Post emergence land rolling influences soybean plant architecture but not yield

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Core ideas:

- The influence of land rolling timing on soybean plant architecture is unknown
- Post emergence land rolling soybean resulted in decreased stand density
- Land rolling soybean after emergence decreased main stem, stem node, and stem pod numbers
- Yields of soybean land rolled from pre-emergence to V4 stage were similar to that of non-rolled soybean

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ABSTRACT

Increasing the number of nodes for subsequent pod development by soybean [*Glycine max* (L.) Merr.] may be an approach to improve yield. Land rolling is a common practice in soybean production to push rocks and corn (*Zea mays* L.) root balls back to the soil surface to protect combine harvesters. Limited research has been done to determine if land rolling can change plant architecture by breaking apical dominance of soybean to induce lateral branching and provide greater node and pod numbers. The objective of this experiment was to determine if land rolling soybeans could break apical dominance to induce lateral branching, increase reproductive node number, and improve yield. Field experiments were conducted in 2017 and 2018 using a randomized complete block design with five replications. Treatments consisted of a control that was not rolled, rolling pre-emergence, and rolling at the V2, V3 and V4 stages of development. Collected data included counts of main stems and branches, nodes on main stems, and branches that did or did not have pods, pod numbers on main stems and branches, stand density, and grain yield. Land rolling decreased main stem numbers, and reproductive nodes and pods on main stems. Land rolling soybean post emergence consistently decreased stand density in 2018 but only decreased stand on one of three post emergence timings in 2017. However, land rolling did not influence branch numbers or branch nodes and pods. Land rolling influenced soybean plant architecture but did not influence yield when done pre-emergence or post-emergence.

PREVIOUS RESEARCH

The use of land rollers in Michigan and other soybean [*Glycine max* (L.) Merr.] producing states has steadily increased over many years. Land rollers have been used for decades pre- and post-emergence in alfalfa (*Medicago sativa* L.) and grass seed production to improve germination and stand establishment and manage rocks (DeJong-Hughes et al., 2012). The production of common bean (*Phaseolus vulgaris* L.) in Michigan played a major role with the initial use of land rollers. Growers were looking to improve harvest efficiency of their common beans. Land rolling provided a much flatter surface which improved the ability to direct cut common beans with a platform header versus two field passes for pulling and windrowing followed by harvesting with a pickup header. Later, growers began to land roll soybeans to improve harvestability and reduce grain and yield losses in Iowa, Minnesota, and other Midwest states (Al-Kaisi et al., 2011). Rolling has positive impacts, especially regarding residue management. Land rolling corn residues helps to break up root balls and improve residue contact with the soil to increase the rate of breakdown (Dejong-Hughes et al., 2012). Land rollers also push rocks down to the soil surface (DeJong-Hughes et al., 2012) which prevents sickle and guard breakage, and precludes them from escaping the rock trap and entering the combine itself, thus preventing damage to the cylinder.

Land rollers also have several potential drawbacks. The initial cost of a roller can range from 17,000 to 65,000 USD depending on the size (Al-Kaisi et al., 2011). Additional operating costs will be incurred from the additional pass across the field. Land rolling can negatively affect soil and water quality due to increased levels of surface compaction, destruction of soil aggregates, and detached residue leading to a potential increase in surface erosion (Al-Kaisi et al., 2011). Several passes with a land roller can have detrimental effects on plant growth and root development. A study performed on cotton (*Gossypium hirsutum* L.) documented significant decreases in root length as a result of multiple passes with a planker (Gürsoy et al., 2019), a packer with similar soil outcomes as a land roller. In a study on weed emergence in field pea (*Pisum sativum* L.), barley (*Hordeum vulgare* L.) and summer fallow, land rolling resulted in increased emergence of small-seeded broad leaf weeds by 2 to 3-fold compared to emergence in non-land rolled controls (Lenssen, 2009). However, Lenssen and Sainju (2019) reported that land rolling did not influence weed recruitment the following year.

Land rolling generally occurs just prior to, or shortly after planting. However, sometimes weather or other factors can interfere with timely land rolling. Rueber and Holmes (2011) evaluated the influence of timing of land rolling on soybean yield. Their primary focus was to determine at what growth stage land rolling decreased yield. They reported that soybean yield was reduced by 8.7 bu/acre when land was rolled at the V6 growth stage, however, land rolling at earlier stages of development resulted in similar yields to soybeans that were not land rolled.

In a study on row spacing conducted by Pedersen and Lauer (2003), soybeans were planted at 7.5, 15 and 30 inches, demonstrating inconsistent results from year to year. The average across the 4-year study showed no differences in yield between the three row spacings (Pedersen and Lauer, 2003). Branching appears to be affected by row spacing and genotype. Wider row spacing can result in greater branching. This effect also appears to be strongly influenced by the genotype of the soybean. Norsworthy and Shipe (2005) conducted a study to evaluate the distribution of seed yield and yield components between the main stem and branches of several different genotypes at two different row widths (7.5 and 38 inch). What they discovered were significant yield differences between row width × genotypes. Certain genotypes were more prone to increased branch yields compared to main stem yields. Knowing how certain genotypes produce the bulk of their yield, through either main stems or branches, can help growers determine the best fit for certain row widths to potentially improve yields (Norsworthy and Shipe, 2005). Similar to row spacing, lower planting rates can potentially show yield compensation through increased branching leading to an increased number of pods per plant and unit area (Carpenter and Board, 1997)

Branching on soybeans is the result of axillary buds breaking dormancy and producing a stem (Pedersen, 2009). Axillary bud growth is generally inhibited by the growth of an apical bud and is known as apical dominance (Ali and Fletcher, 1971). Breaking apical dominance and inducing axillary bud growth leads soybean plants to develop more than one primary stem and potentially increase yield.

Apical dominance is controlled by several plant hormones, particularly indole-acetic acid (IAA) (Ali and Fletcher, 1970). The application of IAA to the cut site of an apical bud can maintain apical dominance (Ali and Fletcher, 1971). Other plant hormones such as gibberellic acid and cytokinins have been found to induce axillary bud growth through direct application to dormant buds (Ali and Fletcher, 1971). Breaking apical dominance through physically removing the apical bud or by applying cytokinins or gibberellic acid to the inactive buds will result in axillary bud growth (Ali and Fletcher, 1970). In addition to clipping, there are other ways to break apical dominance and induce axillary bud growth. The use of PPO inhibitor herbicides such as lactofen can result in death of soybean leaves (Johnson et al., 2002), and sometimes kill the apical bud (personal observations, Nate Boyers and Andrew Lenssen). Land rolling soybeans can result in breakage of the stem below the apical bud. Axial buds are produced at each of the nodes on a soybean main stem, and can produce flowers, branches or remain dormant (Pedersen, 2009). The axial buds located on the lower nodes allow the soybean plant to recover from serious injury including loss of the primary apical node, however, if the primary stem is broken below the cotyledonary node, the plant will not recover (Pedersen, 2009). While conducting soybean field experiments, observations were made on plots in several studies that suffered vegetative loss from animal feeding at an early growth stage from clipping of the main stem above the cotyledons. Despite the early season animal damage, these plots showed good, and quite often, greater yields than plots that were not damaged.

Limited information is available on the effects of land rolling on soybean main stems, branching and partitioning of yield components. The goal of this experiment was to determine if land rolling could be used to increase branch and reproductive branch node and pod numbers, to improve yield.

SITE LOCATION AND METHODS

A field study was established using a randomized complete block design containing five replicated blocks of five treatments. The treatments included a control with no land rolling, land rolling pre-emergence, V2, V3, and V4 growth stages. Growth stages were determined according to the system of Fehr et al. (1971). The experiment was conducted near Mason, MI, and was repeated over two years, 2017 and 2018.

Seed for the experiment was provided by the cooperator. The cooperator planted the plot area utilizing a John Deere (Deere and Company, Moline, IL) 1890 seed drill, a John Deere 1910 commodity cart, and John Deere 7310R tractor. Row spacing was set at 7.5 in. Seeding rate was approximately 140,000 seeds/acre. The plots were 35 ft. wide and 240 ft. long and separated by a 5 ft. buffer between plots. The experiment was conducted using an indeterminate maturity group II commercial cultivar (Pioneer P24T05R in 2017 and Pioneer P26T07L in 2018). Due to a change in the cooperator herbicide program from 2017 to 2018, different soybean varieties were used for the experiment. Both varieties shared similar characteristic scores with the exception that P26T07L had a slightly higher canopy width score. This slightly higher canopy width score indicates that the P26T07L could potentially branch more than P24T05R.

The cooperator was responsible for field preparation. Each year, the previous crop was corn in a corn-soybean-winter wheat rotation. Corn stalks were chisel plowed the previous fall to a depth of 8 inches. The field was then prepared with two passes of a field cultivator. The initial cultivator pass was set to a depth of 5 inches, and the second pass was set to a depth of 2 inches. Both sites used for the experiment were maintained with adequate phosphorus and potassium levels. All nutrients tested were above the above optimum level. Soil pH for the 2017 and 2018 testing sites were 6.4 and 7.2, respectively.

The 2017 and 2018 sites were planted 15 May and 27 April, respectively (Table 1), using a tractor equipped with a John Deere Greenstar RTK (Deere and Co., Moline, IL) system. Field conditions at time of planting were ideal with a moist seedbed. Seeds were planted at a depth of 1.25 inches. Soil temperature at planting was 55°F in 2017 and 50°F in 2018. The experimental areas were located in a relatively uniform soil (Colwood-Brookston and Sebewa loams) (Fine-loamy, mixed, active, mesic Typic Endoaquolls; Fine-loamy, mixed, superactive, mesic Typic Argiaquolls; and Fine-loamy over sandy or sandy-skeletal, mixed, superactive, mesic Typic Argiaquolls, respectively) and plot areas were flagged within the selected fields following planting. After the experimental area was flagged, the first land rolling treatment was applied on 15 May 2017 and 28 April 2018 (Table 1). The remaining treatments were applied to each replication according to the growth stages described by Fehr et al. (1971) and are reported in Table 1. Weekly monitoring of the soybeans took place to ensure timely application of the treatments. Following the application of each land rolling treatment, a visual non-quantitative assessment of each plot was made to determine the extent of damage to the soybean plants.

Land rolling was done with a 40 ft. wide commercial land roller pulled by a John Deere (Deere & Co., Moline, IL) 7000R series tractor equipped with a Greenstar RTK system. Unique colored flags were placed at the front and back of each treatment to identify treatment placement within the replicated blocks. The GPS tracks for each treatment also were generated when the initial treatment was applied pre-emergence and saved in the onboard tractor GPS system. This GPS track was utilized for each of the remaining treatments to maintain the proper heading and treatment spacing. Subsequent data collection was never done in wheel tracks. All treatments were successfully applied without delay from weather.

The following agronomic information were collected and recorded at the time of planting: planting date, air temperature, soil temperature, ground conditions, and planting depth. Weather data, including daily precipitation and temperature, were obtained from the Michigan State University Enviroweather Station located 6 miles south and west of the testing site.

Approximately one week following completion of all land rolling treatments, stand counts were taken from each plot to determine stand density (27 June 2017 and 15 June 2018). Stand counts were collected by counting the plants within a 33-in. diameter ring at random locations within each treatment and replication. Three samples were determined at random locations within each plot in 2017, and five samples were taken in each plot in 2018. The number of plants per acre was then calculated and then compared to the Iowa State University Extension PM 1851 Soybean Replant Decisions (Whigham et al., 2000). The cooperator utilized a post emergence herbicide program to manage weeds. Thunder Master® (imazethapyr and glyphosate, Albaugh LLC, Ankeny, IA) was applied on 12 June 2017 at 3 formulated pt/acre. Reckon™ 280SL (glufosinate, Solera ATO, LLC, Mesa, AZ) was applied on 12 June 2018 at 32 formulated oz/acre. A foliar fertilizer application was made on 16 August 2017 with Maximum N-Pact® (24-0-0, Loveland Products, Greeley, CO) at 1 gal/acre, resulting in an additional 2.4 lb/acre of N. All applications were made by driving across all treatments to minimize track influence from one plot to the next. A summary of treatment application dates and times and chemical application dates is provided in Table 1.

Plants from a randomly selected 6.5 ft. section of row were hand-harvested within each plot at the R6 growth stage (9 September 2017 and 28 August 2018). The samples were evaluated for the following characteristics: number of main stems (main stem or axillary bud stems from the base of the plant in the absence of a primary main stem), number of lateral branches, number of nodes per main stem, number of nodes on branches, total number of nodes per plant, number of reproductive nodes on main stem (node contains at least 1 pod with 1 seed), number of reproductive nodes on branches, total number of reproductive nodes per plant, number of pods on the main stem (pods containing less than 3 seeds were counted as a half pod), number of pods on branches, and total number of pods on each plant. Counts were taken on each of these components and the mean calculated for each plot on a per plant basis. The mean per plant data were then converted to the total per square foot by multiplying the mean per plant data by the plants per square foot for each plot.

The cooperator harvested the soybeans surrounding plot areas prior to harvest of the experimental units. Yield from the experimental plots was taken with a John Deere (Deere & Co., Moline, IL) S670 combine with a 35 ft. John Deere 635FD draper grain platform. Each plot was harvested in the same direction at a constant ground speed. The combine returned to the weight collection site and parked in the same position. Plot weight was collected utilizing an Unverferth (Unverferth Manufacturing Co., Shell Rock, IA) Seed Runner 3750 XL seed tender with an Unverferth 2410 Digi-Star scale that was verified with a known set of weights. Known weights for verification consisted of 4 steel tractor weights. Weights for each of the individual tractor weights were generated utilizing a shipping scale (330 lbs. total). Verification of the Unverferth 2410 Digi-Star scale consisted of evenly distributing the known weights on the seed tender frame and comparing the scale reading to the known weight. The scale was within ±10 lbs during both years. Individual plot weight data for each treatment was recorded in a raw harvest data table. Subsamples were collected from each treatment and placed in a labeled plastic bag. The seed tender was completely emptied out between each sample and the scale tared to zero. Harvest dates for 2017 and 2018 were 25 September and 14 October, respectively.

Following harvest, sample moisture was collected using a Dickey-John GAC (Dickey-John Corp., Auburn, IL) moisture tester model 2100b. The GAC was calibrated before each season by checking constants supplied by the manufacturer, and then updated if necessary. The GAC output was then verified with a local grain elevator system to ensure accuracy. Grain samples were analyzed twice and the mean moisture concentration was calculated.

Data were analyzed using a mixed model in PROC GLM (SAS v9.4, SAS Institute, Cary, NC) to perform an analysis of variance. Analysis of variance was performed on each dependent variable to identify statistical significance at an alpha of 0.05. The effects of land rolling, year, and year by rolling treatment were considered fixed while the rep(yr) term was considered a random effect. Mean separations were done by the LSMEANS procedure in SAS using an alpha of 0.05.

LAND ROLLING TIMING AND STAND DENSITY

All treatments were applied at the appropriate growth stage without delay due to precipitation or excess soil moisture conditions. The effects of year, land rolling, and the year by land rolling interaction were significant for stand density (Table 2). Stand density was influenced by year, land rolling, and the land rolling by year interaction (Table 2). Stand density in 2017 differed by timing of land rolling (Figure 1). The non-rolled control and rolling pre-emergence and at V3 had greater stand density than rolling at V2 (Figure 1). Stand density for land rolling at V4 was intermediate, and similar to all other treatments. We are unable to explain why land rolling at V2 decreased stand density. In 2018 stand density differed between the non-rolled control and all land rolling treatments (Figure 1), with the non-rolled control having greater density than all treatments that were land rolled. Stand density was similar for all treatments that were land rolled, with a mean density across rolling treatments of about 1.9 plants/sq ft, 0.5 plants/sq ft less than the non-rolled control. In 2017 and 2018, all land rolling treatments were applied late afternoon, except for rolling at V3 in 2018 which was applied mid-morning at 10:00 EDT to avoid an approaching rainstorm. Visual observations made following this treatment showed a greater level of plant damage occurred because of applying this treatment when the soybeans were more turgid (personal observation, Nate Boyers). Following the other rolling treatments, which were done in the late afternoon, generally showed that the roller pushed over soybean plants, but typically did not break stems (personal observations, Nate Boyers). Despite the increased damage from land rolling in the one morning, stand density taken following application of all treatments did not show differences for this date compared to other dates of rolling. Soybeans have a great ability to compensate for yield under a wide range of stand densities, and stands were well within the acceptable range for modern soybean production (Weber et al., 1966; De Bruin and Pedersen, 2008).

STEM AND BRANCH NUMBERS AND YIELD COMPONENTS

The effects of land rolling were similar for stem and branch numbers and their respective yield components in both years (Table 2). However, the effect of year differed for density of main stems, stem nodes, stem reproductive nodes, and stem and branch pod number (Table 2). The effect of year did not influence density of branches, branch nodes or branch reproductive nodes. The number of main stems, stem nodes, stem reproductive nodes, and stem pods was greater in 2017 than 2018 (Table 2). The non-rolled soybeans had a greater number of main stems than the soybeans that were land rolled, except for the pre-emergence treatment. Land rolling at V2 and V4 resulted in the lowest number of main stems. All land rolling treatments applied post-emergence decreased the number of main stems compared to the control. When analyzed as the number of main stems/plant, differences were not significant among land rolling treatments. Land rolling post-emergence can decrease main stem density/sq ft of soybean through the reduction of stand density per se.

The number of branches, branch nodes, and branch reproductive nodes were not influenced by land rolling. Soybeans that were not rolled had a greater number of main stems than soybeans rolled at V2, V3, and V4. Soybeans rolled prior to emergence had an intermediate number of branches, similar to the non-rolled and those rolled V3. The number of nodes, reproductive nodes, and pods on main branches was greater for soybean not land rolled and rolled prior to emergence than for soybeans rolled after emergence (Table 2). Soybean plants rolled after emergence were similar for these yield components regardless of land rolling growth stage.

Due to a change in the cooperator's herbicide program, the cultivars used for this experiment for 2017 and 2018 differed. The cultivars could have had differences in growth characteristics including branching. The trait scores for the cultivars were very similar, but the cultivar used in 2018 did have a slightly higher canopy width score. This higher score could indicate that the cultivar used in 2018 would have a slightly greater tendency to branch compared to the cultivar used in 2017. However, despite the higher canopy width score for the cultivar used in 2018, there was no difference in branching for land rolling treatments or year.

Land rolling post-emergence had a negative impact on the number of stem nodes. This difference was likely the result of a lower number of main stems for the post emergence land rolling treatments compared to the non-rolled and pre-emergence treatments. Branch nodes were similar between land rolling treatments and years. The mean number of branch nodes was 35.5 nodes/sq ft across years. Total nodes were different with 12 more nodes/sq ft in 2017 compared to 2018. This difference was likely the result of the greater stand density in 2017.

Reproductive nodes followed a similar trend to the stem and branch nodes/sq ft. This might be expected given the opportunity for plants to develop flowers and pods with a greater number of nodes in 2017 than 2018. The stem reproductive nodes were greater in 2017 by 6 reproductive nodes/sq ft (Table 2). The non-rolled control and pre-emergence rolling treatment had greater reproductive nodes than the post-emergence rolling treatments. Similar to the stem nodes/sq ft, this was likely the result of the greater number of main stems found in the non-rolled and pre-emergence land rolling treatments. Branch reproductive nodes were not different between years or between treatments. The mean number of reproductive branch nodes was 23 over both years. Total reproductive nodes were different between years with 12 more reproductive nodes/sq ft in 2017 compared to 2018 (Table 2). This difference was likely due to the difference in stand density between the two years.

The stem pod counts were greater in 2017 by 19 pods/sq ft compared to 2018 (Table 2). The non-rolled control and pre-emergence land rolling treatment were greater for pod count than the post-emergence rolling treatments. These differences could be the result of the difference in main stems between years and between treatments, or an environmental response. Branch pods were different between years with 12 more branch pods/sq ft in 2017 than 2018. The difference in branch pods cannot be easily explained but may be the result of environmental differences between years. There were no differences in branch pods for land rolling timing. Total pods differed by year with 31 pods/sq ft more in 2017 than 2018.

SOYBEAN YIELD

Soybean yield differed between years (Table 2). However, neither the effect of land rolling nor the year by land rolling interaction influenced yield. Yield in 2018 was greater than in 2017 by 2.2 bu/acre. Despite having differences in stand density between years, with 2018 having a less dense stand and several significantly lower yield components/sq ft, soybean yield was greater, documenting that stand density is not a driver of soybean yield once about 100,000 plants/acre is achieved. Mean monthly air temperature and precipitation differed between years (Table 3), but do not readily elucidate differences in yield or yield components.

This study generated several additional questions on the practice of land rolling soybeans. Visual observations made during this experiment indicated that land rolling soybeans in the morning caused a higher level of damage to the soybean plant (personal observation, Nate Boyers). Additional experimentation should be conducted to compare land rolling at different times of day to determination if plant turgor or other factors influence main stem damage and subsequent branching. Additionally, combining the time of day for land rolling with subsequent application of lactofen herbicide may further decrease apical dominance and lead to greater branching and improve canopy closure in soybeans planted on 30-inch centers, decreasing the yield advantage for narrower row spacing and the need for an additional planter not easily used in most corn production systems. The possible interaction of land rolling by row spacing by planting rate could be explored.

CONCLUSIONS

Land rolling soybeans can provide benefits to farmers with improved harvest efficiency, but land rolling did not increase branching or yield when rolled pre- or post-emergence. Post emergence land rolling had a slightly negative affect on soybean stand density, which varied between years, but stand density remained adequate for near maximum productivity. Land rolling after emergence had a negative effect on the number of main stems and this varied depending on growth stage when the soybeans were rolled. Land rolling at later post emergence dates decreased main stem density. The resulting effect on the number of main stems further influenced the number of nodes on the main stem, the number of reproductive nodes and ultimately the number of pods on the main stem. Despite post-emergence rolling treatments having a negative effect on the main stem, it did not influence yield. Land rolling carries an economic cost with the investment in the roller and an additional field operation. These costs should be factored in when a grower is considering land rolling soybeans.

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Table A. Useful conversions.

To convert Column 1 to Column 2, multiply by	Column 1 Suggested Unit	Column 2 SI Unit
$5/9(^{o}F - 32)$	Fahrenheit, ^{o}F	Celsius, ^{o}C
9.29×10^{-2}	square foot, sq ft	square meter, sq m
67.19	60-lb bushel per acre, bu/acre	kilogram per hectare, kg/ha
25.4	inch	mm

Table 1. Planting and management practices for soybean land rolled on four dates in two years. Mason, MI.

	Planting and Treatment Information	
	2017	**2018**
Planting date:	15 May	27 April
Air temperature (^{0}F):	73	64
Soil temperature (^{0}F):	55	50
Ground Conditions:	Moist, good seed bed	Moist, good seed bed
Planting Depth (in):	1.25	1.25
Not land rolled	15 May 19:00	27 April 8:00
Rolled pre-emergence	15 May 23:00	28 April 18:00
Land rolled V2	12 June 17:30	29 May 19:00
Land rolled V3	16 June 17:00	2 June 10:00
Land rolled V4	21 June 18:30	6 June 19:00
Stand counts (V5-V6):	27 June	15 June
Plant data collection R6	9 September	28 August
Harvest date	25 September	14 October
Herbicide applications	12 June Thunder Master® 3 pt ac^{-1} 16 August Maximum N-Pact® 1 gal ac^{-1}	12 June Reckon™ 280 SL 32 oz ac^{-1}

Table 2. Stand density, main stem and branch nodes, reproductive nodes, and pods, and yield for soybean land rolled over two years. 2017 and 2018, Mason, MI.

Treatment	Stand Density	Main Stems	Branches	Stem nodes	Branch nodes	Total nodes	Stem repro[†] nodes	Branch repro nodes	Total repro nodes	Stem pods	Branch pods	Total pods	Yield
	--- no./sq ft ---												bu/acre
Year (Y)													
2017	2.9 a[‡]	2.7 a	7.3	43 a	38	81 a	30 a	25	56 a	69 a	32 a	101 a	60.7 b
2018	2.0 b	2.0 b	6.7	36 b	33	69 b	24 b	21	44 b	50 b	20 b	70 b	62.9 a
Rolling (R)													
Not rolled	2.7 a	2.7 a	8.1	45 a	36	82	31 a	23	54	70 a	25	94	61.4
Rolled pre-merge	2.5 b	2.5 ab	6.5	43 a	32	75	30 a	19	49	69 a	20	88	62.4
Rolled V2	2.2 c	2.2 c	5.6	36 b	31	66	24 b	19	44	53 b	24	77	61.7
Rolled V3	2.4 bc	2.3 bc	7.2	37 b	36	72	25 b	24	49	53 b	27	80	61.8
Rolled	2.3	2.1 c	7.6	37 b	43	80	25 b	29	54	53 b	33	87	61.7

V4	bc												
P > F													
Year	<0.001	<0.001	0.270	<0.001	0.195	0.007	<0.001	0.115	<0.001	<0.001	0.006	<0.001	0.007
Rolling	<0.001	<0.001	0.071	0.001	0.300	0.149	<0.001	0.186	0.178	0.009	0.275	0.267	0.911
Y × R	0.043	0.091	0.196	0.178	0.277	0.291	0.063	0.384	0.589	0.216	0.433	0.563	0.091
CV (%)	8.8	12.5	28.7	14.3	38.7	19.6	15.6	44.7	20.8	23.5	53.5	22.0	4.3
R^2	0.89	0.79	0.61	0.69	0.50	0.56	0.74	0.48	0.55	0.71	0.50	0.68	0.84

[†] repro = reproductive nodes, nodes with at least one pod

[‡] Means within a column followed by different letters differ at $P<0.05$ by protected LSMEANS test.

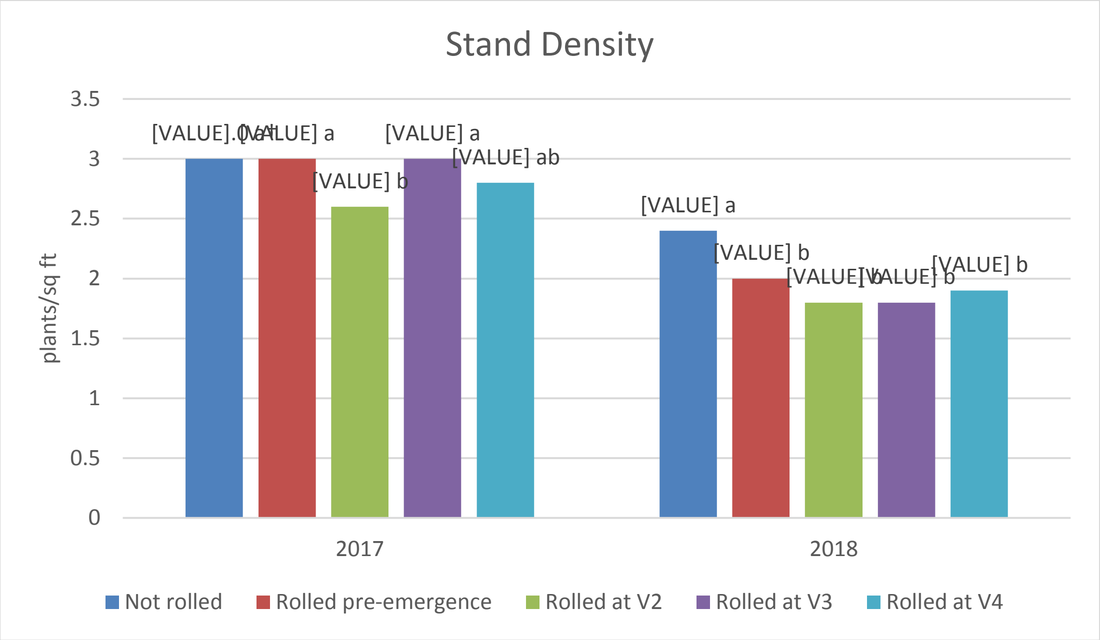
Table 3. Mean precipitation and temperature for the 2017and 2018 growing seasons. Mason, MI.

Month	2017[†]	2018	30 Yr. Avg.[‡]	2017	2018	30 Yr. Mean.
	Precipitation, inches			Mean Temperature °F		
April	4.8	2.5	3.0	52	40	47
May	2.8	7.8	3.4	57	65	58
June	1.3	3.6	3.5	68	69	68
July	1.6	1.1	2.8	71	71	72
August	2.4	3.8	3.2	66	71	70
September	0.5	3.3	3.5	63	64	62
October	9.2	3.5	2.5	55	49	50
Total Precipitation	22.6	25.6	21.9			

[†] Precipitation and mean temperature data were collected from the Michigan State University Enviro-weather station in Leslie, MI, 6 miles from the experimental site (MSU Staff, 2019).

[‡] Mean precipitation and temperature 1981-2010 National Oceanic & Atmospheric Administration, Lansing Capital City Airport, MI (NOAA Staff, 2019).

Figure 1. Year by Land Rolling interaction means for stand density. Mason, MI.



[†] Means within years followed by different letters differ at P<0.05 by protected LSMEANS test.