Can we predict Green Stem Disorder?

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Summary:
Green Stem Disorder (GSD) is when stems remain green and plants sometimes retain their leaves, even when the pods have reached their mature brown color. Broadly, any factor that reduces pod development and seed set in developing soybean plants can lead to green stem. Natural senescence in soybean generally requires a strong draw of nutrients from the vegetative portion of the plant ('source') to the developing seed ('sink'). When sink tissue is reduced, nutrients including proteins and sugars are retained in the source tissue, especially the stems. This allows them to remain in a healthy green state beyond the normal maturation period. Premature loss of pods and/or seeds during mid-reproductive growth stages (R3-R6) inhibits the sink strength. Impacts of green stem vary based on the growth stage at which the environmental stress occurred. Other factors like planting date can complicate management.

To better predict GSD, we first needed to better understand the causes and impacts of this disorder. To do this, we conducted a trial on the St. Paul Campus of the University of Minnesota using a system of shade treatments to reduce photosynthesis, and therefore energy for the developing plant and seeds from the vegetative stages through near maturity. We found stresses imposed either before seed development or later in reproduction, to have little impact on GSD. However, we did find that the occurrence of stress during the early reproductive stages of R2 to R4, generated a high incidence of this disorder. While this work will help us to better predict when GSD might be a problem, the long lag between these conditions and harvest indicated that precisely predicting these issues will be a challenge.

Introduction:
Green Stem is a disorder of soybean in which stems remain green beyond the time when pods and seeds are fully mature and dry. Various names are used to describe the problem including Green Stem Syndrome and the Greening Effect. Green Stem Disorder complicates harvesting of soybeans by significantly increasing the difficulty in cutting and threshing the affected plants during harvest. As a result, combine operators often must reduce ground speed and increase engine power, resulting in poor fuel efficiency and increased harvest time. Harvest delays also increase the chances of lodging, shattering, and seed decay that can reduce grain yield and/or quality.

The causes of Green Stem Disorder are uncertain but can be the result of several different potential factors. Specific causes of Green Stem Disorder vary from year to year and location to location but are frequently associated with plant stress during pod and seed development. A brief but significant period of stress during the reproductive stages can greatly alter the source:sink ratio in soybean and lead to Green Stem Disorder. Previous experiments explored the impact of different stress levels on Green Stem Disorder incidence; however, there have been no attempts to identify the most sensitive period for Green Stem Disorder expression. A better understanding of the effect of the timing of the stress on the expression of this disorder would be useful to predict the occurrence before its expression and make management decisions in advance. This would be helpful for harvest logistics and efficiency. The question that this project wants to answer is: Can we connect stress timing with Green Stem Disorder?

An experiment was conducted at the UMN St. Paul campus. The treatments consisted of shadings with shade cloth to reduce crop growth for periods of 10 days at different crop stages plus a control without shade. High yielding varieties were used. The crop was maintained free of weeds, insects, and diseases. Crops were irrigated to ensure that water was not limiting growth at any point during the cycle. The experimental design was a split plot design with four replicates where the variety was the main plot, and the timing of the stress imposition was the sub-plot.

Table 1: Summary of shade imposition treatments on soybean at St. Paul, MN. It provides detailed information on the stage and midpoint time of the treatment imposition referred to R1 stage; the duration of the shading treatment in days; the phenological stage of the crop at the start and at the end of the treatment imposition; the reduction in incident radiation due to the shade during treatment imposition, the source during the grain filling period estimated by the incident radiation between R4 and R7; the yield variation compared to the control treatment without stress.

Variable	**Treatment**									
	V3	**V6**	**R1**	**R2**	**R3**	**R4**	**R5**	**R5.5**	**R6**	**R7**
Shade timing (days from R1)	-11	-3	6	14	22	30	40	51	61	73
Duration (days)	8	8	9	8	8	8	12	9	11	13
Stage start	V2	V4	R1	R2	R3	R4	R5	R5.5	R6	R6
Stage end	V4	R1	R2	R3	R4	R5	R5.5	R6	R6	R7
Radiation reduction (Mj m-2)	158	137	153	152	140	136	158	146	163	162
Green stem incidence (%)	5.7	4.4	12.3	45.2	77.3	40.1	23.8	10.5	7.1	4.3
Yield variation (g m-2)	-6	-7	-16	8	-14	-49	-93	-68	-37	-22

Th experimental set up was effective in altering the physiological condition of the crop during different stages along the cycle. The data generated confirm that Green Stem Disorder could be connected to the occurrence of stress periods and, also, indicate that the stress timing is relevant in the expression of this syndrome. The occurrence of stress during the early reproductive stages of R2 to R4 (between full flowering and the pod set stage), generated high incidences of Green Stem Disorder (Figure 1). Stress imposition during the vegetative stages and during the late reproductive stages (after R4) presented a reduced effect on Green Stem Disorder. Stresses that increased Green Stem Disorder tended to reduce grain number per unit area and increase weight per grain (Figure 2). These results agree with some other studies that support a link between Green Stem Disorder and an increased source-to-sink ratio during the grain filling period of this crop.

It is worth noting that the stress window that generated the highest impact on green stem incidence took place between 51 and 69 days before the moment that we could visualize the disorder in the field (R7; Table 1). This long delay between the stress and the resulting visual symptoms gives us a clue about why this issue has been so difficult to characterize previously. Not only does the delay affect farmers' and researchers' memories, reducing our ability to connect these factors and symptoms, but the long delay between these two implies that there is likely to be multiple other factors interacting between the cause and effect in this period that could amplify or ameliorate the ultimate symptoms. For instance, additional, later stresses might reduce the overabundance of sink strength late in development that may be a driver of GSD. Or highly favorable conditions during the mid reproductive period might allow additional seed to develop and therefore increase sink strength. So, it is possible that these rather subtle conditions might reduce (or increase) GSD leading to the current assumption that GSD is simply difficult to predict.

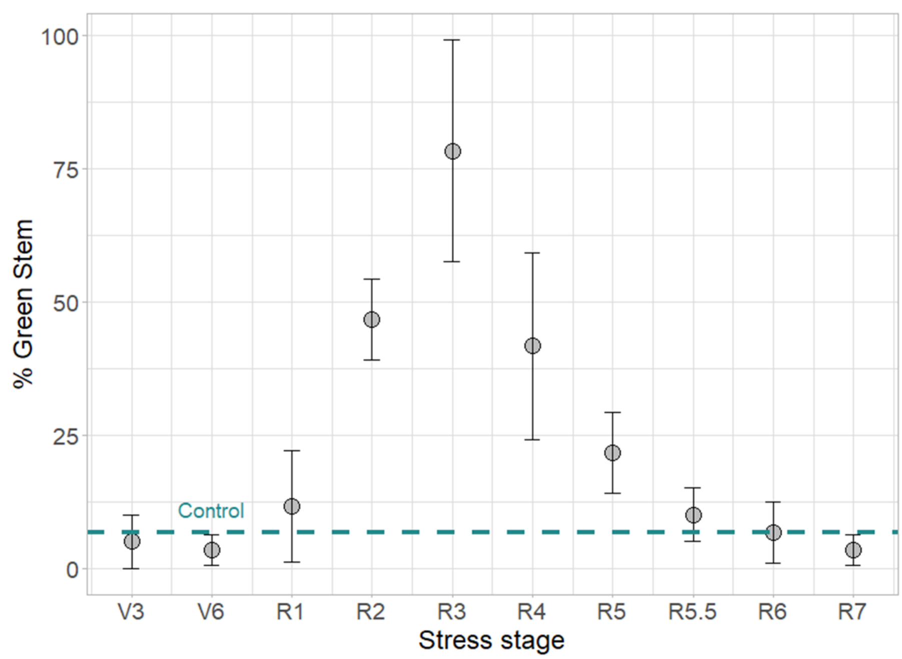

Figure 1: Effect of timing of stress on Green Stem Disorder incidence (%) in soybean at St Paul, MN. Control plots without stress are represented by a horizontal dashed line. The stressor factor was shading. Error bars are ± S.E and are not shown when smaller than the symbol.

Apart from compilating harvest, does GSD reduce yields? This is a question that has not been answered previously as identifying appropriate controls to test GSD affected plants against is difficult. This study was focused on creating conditions for GSD with a focus on identifying mechanisms to predict this issue. However, yield and yield component data from this trial does give us a glimpse at potential yield factors that may be related to GSD. In our experiment we found that the timing of stress imposition that appears to lead to green stems (R2-R4) slightly preceded soybeans' "Critical Period" or the time when soybean yields are most sensitive to environmental stresses (R4-R6). This indicates that GSD might be somewhat decoupled from the most important factors leading to yield loss.

However, the timing of stress imposition and seed (grain) number does overlap. While not perfectly coincident, stresses that resulted in more GSD did partially align with stress timing effects on grain number. This implies that either stress that reduce grain number in soybean may also affect GSD.

Anectodical information around GSD such as increased symptoms in male sterile soybean plants or from seed and pod feeding by stink bugs in the South, has led some of us to believe that reduced sink strength is likely the driver of GSD. This would imply that ultimately yields may be limited early and green stems are simply a visual symptom of this yield 'loss'. This more detailed examination of GSD indicates that it may be possible to have reduced seed numbers with seed size compensation that results in little yield loss (contrast Figure 1. At R3 with Figure 2. at R3). Therefore, it is POSSIBLE, that GSD might be driven more by seed number than by overall sink strength. Many Crop Physiologists might argue that seed number equals sink strength, but if seed size is capable of compensating for reduced seed number, the ultimate yield impacts of GSD may be minimized.

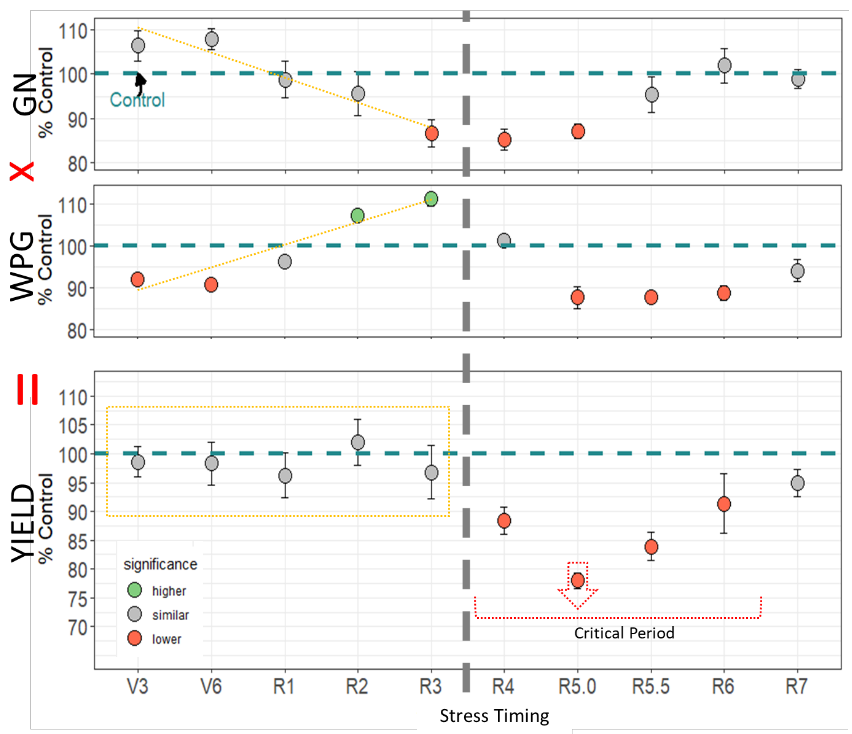

Figure 2: Effect of timing of stress on grain yield and yield components. in soybean at St Paul, MN. Control plots without stress are represented by a horizontal dashed line. The stressor factor was shading. Values are normalized relative to the control plots without stress (horizontal dashed line). Gray symbols show no effect of stress imposition relative to control; red symbols indicate a reduction due to the stress imposition treatment at $P < 0.05$; green symbols indicate an increase due to the stress imposition treatment at $P < 0.05$. Error bars are ± S.E and are not shown when smaller than the symbol.

If we could adequately predict GSD, is it manageable? Management of GSD takes two flavors: a) Management to reduce the ultimate causes (prevention), and b) Management of the symptoms. Prevention is the key, but is very challenging, primarily because soybean producers are generally doing all in their power to reduce stresses during the early reproductive period, already. If GSD is a routine issue for a producer, they should intensify their scouting and consider reducing thresholds for manageable pests (such as stinkbugs in the South). Managing symptoms is more difficult. Waiting until soybeans show GSD in the field is too late to treat affected fields with desiccants, as there is not enough green tissue to take up applied herbicides, and the crops are generally inside of the pre-harvest interval on desiccant labels. If GSD could be predicted, through historical prevalence and noted stresses during the R2-R4 stages identified in this study, a farmer theoretically could apply a desiccant at the R6.5+ stage to try to accelerate desiccation and dry-down of the crop. However, this management strategy is wholly untested and is really only a theoretical management strategy for GSD.