ABSTRACT

Title of Thesis: DOUBLE-CROPPED SOYBEAN RESPONSE TO VARIOUS WHEAT STUBBLE MANAGEMENTS

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Varying responses to wheat (*Triticum aestivum* L.) stubble management preceding double-crop soybean [*Glycine max* (L.) Merr.] have been reported; however, little work has been done in the Mid-Atlantic region of the United States. Additionally, there is limited information for wheat stubble management using glyphosate-resistant soybean. The objectives of this study were to observe the effects of wheat stubble management (WSM) on physiological growth and yield characteristics for double-cropped glyphosate-resistant soybean, evaluate the impacts of WSM on soil moisture retention and soil surface shading, monitor weed response characteristics, and perform a simple economic analysis comparing the four stubble management treatments. During 2003 and 2004, four WSM treatments were evaluated at two locations in a randomized complete block design with four replications. The WSM treatments were: wheat cut at a height resulting in stubble height of 15 cm with straw removed (baling), wheat cut for stubble height of 15 cm with straw returned to the plot, wheat cut for stubble height of 7.5 cm and straw returned to the plot by mowing with a rotary mower following soybean planting, and wheat cut for stubble height of 30 cm straw returned to the plot. Maryland received above normal amounts of rainfall during the 2003 and 2004 growing seasons resulting in exceptional soybean germination, stand establishment, and yield for all treatments. Soil moisture content for all WSM treatments was unaffected by WSM due to ample rainfall. Soybean plant height and lowest pod height (LPH) were greater in the 30 cm stubble treatment; however, these two characteristics did not result in significantly greater yield compared to the other three treatments. Lack of yield response was most likely due to favorable growing conditions that all four treatments experienced during the two years. No significant lodging differences were observed even though the WSM treatments caused height differences. While soil moisture conservation was not observed over the duration of this study, 30 cm stubble provided significantly more soil surface shading for up to 4 weeks following planting, which could decrease evaporation from the soil surface and ultimately aid in soil moisture conservation in years with insufficient rainfall. Even though there are physiological and physical characteristics that can be positively affected by 30 cm wheat stubble, wheat cut for stubble height of 15 cm with the straw removed via baling was the most economically profitable treatment due to the strong straw market that exists in the Mid-Atlantic region.

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by

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DEDICATION

To my wife, Marissa Pearce, my parents, William and Catherine Pearce, and my mother and father in-law, Michael and Cherie Salomone

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CHAPTER 1

LITERATURE REVIEW

Double-Cropping Soybeans

Numerous studies have been performed in the realm of no-till production, establishing it as both an environmentally and economically sound method for producing double-crop soybean [*Glycine max* (L.) Merr.] after a small grain crop. By preserving residue on the soil surface, no-till production promotes better soil physical characteristics such as structure and water retention capacity while maintaining a healthy microbial community. Increased soil structure promotes increased water infiltration as well as water retention, and when combined with increased surface residue, can be attributed with more efficient water interception and decreased run-off and erosion potential (Blevins et al., 1983). Additionally, little to no yield response has been shown for soybean grown on coarse textured soils using conventional tillage involving moldboard plowing in comparison to soybean grown using no-till planting (Roland, 1992). Furthermore, no-till production has the added benefit of reduced labor requirements, energy, and machinery costs, as well as less delay in planting soybean during a time-critical period (Hovermale et. al., 1979, Uri 2000).

While the benefits of no-till production of double-crop soybean are numerous, there are also negative aspects associated with this practice . Many crop residues contain allelopathic compounds that negatively impact both germination and yield of crops that succeed them in the same field. Alfalfa (*Medicago sativa* L.) is known to be both autotoxic and allelopathic and has been shown to diminish plant height and fresh weight of succeeding alfalfa and sorghum [*Sorghum bicolor* (L.) Moench] crops (Hedge and

Miller 1990). Similarly, grain sorghum has been found to delay the development and reduce grain yield of a following wheat (*Triticum aestivum* L.) crop (Roth et al., 2000). While sorghum is not included in the typical double-cropping system in the Mid-Atlantic region, wheat is a small grain that frequently precedes double-crop soybean. Its residue is known to have phenolic acids. These compounds have been found to inhibit ion uptake, nodule formation, growth of *Rhizobia*, and acetylene reductions in double-crop soybean, all of which are essential to attaining maximum yields (Rice, 1984). Hairston et al. (1987) found that increased wheat straw residue stunted early soybean growth and caused chlorosis in many of the treatments that had the greatest amounts of residue. Conversely, it was found that burning the wheat stubble decreased these phytotoxic compounds and jointly decreased weed numbers and the immobilization of nitrogen, all of which translated into increased soybean yield.

While double-cropping soybean following a small grain has become a common practice in much of the country, it usually coincides with planting dates that are later than considered optimal for attaining maximum soybean yield (Van Doren and Reicosky, 1987). Small grain harvest in the Mid-Atlantic region generally occurs from mid-June through mid-July, subjecting double-crop soybean to a shorter growing season during the hottest and driest period of the year. A one-month delay (June vs. July) for planting double-crop soybean has been shown to decrease soybean yield by 27% (Weaver et al., 1991). In the same study, soybean height was inversely proportional to planting date with indeterminate cultivars expressing greater disparity for this characteristic than determinate cultivars (Weaver et al., 1991).

In an effort to avoid the negative factors affecting late-planted soybean, many growers in the southern states have begun planting early maturity group (MG), indeterminate cultivars (MG I to MG IV) (Jones et al., 1995; Kane and Grabau, 1992; Mayhew and Caviness, 1994; Savoy et al., 1992). In Arkansas, MG III and IV cultivars were shown to perform better than later maturing cultivars across a range of early and late-planting dates (May et al., 1989). These results were further substantiated by subsequent studies that found early planted MG I – MG IV cultivars had comparable yields to the MG V – MG VII cultivars that are traditionally grown in the southern states (Mayhew and Caviness, 1994; Sweeney et. al., 1995; Boote, 1981).

However, these earlier maturing cultivars were not without negative agronomic characteristics such as poor seed quality and decreased seed germination (Mayhew and Caviness, 1994; Sweeney et. al., 1995, Boote, 1981). Another negative effect with earlier maturing soybean cultivars compared to more normal maturity group cultivars was reported by Wilcox et al. (1995) who showed a strong relationship between height and length of maturity. Coupled with the additional height for longer maturity cultivars was increased numbers of pods, branches and nodes (Wilcox et al., 1995). Boote (1981) had earlier observed that a reduction in plant height resulted in a greater yield produced in the lower 8 cm of the plant, an area of the plant that is impossible to harvest with modern combines, for earlier maturing cultivars than occurred in full-season cultivars. Later work confirmed that the important advantage attributed to length of maturity was the positive relationship between MG and lowest pod height (LPH), which is the height from the ground to the lowest pod-producing node (Grabau and Pfeiffer, 1990; Sweeney et. al., 1995). Sweeney et al. (1995) noted that the LPH of early maturing cultivars (MG 00, 0,

I) ranged from 2.5 to 10 cm while later maturing cultivars (MG III, IV, and V) had an LPH as high as 20 cm. Growers choosing to plant early MG cultivars may be avoiding late summer periods of drought; however, they are sacrificing both plant height as well as LPH, which can result in suppressed soybean yield.

Wheat Residue Management

Planting date and length of maturity can have a profound effect on the exposure of soybean to timely periods of rainfall; however, double-crop production inherently predisposes soybean to periods of minimal rainfall due to the later planting date as a result of the length of maturity of the previous small grain crop. It is important to strive for moisture conservation with double-crop production rather than hope for drought avoidance. During periods of extreme drought such as occurred in the Mid-Atlantic region in 2002, the retention of soil moisture is critical to crop survival and maximizing yield. Ashley (1982) has shown that more than 500g of water are required to produce 1g of plant dry matter. One method for increasing soil moisture conservation that has been studied is small grain residue management for decreasing both the soil temperature and surface evaporation potential. Peters and Johnson (1960) found that one quarter to one half of all moisture loss in a conventionally tilled soybean field could be attributed to evaporation from the soil surface. NeSmith et al. (1987) found that no-till soybean planted into wheat stubble retained 30 to 40% more water in the top 10 cm of soil than was retained with either burning or bare ground treatments. Also noted were soil surface temperatures 5 to 8° C cooler in those treatments with straw residue (NeSmith et al., 1987). These results concurred with those initially reported by Unger (1978) who noted that soil temperature reduction was directly related to the amount of surface residue.

The retention of surface residue can be critical to conserving moisture; however, the allelopathic effects of wheat straw may outweigh any positive effects of moisture conservation. Both delayed emergence and soybean population reductions by as much as 150,000 plants ha^{-1} have been noted in cases where wheat residue was not removed (Sanford, 1982; Hovermale et al., 1979; Vyn et al., 1998). The causes of these negative effects have been attributed to a combination of allelopathy and poor seed to soil contact resulting from difficulty of planting into the wheat residue. In addition to these emergence problems, stunted or delayed seedling growth accompanied with a period of chlorosis has been observed in those situations where the wheat residue has not been removed via burning or baling (Vyn et al., 1998; Hairston et al., 1987; Caviness et al., 1986; Sanford, 1982). The removal of wheat straw increased total soybean biomass by as much as 16% over the amount of biomass accumulated with either incorporating the residue or leaving it on the surface (Sanford 1982, Boquet and Walker 1984, Hairston et al. 1987, Vyn et al., 1998).

Removal of wheat straw in the Mid-Atlantic region can be a time consuming operation due to the fact that controlled burning of fields is not permitted. However, many growers in this region have found baling straw to be a profitable enterprise due to numerous and readily available markets such as those that the horse and mushroom industries provide. One of the largest weekly hay and straw auctions in the region (located in New Holland, PA) reported straw prices ranging from \$86 to \$177 MT^{-1} in 2004 (MASS 2004). Wheat straw yields between 1.5 and 3.6 MT ha^{-1} are typical (Engel et al., 2003). Utilizing a median price of \$132 MT^{-1}, growers can potentially gross an additional \$198 to \$475 ha^{-1}. Those who bale wheat straw not only remove the phenolic acids that are associated with allelopathy, but also profit from the sale of the straw.

Wheat Stubble Height

Wheat stubble height management at harvest is another area where the subsequent negative effects of straw on double-crop soybean production can be alleviated. Several studies have sought to evaluate the optimum wheat stubble height (WSH) for diminishing the negative impacts of wheat residue on the subsequent soybean crop while retaining the positive aspects (Hovermale et. al., 1979; Hairston et. al., 1987; Vyn et. al., 1998). However, most studies have provided inconclusive results due to environmental variations.

One environmental aspect that is constant is the positive relationship that exists between stubble height and shading, because increased stubble height has more plant matter that intercepts or reflects incoming light. It is well known that the use of crop management practices that improve shading increase the efficiency of cultural and chemical weed control methods (Harwood and Bantilan, 1974). Dry matter production of several weed species from the semi-arid tropics was reduced nearly 80% for shade levels at 90%. It was concluded that manipulating crop canopies to create desired shading could result in substantial weed suppression (Shetty et. al., 1982). Begna et. al. (2002) documented dry matter reductions attributable to shading in three weed species; redroot pigweed (*Amaranths retroflexus* L.), common lambsquarters (*Chenopodium album* L.) and velvetleaf (*Abutilon theophrasti* Medic.). However, this reduction was greater in the roots and reproductive structures of these weed species than in their vegetative shoot tissues. Similar results were found by Neeser et. al. (1997) who found in artificial shading studies that a decrease in the amount of photosynthetically active radiation (PAR) reaching the weed canopy will limit tuber production in purple nutsedge (*Cyperus rotundus* L.).

While excessively tall wheat stubble could provide the level of shading that might impede weed growth, a combine must harvest the wheat at a height that minimizes the loss of grain. A rule of thumb followed by many farmers is to cut wheat at 2/3 of the plant height because the distribution of spikes dictates that this height would allow harvest of 99% of all the spikes. While it can also be noted that increasing stubble height offers greater protection to the soil from evaporation and erosion, a stubble height exceeding 30 cm offers little added protection (Nielson et. al., 2003). Increasing wheat stubble heights to 36-46 cm have been found to reduce double-cropped soybean yields significantly due to early season shading of the young plants (Boquet and Walker 1984).

Acock and Acock (1987) found that soybean plants shaded during the first week after vegetative cotyledon (VC) growth stage (Fehr and Caviness, 1977) had fewer branches at the cotyledonary node. The total number of branch nodes was inversely proportional to the number of weeks during VC-V6 growth stages that they were in the shade. This relationship indicates that an excessively tall stubble height could provide detrimental shading that impedes branch formation during this critical growth period. Due to the fact that there is a positive relationship between the total number of branch nodes and the number of pods and seeds plant^{-1} and that the total number of seeds is the most critical factor to yield (Kakiuchi and Kobata, 2004), stubble height that is too tall may adversely influence yield.

Many studies have sought to determine the optimum wheat stubble height to attain maximum double crop soybean yield. Research conducted in Missouri on three cultivars of dry edible beans (*Phaseolus vulgaris* L.) planted at two different dates showed that beans were 23 to 25% taller and bean yield was 15% greater when planted into 25 cm stubble compared to stubble that had been mowed (Nelson et. al., 2001). A similar project in Kentucky with soybean had varying results (Grabau and Pfeiffer, 1990). During most of the years, there were no differences in lodging or LPH across the stubble height treatments of 0, 15, and 30 cm. Additionally, no significant yield differences were observed among the varying wheat stubble heights except during one year, when a soybean yield increase of 17% was observed at a stubble height of 15 cm compared to the 0 cm stubble height treatment.

Hovermale et al. (1979) obtained optimum soybean yield with a wheat stubble height treatment of 20 cm, but also noted several physiological differences for the soybeans in the taller stubble treatments. In this study, stubble heights of 35 to 40 cm produced taller soybeans. This was attributed to the tall wheat stubble possibly simulating a response similar to what occurs with increased soybean plant population. Increased soybean plant population will alter the red:far red light ratios, which in turn solicits a growth response. Also noted in this study were treatments with increased stubble height tending to have greater lodging scores and an increased LPH, both of which were attributed to shallower root systems caused by cooler, more moist soil conditions.

The LPH can be critical to attaining maximum yield. Modern combines are not able to harvest pods that are less than 7.5 cm above the soil surface. If LPH can be increased, harvestable yield should also increase. The LPH has been found to increase with relative maturity (Sweeney et. al., 1995). Early MG cultivars frequently utilized for double-crop production inherently have a suppressed LPH. The LPH can be increased as much as 4% by decreasing row spacing from 76 cm to 20 cm (Beaver and Johnson, 1981). More dramatically, LPH has been increased by as much as 40-50% by increasing seeding rates (Costa et al., 1980; Dominguez and Hume, 1978). Small grain stubble could effectively simulate an increased soybean population as long as the stubble remains taller than the soybean plants prior to flower formation at the plants' lowest node.

CHAPTER 2

DOUBLE-CROPPED SOYBEAN RESPONSE TO VARIOUS WHEAT STUBBLE MANAGEMENTS

INTRODUCTION:

Soybean is the most widely grown and most valuable (per MT) cereal or oil crop produced in Maryland (MASS 2003). With over 176,000 ha grown in 2003, soybean occupied nearly 21% of the land in agricultural production within Maryland (MASS 2003). Maximum economic return has long been the priority of modern farmers which has lead to double-crop soybean production becoming a common practice in Maryland with approximately 40% of the annual soybean crop produced in a double-crop system (MASS 2003).

A typical double-crop system in the Mid-Atlantic consists of soybean planted utilizing no-till management following the harvest of either wheat or barley (*Hordeum vulgare* L.). Many farmers in the region bale the straw of the small grain for sale in numerous markets, while others forgo the increased time and resources required for such an operation and merely return the residue to the field. While both options have positive and negative aspects, returning the residue to the soil surface provides the most benefit for the overall health of the field. By returning the residue to the soil surface farmers are decreasing the potential of erosion and runoff, while increasing water conservation and soil aggregation (Blevins et. al., 1983).

Regardless of which option they exercise, a question exists about optimum small grain stubble height. For those who sell the straw, leaving less or shorter stubble height yields a greater amount of baled straw. Conversely, harvesting small grain at increased stubble height decreases the amount of material entering the combine, which in turn slightly increases harvest speed. By opting not to bale the small grain residue, farmers not only eliminate the overhead and labor required for such an operation, plus they are able to plant double-crop soybean more timely because of immediate access to the small grain field.

Expeditious planting of double-crop soybean becomes especially critical due to the seasonal decrease in rainfall that is typically experienced during the early summer months. Most recently, possible infection of legume crops planted late in the growing season by Asian soybean rust (*Phakospora pachyrhizi*) has become a serious concern among growers across the country. Accompanied with that trepidation has been a discussion about planting earlier maturing soybean cultivars in order to either avoid or decrease the critical time for infection. However, one concern that has been expressed about earlier maturing cultivars is their tendency to flower lower to the ground, producing lower pods at a height that may not be easily harvested by a combine. Stubble height has been shown to influence LPH; however, whether it can be altered to an extent that affects yield remains a question.

By increasing small grain stubble height, it is possible that there will be an increased amount of shade cast upon the soil, which could correlate with decreased weed pressure as well increased soil water conservation. Decreasing or even slowing weed germination and growth could be particularly beneficial to those larger growers who may not be able to apply a herbicide to all their fields in a timely manner. Any moisture that can be conserved through means such as the alteration of stubble height would prove beneficial to double-cropped soybean.

While the overall health of the field is a critical aspect to growers, it is economic return that fuels growers' decisions. Many positive and negative attributes are associated with various stubble and residue managements; however, soybean response to those attributes has not been consistent. The objectives of this study were to observe the effects of various wheat residue managements on (i) physiological growth and yield characteristics of double-cropped glyphosate [N-(phosphonomethyl)glycine]-resistant soybean, (ii) soil shading and moisture retention, (iii) weed response characteristics, and (iv) economic return.

MATERIALS AND METHODS

Sites

Experiments were conducted during 2003 and 2004 at the Wye Research and Education Center (WREC) located near Queenstown, Maryland, on Mattapex silt loam (fine-loamy, siliceous, semiactive, mesic Typic Hapludult) and at the Central Maryland Research and Education Center (CMREC), located near Beltsville, Maryland, on a Sassafrass sandy loam (fine-loamy, siliceous, semiactive, mesic Alfic Normudult).

Wheat Management

'Roane' cv. soft red winter wheat was planted 25 October 2002 and 21 October 2003 at WREC and 23 October 2003 and 29 October 2004 at CMREC. Wheat was seeded at a rate of 3.7 million seeds ha^{-1} in 19 cm rows using a Great Plains no-till drill (Great Plains Manufacturing, Inc., Salina, KS). Nitrogen (as urea-ammonium nitrate) was applied at 67 kg ha^{-1} in combination with Harmony Extra [thifensulfuron-methyl (50% by weight) and tribenuron-methyl (25% by weight)] at 73 ml ha^{-1} in the spring at Feekes GS 2/3 (Large, 1954) each year. The fields were evaluated for uniformity of stands throughout the spring. Plots (12.2m by 3.05m) were established within the solid planted fields. The uniformity of those stands within each plot was confirmed by counting tillers m^{-2} at five randomly selected, 0.9 m long sections of row plot^{-1} prior to wheat harvest. Wheat was harvested 21 July 2003 and 28 June 2004 at WREC and 21 July 2003 and 28 June 2004 at CMREC using a John Deere 6620 (Deere & Co., Moline, IL) and a Case-IH 2366 (Case IH, Racine, WI) respectively, to establish the four wheat stubble management treatments. Average wheat yield for all treatments was calculated using grain monitors that were equipped on the combines.

Treatments and Management

The experiments at each location had the four treatments established in a randomized complete block experimental design with four replications. The four wheat stubble management treatments were selected to reflect common production practices of the Mid-Atlantic region and are as follows:

(i) Wheat stubble height (WSH) of 15 cm with the residue removed from the plot (baled)

(ii) WSH of 15 cm with the residue returned to the plot with a straw chopper

(iii) WSH of 7.5 cm with the residue mowed following soybean planting

(iv) WSH of 30 cm with the residue returned to the plot with a straw chopper.

Wheat residue biomass from the baled treatment (i) was collected and weighed prior to soybean planting. Once the treatments had been imposed on the plots, each plot's stubble height was measured at five randomly selected locations within the plot to ensure the WSH treatments did not deviate greater than 2 cm from their intended height.

UniSouth Genetics (USG) brand 7398 glyphosate-resistant soybean were planted on 28 July 2003 and 30 June 2004 at WREC and 28 July 2003 and 29 June 2004 at CMREC at a rate of 445,000 viable seeds ha^{-1} in 19 cm rows using a Great Plains no-till drill. Prior to soybean emergence in 2003 and at CMREC in 2004, glyphosate was applied to the plots at 1.12 kg ha^{-1} a.i. to manage weed growth. Glyphosate was applied to the plots at 1.12 kg ha^{-1} a.i. two weeks following soybean planting at WREC in 2004.

Percent Ground Cover

Immediately following soybean planting, percent ground cover was measured via the line transect method (Sloneker and Moldenhauer, 1977). Observations for ground cover were made and recorded every 10 cm along two, 5 m transects placed diagonally across each plot. The number of marks transecting any piece of residue was counted and the resulting relative percent ground cover was calculated.

Soil Water Content

Soil moisture was monitored weekly from wheat harvest until the soybean plants reached R1-R2 growth stage (Fehr and Caviness, 1977). At this time the soybean plants had closed the canopy, so any moisture conservation benefits from the treatments were assumed realized. Soil moisture was measured gravimetrically in 2003 by taking soil cores at five random locations within each plot at depths of 0 to 7.5 cm and 7.5 to 15 cm. The wet soil samples were weighed and then dried for 96 hours at 60^{0} C. Dry samples were weighed and the gravimetric water content was determined by the following formula:

$$[(\text{Wet weight} - \text{Dry weight})/\text{Wet weight}] \times 100$$

The means for 0 to 15 cm were then calculated and the gravimetric moisture measurements were converted to volumetric moisture levels using the following equation:

Volumetric water content = bulk density of soil X gravimetric water content

In 2004, soil moisture was measured volumetrically using a Trace System I time domain reflectometer with 15 cm waveguides (Soil Moisture Equipment Corp., Santa Barbara, CA) (Topp et al. 1980). Measurements were performed at five random locations within the plot to a 15 cm depth.

Soil Surface Shading

[Photosynthetically Active Radiation (PAR) at soil surface]

Percent soil shading was monitored weekly from wheat harvest until R1-R2 growth stage using an AccuPAR linear PAR ceptometer (Decagon Devices, Inc., Pullman, WA). The PAR was measured at ten randomly selected locations in each plot at locations just above the plant canopy in direct sunlight and at the soil surface. The percent of light that was intercepted by either the wheat stubble or soybean plant canopy was then calculated, resulting in the percent PAR that reached the soil surface.

Plant Development

Upon soybean emergence, plant height and growth stage (according to Fehr and Caviness, 1977) was measured weekly until the plants reached R2. Plant height (height from soil surface to terminal node) was measured and growth stage was determined for five randomly selected plants in each plot.

Soybean Stand Emergence

Soybean plant populations were measured three weeks following planting. This was performed by counting the number of emerged plants within an area of 0.405 m^2, at ten randomly selected locations within each plot.

Lodging

Prior to harvest, lodging scores were assessed in each plot. Lodging assessment scores ranged from 1 to 5 where 1= all plants vertical and 5= all plants horizontal. Lodging score for each plot was the average of the scores assigned by two different observers evaluating each plot.

Yield components

Prior to harvest, twenty random plants selected from the border rows adjacent to the harvest area were clipped at ground level and stored until they could be analyzed for several factors. These factors included:

- Final plant height, measured from the bottom of the plant to the terminal node.
- Lowest pod height (LPH), measured from the bottom of the plant to the first pod-producing node.
- Total number of pods $plant^{-1}$.
- Seeds per pod, calculated by measuring the total number of seeds $plant^{-1}$ and dividing the total number of pods $plant^{-1}$ by total number of seeds $plant^{-1}$.
- Seed weight, calculated by measuring the weight of five random samples of 100 seeds.

Soybean Yield

Soybean harvest occurred on 13 October 2003 and 9 November 2004 at WREC and 15 October 2003 and 11 November 2004 at CMREC. A Massey Ferguson 8XP plot combine (Kincaid Equipment Manufacturing, Haven, KS) equipped with an HM-400 Plot Harvest Data System (Juniper Systems, Inc., Logan, UT) harvested an area 12.2 m long by 1.52 m wide and determined the total weight of seed and seed moisture content.

Statistical Analysis

Statistical analyses were performed using SAS 8e software (SAS Institute, 1995, Cary, NC). All data were analyzed as a randomized complete block design using a mixed model with location, year and treatment considered as fixed effects and replication considered a random effect. Soil water content, percent shading, and plant height were analyzed as repeated measures using the PROC MIXED procedure of SAS. Analysis of variance was performed on all other variables using the PROC MIXED procedure. Years and locations were combined whenever significant interactions did not exist. Mean separation was conducted using Fisher's Protected Least Significant Difference Test and treatment differences were considered significant at an alpha level of 0.05.

RESULTS AND DISCUSSION:

Weather Conditions

The 2003 growing season was marked by an excessive amount of precipitation that fell not only at the two research sites but also throughout the Mid-Atlantic region (Figure 1). Fields remained saturated or nearly saturated throughout much of the year. Small grain harvest and double-crop soybean planting were delayed by nearly one month in 2003 due to wet field conditions. Less rainfall was received during the 2004 growing season; however, seasonal totals during 2004 were well above average and adequate moisture was present throughout the summer months (Figure 1). Combined with adequate to excessive rainfall were temperatures that were below average during the summer months for both 2003 and 2004 (Figure 2). Because of these climatic conditions, there were no permanent visibly observed moisture or heat related stresses on the soybean crop that ultimately resulted in good to outstanding growth and yield across all treatments at both locations and years.

Wheat Grain and Straw Yields

Wheat grain yields were calculated per location rather than per treatment due to fact that the plots were established within a production wheat field that had uniform stands throughout each plot. Each plot was treated identically with the exception of the height at which the wheat was harvested. Wheat grain yields were greater at WREC both years (Table 1), which was due to differences between productivity potential for the two different soils. Wheat at CMREC was impacted by the poor growing conditions in 2003 (Table 1) resulting in both grain and straw yields that were less than half those attained at WREC. However, in 2004, grain and straw yields were similar between the two locations.

Percent Ground Cover

Maximizing the amount of ground coverage has benefits for double-crop soybean. First, it should provide greater protection of the soil from evaporation. Second, covering the soil decreases the amount of PAR that reaches the soil surface and should maintain a cooler seedbed. A third benefit should be less weed competition because of the decreased germination and emergence potential of shallow weed seeds caused by cooler soil temperatures, less light reaching the soil surface and the shading competition of the residue impeding development of emerging weed seedlings. However, increased surface residue levels have also been shown to impede soybean stand establishment due to poor seed to soil contact as a result of the residue being incorporated in the furrow with the seed by the no-till coulters (Sanford, 1982).

Percent ground cover was significantly affected by the different WSM treatments that were established in plots that had similar wheat stands (i.e. tillers m^2) (Table 2). Locations were unable to be combined due to significant location by treatment interaction that was the result of significantly denser stand (i.e. tiller counts) at WREC than at CMREC (Table 2). However, the analyses were combined over the two years for each location. The 7.5 cm mowed treatment produced the greatest amount of ground cover at WREC. At CMREC, this treatment was comparable to the 30 cm treatment (Table 2).. The amount of ground cover for the 7.5 cm treatment was not surprising since a greater percentage of the post-harvest wheat residue was returned to the soil surface with this treatment compared to the other three treatments (Table 2). The greater amount of ground cover for the 7.5 cm treatment at WREC was attributed to the significantly greater amount of wheat residue present at that location (see differences in tiller counts in Table 2) resulting in a much thicker mat of straw on the soil surface following mowing. A sparse wheat stand at CMREC allowed much of the stubble for the 30 cm treatment to be lodged rather than remain upright as the no-till soybean drill passed, thus contributing to the amount of measured ground coverage. At WREC, a smaller amount of the stubble in the 30 cm treatment was lodged with soybean planting because the denser stand maintained a more upright stature of the wheat stubble following soybean planting.

Because of the relationship between amount of stubble lodging following soybean planting and density of wheat stands, a stubble height of 30 cm can be expected to provide levels of ground coverage that are comparable to a mowing treatment in sparse stands of wheat but may not do so in dense stands of wheat. Harvesting wheat at a stubble height of 30 cm would be a more timely and cost efficient manner of providing maximum ground cover than mowing the wheat stubble following planting.

As was expected, the 15 cm non-baled treatment provided an intermediate amount of ground coverage due to nearly all the stubble remaining upright, while returning a considerable amount of straw to the soil surface (Table 2). In contrast to the three other WSM treatments, the 15 cm baled treatment resulted in significantly less ground cover at CMREC because the residue was completely removed from the plot (Table 2). The removal of considerable surface residue by baling is thought to create field conditions that should be more conducive to attaining maximum stand establishment. Conversely, at WREC where the wheat stand was denser , the 15 cm baled treatment had ground cover that was similar to the 15 cm non-baled and 30 cm treatments (Table 2). The baled and non-baled treatments were similar due to the fact that there was a considerable amount of residue left on the soil surface even after baling, suggesting that baling does not adversely affect ground coverage in fields where wheat stands are dense, whereas returning the wheat residue to the soil surface is necessary in sparse stands of wheat in order to attain the same benefits.

Emerged Plant Population

A significant location by treatment interaction existed during 2003 that did not permit a combined location ANOVA for emerged plant population. No differences in emerged population were seen at CMREC during 2003 (Table 3). However, at WREC during 2003, the 15 cm baled treatment had the greatest emerged population, which was similar to the results of Vyn et. al. (1998) who found that removing wheat straw via baling increased emerged population by 150,000 plants ha^{-1}during one year. This response was attributed to the removal of both the wheat straw and the allelopathic compounds that are associated with it. It is also noted that the emerged populations averaged only 76% of the seeding rate goal of 445,000 plants ha^{-1} in 2003. Poor populations across all treatments were possibly due to cool, wet seedbeds that were present at the time of planting. Locations were not combined in 2004 in order to elaborate on several differences that existed between them with regard to yield components. While locations were not combined, the different WSM treatments did not significantly affect the emerged plant population for double-cropped soybean during 2004 (Table 3). Emerged populations exceeded the seeding rate target of 445,000 plants ha^{-1} in 2004. Populations averaged 147% and 102% of the target population at CMREC and WREC, respectively. The disproportionate populations that occurred at CMREC were due to an improperly calibrated grain drill. Both locations had nearly ideal soil moisture and temperature conditions allowing excellent seed germination and seedling emergence in 2004. Because of these good environmental conditions, germination and emergence were exceptional across all treatments and ultimately resulted in no significant differences in emerged plant population.

Soil Moisture Content

A repeated measures analysis of variance was conducted to determine if WSM treatments had an effect upon soil moisture content over time. Years could not be combined for the ANOVA due to a significant interaction that may have been the result of different sampling techniques used each year. By definition, gravimetric soil moisture content (2003 measurement) is always lower than volumetric soil moisture content (2004 measurement), but gravimetric moisture content can be converted to volumetric moisture content by multiplying it by the bulk density of the soil.

Locations within years could not be combined due to significant location by time interactions that were present. Due to the weather experienced during the 2003 and 2004 growing seasons (Figures 1 and 2), soil moisture contents were not significantly affected by any of the WSM treatments (Figures 3 and 4).

Though there were no significant WSM treatment effects present for soil moisture content, this variable did fluctuate through the course of both years allowing several consistent trends to be noted. First, soil moisture content in 2003 appeared to gradually decrease from the time of soybean plant emergence in late July until late August when canopy closure was complete, at which time it reversed and started to increase (Figures 3). This trend was attributed to a decrease in weekly rainfall throughout early August (Figure 1) and because soybeans were in peak vegetative growth during this time utilizing much of the soil moisture that was present. The downward moisture trend in 2003 was reversed due to rainfall incidents that occurred during the last week in August and early September (Figure 1). In 2004, moisture levels remained more static (Figure 4) throughout the time period they were measured compared to 2003 due to timely rainfall events that occurred weekly throughout July and early August (Figure 1) that never allowed the soil to become depleted of moisture.

Another trend that was consistent both years was soil moisture content was consistently higher at WREC than at CMREC. While soils at both locations contain similar clay compositions, the difference in moisture contents between the two locations is due to sandier soil at CMREC resulting in a lower field capacity moisture content and a lower wilting point moisture content compared to more silty soil at WREC. In soils containing similar clay compositions, difference between field capacity and permanent wilting point for water-holding capacity is smaller in a sandier soil compared to a silty soil. Because there is less plant available water in a sandier soil, moisture conservation for sandier soils is critical. Sandier soils could be more sensitive to WSM in a year when moisture becomes a limiting factor to plant growth.

Plant Development

Plant development was monitored both years from date of emergence (VE) until growth stage R3 (Table 4). There were no visible growth stage differences between the treatments throughout the course of either season, which was due to favorable growing conditions that were present from soybean planting until physiological maturity. In 2003, soybean planting occurred 28 July at both locations, a date considered extremely late for double-crop soybean in Maryland. Planting was earlier in 2004 with both locations planted on 29 June. Consequently, the amount of moisture present in the soil and the disparity between the two planting dates resulted in soybean growth rates that were different between the two years (Table 4). Plants were three days faster to emerge in 2004 compared to 2003. Soybean grown in 2004 consistently maintained a one to two vegetative growth stage advantage for the same number of days after planting over those in 2003. Additionally, while the plants reached R3 at the same number of days post-planting , virtually all vegetative growth had stopped in 2003 at this time, whereas in 2004 the plants continued vegetative growth well after they reached R3. This increased vegetative growth allowed plants in 2004 to add more nodes, which established a greater potential for increased soybean yield in 2004 compared to 2003.

Soil Surface Shading

Significant differences in percent soil surface shading were observed among the four WSM treatments. Neither locations nor years could be combined in the ANOVA due to significant interactions that existed between those variables and the WSM treatments so analyses were conducted by location each year. At WREC in 2003, 30 cm stubble provided significantly more shading than all other treatments for 3 weeks post-planting (WPP). This response was observed for 4 WPP at CMREC in 2003 (Figure 5). In 2004, similar trends were observed with the exception that the shading response to 30 cm stubble was observed for 4 WPPat WREC (Figure 6) and for only 3 WPPat CMREC (Figure 6). At these points in time, the soybean canopies for all four treatments were nearly fully developed, equalizing the shading effect. Conversely, the 7.5 cm WSM treatment provided the least amount of shading at both locations for the first two WPP in 2003 (Figure 5) and for the first 3 WPP at CMREC in 2004 and for 5 WPP at WREC in 2004. Both the 15 cm non-baled and baled treatments provided an amount of shading that fell intermediate to the two more extreme treatments of 30 cm and 7.5 cm with no consistent difference between non-baling and baling.

Another factor of note is the shape of the shading curves at WREC in 2004. All other locations and years appear to follow a similar trend having a sharply increasing amount of shade followed by an asymptotic relationship from about 90 to 100% (Figures

5 and 6). However, at WREC in 2004, the curves never appear to reach an asymptote at 90 to 100% due to the fact that constant deer grazing during the first three weeks following planting suppressed soybean growth and essentially delayed canopy closure. Shading measurements were only made until the point at which the soybeans reached R3; however, canopy development more than likely continued past this time at WREC in 2004 and this asymptotic relationship likely would have been observed had measurements been continued past that time.

Weed Community Characteristics

Weed community characteristics were not assessed in either year. In 2003, weed growth following wheat harvest at both locations was so excessive across all the plots that glyphosate was applied at soybean planting. Glyphosate was also applied at soybean planting at CMREC in 2004 in order to manage excessive weed growth. Weed growth was not as severe at WREC in 2004 at the time of planting; however, glyphosate was inadvertently applied to the plots prior to the scheduled time for assessment of the weed communities. Subsequent weed growth was adequately controlled throughout the growing season at both locations and years by the single application of glyphosate.

Plant Height

Combined ANOVA for locations and years indicated that a significant interaction existed that did not allow combined analysis over years. Locations could be combined in 2003, but in 2004 a significant interaction existed that did not allow the combination of locations. Soybean grown in 30 cm wheat stubble was significantly taller than soybean grown in the other three WSM treatments at both locations across both years (Table 5), however these differences at 3-4 locations were relatively small (2-4 cm). The greatest disparity in plant height caused by the 30 cm treatment compared to the other three treatments occurred at WREC during 2004 (Table 5). This difference was due to severe deer grazing that occurred during the first three weeks following planting. This grazing stress most severely impacted the 7.5 cm treatment resulting in this treatment having the shortest soybean height in 2004. Initially, the deer avoided grazing soybeans in the 30 cm stubble; however once soybean growth exceeded the stubble height there was no discrimination between treatments. An electric fence was erected in order to discourage deer entry into the plot area once the severity of the deer grazing was realized.

Regardless of location or year, these results were consistent with Hovermale et. al. (1979) who found taller soybean in stubble heights of 35 to 40 cm compared to 10 to 20 cm stubble height. This response has been attributed to the shading provided by the increased stubble height that decreases the rate of photodecomposition of auxins in the plant causing increased elongation of the soybean stems (Taiz and Zeiger, 2002). Additionally, the height response to the 30 cm treatment appears to be a shade avoidance response by the soybean plant. The 30 cm stubble increased shade levels for three to four weeks following planting. As shading increases, the ratio of red (650-680 nm): far red (710-740 nm) light decreases which in turn elicits the shade avoidance response of increased rate of stem extension (Taiz and Zeiger, 2002).

Lowest Pod Height

The LPH had a similar response to wheat stubble management as observed with plant height (Table 5). ANOVA indicated that a significant interaction between treatments and years existed; however, locations could be combined within each year. In 2003 and 2004, LPH was significantly greater in the 30 cm stubble treatment compared to the other three treatments. This response for 30 cm stubble height concurred with Hovermale et. al. (1979) who noted lowest branch height was strongly proportional to wheat stubble height, which again can be attributed to a shade avoidance response. In 2004, the LPH was greater for the 15 cm baled treatment than for either the 15 cm non-baled or the 7.5 cm treatments; a result that could possibly be due to the removal of the inhibitory allelopathic compounds associated with the wheat straw residue. Also noted is the nearly 2X difference for LPH among the four treatments in 2004 compared to 2003 (Table 5). This is attributed to increased growth rates early in plant development (Table 4). VE occurred 3 days faster in 2004 as compared to 2003. Also, in 2004 soybean plants had reached V3-4 14 days post-planting, whereas in 2003 soybean plants had only reached V2-3 16 days following planting. This increased growth rate occurred at the time when the plants were developing nodes closest to the ground, which ultimately resulted in an increased LPH in 2004 as compared to 2003.

While a significant WSM effect existed, LPH was sufficient to allow the mechanical harvest of the lowest pods across all treatments during both years. This was due to the soybean crop never undergoing moisture stress throughout the course of the season. In those years when soil moisture drops to levels that become stressful, soybeans tend to flower lower to the ground, thus decreasing LPH. In dry years, soybeans grown in 30 cm stubble could produce lowest pods at a height that can still be harvested while soybeans grown using shorter WSM treatments may result in lowest pods that may not be able to be harvested.

Lodging

Lodging was not significantly influenced by any of the WSM treatments (Table 5). This can be attributed to three factors. First, favorable climatic conditions contributed to development of strong soybean stems. Second, timely harvest of the plots decreased the potential time available for lodging to occur and, third, plots were harvested before any severe weather events could impact them.

Yield and Yield Components

Exceptional grain yields were observed at both locations both years (Table 3) due to the favorable growing conditions experienced throughout this study. These exceptional yields can be attributed to several factors, the first of which is LPH. Though WSM significantly affected LPH, lowest pods in all treatments were at a height that allowed them to be successfully harvested, resulting in no significant influence upon yield.

Soybean yield is affected by four yield components: plant population, pods plant-^{1}, seeds pod^{-1}, and seed weight (Pederson and Lauer, 2004). Compensatory responses mean that when one yield component is low, another will compensate for it. For example, in this study a compensatory response occurred at WREC in 2003 between population and pods per plant (Table 3). Neither yield, beans pod^{-1}, nor seed weight were affected by WSM; however, significant treatment effects were detected in population and pods plant^{-1}. The 30 cm treatment had a lower population, but the potential for a lower yield response for this treatment was offset by a greater number of pods plant^{-1}. While both of the 15 cm treatments and the 7.5 cm mowed treatment responded erratically across locations and years, the 30 cm height consistently produced a high number of pods plant^{-1} at all locations and years (Table 3). The observation that the 30 cm WSM treatment always produced among the highest number of pods plant^{-1} for the four treatments can be explained by the fact that this treatment also realized the greatest overall height, which is positively related to the number of nodes plant^{-1}. While significant physiological differences for plant height and LPH were observed for the 30 cm treatment, none of the yield components were significantly affected enough to provide a significant yield benefit to this stubble management treatment.

Economic Analysis

While there were no significant yield differences caused by WSM treatments, major differences in the economic advantages and disadvantages of the four treatments can be shown. For this analysis, it was assumed that production costs (not including specific costs for managing the stubble per each treatment protocol) and net revenues from the sale of soybean were the same across all the treatments because there were no statistical differences between soybean yields, which averaged 2860 kg ha^{-1} across both locations and years. To determine the costs for the various straw management treatments, custom rates (MASS 2002) were used to perform a simple economic analysis for the four WSM treatments (Table 6). There was no net increase or decrease in profit with either the 15 cm non-baled treatment or the 30 cm stubble treatment because no additional operations were performed. However, the 7.5 cm mowed treatment resulted in a net decrease of \$23.77 ha^{-1} due to the additional mowing operation that was performed. Conversely, the 15 cm baled treatment resulted in a \$94.66 ha^{-1} net increase. This calculation was performed using the average straw yield of 2.61 MT ha^{-1} measured from the 15 cm baled treatment plots over two locations and two years (Table 1). This estimation was performed using a conservative assumption of the low average straw price during June, July and August of 2003 at \$89.80 MT^{-1}, and no straw storage costs. Assuming a soybean price of \$0.22 kg^{-1}, both the 15 cm non-baled and 30 cm treatments would need to realize 430 kg ha^{-1} additional yield in order to equal the economic returns of the 15 cm baled treatment. The 7.5 cm mowed treatment would require 108 kg ha^{-1} additional yield to equal the 15 cm non-baled and 30 cm treatments and a 538 kg ha^{-1} response to equal the baling treatment. However, these economic differences do not reflect any yield benefit that may be gained by an earlier planting date of double-cropped soybean by not baling the straw. An efficient process for harvesting small grain and baling straw occurs when both are accomplished concurrently allowing the soybean planting within a day or two of small grain harvest. In years when rainfall occurs frequently, baling straw can become a costly operation because an additional raking operation in order to dry the straw may be necessary. The longer the straw remains on the field, the longer the delay in soybean planting. Any delays in planting double-crop soybean during what is frequently a moisture critical time of the year can have a negative effect on yield potential. During years when rainfall is limited, removal of straw could increase evaporation of soil moisture, which could negatively impact soybean yield.

Conclusions

The 2003 and 2004 growing seasons were most noted for the inordinate amount of precipitation that fell in the Mid-Atlantic region. This weather pattern caused many of the variables that may be influenced by the different wheat stubble management treatments and that were measured in this study to not reflect treatment differences. There were, however, some responses to the WSM treatments that were significant.

Wheat stubble that was mowed to 7.5 cm following soybean planting was found to provide the greatest amount of ground cover while removing wheat straw residue via baling provided the least amount of ground cover. A comparable amount of ground cover to the 7.5 cm mowed treatment was observed for the 30 cm treatment whenever wheat stands were less dense indicating that cutting wheat stubble high can also establish a favorable amount of ground cover. These differences in percent ground cover did not translate into a yield response for this study. This was likely due to no consistent effect upon soybean population establishment that could have occurred with the different WSM treatments; however, the treatment in which wheat straw residue was removed (baling) did observe a significantly greater soybean population during one year at one location.

Ground cover alone can greatly influence the moisture retention of the soil; however, in this study neither changes in the percent ground cover nor soil surface shading affected soil moisture levels in the top 15 cm due to the timely precipitation that was received throughout 2003 and 2004. Soil moisture levels that were near saturation at the time of planting in 2003, contributed to poor soybean populations that year. However, above normal precipitation and excellent soil moisture levels throughout the growing season resulted in good soybean grain yields in 2003 as well as for 2004.

While none of the four WSM treatments were found to have a significant effect on soybean yield or lodging during the two years of this study, several positive aspects to managing wheat stubble were recognized with this research. Stubble height cut to 30 cm increased soil surface shading for up to four WPP. A decrease in the amount of evaporative radiation that contacts the soil surface could be beneficial for conserving soil moisture during summers when moisture is a limiting factor to obtaining optimal germination, growth and yield. Additionally, when soybean plants become drought stressed they have a tendency to flower lower to the ground, thus producing pods too close to the ground to be harvested by a combine. Stubble height at 30 cm was shown to increase both overall height and LPH for soybean, both characteristics that could translate into a positive yield response during years of limited soil moisture. One of the negative characteristics observed with the three shorter stubble height treatments was decreased shading potential compared to the 30 cm treatment. However, favorable moisture conditions diminished any of the expected soil moisture responses for the shorter WSM treatments from being observed in this study.

No serious allelopathic effects such as soybean plant chlorosis or a consistent negative impact on soybean emergence was observed in this study as evidenced by the performance of both the 15 cm baled and non-baled treatments. However, an attempt to minimize the presence of any potential allelopathic compounds via the removal of wheat straw residue by baling could potentially increase the evaporation rate due to the minimal amount of mulch that is left to protect the soil surface, ultimately increasing the potential of a moisture stress situation. Conversely, the removal of wheat straw by baling can be the most profitable management approach in areas where a sufficient market exists.

Further research should be conducted that addresses several critical aspects in order to gain a more complete understanding of the effects of wheat stubble management on double-cropped soybean. First I would suggest that a similar study be conducted over more years and locations. Eventually, there would be some stressful situations established that would allow for measurements of those variables that were not influenced greatly during the two years of this study. Additionally, due to the variability of the weather during a given growing season, as well as the severity of the impact it had on this particular study, I would suggest a similar experiment be conducted on a smaller scale in a greenhouse or growth chamber, as opposed to a field setting. In establishing plots, I would suggest using soil in which there is no previous crop residue and utilizing those treatments outlined in this experiment with the addition of treatments in which residue is removed from each stubble height. While these additional treatments would not be pertinent to practical large scale production systems, they would eliminate any confounding effects of allelopathy that may be present. A greenhouse experiment would not allow for an assessment of final grain yield as accurate as would occur with a large scale field trial; however, it would allow one to measure the impacts of wheat straw management on the physiological characteristics of double-cropped soybean as well as soil moisture characteristics under specific precipitation allowances. In addition to those soybean characteristics that were monitored in this study, soybean leaf area index (LAI) should be monitored to determine a response to wheat stubble management as well as more frequent and intensive growth stage monitoring that lasts the duration of the season.

I would also suggest the addition of both thermocouples and TDR probes connected to a data logger in each plot. This would allow for the measurement of both soil temperature and volumetric moisture content more frequently and would generate a more complete graphical representation of the effects of wheat straw management on both soil characteristics while minimizing interpolation of less frequent data points. Such an experiment would eliminate the variability caused by unpredictable weather conditions as well as provide a more thorough estimation of the effects of various wheat stubble management treatments on soil and plant characteristics of double-cropped soybean.

Table 1: Wheat grain and wheat straw yield in double-cropped soybean response to various wheat stubble managements study conducted at the Central Maryland Research and Education Center (CMREC) located near Beltsville, MD and the Wye Research and Education Center (WREC) located near Queenstown, MD during 2003-2004.

Location	**Wheat grain yield**	**Wheat grain yield**	**Straw yield**	**Straw yield**
	2003	**2004**	**2003**	**2004**
	--------kg ha^{-1}--------		**-------MT ha^{-1}-------**	
CMREC	1928	3164	0.83	3.33
WREC	4339	3237	3.20	3.08
Maryland average	2491	4106	-	-

Table 2: Wheat stand density (tillers m^{-2}) at approximately Feekes growth stage 10.5 (Large, 1954) and percent ground cover at soybean planting in response to various wheat stubble managements measured by the line transect method during 2003-2004 at the Central Maryland Research and Education Center (CMREC) located near Beltsville, MD and the Wye Research and Education Center (WREC) located near Queenstown, MD.

Wheat stubble management	**Wheat stand density**		**Ground cover**	
	WREC	**CMREC**	**WREC**	**CMREC**
	-------Tillers m^{-2}-------		-----------%-----------	
15 cm	349	227	80	65
15 cm baled	353	240	75	57
7.5 cm	385	240	93	84
30 cm	373	223	81	81
LSD $_{0.05}$	NS	NS	9.8	5.7

Table 3: Soybean yield and yield components measured in response to wheat stubble management treatments during 2003-2004 at the Central Maryland Research and Education Center (CMREC) located near Beltsville, MD and the Wye Research and Education Center (WREC) located near Queenstown, MD .

Location/Year	**Wheat stubble management**	**Yield**	**Soybean population**	**Pods plant^{-1}**	**Beans pod^{-1}**	**Seed weight**
		kg ha^{-1}	**plants ha^{-1}**	**No.**	**No.**	**mg seed^{-1}**
CMREC 2003	15 cm	2204	307646	25.8	2.3	210.2
	15 cm baled	2297	285407	33.5	2.4	222.4
	7.5 cm	2217	295291	30.5	2.3	213.9
	30 cm	2241	306411	30.1	2.2	217.3
	lsd $_{0.05}$	NS	NS	4.43	NS	84.0
WREC 2003	15 cm	3304	347183	27.6	2.2	306.4
	15 cm baled	3120	412048	28.2	2.2	306.5
	7.5 cm	3133	388573	25.2	2.2	310.4
	30 cm	3175	357743	30.8	2.2	309.5
	lsd $_{0.05}$	NS	40953	4.00	NS	NS
CMREC 2004	15 cm	3504	635071	33.9	2.2	141.5
	15 cm baled	3294	668900	29.2	2.1	145.6
	7.5 cm	3462	605856	30.5	2.2	149.8
	30 cm	3234	699654	33.6	2.2	153.2
	lsd $_{0.05}$	NS	NS	3.90	NS	78.0
WREC 2004	15 cm	2526	468828	32.1	2.1	144.0
	15 cm baled	2610	445867	28.7	2.1	142.8
	7.5 cm	2526	440124	36.9	2.2	143.1
	30 cm	2912	463088	32.0	2.1	146.0
	lsd $_{0.05}$	NS	NS	6.00	NS	NS

Table 4: Soybean plant developmental growth stage measured from planting date until R_3 growth stage for double-cropped soybean in response to various wheat stubble management treatments during 2003-2004. Locations were combined within years.

Growth Stage	**2003**	**2004**
	------days after planting------	
V_E	7	4
V_{1-2}	11	7
V_{2-3}	16	-
V_{3-4}	-	14
V_{4-5}	24	-
V_{6-7}	-	25
V_{7-8}	30	-
V_{8-9}	-	31
V_{9-10}	38	-
V_{10-11}	45	38
V_{12-13}	-	45
R_{2-3}	52	52

Table 5: Soybean plant height, lowest pod height (LPH) and lodging score in response to wheat stubble management treatments during 2003-2004 at the Central Maryland Research and Education Center (CMREC) located near Beltsville, MD and the Wye Research and Education Center (WREC) located near Queenstown, MD.

Treatment	**Soybean height**			**Lowest pod height**		**Lodging**
	2003	**CMREC 2004**	**WREC 2004**	**2003**	**2004**	**Score**[†]
	--------------------------------		cm	--------------------------------		
15cm	53	51	40	8.3	14.5	2.1
15cm baled	52	52	41	8.4	16.7	2.1
7.5 cm	53	50	37	8.1	14.3	2.3
30cm	55	55	52	9.5	18.9	2.1
LSD $_{0.05}$	1.6	3.7	3.4	1.02	1.33	NS

[†] Lodging based on a scale from 1 to 5, with 1 = all plants nearly vertical and 5 = all plants horizontal.

Table 6. Economic spreadsheet of net revenues received from wheat stubble management study averaged across locations and years [Central Maryland Research and Education Center located near Beltsville, MD (CMREC) and the Wye Research and Education Center located near Queenstown, MD (WREC) during 2003 and 2004].

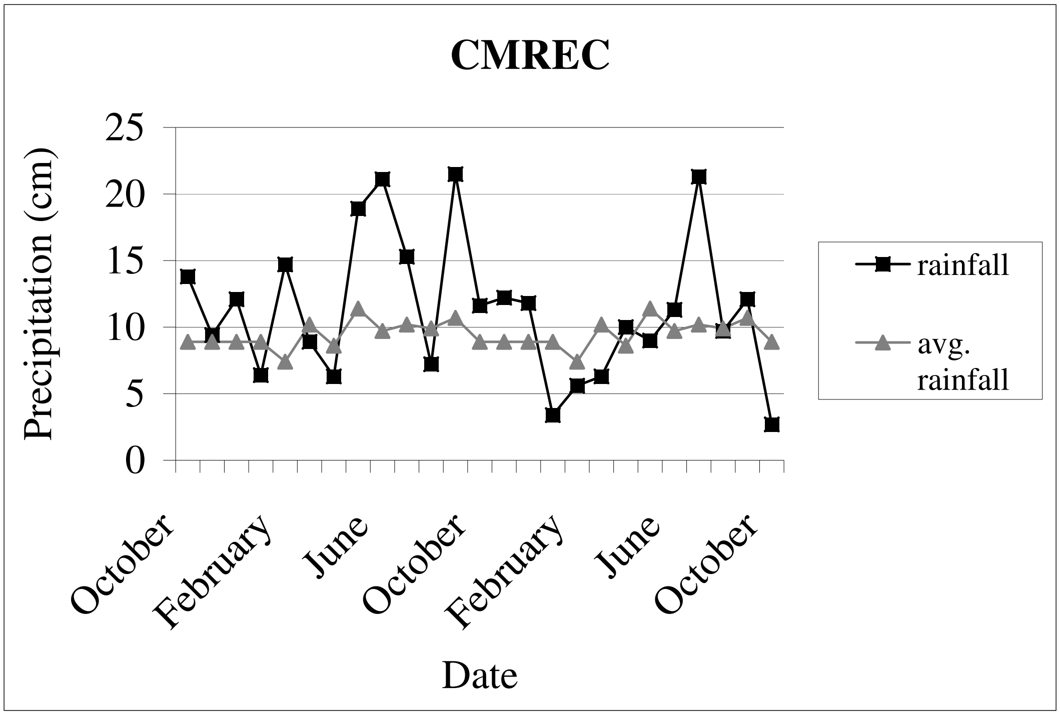
Operation	**Cost**	**Return**
15cm non-baled		
net	0	0
15 cm baled		
baling[†]	\$17.16/MT	
bale pick-up[††]	\$24.74/MT	
loading[††]	\$7.26/MT	
hauling[†]	\$4.37/MT	
straw sale[†††]		\$89.80/MT
net(MT^{-1})		\$36.27
straw yield		*2.61 MT/ha
net(ha^{-1})		\$94.66/ha
7.5 cm mowed		
straw mowing[†]	\$23.77/ha	
net	\$23.77/ha	
30 cm		
net	0	0

[†] Price based on custom rates provided by MASS (2002).

[††] Price based on personal conversation.

[†††] Price based on average from a hay/straw auction at New Holland, PA (MASS 2004).

Figure 1. Monthly precipitation received during the WSM study period of October 2002 through October 2004 at Central Maryland Research and Education Center (CMREC) and Wye Research and Education Center (WREC) and the 30-year Maryland state average.



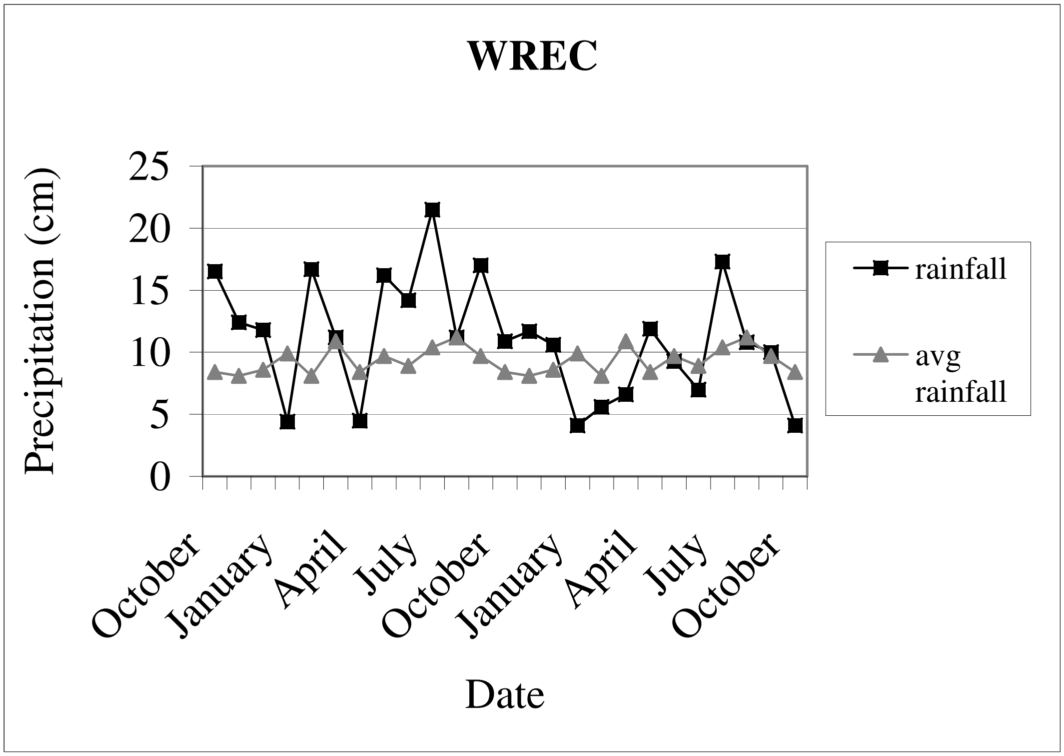


Figure 2. Average monthly temperatures at the two locations for the WSM study and 30-year average temperatures for the period of October 2002 until October 2004 . Central Maryland Research and Education Center (CMREC) is located near Beltsville, MD and the Wye Research and Education Center (WREC) is located near Queenstown, MD.

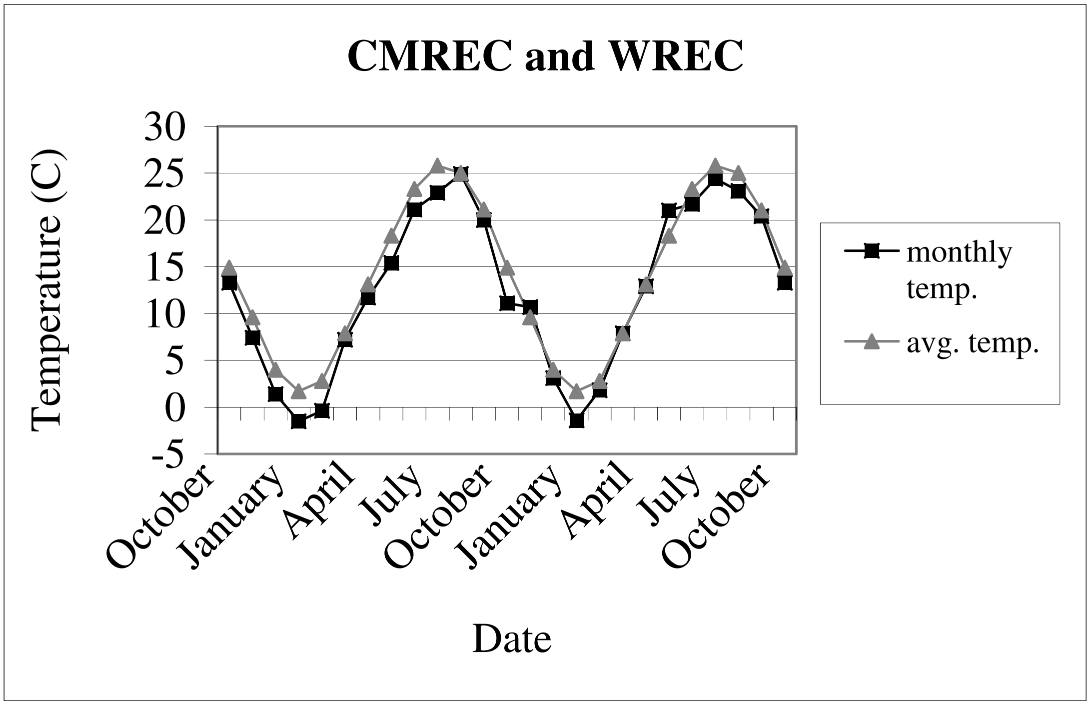
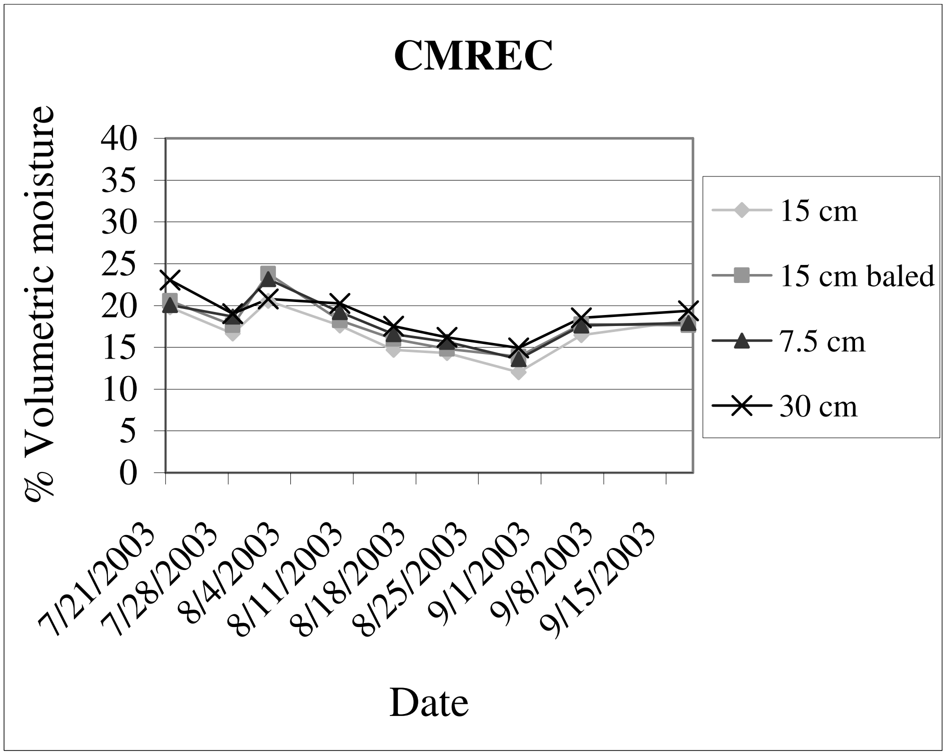


Figure 3: Weekly volumetric soil moisture contents measured in the top 15 cm of soil for the wheat stubble management study conducted during 2003 at Central Maryland Research and Education Center (CMREC) located near Beltsville, MD and the Wye Research and Education Center (WREC) located near Queenstown, MD.



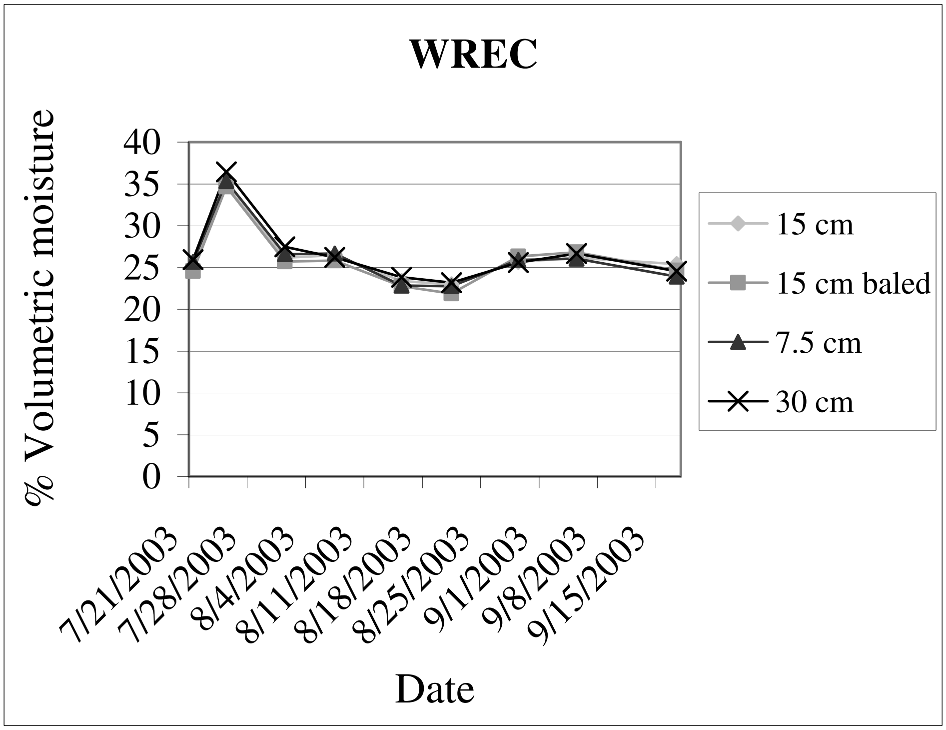
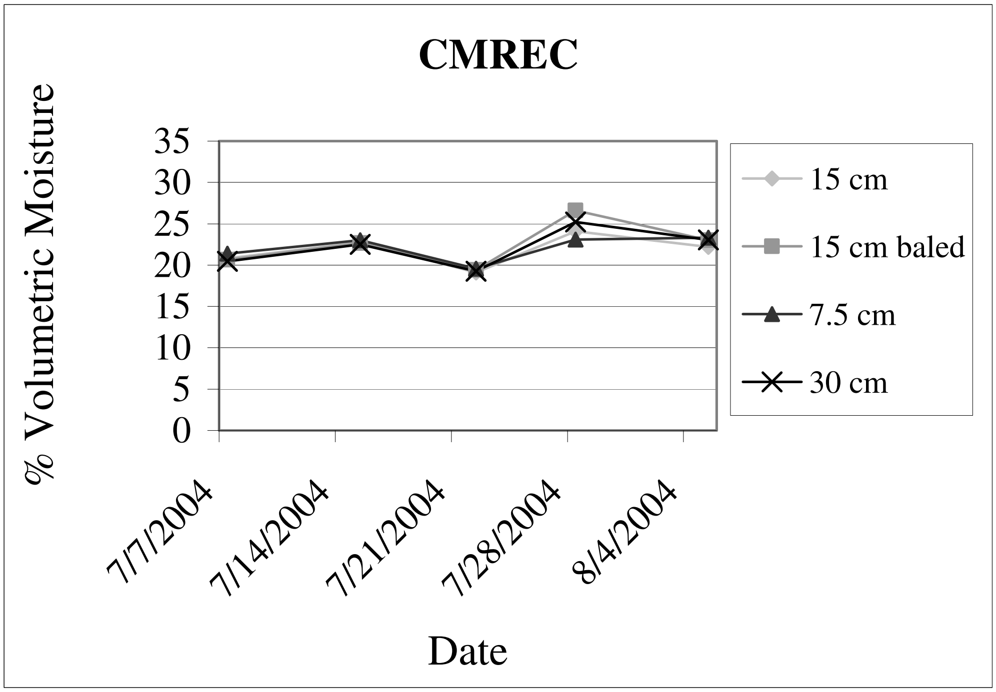


Figure 4: Weekly volumetric soil moisture contents measured in the top 15 cm of soil for the wheat stubble management study conducted during 2004 at Central Maryland Research and Education Center (CMREC) located near Beltsville, MD and the Wye Research and Education Center (WREC) located near Queenstown, MD.



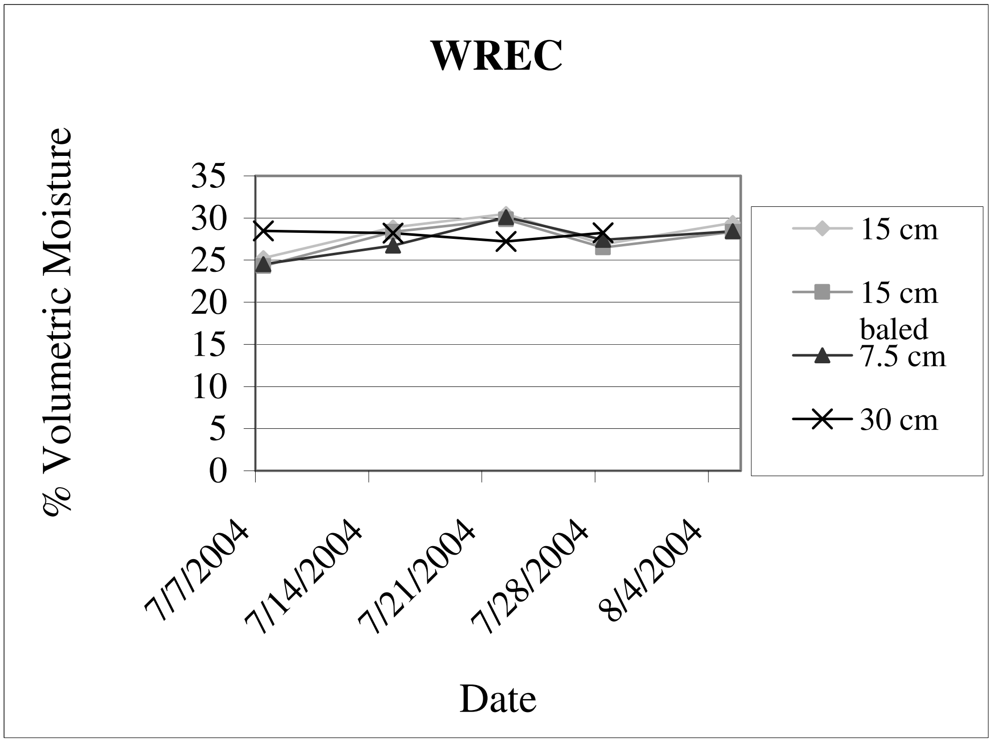
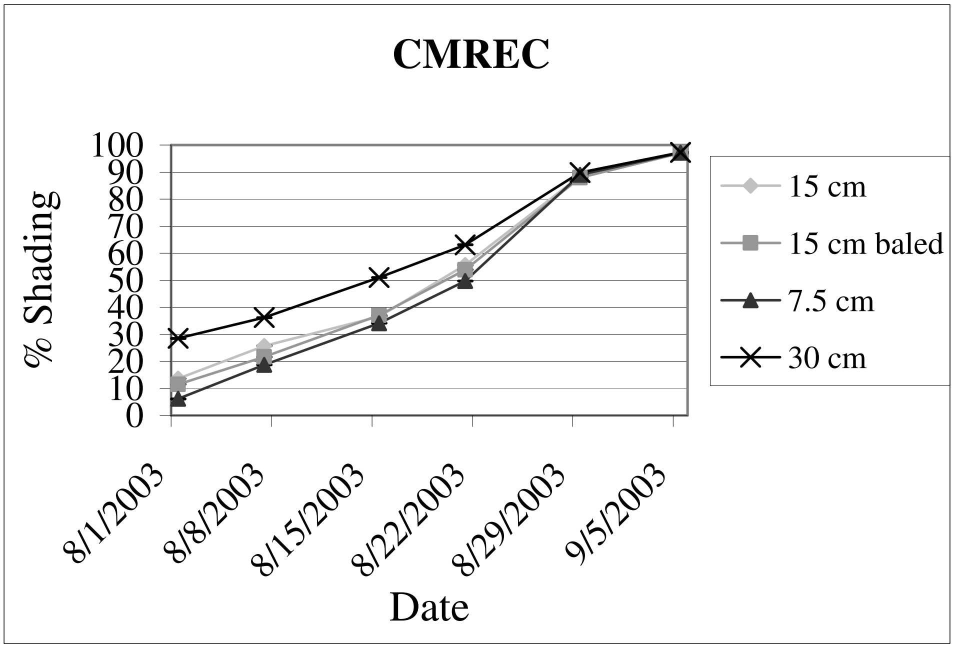
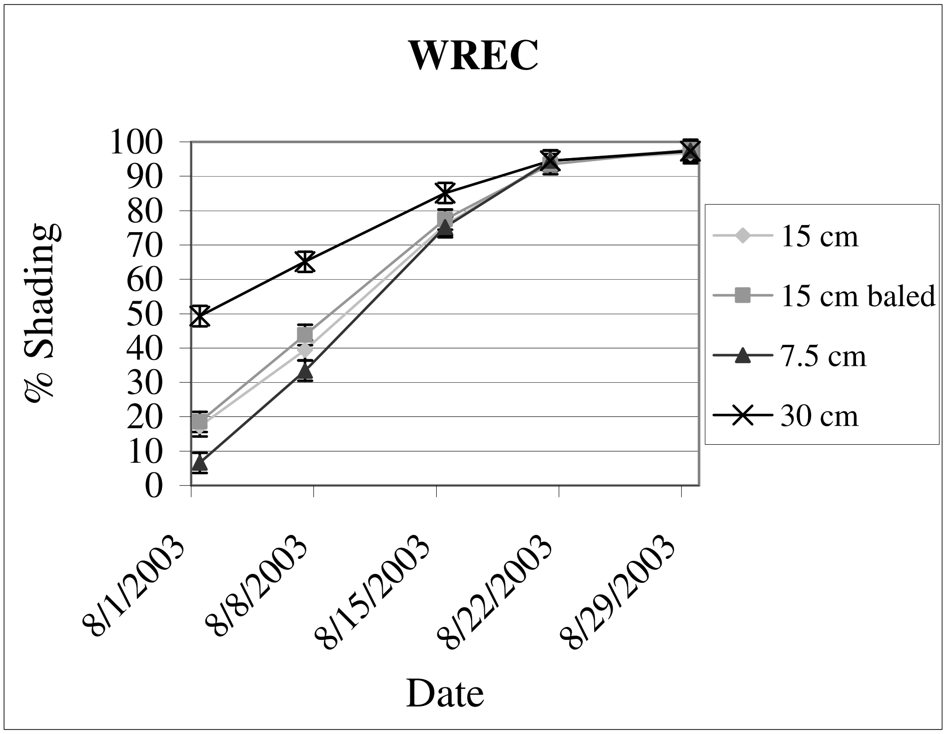


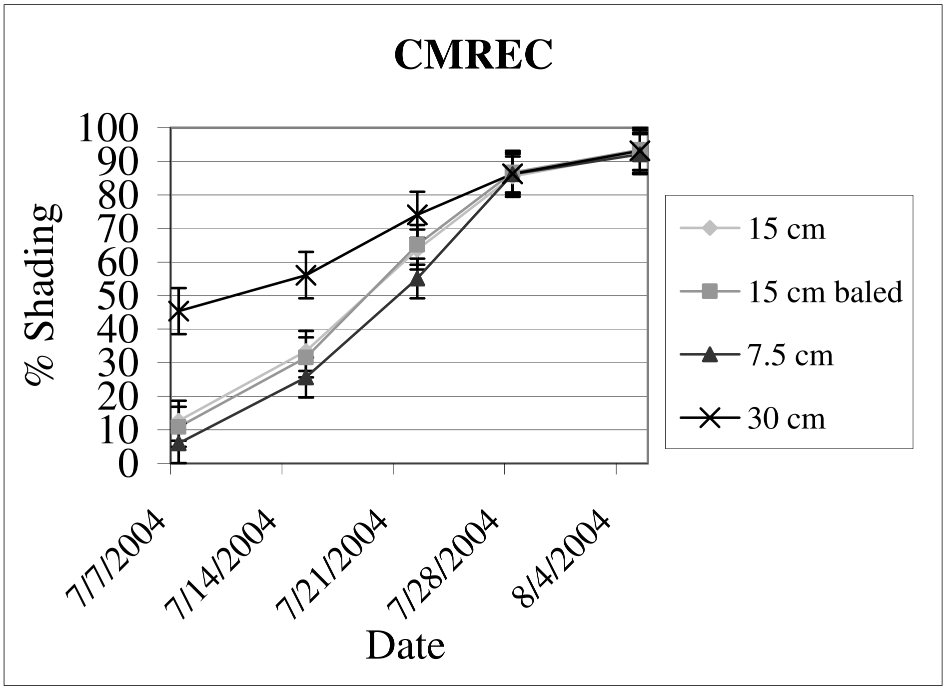
Figure 5. Percent photosynthetically active radiation (PAR) shading at the soil surface that was measured in response to wheat stubble management treatments during 2003 at the Central Maryland Research and Education Center (CMREC) located near Beltsville, MD and the Wye Research and Education Center (WREC) located in Queenstown, MD.

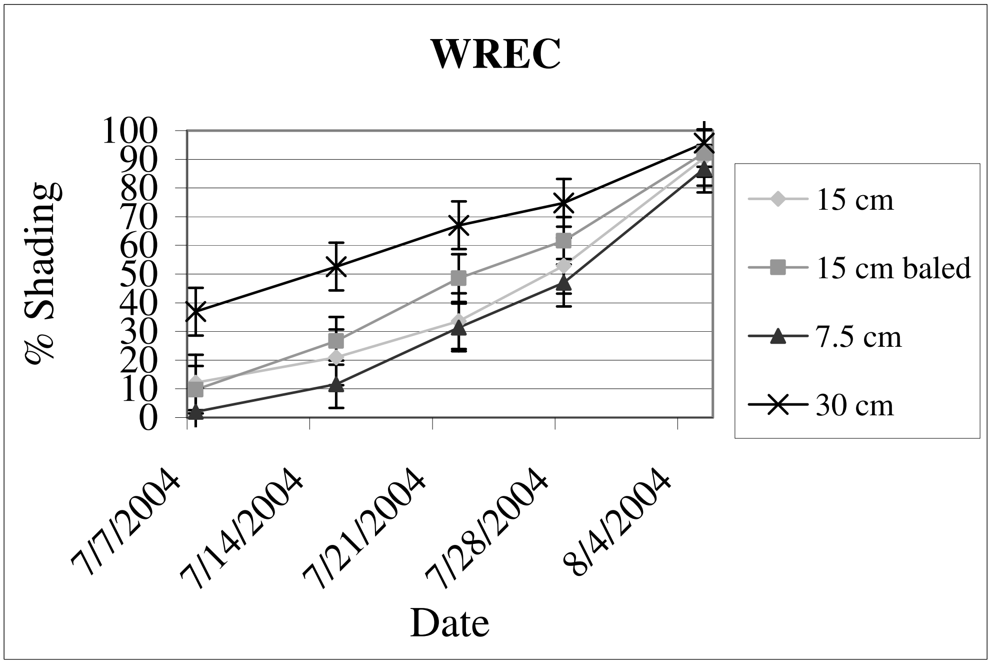




†Bars are two times the standard error.

Figure 6. Percent photosynthetically active radiation (PAR) shading at the soil surface that was measured in response to wheat stubble management treatments during 2004 at the Central Maryland Research and Education Center (CMREC) located near Beltsville, MD and the Wye Research and Education Center (WREC) located in Queenstown, MD.





[†] Bars are two times the standard error.

Appendix A. Table 1. Summary of analyses of variance for the effect of wheat stubble managements on soil volumetric moisture content during 2003-2004 at the Central Maryland Research and Education Center located in Beltsville, MD (CMREC) and the Wye Research and Education Center located in Queenstown, MD (WREC).

Source of variation	**2003**				**2004**			
	CMREC		**WREC**		**CMREC**		**WREC**	
	df	**P > F**	**df**	**P > F**	**df**	**P > F**	**df**	**P > F**
Treatment(T)	3	<.0001	3	<.0001	3	0.0007	3	0.0003
Time(Ti)	5	<.0001	4	<.0001	4	<.0001	4	<.0001
T X Ti	15	<.0001	12	<.0001	12	<.0001	12	0.0008

Appendix A. Table 2. Summary of analyses of variance for the effect of wheat stubble managements on plant height during 2003-2004 at the Central Maryland Research and Education Center located in Beltsville, MD (CMREC) and the Wye Research and Education Center located in Queenstown, MD (WREC).

Source of variation	**2003**				**2004**			
	df	**% Moisture**	**df**	**Height**	**df**	**% Moisture**	**df**	**Height**
location (L)	1	<.0001	1	<.0001	1	0.0002	1	0.0029
treatment (T)	3	0.152	3	0.0032	3	0.8221	3	<.0001
L X T	3	0.3181	3	0.9409	3	0.1863	3	0.0106
time (Ti)	8	<.0001	5	<.0001	4	<.0001	4	<.0001
L X Ti	8	<.0001	5	<.0001	4	<.0001	4	0.0742
T X Ti	24	0.2222	15	0.4086	12	0.9527	12	0.5884
L X T X Ti	24	0.4537	15	0.31	12	0.7051	12	0.0018

Appendix A. Table 3. Summary of analyses of variance for the effect of wheat stubble managements on double-cropped soybean grain yield, population, pods plant^{-1}, beans pod^{-1}, and seed weight during 2003-2004 at the Central Maryland Research and Education Center located in Beltsville, MD (CMREC) and the Wye Research and Education Center located in Queenstown, MD (WREC).

Source of variation	**df**	**Grain yield**	**Soybean population**	**Pods plant^{-1}**	**Beans pod^{-1}**	**Seed weight**
Environment (E)	3	<.0001	0.0998	0.0159	0.0848	<.0001
Treatment (T)	3	0.3843	0.8454	0.374	0.871	0.6399
E X T	9	0.1979	0.822	0.0057	0.2592	0.9399
CV, %		13.36	5.31	9.15	3.26	11.35

Appendix A. Table 4. Summary of analyses of variance for the effect of wheat stubble managements on wheat tillers m^2, % ground cover, double-cropped soybean lowest pod height and soybean plant lodging during 2003-2004 at the Central Maryland Research and Education Center located in Beltsville, MD (CMREC) and the Wye Research and Education Center located in Queenstown, MD (WREC).

Source of variation	**df**	**Tillers m^2**	**% Ground cover**	**Lowest pod height**	**Lodging**
Environment (E)	3	0.0028	0.0149	<.0001	0.8088
Treatment (T)	3	0.6871	0.7599	<.0001	0.6063
E X T	9	0.7832	0.0026	<.0001	0.7259
CV, %		13.87	7.13	8.12	31.13

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