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Strip tillage improves soil biological activity, fruit yield and sugar content of triploid watermelon

Daniel Leskovar*, Yahia Othman, Xuejun Dong

Texas A&M AgriLife Research and Extension Center, Texas A&M University, Uvalde, TX 78801, USA

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ABSTRACT

Tillage practices are critical for sustaining soil quality necessary for successful crop growth and productivity. A three-year study (2012–2014) was carried out to evaluate the influence of strip and conventional tillage practices and three water status levels [T1 = 100% of evapotranspiration (ET) demands, T2 = 0.75T1and T3 = 0.5T1] on plant morphology, physiology, yield and quality of triploid (seedless) watermelon (*Citrullus lanatus* cv. Magestic). Soil chemical and biological properties were also assessed at the end of the experimental study. Tillage practices (strip or ST and conventional or CT) started in 2009 and are being carried out to the present date of 2016. Irrigation was established using a center pivot system. Photosynthesis rate (*Pn*), stomatal conductance (*gs*), and chlorophyll content index (SPAD) were measured at flowering, fruit development and harvest stage and vine length measured at the harvest stage. Total marketable yield and fruit quality (firmness and sugar content) were determined during the harvest period. Soil chemical and microbial analysis were conducted at the end of the experimental period (March 2015). No significant differences ($P = 0.05$) were found between water deficit treatments in vine length, SPAD, *Pn*, *gs*, fruit firmness, and sugar content during the three-year study, except for vine length in 2013. But, marketable yield from T1 treatment was significantly higher ($P = 0.03$) than T3 in 2013. Vine length and SPAD measured from the ST plots were higher than CT, especially in 2012. Interestingly, marketable yield from ST was 8.6, 9.7 and 14.9 t ha^{-1} higher than CT in 2012, 2013 and 2014, respectively. Additionally, fruit sugar content under ST was statistically higher ($P = 0.05$) than those from CT. After 6 years of tillage practices (2009–2015) in the same site, ST increased total bacteria by 49%, active bacteria by 27%, active and total fungi by 37%, nematodes by 275%, and electrical conductivity by 14% compared to CT. However, ST significantly increased root-feeding nematodes (harmful to plant roots) and reduced phosphorus and nitrate-N compared to CT. Although long-term studies aimed at assessing soil quality and cumulative yield are required to further validate our results, yield and fruit quality (sugar content) responses were consistent across three years and with promising abundance of soil microbial activities.

1. Introduction

Adopting conservation agriculture practices such as no or minimum soil disturbance (strip) tillage, cover crops, and crop rotation can lead to improvements in soil properties, net returns and crop yield (Wilson et al., 1982; Gathala et al., 2015). Adopting leguminous cover crops system improves soil organic matter, soil N and water retention in the top layer of the soil (Wilson et al., 1982). Soil moisture and macro- and micro-aggregate stability were significantly affected by tillage intensity (Al-Kaisi et al., 2014). Therefore, suitable tillage practices are critical for sustaining soil quality that is required for successful crop growth and development (Jabro et al., 2009). For example, maize (*Zea mays*) planted on no-till had higher water use efficiency (16%) and used less irrigation water (25%) than conventional tillage (CT), increasing the total net return of no-till by \$281 ha^{-1} (Jat et al., 2013). Yield of wheat (*Triticum aestivum*) grown with no-tillage practices was either higher or equal to CT and had 6% more profit income than the CT (Saharawat et al., 2010).

Twenty years of CT research in subarctic Alaska revealed that no tillage led to higher soil saturated hydraulic conductivity and water retention against gravitational forces than reduced and CT (Sharratt et al., 2006). However, because of an increase in weed pressure management, reduced tillage was recommended as a more sustainable management practice in that region

* Corresponding author.
E-mail address: d-leskovar@tamu.edu (D. Leskovar).

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(Sharratt et al., 2006). While no-till increased soil water content and germination of winter wheat, it had no positive effect on soil physical properties under a crop rotation in a semi-arid region (Gozubuyuk et al., 2014). In fact, no-till treatment had the lowest soil total porosity and the highest bulk density in the 30 cm top-soil layer (Gozubuyuk et al., 2014). Although no-tillage can improve organic matter, aggregate stability and cation exchange capacity, it increased the bulk density and the penetrometer resistance of the top-soil layer (Cannell and Hawes, 1994). Moreover, no-tillage increased the concentration of phosphorus (P) and extractable potassium (K) in the topsoil (0–5 cm) (Horne et al., 1992). This is due to slow movements of both P and K fertilizers when placed under the soil surface and also, due to shoot nutrient deposit after plant residues decomposed and incorporated in the soil (Cannell and Hawes, 1994).

Strip tillage (ST) is a conservation tillage practice that consists of seedbed ploughs in strips of about 20 cm wide, and 15–20 cm deep, leaving the non-till area with crop residues and undisturbed soil to cover at least 30% of the topsoil surface (Hendrix et al., 2004; Trevini et al., 2013; Vyn and Raimbault, 1992). Although ST is qualified for conservation agriculture when the disturbed area is only less than 25% of cropped area (FAO, 2016), a slightly wider strips might be required for vegetable production systems. This is because transplanters which are widely used in vegetable production require loosening wider in-row subsoil to maximize root-media-soil contact to improve water uptake and reduce transplant 'shock' upon transplanting.

Partial cover of the soil surface by maintaining crop residues leads to protection against soil erosion and increases in soil moisture and productivity (Celik et al., 2013; Mullins et al., 1998). Strip tillage also warms soils during cold early spring and creates a suitable microclimate for seed germination as compared with no-till system (Al-Kaisi and Hanna 2008). Strip tillage is considered as effective as CT in improving plant emergence and in conserving soil moisture (Licht and Al-Kaisi, 2005a). Übelhör et al. (2014) found that nitrogen uptake and yield under fall ST was as effective as CT for white cabbage (*Brassica oleracea*). But, intensive ST (fall and summer tillage) had lower N-uptake than fall ST (Übelhör et al., 2014).

However, studies that evaluated ST practices are controversial. While ST reduces water deficit stress by partially covering the topsoil (Morse, 1993), it negatively affects soil physical properties since some studies reported an increase in soil mechanical impedance (Vyn and Raimbault, 1992). Conventional tillage aerates soil organic matter, reduces soil compaction (top-layer) temporarily, control weeds, alleviate soil-and residue-borne diseases and pests problems, and incorporates fertilizers and previous crop residues (Hobbs, 2007). Wiatrak et al. (2005) found that ST system did not significantly improve yield and plant morphology of cotton (*Gossypium hirsutum* L.) in southeast U.S. compared to CT. Also, nitrogen uptake and water use in ST did not differ statistically when compared with no-tillage and CT (chisel plow) after 2 years of corn plantings (Licht and Al-Kaisi, 2005b). However, conservation agriculture such as permanent beds and conservation tillage practices (ST) increases farmer net income and benefit cost ratio when compared with CT (Gathala et al., 2015). Strip tillage may not increase yield significantly over CT practice but it can potentially increase farmer net incomes by reduced production cost and labor use (Saharawat et al., 2010; Gathala et al., 2015). In fact, due to frequent tillage practices, the CT system has a higher soil bulk density and penetration resistance in the 10–15 and 15–20 cm soil depth (Jat et al., 2013). A 3-year field study on dry bean (*Phaseolus vulgaris*) using various tillage management systems showed that no-till, strip, and sweep tillage enhanced earliness to maturity by 7–10 days and eliminated zinc deficiency when compared with CT (Deibert, 1995). Overstreet et al. (2010) found that long term ST (10 years) increased earthworm population more effectively than organic inputs in vegetable production system.

Tillage practices can potentially affect soil physical, biological and hydraulic properties; therefore, it is critical to identify a tillage practice that sustains the soil quality required for successful crop development and yield (Jabro et al., 2009). For example, a 10 years study on nematode and earthworm communities under ST and CT in vegetable production system showed that the total nematode number of moldboard plow (CT) was 52% of ST (Overstreet et al., 2010). Conservational tillage such as ST has been assessed in few vegetables crops such as cabbage (Morse, 1993; Roberts et al., 1999; Übelhör et al., 2014) and pickling cucumber (*Cucumis sativus*) (Osmond et al., 2011). However, despite the high economic importance of watermelon in the U.S., value of $483 million (USDA-NASS, 2015) there is no study that we are aware of that has assessed the influence of ST on watermelon yield, crop morphology and physiology, and soil quality (biological and chemical). The objective of this study was to evaluate the impact of strip and conventional tillage practices on plant morphology, physiology, yield, fruit quality and soil biology and chemistry of triploid watermelon grown under different water regimes.

2. Materials and methods

2.1. Site description

The study was conducted in 2012, 2013 and 2014 at the Texas A&M AgriLife Research and Extension Center, Uvalde, Texas (long. 29°12′57.6″ N, lat. 99°45′21.6″ W) to assess the effects of two tillage practices (strip and conventional) and three irrigation levels (T1 = 100% ET, T2 = 0.75T1and T3 = 0.5T1) on watermelon cv. Magestic. The study was conducted over three spring seasons (March through August of 2012–2014) in a clay soil site (Knippa clay, 0–1 percent slopes) (USDA, 1976). Irrigation was applied using a center pivot system (Zimmatic, Lindsay Co., Omaha, NE). The irrigation system used rotating-spray sprinkler nozzles placed 1 m above the soil surface with 2 m sprinkler heads apart. The surface area coverage was 13 m^2 at 0.32 MPa, with 1 m coverage overlap. The pivot irrigation system radius was 250 m and the total coverage area was 19.6 ha. N-P_2O_5-K_2O was applied during the experiment at the rate of 41–66–30 kg ha^{-1} in 2012, 110–44–0 kg ha^{-1} in 2013 and 62–62–62 kg ha^{-1} in 2014. Fertilizer amounts for each season were determined based on soil analysis history of the field. During the study period, the total seasonal precipitation was 340 mm in 2012, 578 mm in 2013 and 535 mm in 2014. Seasonal mean temperature, relative humidity and total radiation was 22 °C, 65% and 900 $\mu mol\ m^{-2}\ s^{-1}$, respectively (Fig. 1).

2.2. Plant material, tillage and irrigation treatments

Watermelon seeds cv. Magestic were sown in polystyrene Speedling trays with 128 cells (3.2 × 3.2 cm square and 6.4 cm deep) and transplants grown following commercial standard nursery production practices. Mature 6-week old transplants were then established in the field in either ST or CT beds with plants spaced 0.9 m apart in rows spaced 2.0 m apart. Seedlings were transplanted in the field in April, 2, 8 and 18 in 2012, 2013 and 2014, respectively.

Conservation tillage (ST) and CT practices under the center pivot area were practiced since 2009. The previous crop history of the field was corn in 2009, cotton in 2010, and corn 2011–2015. Therefore, the soil analysis conducted at the end of the study represented 6 years of tillage practices using corn and cotton as previous cover crops. The experimental set up was designed as split plot replicated four times with soil tillage and irrigation level as main and subplot, respectively. Strip tillage beds were made