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Canopy temperature, yield, and harvest index of corn as affected by planting geometry in a semi-arid environment

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ABSTRACT

Selection of an appropriate planting geometry is important for determining crop yield under water-limited conditions. Four studies, consisting of six experiments, were conducted to investigate the feasibility of alternative planting geometries for sustainable corn (*Zea mays* L.) production on a commercial scale. Clump (three plants clustered), cluster (five plants clustered), and skip-row (one row planted, one row skipped) geometries were tested against the commonly used evenly spaced planting within the row (ESP) geometry under limited irrigation and/or dryland conditions. Among the four studies, harvest index (HI) for alternative geometries was significantly higher (9–18%) in three of them compared to ESP. Aboveground biomass and grain yield showed mixed results. Although kernel weight for alternative geometries was significantly higher (2–10%) in all studies, grain yield was significantly higher only when kernel number was also higher for alternative geometries. Decreased HI in ESP was mainly due to more tillers because tillers increased vegetative mass, but did not contribute to grain yield. Plants in ESP had 0.57–1.81 tillers plant^{-1}, but the plants in cluster geometry had only 0.22–0.48 tillers plant^{-1}. Canopy temperature (CT) between planting geometries was compared in two studies, where plants in ESP had higher CT (32.2–39.4 °C) than those in clusters (30.7–38.5 °C). Although alternative geometries did not always increase the yield, decreased tillers, reduced CT, and increased HI and kernel weight associated with the alternative geometries may help to reduce corn production risk under water-limited environments.

1. Introduction

Corn production in the semi-arid Texas High Plains, which usually receives less than 250 mm of growing season precipitation, is mostly dependent on irrigation from the Ogallala Aquifer, the primary source of groundwater in the region (Howell, 2001). However, the region's ability to produce irrigated crops has declined as water use has exceeded recharge, leading to the continued depletion of the aquifer (Roberts et al., 2007; Colaizzi et al., 2008; McGuire, 2017). Hence, there is an increasing interest in growing corn under dryland conditions or with very limited amounts of irrigation. In addition to the limited growing season precipitation in the Texas High Plains, a high evaporative demand characterizes the area, attributable to high wind speed, solar radiation, and temperature (Stewart and Burnett, 1987). Although corn plants are relatively tolerant to water stress during the vegetative growth and seed-ripening stages (Doorenbos and Kassam, 1979), water stress at critical growth stages such as seed germination and emergence, late vegetative growth, and silking and grain filling can reduce the plant height, leaf area, and grain yield (Traore et al., 2000; Payero et al., 2006). For example, the 2012 drought in the U.S. Corn Belt reduced corn yields by 21% and increased grain prices by 53% compared to the five previous non-drought years (Boyer et al., 2013).

Many factors such as crop species and cultivars, planting geometry, and plant population affect plant growth and yield under water-limited environments (Thapa et al., 2016). When soil resources such as water are nonlimiting, uniform cropping will provide the greatest efficiency in light interception and photosynthesis, but when resources are limiting, nonuniform treatment of the land or the crop can be an advantage

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Table 1
Use of different planting geometries, corn hybrids, fertilizers, seed rates, and planting dates for all studies. The irrigation used in study-1 was limited and for each study, fertilizers were applied based on the pre-planting soil test. ESP = evenly spaced planting within the row.

Study	Year	Location/treatment	Geometry used	Hybrid used	Fertilizer used	Seed rate (seeds ha^{-1})	Planting date
1	2009	Dumas, irrigated	clump, cluster, skip-row, and ESP	Pioneer 35F40	N-P-K = 82-0-0 (22.7 kg ha^{-1})	31,000	04/18/2009
	2009	Dumas, dryland	clump, cluster, skip-row, and ESP	Pioneer 35F40	–	31,000	04/18/2009
2	2009	Dumas, dryland	clump, cluster, skip-row, and ESP	Pioneer 35F40	N-P-K = 10-34-0 (13.2 kg ha^{-1})	31,000	05/01/2009
	2010	Dumas, dryland	clump, cluster, skip-row, and ESP	Pioneer 35F40	N-P-K = 10-34-0 (13.2 kg ha^{-1})	35,000	06/10/2010
3	2016	Dumas, dryland	cluster and ESP	Pioneer P0365AM	N-P-K = 10-34-0 (13.2 kg ha^{-1})	31,000	04/15/2016
4	2016	Stratford, dryland	cluster and ESP	Pioneer P0365AM Pioneer P1151AM	N-P-K-S = 28-0-0-5 (140 kg ha^{-1})	31,000	06/10/2016

(Loomis, 1983). Reducing the plant populations, widening the row spacing, and skip-row configuration are some of the strategies that have been adopted for better utilization of available soil water in semi-arid environments (Larson and Vanderlip, 1994; Stewart, 2009). Studies evaluated the yield performance of clump and cluster geometries (which together with skip-row are called alternative geometries in this paper) under water-limited conditions. Thapa et al. (2016, 2017) found that planting corn and grain sorghum (*Sorghum bicolor* L. Moench) in clumps reduced canopy temperature (CT) and vapor pressure deficit (VPD) within canopy and increased harvest index (HI) (dry weight of kernels divided by the dry weight of aboveground biomass). Some other studies reported greater grain yield in clumps (Bandaru et al., 2006; Kapanigowda et al., 2010; Mohammed et al., 2012) and in skip-row configurations (Simons et al., 2008; Vigil et al., 2008) compared to the evenly spaced planting within the row (ESP). However, skip-row planting of corn under limited irrigation scenarios resulted in reduced grain yields (Musick and Dusek, 1972; Baumhardt, 2010). Further, Lyon et al. (2009) found that skip-rows resulted in increased yield than that for ESP when the mean grain yield for ESP was 1.12 Mg ha^{-1} but skip-rows resulted in decreased yield when the mean yield for ESP was 3.44 Mg ha^{-1}.

Under high solar radiation and drought conditions, once plants are under water stress, their stomata begin to close and cease to transpire, resulting in higher CT (Urban et al., 2007; Martin, 2009). In addition to the environmental factors, several plant traits such as root morphology, leaf orientation (Balota et al., 2008), canopy size, canopy architecture, and canopy color significantly affect the CT (Ferguson et al., 1973; Zheng et al., 2008). Canopy temperature can provide plant-based information on crop water status (Mahan et al., 2012). Many studies have used thermal imaging or infrared thermometers (IRT) to monitor CT in drought and heat stress experiments (Reynolds et al., 1994; Lopes et al., 2012; Thapa et al., 2016, 2018). Thermal imaging is useful to study plant water relations and has the ability to include large number of individual plants in a single image when calculating temperature measurements (Jones et al., 2009).

The objective of this research was to characterize the impact of planting geometry on grain yield and to analyze the traits related to yield determination such as aboveground biomass, HI, kernel weight, kernel number, CT, and tiller number. Using ESP and alternative planting geometries, we conducted multi-year (2009, 2010, 2016) corn field experiments at a commercial production scale. The alternative geometries reduce plant spacing and leave more free space between clumps, clusters, or rows. In the 2009 and 2010 growing seasons, our hypothesis was that in the semi-arid environment, plants in alternative geometries would benefit from mutual shading as well as the additional soil water in the free spaces, especially at later growth stages, resulting in more grain yield. Although no data were collected for tillers, field observations in 2009 and 2010 suggested that corn plants in alternative geometries had fewer tillers than in ESP. Further, plants in alternative geometries were less stressed visually during the hottest part of a day. Hence in 2016, the hypothesis was further elaborated to evaluate tillers and CT in alternative geometries. The resultant study data would subsequently be useful to assess the feasibility of alternative planting geometries for sustainable corn production under water deficit conditions.

2. Materials and methods

Most of the previous studies that compared the yield performance of planting geometries used small plot size (< 200 m^2), two planting geometries (ESP vs. clump or cluster or skip-row), and manually harvested plant samples to compare the yield. We implemented clump, cluster, and skip-row, as well as regular ESP geometries, in a commercial production field with larger plots (> 1000 m^2 per plot) and grain yields were compared after harvesting the entire plot using a commercial combine harvester. For all studies, the use of planting geometries, corn hybrids, fertilizers, seed rate, and planting dates are presented in Table 1.

2.1. Study-1 and study-2 (2009 and 2010)

Study-1 and study-2 were conducted in Dumas, TX (35°56′ N, 101°58′ W, 1098 m elevation) on Sherm silty clay loam soil. According to the USDA classification, soil in Dumas is fine-loamy, mixed, mesic Aridic Peleustolls. The properties of the 0 - 0.15 m soil layer were, pH 7.9, sand 16.8%, silt 47.2%, clay 36.0%, and organic matter 2.2% (Unger and Pringle, 1986). For both studies, corn (Pioneer 35F40 hybrid) was grown in four planting geometries (clump, cluster, skip-row, and ESP), using a 12-row planter (John Deere Co.). The hybrid was selected based on its adaptability in a semi-arid climate of the Texas High Plains.

The first study (Reznik Farm at Dumas) consisted of irrigated and dryland corn. Irrigation was limited and carried out at seed germination/emergence, tasseling/silking, and grain filling growth stages, using a center pivot irrigation system (total of 117 mm irrigation water was applied). Dryland corn was planted at the North-East side of the sprinkler. The land was fallowed for about 10 months after harvesting winter wheat (*Triticum aestivum* L.) in June 2008. Based on soil test, anhydrous ammonia (N-P-K = 82-0-0) was applied with a strip till-rig at 22.7 kg ha^{-1} for irrigated corn (Table 1). No fertilizer was applied for dryland corn because the soil test showed adequate nutrients for dryland corn production. The experimental design was randomized complete block design (RCBD) for both irrigated and dryland corn. Each planting geometry was replicated three times and each plot had 12 rows of plants with 0.76 m row spacing (a 9.14 m wide strip) under both irrigated and dryland conditions. Corn rows (North-South) ran throughout the field length of about 250 m in dryland and 475 m in irrigated plots. Same seeding rate (31,000 seeds ha^{-1}) was used for