PRECISION PLANTING OF MAIZE (*Zea mays L.)* TO MANIPULATE CANOPY GEOMETRY AND THE EFFETC ON LIGHT INTERCEPTION AND GRAIN YIELD

Research Proposal

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CHAPTER I

ABSTRACT

Precision planting of corn has the potential to control some of the parameters that influence final grain yield such as plant density, in-row plant spacing, planting depth and seed orientation. The purpose of this research project is to increase corn grain yield through precision planting. The hypothesis is that the effects of controlled leaf geometry could facilitate planting higher populations with the potential for increasing grain yield and/or allow the maintenance of grain yields while reducing seed rates. If corn seed orientations can be controlled at planting, then leaf angle and time from planting to emergence can be preferentially manipulated. This preferential manipulation of leaf azimuths and time from planting to emergence will likely have implications on plant-to-plant competition as well as, affect the amount and efficiency of photosynthetically active radiation (PAR) that is intercepted throughout the entirety of a growing season consequently influencing on final grain yield. This technique would not only improve the plant’s ability to intercept more light but also offer a competitive advantage for the crop due to quicker canopy closure, more efficient soil shading, reduced inter and intra-specific competition.

CHAPTER I

INTRODUCTION

Over the past years corn grain yields have increased drastically in the U.S. Data from 1930 showed that average corn yield in the United States was about 1 Mg ha-1 and increased to 7 Mg ha-1 in 1990 (Troyer, 1990). Many strategies have being used to promote this yield increase including genetic improvements, the use of fertilization especially nitrogen, weeds, pests and diseases control, tillage practices, crop rotation, reduced row spacing and increased plant population. Increased light interception has a positive effect on productivity, often described as a linear function when the crop does not experience biotic and/or abiotic stress. Stinson and Moss (1960) suggested that light can be a limiting factor in corn production when nutrients and soil moisture are adequate. Precision corn planting and its resultant effect on leaf azimuth and can be used to increase light interception and consequently crop yields.

According to Duvick (1992) and Cardwell (1982), 60% of the yield improvement can be credited to genetic advances while the remaining 40% is the result of improved management practices. Increase plant densities spacing is a well known strategy to improve corn grain yield. Karlen et al., (1985) found dry matter yield increase of 4 Mg ha-1 increasing plant densities from 6.7 and 13.5 plants m-2. Another effect of high plant

density is the increase in leaf area index (LAI). Olson and Sanders (1988) found that by increasing plant density LAI was improved whereas Hunter (1980) found that increased leaf area per plant of short-season maize resulted on grain yield increase. Additionally, Alessi and Power (1974) demonstrated that depending on hybrid and season, LAI can be enhanced up to 4.9 by planting early maturing maize hybrids at densities of 74.0 thousand plants ha-1. The increase in LAI has a direct impact on light interception and dry matter accumulation; as a result yield is directly related leaf area (Gardner et al., 1985).

Leaf architecture of modern corn hybrids can optimize light interception to increase grain yield (Stewart et al., 2003). The effect of increased light interception confers the crop a competitive advantage in relation to weeds, because available light for weed will be reduced. Boyd and Murray (1982) suggested that light transmittance through the crop canopy is affected by leaf architecture therefore influencing weeds development. Pendleton and Hammond (1969) showed that relative photosynthetic potential of corn leaves was two times greater in the upper portion of the canopy than the middle portion and five times greater than the bottom part of the canopy. It was reported by Reichert et al. (1958) and by Stinson and Moss (1960) that reductions of available light can result in yield reductions. They used artificial shading to reduce the available light and the result was grain yield decrease. Prine and Schroder (1964) showed that ear number and yield by plant can reduce with mutual shading of plants.

According to Peters (1961) seed planting techniques could be used to provide systematic leaves orientation for capturing more light and consequently more efficient soil shading. The technique referred by Peters is supported by the findings of Fortin and Perce (1996) who observed that random seed placement results in random ear leaf orientation. Giardin and Tollenaar (1994) studied the systematic nature leaf azimuths and credited these changes in the canopy to intra-specific interference which provided a more uniform light distribution. Bosy and Aarssen (1995) showed that rates and germination success of eight weed species were highly dependent on seed orientation in controlled environment germination. Research by Patten and Van Doren (1970) found earlier more complete emergence with more seedling growth with maize planted with the proximal end of the seed down. Similarly, Torres et al., (2011) found that leaf position and emergence are significantly affected by seed position at planting. These researches suggests that if seed are systematically planted in the same matter, emergence would be more uniform and leaves will be systematically oriented resulting in more homogeneous crop stands that intercept light more efficiently, have a quicker canopy closure, decreased inter and intra-specific completion. Further, homogeneous corn stands can decrease plant-to-plant variability and avoid yield depressions (Martin et al., 2005).

Other effects related to the manipulation of crop canopy include changes in soil surface evaporation (Karlen et al., 1985), plant transpiration and photosynthesis. Stewart (1986) indicated that grain yield of sorghum was benefited by each millimeter of available water for evapotranspiration. Research done by Steiner (1986) demonstrated a positive relation between photosynthetically active radiance (PAR) and cumulative evapotranspiration. Finally, Muchow (1990) reported that light interception by the canopy directly affect crop photosynthesis. Therefore, the summation of these benefits would likely result on a more friendly environment for the crop to produce higher yield.

The search for more efficient use light can provide means for the continual yield increase experimented over the past decades, that was achieved due to improved management practices and breeding. Further, environmental concerns associated with the use pesticides and fertilizers in agriculture and the challenge to feed a growing population motivates the development of innovative management practices. The main goal of this research is to prove that precision planting of corn can be used to manipulate leaf geometry enhancing the plant’s ability to intercept light, influencing the photosynthesis and consequently increase grain yield.

CHAPTER I

OBJECTIVES AND HYPOTHESIS

The objectives of this experiment is to investigate and evaluate the effect of seed position at planting on corn leaf orientation and it’s resultant effect on light interception and grain yield. Three different plant densities at each site using two fixed seed positions and the control (random seed planting) and two hybrids with different leaf architectures (plagiophile and erectophile). The hypotheses are: (1) controlled planted corn seeds will result in non-random (controlled) leaf orientations; (2) manipulation of crop canopy will influence light interception; and (3) seed orientation at planting can result on yield increase.

Additionally, this experiment will use crop modeling techniques to determine what are the physiological features related to leaf orientation and the resultant effects on light interception and use efficiency that will influence final grain yield. The hypothesis is that the advantage of using precision planting of corn to manipulate canopy geometry will have implications on the total amount of PAR intercepted throughout the entire growing season. The reason behind this increased amount of total PAR during the growing season is that from early stages (V4) until maturity oriented corn plant would intercept more light than random corn plants, due to the reduction of shading of on plant to the next.

CHAPTER I

MATERIALS AND METHODS

Field trials were established at two sites in the 2010, 2011, and 2012 to evaluate the influence of seed orientation at planting on leaf orientation, light interception, and grain yield using three plant densities, two corn varieties, and three seed positions. Experiments will be conducted at the experimental site located at Lake Carl Blackwell (LCB) near Stillwater-OK, on a Port silt loam-fine-silty, mixed, thermic Cumulic Haplustolls at plant densities of 49.4, 74.1 and 98.8 thousand plants ha-1. The other experimental site is located at Efaw in Stillwater-OK, on a Norge loam, fine-silty, mixed thermic Udic Paleustoll at plant densities of 37.0, 49.4, and 61.7 thousand plants ha-1.

Seed positions are (1) laying flat, embryo up, perpendicular to the row, (2) upright with caryopsis pointed down, parallel to the row, and (3) random seed position. The row spacing for all treatments will be 0.76 m. Corn varieties to be planted for both sites are ‘P0902HR’ that have prostrate leaf architecture characteristics in a randomized complete block design and ‘P1173HR’ with erect leaf architecture within an incomplete factorial arrangement with three replications (Tables 1 and 2). The method that will be used for planting the oriented seed treatments will consist of blocking the two central seed boxesin the planter and raising the pressing wheels with the objective of having two blank furrows where theyremain open. Later, the plots with oriented seed placement treatments will hand planted using a meter stick to achieve the desired population. Plots with random seed position will be planted using a four-row planter. Experimental plots have 6.09 m long and 3.50 m wide. All plots will receive pre-plant nitrogen rates of 200 kg of N ha-1 and top dress of 60 kg of N ha-1 of urea ammonium nitrate (UAN, 32%). Phosphorus and potassium will be applied according to soil test to be determined each year.

Light interception data will be collected as a fraction of photosynthetically active radiation intercepted by the crop from V4 to R1 using the line quantum-sensor LI-1400 (LI-191SA, LI-COR, Lincoln, NE). Three measurements will be taken in each plot and the mean intercepted photosynthetic active radiation (IPAR) will be expressed as percentage of the total incoming PAR. Intercepted photosynthetic radiation is calculated as the ratio of radiation collected at the soil level and the total incoming solar radiation. Light interception data will be collected around solar-noon placing the line quantum sensor close to the ground (under the crop canopy) at an angle across a single inter-row space between the two center rows and then taking a measurement over the crop canopy to access the amount of incoming radiation.

Other variables that are going to be measured are; normalized differential vegetative index (NDVI), plant height, distance between plants, LAI, number of leaves per plant, time from silking to black layer (physiological maturity), and reflected PAR. Before grain harvest, total biomass will be collected by sampling 1 meter square on each plot. Further, leaf angle in relation to the corn row will be measured by treatment using a protractor. These measurements will be used to model total IPAR accumulated during the growing season and to better understand the physiological effect of increased light interception on final grain yield.

Statistical analysis will be performed and mean values for each treatment will be computed using the MIXED procedure from SAS software using alpha equal to 0.05 to be considered significant. Additionally, frequency distribution, correlations and regression analysis will be used to investigate how the leaves are distributed as affected by seed orientation at planting and to investigate the effect of leaf angle on grain yield and light interception.

|  |  |  |  |
| --- | --- | --- | --- |
| Lake Carl Blackwell | | | |
| Treatment | **Leaf architecture** | **Seed orientation** | **Population**  **(plants ha-1)** |
| 1 | Prostrate | Upright | 49,400 |
| 2 | Prostrate | Flat | 49,400 |
| 3 | Prostrate | Random | 49,400 |
| 4 | Prostrate | Upright | 74,100 |
| 5 | Prostrate | Flat | 74,100 |
| 6 | Prostrate | Random | 74,100 |
| 7 | Prostrate | Upright | 98,800 |
| 8 | Prostrate | Flat | 98,800 |
| 9 | Prostrate | Random | 98,800 |
| 10 | Erect | Upright | 74,100 |
| 11 | Erect | Flat | 74,100 |
| 12 | Erect | Random | 74,100 |

|  |  |  |  |
| --- | --- | --- | --- |
| EFAW | | | |
| Treatment | **Leaf architecture** | **Seed orientation** | **Population**  **(plants ha-1)** |
| 1 | Prostrate | Upright | 37,050 |
| 2 | Prostrate | Flat | 37,050 |
| 3 | Prostrate | Random | 37,050 |
| 4 | Prostrate | Upright | 49,400 |
| 5 | Prostrate | Flat | 49,400 |
| 6 | Prostrate | Random | 49,400 |
| 7 | Prostrate | Upright | 61,750 |
| 8 | Prostrate | Flat | 61,750 |
| 9 | Prostrate | Random | 61,750 |
| 10 | Erect | Upright | 49,400 |
| 11 | Erect | Flat | 49,400 |
| 12 | Erect | Random | 49,400 |

Table 1 and 2. Treatment structure for Lake Carl Blackwell and EFAW

CHAPTER II

ABSTRACT

Better use of resources and improved sustainability remain important for today’s agricultural production. Improvement in light interception has been achieved with increased plant population and reduced row spacing. Currently, the research involving plant population and row spacing in corn is aimed at twin row cropping systems. Twin row planting allows the crop to explore the benefits of increased plant population densities without having to reduce the space between rows. Twin row configurations have being intensively investigated and are well documented. In contrast, leaf azimuth controlled by seed orientation at planting as a way to influence the crop’s ability to intercept and use light has received modest attention. Research shows that light interception and grain yield are affected by changes in planting configuration and plant population density. However, fewer studies have focused on the response of maize as influenced by seed orientation. Additionally, there are no reports in the literature combining row configuration and plant population with seed orientation at planting. Therefore, the purpose of this study is to describe and examine the effects of seed orientation, row configuration and plant population on leaf azimuth, light interception, soil moisture and grain yield.

CHAPTER II

INTRODUCTION

The challenge of feeding a growing population lays on how to achieve this objective with limited resources and in a sustainable way. Therefore, it is extremely important to search for more efficient use of resources. Better use of nutrients and water are usually the main concerns because of the interest in optimizing returns and because they have a direct impact on production costs. Although, improvements in the use of solar radiation have not been the main focus of producers, it is usually accomplished with management practices such as reduced row spacing and increased plant population that translate into improved solar radiation use and increased yield.

Pioneering work done by Shibles and Weber (1965) showed a positive linear relation between accumulated intercepted photosynthetic active radiation (CIPAR) and dry matter increase for soybean. Andrade et al. (1992) also observed that dry matter production is proportional to the amount of CIPAR accumulated during the growing season. Although, it’s recognized that this relation only holds true if water and nutrients are at sufficiency levels. Pendleton et al. (1967) and Stinson and Moss (1960) indicated that, when nutrients and water are sufficient, light can be the primary limiting factor for crop production. Among the strategies that can be used to improve light interception are;

increased plant population, reduced row spacing, systematic seed orientation at planting, leaf architecture of modern corn hybrids and hybrid maturity.

Plant population density and row spacing are common management practices used to improve the ability of a crop to intercept more light, because crop leaf area is increased by these management practices. Edwards et al. (2005) conducted a study to investigate the effect of narrow row spacing and increased plant population. Short and full-season maize hybrids were seeded at rates ranging from 5 to 20 plants m-1 and reported that yield of short-season hybrids at approximately 19 plants m-1 produced the same yield as a full-season hybrid at about 8 plants m-1. The author indicated that CIPAR was increased by increased plant population which favored the yield of a short-season hybrid that produced similar yields compared to a full-season corn hybrid. Downey (1971) demonstrated that the relationship between yield and plant population is a parabola, because at lower populations yield is restricted due to reduced number of plants and as plant population increases competition increases which causes yield to be limited. Nafziger (2002) showed a quadratic response of yield as affected by increases in plant population. They also found small differences when comparing 0.50 m and 0.76 m row spacing at the same population. Cox and Cherney (2001) investigated the effect of row spacing, plant density and nitrogen rates on corn silage and reported greater dry matter production for 0.38 m versus 0.76 m row spacing.

Twin row configuration, have being extensively investigated in the Corn Belt, because it allows for increased plant population without having to reduce row spacing, maximizing the space for each individual plant and the crop’s ability to intercept more light throughout the growing season. It is believed that with twin row configuration, producers would be able to take advantage of the benefits of reduced row spacing without major investments in equipment. However, contradictory results have being reported regarding the benefits of the twin row system. Nafziger (2006) reported significantly higher light interception at V10 growth stage for 0.20 m twin row with 0.56 m centers when compared to 0.76 m rows at plant population densities of 67.1 and 85.2 thousand plants ha-1. However, no difference between twin and single row planting was observed at R2 growth stage. Further, it was demonstrated by Nafziger (2006) that the advantage in light interception at V10 growth stage did not result in increased yield. Nelson and Smoot (2009) conducted small and large plot trials to compare twin rows (0.18 m twin row on 0.76 m centers) versus 0.76 m single row to determine the effects of row spacing and plant population on IPAR and grain yield. Their results showed no significant differences for IPAR and grain yield when these planting configurations were compared.

The first report that seed orientation at planting influenced the leaf distribution came from Peters and Woolley (1959). They noted that preferential plant growth allowed the leaves of oriented seeds to grow perpendicular to the row thus avoiding overlap of leaves fromneighboring plants. Leaves in this system occupied spaces between the rows increasing light interception. Because leaves intercepted up to 90% of incoming solar radiation, soil shading was enhanced resulting in reducedevaporative loss, and conserved moisture at the soil surface. Recently, Torres et al. (2011) conducted a greenhouse experiment and documented a significant effect of seed orientation at planting on maize leaf azimuth and emergence. At the V4 corn growth stage when seeds were planted upright, caryopsis pointed down, parallel to the row and laying flat perpendicular to the row, 70 to 90% and 77 to 90% of plants had leaf azimuths between 60 to 90°, respectively. Other benefits related to seed orientation at planting comes from work by Patten and Van Doren (1970). They showed that seed orientation influenced emergence rate, root penetration, root length and leaf area.

Some of the plant and crop characteristics that affect solar radiation interception and use are; leaf area index (LAI), leaf inclination, rate of dry matter production, leaf area duration (LAD), and leaf azimuth. These properties that influence light penetration into the crop canopy were combined by Monsi and Saeki (1953) into a single coefficient denoted canopy extinction coefficient (*k*) and was used to calculate light interception at a given point of the canopy. The relationship between IPAR and LAI have being well documented for a variety of crops and in general to achieve 90% of IPAR, LAI values of 3 to 5 are needed, although for maize crops LAI can get up to 6 in order to reach a critical level of IPAR (Hipps et al., 1983; Wells, 1991; Williams et al., 1965; Gallo and Daughtry, 1986). The implications of LAI beyond a critical level is that IPAR will start to decrease because of shading of the bottom leaves of the canopy that will become sinks instead of sources consequently affecting productivity.

Even though numerous experiments have been established with the goal of showing how IPAR and grain yield respond to changes in plant population and planting pattern, little work has been done to investigate the effects of seed orientation on crop properties. Additionally, there is no evidence of research that investigated the interaction between seed orientation, plant population density and planting configuration.

CHAPTER II

OBJECTIVES AND HYPOTHESIS

The objective of this experiment is to investigate and document the effects of maize (*Zea mays L*.) leaf azimuth, planting configuration and plant population density on light interception, soil moisture and grain yield. To accomplish this purpose a factorial treatment structure was designed with 3 leaf azimuth (across-row, with-row and random) two planting configurations (single and twin rows) and two plant populations densities (49.4 and 74.1 thousand plants ha-1).

It is hypothesized that seed orientation at planting and its resultant leaf azimuth combined with twin row planting configuration could be used to maximize light interception, promote faster canopy closure, reduce inter and intra-specific competition and conserve soil moisture, offering a competitive advantage for the maize crop. Some of the questions to be answered by this experiment are: (1) what are the effects of across-row leaf azimuth light interception, soil moisture and grain yield compared to random and with-row leaf azimuth; (2) can twin row planting configuration be more efficient in relation to single row planting configuration; (3) what is the effect of the interaction between planting configuration and leaf azimuth; and (4) what is the influence of higher plant population density on light interception, soil moisture and grain yield.

CHAPTER II

MATERIALS AND METHODS

The interaction between leaf orientation, planting configuration and plant population density is expected to influence light interception, soil moisture and final grain yield. Therefore field experiments will be conducted at two experimental stations near Stillwater during 2012. A factorial arrangement of treatments will be evaluated in a randomized complete block design with three replications and will be established in a north-south orientation at two sites: (1) Lake Carl Blackwell (LCB) experimental station, on a Port silt loam-fine-silty, mixed, thermic Cumulic Haplustoll and (2) Efaw experimental station, on a Norge loam, fine-silty, mixed thermic Udic Paleustoll.

For the experiment located at LCB populations of 49.4 and 74.1 thousand plants ha-1 will be evaluated and at EFAW populations of 37.0 and 49.4, thousand plants ha-1. The explanation for this difference in plant population density between the two sites is that LCB will be managed under a lateral pivot irrigation system whereas the trial located at EFAW will receive irrigation with a drip system only if periods of drought are experienced during the crop development.

Prior to the establishment of the experiment a composite soil sample will be collected to determine the soil properties such as pH, soil phosphorus and potassium levels as well as N-NH4 and N-NO3 and total N. Phosphorus and potassium fertilization rateswill be determined accordingly based on the collected soil samples for each site. Pre-plant nitrogen rates of 100 kg N ha-1 and top-dress rates at 60 kg N ha-1 using urea ammonium nitrate (UAN, 32%) will be applied to ensure that the crop does not experience any kind of nutrient deficiency that could confound the effects of leaf azimuth, planting configuration and plant population density.

Seed orientations identified by Torres et al. (2011) will be used to manipulate the crop canopy and promote preferential leaf azimuths. For the treatments with across-row leaf orientation corn seeds will be planted laying flat, embryo up, and perpendicular to the row. To achieve a with-row leaf azimuth corn seeds will be planted laying flat, embryo up, but parallel to the row. The plot size will be 6.09 m long and four-rows wide and treatments with oriented seeds will be hand-planted while the plots with random seed position will be planted using a John Deere max-emerge four row vacuum planter.

Leaf azimuth treatments will be planted under two configurations, first is a conventional single row pattern with row spacing of 0.76 m and the second will be a twin row system with row spacing of 0.20 m for the narrow rows and 0.76 m centers. To measure leaf angle a digital picture will be taken over the canopy of 5 consecutive plants of the two central corn rows, starting at 1 m distance from the border of the plot. The pictures will be taken using a digital camera mounted on a stand between V3 and V6, and all visible leaf azimuths in the picture will be recorded as the deviation from the row using a free image manipulation program capable of determining angles (GIMP 2.6, 2011. Subsequently, leaves will be classified from angle ranges of 15° from an across-row leaf azimuth to a with-row leaf azimuth. Additionally, after leaf azimuth is measured, the percentage of oriented plants per plot will be computed. Leaf azimuths will be measured during the morning to avoid high temperatures and potential diurnal heliotropism. Photosynthetic photon flux density (PPFD) in *µ*mol m-2 s-1 will be measured within 1.5 hour of solar noon using a portable quantum line sensor LI-191 (LI-COR, Lincoln, NE). Consequently, IPAR will be calculated by the following formula as measured by PPFD:

where *I* is the incident PAR at the soil surface under the crop canopy and *I*0 is the incident PAR at top of the canopy. The method to measure IPAR will use the procedures suggested by Gallo and Daughtry (1986) for sensor placement. Measurements will be taken under clear skies every 7 to 10 days. Reflected photosynthetic active radiation (RPAR) will be measured above the canopy of each plot by positioning the quantum line sensor upside down.

To investigate the effect of leaf azimuth, plant population density and planting configuration on soil moisture a hand-held sensor that measures water content, model CS659 coupled with a CSA Hydrosense II data logger (Campbell Scientific, Inc., Logan, UT) will be used. To collect soil water content (SWC) a transect from the middle of one row to the middle of the next will be drawn and 5 to 6 measurements at 0.12 m depth will be taken with four repetitions in each plot. Soil moisture content will be measured 2 to 3 days after an irrigation or precipitation event.

Normalized difference vegetative index (NDVI) data will also be collected every 7 to 10 days to monitor crop development. Also, measurements will be taken in the two middle rows and averaged by plot using a GreenseekerTM handheld sensor. In addition, plant height, distance between plants?, period from silking to black layer, grain yield and N concentration in the grain will be recorded.

Collected data will be processed and analyzed to verify the consistency of treatments as affected by different environments as well as to better understand the interactions between leaf azimuth, plant population density and planting configuration. Analysis of variance will be used to investigate treatment performance and mean values for the measured variables will be reported. Regression analysis and simple correlation will be used to understand the relationships between dependent and independent variables. In addition, frequency distribution analysis will be performed to explore the influence seed orientation, plant population, and planting configuration on leaf azimuth distribution.

|  |  |  |  |
| --- | --- | --- | --- |
| Treatment | Leaf Orientation | Planting Configuration | Plant Population ('000 plants ha-1) |
| 1 | Across-row | Single | 49.40 |
| 2 | Across-row | Single | 74.10 |
| 3 | Across-row | Twin | 49.40 |
| 4 | Across-row | Twin | 74.10 |
| 5 | Random | Single | 49.40 |
| 6 | Random | Single | 74.10 |
| 7 | Random | Twin | 49.40 |
| 8 | Random | Twin | 74.10 |
| 9 | With-row | Single | 49.40 |
| 10 | With-row | Single | 74.10 |
| 11 | With-row | Twin | 49.40 |
| 12 | With-row | Twin | 74.10 |

|  |  |  |  |
| --- | --- | --- | --- |
| Treatment | Leaf Orientation | Planting Configuration | Plant Population ('000 plants ha-1) |
| 1 | Across-row | Single | 37.05 |
| 2 | Across-row | Single | 61.75 |
| 3 | Across-row | Twin | 37.05 |
| 4 | Across-row | Twin | 61.75 |
| 5 | Random | Single | 37.05 |
| 6 | Random | Single | 61.75 |
| 7 | Random | Twin | 37.05 |
| 8 | Random | Twin | 61.75 |
| 9 | With-row | Single | 37.05 |
| 10 | With-row | Single | 61.75 |
| 11 | With-row | Twin | 37.05 |
| 12 | With-row | Twin | 61.75 |

Table 3 and 4. Treatment structure for Lake Carl Blackwell and EFAW.

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