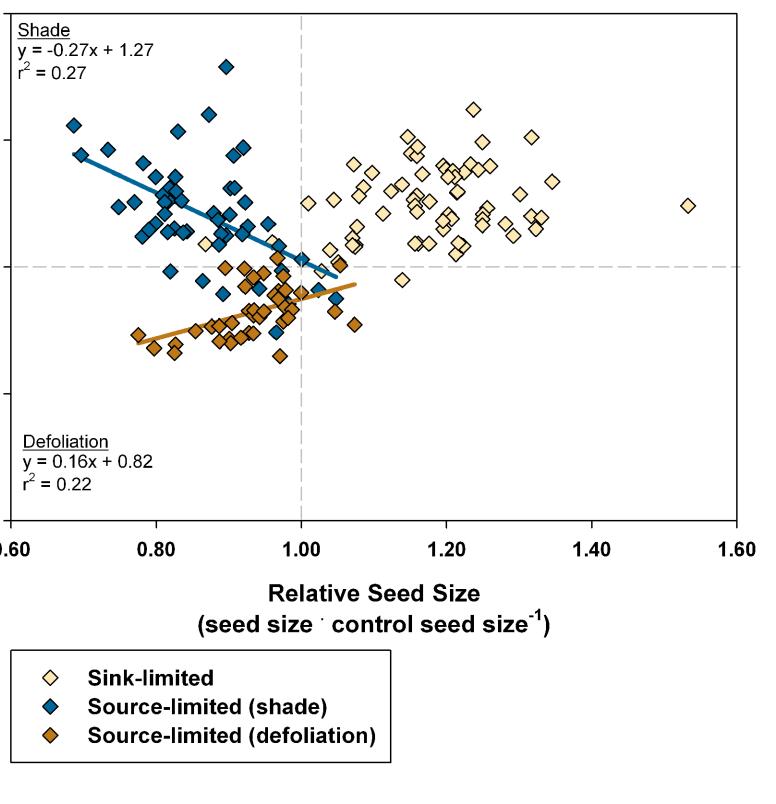




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Figure 6. Relationship between seed yield and components of yield for soybeans treated with partial pod removal prior to seed filling. Yields, seed sizes, and seed numbers were indexed to the control within a particular environment, and are reported on a fractional basis. Each data point represents one plot at one environment.



Relationship between seed size and seed protein concentration

under source- and sink-limited conditions

Figure 8. Relationship between seed size and seed protein concentration for soybeans treated with partial pod removal, shade, or defoliation prior to seed filling. Yields, seed sizes, and seed numbers were indexed to the control within a particular environment, and are reported on a fractional basis. Each data point represents one plot at one

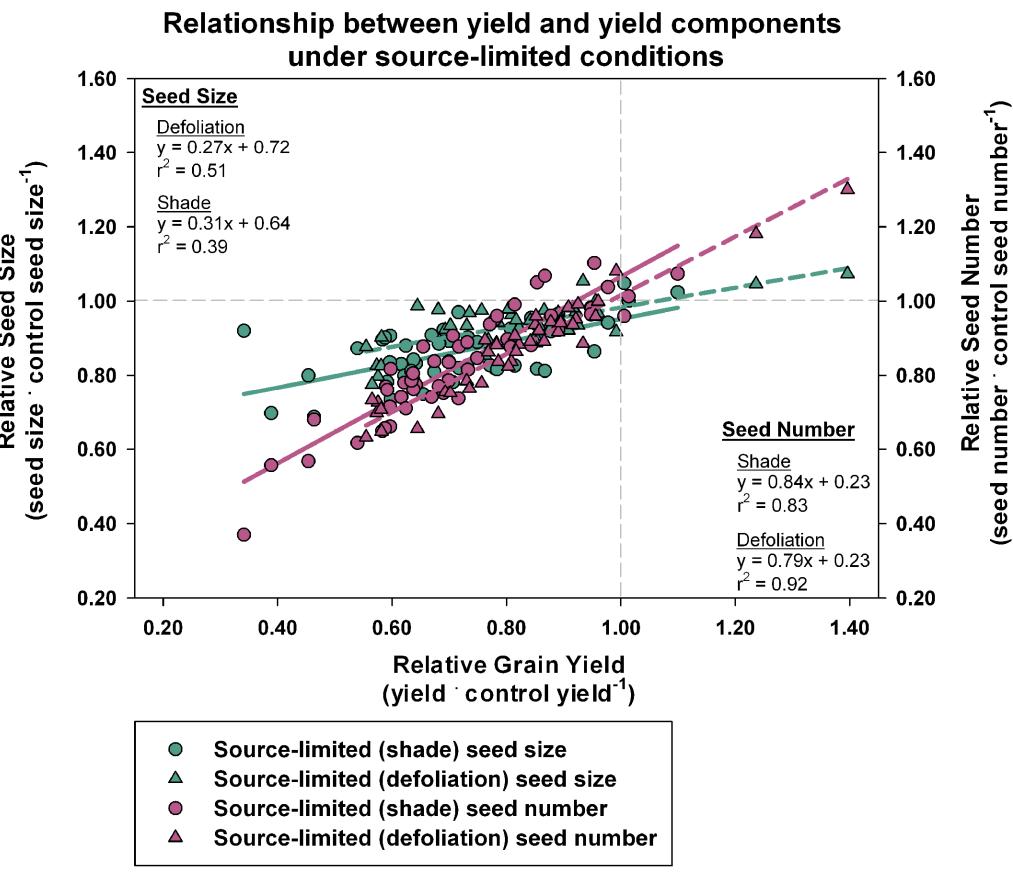
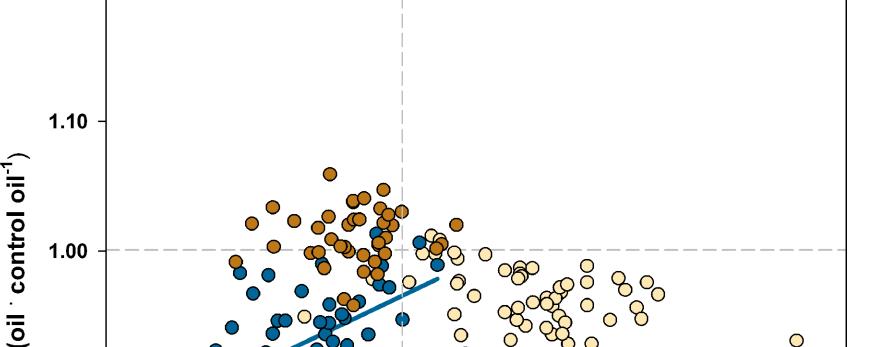


Figure 7. Relationship between seed yield and components of yield for soybeans treated with shade or defoliation prior to seed filling. Yields, seed sizes, and seed numbers were indexed to the control within a particular environment, and are reported on a fractional basis. Each data point represents one plot at one



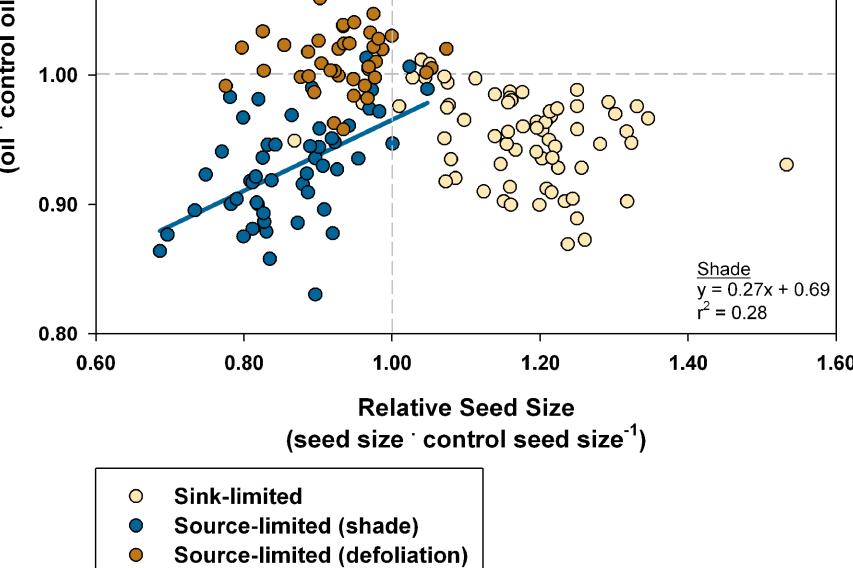


Figure 9. Relationship between seed size and seed oil concentration for soybeans treated with partial po removal, shade, or defoliation prior to seed filling. Yields, seed sizes, and seed numbers were indexed to the control within a particular environment, and are reported on a fractional basis. Each data point represents one plot at one environment.



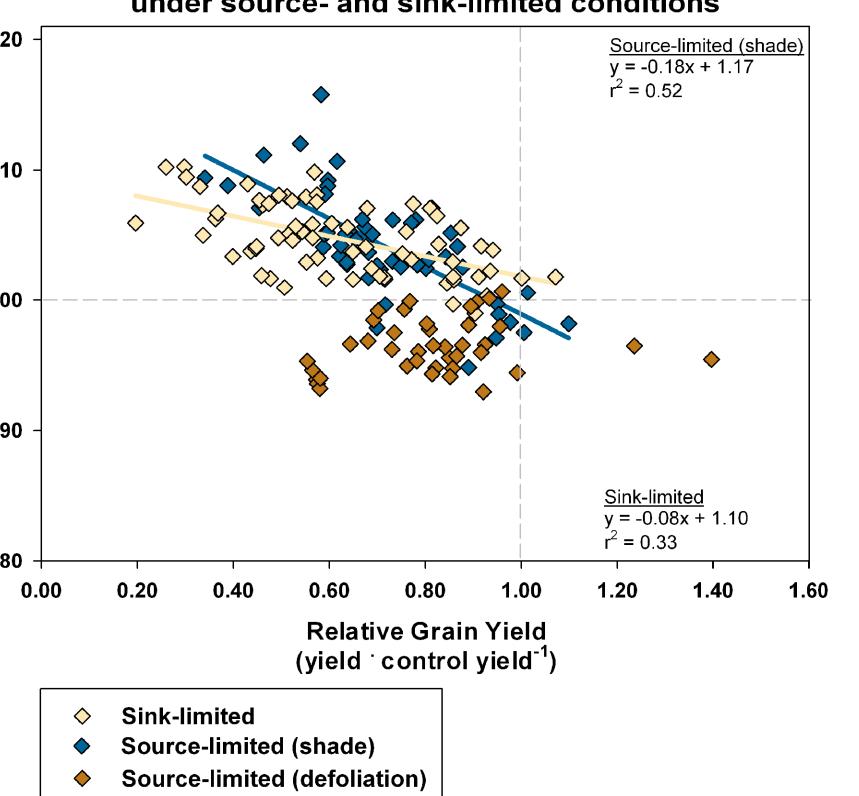


Figure 10. Relationship between seed yield and seed protein concentration for soybeans treated with partial pod removal, shade, or defoliation prior to seed filling. Yields, seed sizes, and seed numbers were indexed to the control within a particular environment, and are reported on a fractional basis. Each data point represents one plot at one

Relationship between seed yield and seed oil concentration under source- and sink-limited conditions

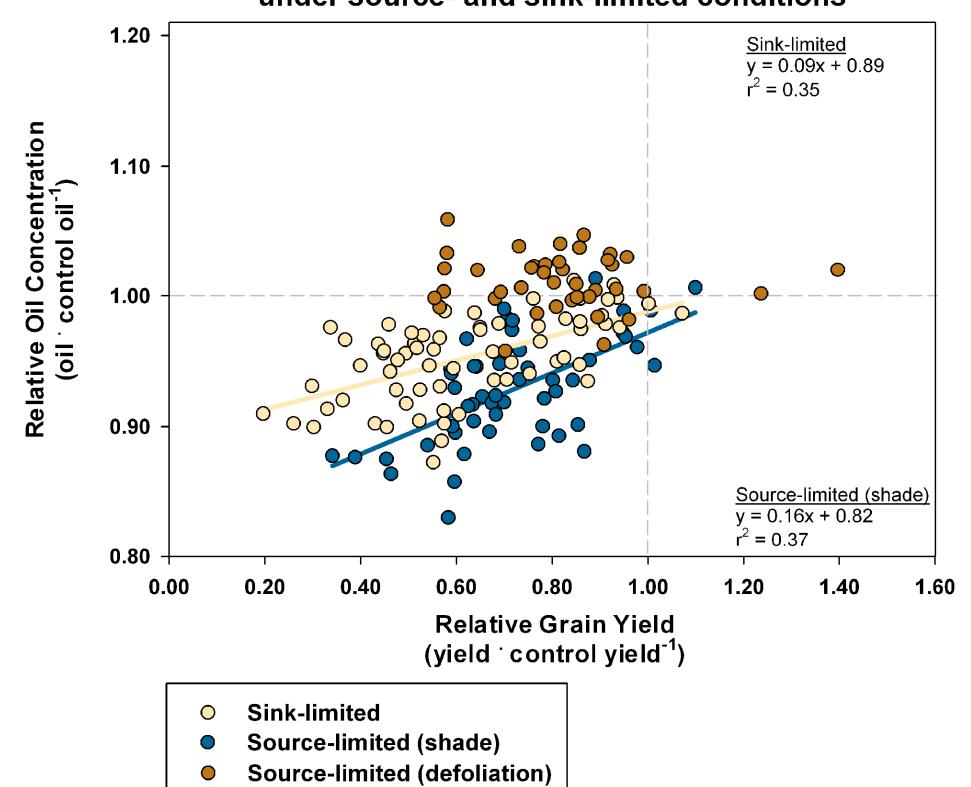


Figure 11. Relationship between seed yield and seed oil concentration for soybeans treated with partial pod removal, shade, or defoliation prior to seed filling. Yields, seed sizes, and seed numbers were indexed to the control within a particular environment, and are reported on a fractional basis. Each data point represents one plot at one environment.

