Effect of Tillage, Irrigation Amounts, and Nitrogen Rates in Sugar Beet (*Beta vulgaris* L.)

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AUTHORIZATION TO SUBMIT THESIS

This thesis of Kelli M. Belmont, submitted for the degree of Master of Science with a Major in Plant Science and titled "Effect of Tillage, Irrigation Amounts, and Nitrogen Rates in Sugar Beet (*Beta vulgaris* L.)," has been reviewed in final form. Permission, as indicated by the signatures and dates below, is now granted to submit final copies to the College of Graduate Studies for approval.

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ABSTRACT

A 2-year study was conducted near Kimberly, ID to determine the effects of tillage type, irrigation amount, and nitrogen (N) rate on sugar beet. Three tillage treatments were compared: conventional tillage (CT), strip tillage (ST), and direct seed (DS). Irrigation treatments were established as 50, 100, and 150% of the sugar beet evapotranspiration (ET) model. Four N fertility rates were applied: 60, 80, 100, and 120% of recommended rate for CT sugar beets. Weed emergence and control ultimately were the same between CT, ST, and DS, regardless of irrigation and N rate. Pestiferous insects were no greater or less in response to tillage treatment. Root yield was greater in CT and ST than DS, but estimated recoverable sucrose was equal between CT, ST, and DS. Yield and quality results had no significant interactions between tillage, irrigation, and N rates suggesting N recommendations do not need to be adjusted for tillage.

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DEDICATION

To the one who kept my glass half full throughout my graduate program, I’d like to thank the many bottles of wine that helped with this thesis.

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INTRODUCTION

Much is not yet clearly understood about the interactive effects of nitrogen fertilizer rates, irrigation amounts, and tillage systems on the incidence and management of insects, diseases, and weeds in sugar beet.

Objectives

The objectives of the two year field study was to compare tillage type, irrigation amount, and nitrogen fertilizer rate effects in sugar beet production system. Many studies have examined the effect of tillage on yield (Stevens et al., 2010; Overstreet et al., 2008; Tarkalson et al., 2012; Evans et al., 2010); however, not many have considered the effect reduced tillage has on irrigation and N requirements compared with conventional tillage. Furthermore, no research has examined the entire sugar beet system under different tillage treatments. This is an interdisciplinary study consisting of irrigation management, soil fertility management, entomology, plant pathology, and weed science. The overall objectives of this study was to examine effect of nitrogen fertilizer rates, irrigation amounts, and tillage type on:

1. Moisture content and temperature within the soil profile
2. Emergence and stand establishment of sugar beet crop
3. Abundance of insect pests and severity of associated crop damage
4. Onset, development, and severity of disease
5. Weed emergence and control
6. Root yield, sugar content, and estimated recoverable sucrose

Organization

The following thesis consists of a literature review, a manuscript prepared for submission to a refereed journal, and a manuscript prepared for submission as a peer-reviewed extension publication presented for partial fulfillment of the requirements for the degree, Master of Science with a major in Plant Science. The author of the thesis is Kelli Belmont. Dr. Don W. Morishita served as major professor and Dr. Erik J. Wenninger and Dr. David D. Tarkalson served as committee members and provided assistance for technical consulting and manuscript review. Chapter 1 is a review of literature concerning reduced tillage, irrigation, and N management in sugar beet. Chapter 2 is the manuscript to be submitted to the Journal of Sugar Beet Research, entitled "Effect of Tillage, Irrigation Amounts, and Nitrogen Rates in Sugar Beet (*Beta vulgaris* L.)". Chapter 3 is an extension publication manuscript entitled "Strip Tillage and Direct-Seeding in Sugar Beet Production".

CHAPTER 1. LITERATURE REVIEW

Tillage

Conservation tillage is any tillage practice that leaves 30 percent or more of the soil surface with crop residue (ASABE Standards, 2013). Reduced tillage approaches range from no-till (NT) or direct seeding (DS) to strip till (ST). Furthermore, ASABE defines strip tillage as a method of conservation tillage in which crops are grown in narrow, tilled strips of previously undisturbed soil, and no more than a third of the surface residue is disturbed and the crop residues are maintained on the soil surface year-round (ASABE Standards, 2013). Strip tillage alternates between properties of no-till in the inter-row while forming a seedbed similar to conventional tillage in the row (Overstreet, 2009). This method tills a strip (20 to 30 cm wide and ≤ 7.5 cm deep) into existing crop residue. Strip tillage generally consists of a two-pass operation with the first pass tilling strips into the previous crops residue and the second pass for planting. Equipment for ST consist of varying configurations of conical, fluted, or flat disks or coulters that loosen soil and prepare the seed bed (Evans et al., 2003; Khan and McVay, 2014). The use of shank or ripper in combination with disks loosen the soil and allow liquid or dry fertilizer to be applied beside or below the seed row through knives. Packer wheels or rolling baskets firm the tilled soil and breaks up large clods in the strip (Evans et al., 2003). Retaining crop residue on the soil surface reduces evaporation and can improve water infiltration (Hatfield et al., 2001). Planting into standing grain stubble rather than a planted cover crop, wind speed at the soil surface is reduced, snow is trapped over winter, and sugar beet seedlings are protected without the risk of phytotoxicity from a cover crop (Halvorson and Hartman, 1984).

Strip tillage is widely used in large seeded crops such as corn (*Zea mays* L.); however, much is to be learned in small seeded crops like sugar beet. A concern with small seeded crops and equipment used in ST operations is the formation of a firm seed bed since even small air pockets interfere with stand establishment. Good seed-soil contact and ensuring seed furrows are closed is critical to establishing sugar beet. Similar to ST crop production systems, NT or DS, has advantages including reduced fuel, equipment, and labor costs, and reduced soil erosion associated with soil disruption.

Reduced tillage has been shown to conserve soil moisture due to increased water infiltration, decreased runoff or loss due to evaporation, trap snow which increased soil moisture supply (Deibert, 1983; Hatfield et al., 2001; Overstreet, 2009). Deibert (1983) concluded 50 to 60% of non-growing precipitation can be stored in soil with residue left standing over winter compared to bare fallow ground in a study conducted in North Dakota. Soil moisture in the germination zone (8 cm) was significantly lower in CT than ST or DS during stand establishment (Sojka et al., 1980).

Tillage practices affect many soil properties that may influence crop growth and development. Under continuous NT, bulk density has been reported to increase (Hill, 1990) although other research has shown no effect on bulk density (Ismail et al., 1994). Soil pH is reported to decrease under no tillage due to high rates of nitrogen fertilizer (Blevins et al., 1983). Increased crop residue levels in reduced tillage results in increased organic matter in the top 15 mm of soil (Reicosky et al., 1995). With the altered soil environment, chemical reactions and microbial distribution and activity are modified in NT compared with CT (Blevins et al., 1983). Aerobic microbial activity extends to a greater depth in CT relative to NT (Doran, 1980). Consequently, mineralization and nitrification potential is higher in CT.

Soil erosion is less in reduced tillage systems because the crop residue protects the soil surface from wind and water erosion. Strip tillage and DS reduce wind erosion by reducing wind velocity at the soil surface, and the standing stubble traps soil suspended in the wind (Overstreet, 2009). Sojka et al. (1980) reported maximum wind speeds were reduced by almost 50% in reduced tillage compared with conventional tillage when measured 5 cm above the soil surface. Sugar beet seedlings are susceptible to damage by wind due to the large cotyledon leaves and delicate hypocotyl. Similarly, water erosion is reduced by reducing the velocity of moving water on the soil surface, allowing for greater infiltration of water and less runoff (Overstreet, 2009).

Many studies have evaluated the affect reduced tillage has on yield and quality in sugar beet. Crop yields have been maintained or sometimes increased in reduced tillage (Stevens et al., 2010; Overstreet et al., 2008; Tarkalson et al., 2012). An irrigated study using a non-glyphosate resistant sugar beet found no difference in yield or quality between CT and ST, and in fact, one year ST had a higher root yield due to a wind storm early in the season (Evans et al., 2010). Root yield and estimated recoverable sucrose (ERS) were the same between CT and ST in the rainfed Red River Valley of North Dakota and Minnesota (Overstreet et al., 2008). Liu et al. (2013) concluded the economic return in reduced tillage corn was greater than that of CT. Strip tillage has been shown to obtain root yield comparable to CT and lowered tillage costs by 53 to 76% relative to CT practices used in the study (Tarkalson et al., 2012).

Irrigation

Sugar beet requires about 6.5 mm of water daily and evapotranspiration (ET) ranges from 500 to 1200 mm during the growing season depending on location, time of year, irrigation method, and climate (Hills et al., 1990; Dunham, 1993). The deep taproot of sugar beet effectively extracts water from the soil profile at depths of 90 to 120 cm in soils with no restrictive horizons (Neibling and Gallian, 1997).

Because of limiting water supplies for irrigation, sugar beets grown in the Magic Valley of southern Idaho can be subjected to periods of water stress. Sugar beets have some tolerance to mid and late-season plant water stress (Carter et al., 1980; Winter, 1980). Late season water stress reduces fresh root weight though sucrose concentration has been shown to increase (Carter et al., 1980).

Sugar beet response to drought stress has shown a wide range in responses. Varying sugar beet responses to drought stress are attributed to different research methodology, soils, climate, and different relationship of sugar beet water stress to soil water stress in the varied environments (Kramer, 1963). Sugar beet response to drought results in metabolic accumulation of soluble osmolitic compounds in the root tissue such as potassium, amino acids and nitrate (Winter, 1989; Gzik, 1996; Morgan, 1984). With an increase in such compounds, sugar beet impurities are increased resulting in sucrose losses (Harvey and Dutton, 1993).

Heavy irrigation can increase sucrose content in roots due to the associated leaching of nitrate from permeable soils (Winter, 1980). Additionally, excessive irrigation leads to the development of sugar beet diseases such as rhizomania, Pythium and Phytophthora root rots, and Rhizoctonia root and crown rot (Neibling and Gallian, 1997). When soil moisture remains high for a longer period of time following irrigation, this creates conditions favorable for disease development.

Jabro et al., (2014) observed ST used 0.0093 m^3 and 0.061 m^3 less irrigation water than CT system to produce 1 kg of sugar beet root and 1 kg of sucrose, respectively**.** In a non-irrigated production system, Deibert and Giles (1979) observed a 4% greater ERS yield from ST relative to CT in a particularly dry year. Reduced tillage has shown an increase in water storage within the soil profile because of reduced evaporation losses (Aase and Pikul, 1995). In strip tillage, the inter-row area acts as a storage reservoir for water, with a greater plant-available moisture content than that of the tilled area (Gegner et al., 2008). Overstreet et al. (2008) found ST had 3.5 to 5.5% greater moisture than CT treatments at 5 cm depth. Improved water infiltration and reduced evaporation in ST can be a major advantage in arid environments and on well-drained soils particularly sandy soils (Overstreet, 2009). Furthermore, no tillage improves crop water productivity and soil health across soils, cropping systems, and climates (Hobbs, 2007).

Nitrogen Management

Nitrogen management is critical to sugar beet production in order to optimize yield, quality, and fertilizer costs. Nitrogen requires the most specific management for optimum sugar beet growth and quality (Amalgamated Sugar Company, 2015). The amount of available N is a major factor affecting sugar beet quality. Leaf growth and expansion is due to N leading to canopy closure and maximum solar radiation interception (Malnou et al., 2006). Low N levels reduce root yield while high N levels results in high root yield, but reduces the processing quality including ERS (Halvorson et al., 1978).

Adequate fertilization is a concern in reduced tillage since fertilizers are often broadcast on the soil surface and incorporated by irrigation or rainfall in order to become available to the sugar beet. In ST, fertilizer needs can be met by injecting fertilizer below the seed (Stevens et al., 2007). Loss of N to volatilization when applied broadcast can result in reduced N availability to the crop, particularly with urea (Fenn and Hossner, 1985). In addition, reduced tillage soils have cooler temperatures, which lower biological activity resulting in reduced N mineralization from organic matter (Deibert and Giles, 1979).

There has been much research on N management in sugar beet; however, few studies have evaluated N needs under different tillage and irrigation amounts. Tarkalson et al. (2012) observed no differences in N response between CT and ST systems. Similarly, Khan and McVay (2014) detected no tillage by N interaction, suggesting fertilizer N recommendations require no adjustments for tillage. Irrigation method can affect N management since irrigation water has the potential to move N in the soil profile (Spalding et al., 2001).

Nitrogen management can increase the ability of crops to compete with weeds and is a factor in integrated pest management (Blackshaw et al., 2008; Spangler and Sprague 2013). However, the amount of time weeds compete with a crop and the amount of N available influence the competitive ability of weeds (Evans et al., 2003). Sugar beet requires available N at the four to five leaf stage for rapid uptake, and must remain available until the canopy closure (Armstrong, 1986). Effective and timely weed control are necessary for sugar beet to utilize available N (Spangler et al., 2014). Furthermore, glyphosate efficacy is reduced by low soil N because low soil N reduces glyphosate translocation in certain weed species (Mithila et al., 2008).

Weeds

Establishing a weed-free stand early in the growing season is necessary to prevent substantial yield loss (Scott and Wilcockson, 1976). Sugar beet slow canopy closure and low plant height makes the crop particularly vulnerable to weed competition (Scott and

Wilcockson, 1976). Weed management is a major production cost (Kniss et al., 2004). Weeds interfere with crop growth and development due to competition for nutrients, water, and light (Schweizer and May, 1993).

With the immediate adoption of glyphosate-resistant sugar beet, the flexibility and effectiveness of glyphosate enabled the potential for reduced tillage (Duke and Powles, 2008). Glyphosate controls larger weeds than the older registered postemergence herbicides, offering greater flexibility in application timing (Kemp et al., 2009).

Residue on the soil surface affect weeds by blocking sunlight, decreasing temperatures, and providing an environment for insects to eat weed seeds. In reduced tillage, weed species can shift. Without tillage to bury seeds deeper in the soil, weed seeds remain on the soil surface, under crop residue. The environment under crop residue favors small seeded weeds more than large seeded weed species. Generally, grass weeds are more abundant in reduced tillage; however, small seeded broadleaf weeds such as common lambsquarters (*Chenopodium album* L.) and redroot pigweed (*Amaranthus retroflexus* L.) can remain a problem. Such weeds can be controlled with herbicides like glyphosate in glyphosate-resistant sugar beet.

Tillage affects the weed seed bank by mixing the soil, which impact seed bank characteristics such as seed viability, seed dormancy, and species composition (Ball and Miller, 1990). Weed seed buried in the soil retains viable longer than seed near the surface, and seed longevity varies by species (Roberts and Dawkins, 1967).

Herbicides are relied on more heavily to control weeds without tillage. Split or sequential herbicide applications allow for control for early and late germinating weeds.

Tank mixing herbicides with a residual soil-active herbicide can control later germinating summer annual weeds.

Insects

Insects that overwinter in the soil or crop residue can interfere with crop growth and development. Tillage affects the conditions and environment for both pests and beneficial insects (Andersen, 1999; Andersen, 2003). Tillage can kill surface or soil dwelling insects by exposure to the elements and disturbance of habitat (Gebhardt et al., 1985). Beet leafminers (*Pegomya betae* (Curtis)) overwinter as pupae in the soil within sugar beet fields (Harveson et al., 2009). By reducing tillage, there is a reduction in soil disturbance and favors a more stable environment for arthropods in soil and on standing residue (Stinner and House, 1990). Increased residue in reduced tillage systems may reduce feeding damage to sugar beet seedlings by providing an alternative food source (Heimbach and Garbe, 1996). In a review, Stinner and House (1990) showed that 28% of insect pests increased in reduced tillage, 29% showed no affect due to tillage, and 43% decreased in the reduced tillage. The cooler temperatures of reduced tillage may delay insect emergence relative to conventional tillage, but are more abundant because they were not disturbed or eliminated through tillage (Gebhardt et al., 1985). Reduced tillage may increase beneficial insects such as ground beetles, rove beetles, and spiders (Stinner and House, 1990).

Winged aphids prefer bare-ground rather than residue-covered ground, and this can limit infestations in reduced tillage (Kennedy et al., 2010). Wireworm numbers have increased in general in the past few years, with some research suggesting a link to reduced tillage (Gregory and Musick, 1976), but other research finding no relationship between wireworm infestation and tillage system (Belcher, 1989). Increased soil moisture in reduced tillage keeps wireworms closer to crop (Gregory and Musick, 1976).

Differences between conventional and reduced tillage may indirectly affect pestiferous arthropods. The effects of reduced tillage such as temperature, moisture, and soil properties (Overstreet, 2009) can affect crop physiology (Stinner and House, 1990) and indirectly affect crop susceptibility to pests.

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CHAPTER 2. EFFECTS OF TILLAGE, IRRIGATION AMOUNTS, AND NITROGEN RATES IN SUGAR BEET (*Beta vulgaris* L.)

Abstract

Much is not yet clearly understood about the interactive effect of nitrogen (N) fertilizer application rates, irrigation amounts, and tillage level in sugar beet production. A 2-year study was conducted near Kimberly, ID to determine the effects of tillage type, irrigation amount, and nitrogen fertilizer rate on sugar beet yield and quality, weed emergence, and insect pest densities. Three tillage treatments were compared: conventional tillage (CT), strip tillage (ST), and direct seed (DS). Irrigation treatments were established as 50, 100, and 150% of sugar beet evapotranspiration (ET) model for CT sugar beet. Four N fertility rates were applied: 60, 80, 100, and 120% of recommended rate for CT sugar beets. By 12LSB common lambsquaters and green foxtail densities did not differ among CT, ST, and DS at optimum irrigation and N rate. In 2013 leafminer egg and larval densities were greatest in CT compared with DS and ST. Averaged over 2 years, root yield was 8.7 and 6.7 Mg ha^{-1} higher in CT and ST, respectively, than DS, but estimated recoverable sucrose did not differ among CT, ST, and DS. Combined yield and quality results over the 2 years indicated no significant interactions among tillage, irrigation, and N rates suggesting N recommendations do not need to be adjusted for tillage.

Additional Key Words: strip tillage, direct seed, chisel plow, nitrogen, *Chenopodium album* L., *Setaria viridis* (L.) Beauv, weed density, *Aphis fabae* Scopoli, *Pegomya betae* Curtis, *Pemphigus betae* Doane

Abbreviations: ST = strip tillage, CT = conventional tillage, DS = direct seed, ERS = estimated recoverable sucrose, ET = evapotranspiration, UAN = urea ammonium nitrate

Introduction

Strip tillage (ST) is widely used in large-seeded crops such as corn (*Zea mays* L.); however, much is to be learned in small-seeded crops like sugar beet (*Beta vulgaris* L.). A concern with small-seeded crops and equipment used in ST operations is the formation of a firm seed bed since even small air pockets interfere with stand establishment. Good seed-to-soil contact and ensuring seed furrow closure are critical to establishing sugar beet. Similar to ST, no-till, referred to as direct seed (DS), has advantages including reduced fuel, equipment, and labor costs, and reduced soil erosion associated with soil disruption (Overstreet, 2009).

Reduced tillage has been shown to conserve soil moisture due to increased water infiltration, decreased runoff or loss due to evaporation, and more trapped snow, which increases soil moisture accumulation (Deibert, 1980; Hatfield et al., 2001). However, reduced tillage has been shown to have cooler soil temperature (Deibert and Giles, 1979), although Halvorson and Hartman (1984) found no differences in soil temperature between conventional and reduced tillage.

Strip tillage reduces wind erosion by reducing wind velocity at the soil surface, binding soil to previous crop roots, and standing cereal grain stubble traps soil suspended in the wind (Overstreet, 2009). Furthermore, water erosion is reduced because the velocity of moving water on the soil surface is reduced, allowing for greater water infiltration and less runoff (Overstreet, 2009).

Crop yields have been maintained or sometimes increased in reduced tillage (Stevens et al., 2010; Halvorson and Hartman, 1984; Evans et al., 2010). ST has been shown to produce root yield comparable to CT and lowered tillage costs by 53 to 76% relative to CT practices (Tarkalson et al., 2012).

Jabro et al. (2014) observed ST used 0.0093 m^3 and 0.061 m^3 less irrigation water than CT to produce 1 kg of sugar beet root and 1 kg of sucrose, respectively. Deibert and Giles (1979) observed a 4% greater estimated recoverable sucrose yield from ST relative to CT in a particularly dry year under rainfed conditions. Reduced tillage has shown an increase in water storage within the soil profile because of reduced evaporation losses (Aase and Pikul, 1995). Improved water infiltration and reduced evaporation in ST can be a major advantage in arid environments and on well-drained soils—particularly sandy soils (Overstreet, 2009). Additionally, no-tillage improves crop water productivity and soil health across soils, cropping systems, and climates (Hobbs, 2007).

There has been much research on nitrogen (N) management in sugar beet; however, few studies have compared N needs under different tillage and irrigation amounts. Tarkalson et al. (2012) observed no differences in N response between CT and ST systems under irrigation. Similarly, Khan and McVay (2014) detected no tillage by N rate interaction under rainfed conditions, suggesting fertilizer N recommendations require no adjustments for tillage.

The slow canopy closure and low plant height of sugar beet makes the crop particularly vulnerable to weed competition (Scott and Wilcockson, 1976). Weeds interfere with crop growth and development due to competition for nutrients, water, and light (Schweizer and May, 1993). With the introduction of glyphosate-resistant sugar beet in 2008, the flexibility and effectiveness of glyphosate enabled the potential for producing sugar beet with less tillage. Glyphosate controls larger weeds than standard postemergence sugar beet herbicides, offering greater flexibility in application timing (Kemp et al., 2009).

Differences between conventional and reduced tillage may indirectly affect pestiferous arthropods. The effects of reduced tillage on temperature, moisture, and soil properties (Overstreet, 2009) can affect crop physiology and indirectly affect crop susceptibility to pests. Tillage can kill soil- and surface-dwelling insects by exposure to the elements and disturbance of habitat (Stinner and House, 1990). In reduced tillage, there is a reduction in soil disturbance that contributes to a more stable environment for arthropods in soil and on standing residue (Stinner and House, 1990). Increased residue in reduced tillage systems may reduce feeding damage to sugar beet seedlings because the remaining crop residue serves as an alternative food source and can have greater beneficial insects (Heimbach and Garbe, 1996).

With the rapid adoption of glyphosate-resistant sugar beet, reduced tillage and direct-seed systems are a viable option and effects due to reduced tillage need to be evaluated. The objectives of this study were to compare tillage systems, irrigation amounts, and nitrogen rates on: soil moisture content and temperature within the soil profile; sugar beet emergence and stand establishment; abundance of insect pests and severity of associated crop damage; onset, development, and severity of disease; weed emergence and control; root yield, sugar content, and estimated recoverable sucrose.

Materials and Methods

A field study was conducted in 2013 and 2014 at the University of Idaho Kimberly Research and Extension Center near Kimberly, ID on a Portneuf silt loam soil (coarse-silty, mixed, superactive, mesic Durinodic Xeric Haplocalcid). Previous crops were spring barley and spring wheat grown under sprinkler irrigation, which were blocked to account for variation. Barley was grown prior to the 2013 study and wheat and barley were grown prior to the 2014 study. In 2014, one half of the study was established in barley stubble and one half in wheat stubble. Following grain harvest in 2012 and 2013, tillage operations were performed in convention tillage and strip tillage blocks. Crop residue levels prior to any tillage operations averaged 8,414 and 5,813 kg ha^{-1} in 2012 and 2013, respectively.

The experiment was arranged as a split-block split-plot design with tillage treatment as the main plot, irrigation treatment as sub-plots, and N rate as sub-sub-plots. All treatments were replicated six times. Three tillage treatments—conventional tillage (CT), strip tillage (ST), and direct seed (DS)—were established in the fall of each year. Conventional tillage consisted of chisel plowing and disking in the fall, followed by disking and final seedbed preparation with a roller harrow in the spring. Strip tillage consisted of fall tillage with a 4-row strip tillage implement (Orthman Manufacturing Incorporated, 75765 Rd. 435, P.O. Box B, Lexington, NE 68850). Direct seed had no tillage operations. Each tillage plot was 80.5 m wide (144 rows) by 9.1 m long. The three irrigation treatments were randomly assigned across the three tillage treatments and the N rates were randomly assigned within each irrigation treatment.

'Holly Hybrid SX1502RR' sugar beet seed (Holly Seed Company, 1967 W Fifth St, P.O. Box 764, Sheridan, WY 82801) was planted 1.9 cm deep on April 26, 2013, and April 16, 2014, at a seeding rate of 149,716 seed ha^{-1} in 56 cm rows. The seed were treated with mefenoxam (ApronXL, Syngenta Crop Protection, Inc., P.O. Box 18300, Greensboro, NC 27419) and thiram (42-S Thiram, Bayer CropScience, 2 T.W. Alexander Dr., P.O. Box 12014, Research Triangle, NC 27709) for disease control during stand establishment. Weed control was accomplished with three glyphosate applications (Roundup PowerMax, Monsanto Co., 800 N. Lindbergh Boulevard, St. Louis, MO 63167) at 0.84 kg ae ha^{-1} plus ammonium sulfate (AMS) (Bronc Max, Wilbur-Ellis Co., PO Box 1286, Fresno, CA 93715) at 2.5 kg ha^{-1}. The first herbicide application was made immediately after planting, primarily to control emerged weeds in the ST and DS treatments. The second herbicide application, applied at the two-leaf growth stage, was a tank mixture of glyphosate plus dimethenamid-P (Outlook, BASF Ag Products, P.O. Box 13528, 26 Davis Drive, Research Triangle Park, NC 27709-3528) at 0.95 kg ha^{-1} and AMS. In both years, glyphosate and AMS was applied using the same rate described previously at the 4 to 6-leaf stage for the third application.

Irrigation amounts were based on the amount of water needed to meet 50, 100, and 150% evapotranspiration (ET) based on the Penman-Monteith model for CT sugar beets. Weather data collected from an AgriMet weather station (U.S. Bureau of Reclamation; Pacific NW Region; 1150 North Curtis Road, Suite 100, Boise, ID 83706) located <0.8 km from the study site was used for the model. A solid set irrigation system was set up to deliver the desired rates of water for each treatment. Immediately after planting, an equal amount of water was sprinkler-applied at 3- to 4-day intervals across the study site to aid with sugar beet emergence. Starting May 24, 2013 and June 11, 2014 the different irrigation treatments were watered at 3 to 4 day intervals to meet the desired ET rates. Individual irrigation plots were 26.8 m wide (48 rows) by 27.4 m long.

Prior to planting in the spring, soil samples were collected randomly in 15 cm increments to a depth of 60 cm in 2013 and 2014 in each tillage system main plot of each replication to determine soil nutrient requirements. Soil samples were analyzed for N, phosphorus (P), and potassium (K). Nitrate-N was extracted by a $CaSO_4$ solution and colored with phenol-disulfonic acid (PDA) for colorimetric analysis (Sims and Jackson, 1971). Soil P and K were tested for sodium bicarbonate extractable P and available K concentrations

(Olsen et al., 1954; McLean and Watson, 1985). In the spring, a mixture of 11-37-0 and urea ammonium nitrate (UAN) was used as a starter fertilizer to apply 45 kg ha^{-1} N and the recommended amount of P was injected 5 cm to the side and 5 cm below the seed at planting for all tillage treatments. At the sugar beet 4-leaf stage, additional UAN (32-0-0) was applied broadcast for the four N rates on June 6, 2013 and June 3, 2014 with CO_2-pressurized bicycle-wheel plot sprayers. Immediately after N application, 1.9 cm of water was applied to incorporate N into the soil. This application followed by immediate irrigation incorporation simulated a chemigation application.

The four N fertilizer rate treatments were: 0.6X, 0.8X, 1X and 1.2X, where 1X was the recommended rate based on The Amalgamated Sugar Company's fertilizer guide for CT sugar beet, which recommends 3 kg N Mg^{-1} sugar beet roots with a yield goal of 78 Mg ha^{-1} (Amalgamated Sugar Company, 2015). Based on soil test results, the 1X rate required 168 kg N ha^{-1} and 175 kg N ha^{-1} in 2013 and 2014, respectively. Each fertilizer rate sub-sub-plot was 6.7 m (12 rows) wide by 9.1 m long.

Soil temperature was monitored to track differences in soil temperature among tillage treatments in the 100% ET plots from May 10 to May 24, 2013; however, the following year soil temperature was recorded from March 19 to May 14, 2014. HOBO® data loggers (Onset Computer Corp., 470 MacArthur Blvd, Bourne, MA 02532) recorded hourly temperatures at 2.5 and 15 cm depths.

Soil moisture was measured to evaluate soil water content between tillage practices and was monitored throughout the season using a neutron probe (Campbell Pacific Nuclear, 5052 Commercial Circle, Concord, CA 94520) (Evett and Steiner, 1995) with access tubes located in every tillage and irrigation treatment at the 1X N rate. The neutron probe recorded soil moisture at 9 depths to 1.35 m in 0.15 m increments. Soil moisture readings were taken four times throughout the 2014 season when the soil profile was at the driest between irrigations. Cumulative precipitation and irrigation during the 2014 growing season was measured to confirm differences in irrigation treatments (Figure 1).

Sugar beet stand counts were taken weekly for five weeks beginning shortly after the first beets emerged on May 14 and 16 and ended June 12 and 19 in 2013 and 2014, respectively. Stand emergence was measured by counting sugar beet in the two designated harvest data rows within each N rate sub-sub plot.

Weed seedling emergence by species was taken four times within a fixed 0.125 m^2 area within the row and between the row in the harvest data rows of each sub-sub plot. The purpose for counting within the row and between the row was to take into consideration the stratification of disturbed and undisturbed soil of ST. Counts were taken prior to the second and third herbicide applications and four weeks after the last application. These application timings were equivalent to the following sugar beet growth stages: 2-leaf sugar beets (2LSB), 6-leaf sugar beets, and 12-leaf sugar beets (12LSB). The two predominant weed species were common lambsquarters (*Chenopodium album* L.) and green foxtail (*Setaria viridis* (L.) Beauv.). Additional weed species found in plots included redroot pigweed (*Amaranthus retroflexus* L.), kochia (*Kochia scoparia* (L.) Schrad.), common mallow (*Malva neglecta* Wallr.), hairy nightshade (*Solanum physalifolium* Rusby), Russian thistle (*Salsola tragus* L.), annual sowthistle (*Sonchus oleraceus* L.), flixweed (*Descurainia sophia* (L.) Webb ex Prantl), shepherd's-purse (*Capsella bursa-pastoris* (L.) Medik.), barnyardgrass (*Echinochloa crus-galli* (L.) Beauv.), purselane (*Portulaca oleracea* L.), prickly lettuce (*Lactuca serriola* L.).

Bean aphids (*Aphis fabae* Scopoli) were counted two times (July 22 and August 7) in 2013 and three times (July 8, 21 and August 14) in 2014 across all of the tillage and N rates at the 100% ET treatments, with 5 beets were selected in a stratified random fashion in each of the two harvest data rows counted for a total of 10 sugar beets per plot.

Sugar beet leafminer (*Pegomya betae* Curtis) eggs and mines were sampled twice across all of the tillage and N rates at the 100% ET treatments. Five beets were selected in a stratified random fashion in each of the two harvest data rows were counted for a total of 10 sugar beets per plot (May 31 and June 12, 2013 and June 6 and June 16, 2014).

Sugar beet root aphid (*Pemphigus betae* Doane) infestations were evaluated using an established rating scale (Hutchison and Campbell, 1994). The rating index ranges from 0 to 5 and is based on the size and number of aphid colony distributions on the sugar beet root (Hutchison and Campbell 1994). Sugar beet root aphid was sampled across all tillage and N rates at the 50% ET irrigation treatments by digging 8 beets in a stratified random fashion per plot and rating each one. The lowest irrigation rate was chosen for evaluating sugar beet root aphid infestations because this aphid species colonizes roots and it was speculated that the highest infestations would be in the driest sugar beets (Hutchison and Campbell, 1991). Beet root ratings were averaged for each plot sampled.

In 2014 wireworms were sampled during stand establishment in two 0.3 m^2 locations within each tillage treatment of every replication for a total of 36 wireworm traps. The wireworm traps were set up on April 25 and consisted of burying a nylon stocking with 240 mL of water-soaked barley inside the stocking. Traps were collected May 5 and wireworms were later identified to species. Terbufos (Counter 20G, Amvac Chemical Corporation, 4100 E. Washington Blvd., Los Angeles, CA 90023) insecticide was applied preemergence to the crop on two non-harvest data rows of every plot in order to determine whether wireworm impacted sugar beet emergence, stand establishment, and yield.

Sugar beet root yield was determined by harvesting 7.6 m of the two data rows in each N rate sub-sub plot with a plot harvester and recording the root weights. Two sample bags of roots weighing 9 to 11 kg were then collected and used to determine tare and sugar beet quality. All quality analyses were conducted by The Amalgamated Sugar Company Tare Laboratory near Paul, ID. Estimated recoverable sucrose (ERS) yield is a calculated variable that integrates root yield and quality parameters such as sucrose content, nitrate concentration, and conductivity.

Sucrose content was determined using an Autopol 880 polarimeter (Rudolph Research Analytical, Hackettstown, NJ) and a half-normal weight sample dilution and aluminum sulfate clarification method (ICUMSA Method GS6-3, 1994). Conductivity was measured using a Foxboro conductivity meter Model 871EC (Foxboro, Foxboro, MA) and nitrate was measured using a multimeter Model 250 (Denver Instruments, Denver, CO) with Orion probes 900200 and 9300 BNWP (Krackler Scientific, Inc., Albany, NY). Estimated recoverable sucrose yield per ton of roots was calculated using the following equation: [(extraction) × (0.01) × (gross sucrose/ha)]/ (t/ha), where extraction = 250 + [[(1255.2) × (conductivity) – (15000) × (percent sucrose – 6185)]/[(percent sucrose) × (98.66 – [(7.845) × (conductivity)])]] and gross sucrose = [[(t/ha) × (percent sucrose)] × (0.01)] × (1,000 kg/t). The mean of the two samples from each plot was used for data analyses.

The SAS UNIVARIATE procedure (SAS 9.3, SAS Institute Inc., Cary, NC) was used to test for normality. All yield and quality data were pooled across both years for statistical analysis due to no year effect. Analysis of variance was performed using SAS 9.3 GLIMMIX model procedures for tillage system, irrigation rate, N rate and year as main effects and the interactions for yield and quality parameters. These parameters includes root yield, estimated recoverable sucrose (ERS) yield, sucrose content, nitrate concentration, and conductivity. Least squared means were used for mean separation comparisons following significant treatment effects (p = 0.05).

Statistical analysis was conducted separately by year for crop emergence, leafminer and black bean aphid counts, and sugar beet root aphid ratings due to temporal variability between years. Analysis of variance utilizing SAS 9.3 GLIMMIX procedure was conducted for tillage system, irrigation rate, and N rate as main effects and the interactions. A Kruskal-Wallis nonparametric analysis was used for one counting date in 2013 for bean aphid density.

Weed emergence data were analyzed by pooling the years. Since the weed emergence dates were not exactly the same between year, the weed count dates were grouped into three counting times corresponding to when the weeds were sprayed using the following sugar beet growth stages: 2 leaf sugar beet (2LSB), 6 to 8 leaf sugar beet (6LSB), and 12 leaf sugar beet. Analysis of variance was used with the GENMOD procedure to determine significance and least squared mean was used for mean separation.

Results and Discussion

Soil Moisture

Soil moisture differences between tillage treatments were not observed in the 50% ET irrigation rate (Figure 2). In the 100% ET irrigation rate, CT was a significantly drier compared to DS at 30 and 45 cm depths by 14 and 11%, respectively. Similarly, at the 150% ET irrigation rate, there were 6 and 8% reductions in volumetric water content in CT compared to DS at 15 and 45 cm, respectively. Aside from two measurements in the upper soil profile, there were no differences in soil moisture due to tillage treatment. Drier conditions in CT were expected due to increased evaporation; however differences were only detected in the top 45 cm of the soil in 100 and 150% ET irrigation rates. Soil moisture throughout the profile did not differ among tillage treatments of the 50% ET irrigation rate. Reduced tillage has shown an increase in water storage within the soil profile because of reduced evaporation losses (Aase and Pikul, 1995). Therefore, greater soil moisture was expected in DS and ST compared to CT. The crop residue on the soil surface enabled greater water infiltration and reduced evaporation compared to the disturbed soil surface in CT.

Soil Temperature

Mean daily temperatures differed among tillage treatments prior to planting at 2.5 cm depth in 2014. No soil temperature data were collected prior to planting in 2013. At 28, 21, and 7 days before planting, CT had 10 to 20% higher temperatures compared to DS and ST, respectively (Table 1). Interestingly, mean soil temperature in DS was 11% higher than the average of CT and ST at 14 days before planting. However, at planting and up to 28 days after planting there were no differences in mean daily temperature between the tillage treatments. Though mean daily temperature was greatest in CT prior to planting, suggesting an earlier planting date in CT relative to DS and ST, there is a greater risk of frost damage if planted at those earlier dates. Although there were relatively wider ranges in maximum and minimum temperatures before and after planting than the average daily temperatures, there were no differences between tillage treatments. This likely was due to the fact that average daily temperatures contained multiple data points from the recorded temperature at hourly intervals and thus, had much less variability than the maximum and minimum recorded daily temperatures, which were endpoints. At the 15 cm depth, mean soil temperature differed by tillage treatment before and after planting, although the after planting temperature difference did not occur until 28 days after planting (Table 2). Conventional tillage temperature was on average 10% higher than ST and DS 28, 21, 7, and 0 days before planting in 2014. Maximum soil temperature at 15 cm was statistically the same among tillage treatments except for 21 days before planting when CT soil temperature was 19% higher than DS and ST. There were no differences in minimum temperatures among the tillage treatments at 15 cm. These results are similar to those reported by Halvorson and Hartman (1984). The exposed soil of CT was able to warm up faster than DS and ST due to the dark color of the soil surface in contrast to the light standing stubble and possibly due to the insulating factor of the previous crop residue. Also, the greater soil moisture in DS and ST suggests better drainage in surface soils thereby allowing resistance to temperature increases due to water.

Sugar Beet Emergence

Crop emergence differed by year, so the data are presented by individual years. In 2013, sugar beet emergence in DS was lower than CT and ST at each counting date by an average of 24% (Table 3). Conventional tillage and ST stand counts did not differ, except at the fourth of five counting dates where the ST stand was 189 plants 30 m^{-1} row and CT was 175 plants 30 m^{-1} row. On the final counting date, CT and ST averaged 158 plants 30 m^{-1} row, compared to DS, which averaged 132 plants 30 m^{-1} row. The heavier crop residue (8,414 kg ha^{-1}) and standing grain stubble in DS delayed emergence in 2013. In contrast, there were no differences in 2014 emergence among the tillage treatments with a lighter crop residue level (5,813 kg ha^{-1}). Average stand counts for all three tillage treatment at each counting date were 117, 137, 153, and 123 plants 30 m^{-1} row (Table 3).

Weed Emergence

Common lambsquarters (*Chenopodium album* L.) was the most abundant broadleaf weed and green foxtail (*Setaria viridis* (L.) Beauv) was the most abundant grass weed for both years. Thus, weed emergence counts were focused on these two species. Analysis of variance tables for common lambsquarters, green foxtail and total weed emergence are presented in Tables 4, 8, and 11.

Common Lambsquarters

Between-Row Counts. Common lambsquarters density between-rows at 2LSB had a significant tillage by irrigation interaction (Table 4). Common lambsquarters density in ST remained the same with increasing irrigation rates, whereas common lambsquarters density in DS increased from 45 and 75 plants m^{-2} in the 50 to 100% ET irrigation rates, but then was equal to the 150% ET rate (Table 5). At the 100% ET irrigation rate in CT, common lambsquarters density was statistically equal to the 50% ET rate, but was lower than the 150% ET irrigation rate. Common lambsquarters density was greater in CT compared to ST and DS with the exception at 100% ET in which direct seed had the most common lambsquarters.

At 6LSB, between-row common lambsquarters emergence had a significant three-way tillage by irrigation rate by N rate interaction (Table 4). At the 50% ET irrigation rate, common lambsquarters density in the CT, DS, and ST did not respond to increasing N rates (Table 5). Common lambsquarters density in CT did not differ from 80 to 120% N rates. In the DS, there were no differences in common lambsquarters density among the N rates, with the exception of the 80% N rate, which had 37 plants m^{-2} compared to an average of 17 plants m^{-2} for the other three N rates. Common lambsquarters densities in ST were statistically equal and averaged 15 plants m^{-2} across all N rates. At the 100% ET irrigation rate, common lambsquarters densities in DS and ST did not differ across the N rates. There was a general trend for common lambsquarters in DS and ST to increase from 60% to 100%

of the recommended N rate, although the densities in both tillage treatments dropped to an average of 20 plants m^{-2} at the 120% N rate. However, there was no clear response of common lambsquarters density to increasing N rate among the tillage treatments at the 100% ET irrigation rate. Common lambsquarters densities in the 150% ET rate generally declined from the 60 to 120% N rates, although there was usually no difference among succeeding rates. For example, there was no difference in common lambsquarters density in the CT among any of the N rates, with the exception of 80 and 120% N, which averaged 47 and 27 plants m^{-2}, respectively. In the DS, the only density difference was between the 60% N rate and all other rates. In the ST, common lambsquarters densities were significantly lower in the 100 and 120% N rates compared to the 60 and 80% N rates. Overall, common lambsquarters response to tillage, irrigation rate and N rate did not follow a clear pattern.

Analysis of densities of common lambsquarters between-row at 12LSB had a significant tillage by irrigation interaction and an irrigation by N rate interaction (Table 4). Common lambsquarters density in CT did not increase with increasing irrigation rates and averaged 33 plants m^{-2}, whereas DS had an increase in common lambsquarters density from 29 to 47 plants m^{-2} at 50 to 150% ET rates, respectively (Table 5). Strip tillage at 50% ET rate had the lowest density (15 plants m^{-2}), but increased to an average of 33 plants m^{-2} at the 100 and 150% ET rates.

In the irrigation rate by N rate interaction, the highest between-row common lambsquarters densities were in the 150% ET treatments at the 60 and 80% N rates (Table 6). When the 150% ET treatments received 100 or 120% N, there was a significantly lower density of common lambsquarters than at 60 and 80% N. For 100% ET, densities were lowest at the 60% N and increased at the 80, 100, and 120% N, which were statistically equal. At the 50% ET irrigation rate, the 80% N rate had a greater density of common lambsquarters than the 60% N rate.

Within-Row Counts. There was a significant response to the three main effects for common lambsquarters densities within-row and no difference between years (Table 4). Unlike for between-row counts, within-row response of common lambsquarters to tillage at the 2LSB, 6LSB and 12LSB was not influenced by irrigation rate (Table 7). The density of common lambsquarters in DS was similar to CT at the 2LSB counts, but was 33 and 28% lower at the mid and 12LSB counts, respectively. Common lambsquarters density in ST was equal to DS at all counting periods.

Common lambsquarters density within the row during the 2LSB responded only to irrigation rate and had lower densities averaging 68 plants m^{-2} in 50 and 100% ET irrigation rates compared to 150% ET irrigation, which had 97 plants m^{-2} and was significantly greater (Table 7). This was somewhat different from what was observed between-row in which there was no clear difference in common lambsquarters density with higher irrigation rates.

6LSB common lambsquarters density within-row was affected by tillage and N rate as main effects (Table 4). Within the CT and ST rows, common lambsquarters density averaged 39 plants m^{-2} compared to DS, which averaged 27 plants m^{-2} (Table 7). In the between-row counts, CT had higher densities than ST and DS. Thus, common lambsquarters occurred more frequently in tilled soils compared with undisturbed soil. Common lambsquarters density within-row also responded to N rate, with higher densities, averaging 41 plants m^{-2} in the 60 and 80% N, compared to 100 and 120% N, which averaged 29 plants m^{-2}.

12LSB common lambsquarters density within-row responded to the main effects of tillage, irrigation rate, and N rate separately (Table 4). Similar to 6LSB counts, common lambsquarters density in CT was greater than DS, with 36 and 26 plants m^{-2}, respectively. Unlike the 6LSB count, there was no difference between ST and DS (Table 7). Similar to 2LSB counts, common lambsquarters densities were highest in 150% ET irrigation, averaging 36 plants m^{-2} compared to 50 and 100% ET irrigation, which averaged 28 plants m^{-2}. 12LSB common lambsquarters density also responded similarly to the 6LSB counts. Common lambsquarters density in the 60 and 80% N rates averaged 36 plants m^{-2} and were significantly greater than the 100 and 120% N rates, which averaged 26 plants m^{-2}.

Some of the differences in common lambsquarters densities at each of the between-row counting periods did not correspond with a clear response to irrigation rate or N rate. Within-row, more common lambsquarters were counted in the CT and ST compared to DS after the 2LSB, which indicates that common lambsquarters emerges better in disturbed soil than in non-disturbed soil. At the mid and 12LSB counts there was no between-row difference in common lambsquarters density at the 100% ET irrigation rate and 100% N rate among tillage treatments. This indicates that at optimum irrigation and N rate, the level of common lambsquarters control will be the same among CT, ST, and DS.

Green Foxtail

Between-Row Counts. 2LSB for green foxtail density between-row had a tillage by irrigation interaction (Table 8). Green foxtail density decreased in ST from 80 to 37 plants m^{-2} in the 50 to 150% ET irrigation rates (Table 9). Direct seed had a similar decrease in green foxtail density of 93 to 29 plants m^{-2} from the 50% to 100% ET irrigation; however, there was a dramatic increase in density at 150% ET irrigation to 101 plants m^{-2}. In contrast, green foxtail in CT increased in density from 50% and 150% to 100% ET. It is not clear why green foxtail responded this way in the DS and CT.

During the mid-spray season there was a significant tillage by irrigation by N rate interaction for green foxtail emergence between the rows (Table 8). In the 50% ET treatment, green foxtail densities in CT were not influenced by N rates (Table 9). For DS and ST there was a decrease in green foxtail abundance from the 60% N and 120% N. At the 100% ET treatment, green foxtail emergence was not affected by increased N despite tillage type. In the 150% ET, green foxtail was not affected by N in DS and CT. In ST, green foxtail emergence was highest in 100% N, at 32 plants m^{-2}, but densities were lowest in 80% and 120% N.

Similar to mid-spray season, there was a significant tillage by irrigation rate by N rate interaction at the 12LSB green foxtail density counts between-row (Table 8). At the 50% ET irrigation rate, green foxtail densities were not affected by N rates in the CT and ST systems (Table 9). However, DS densities were 31 and 37 plants m^{-2} at 60 and 80% N, respectively and were significantly higher than the densities at the 100 and 120% N rates. There were no differences in green foxtail density between CT and ST at all N rates. In the 100% ET irrigation rate, there were no differences in green foxtail density among the tillage treatments and N rates with the exception of CT at the 80% N rate, which had a density of 25 plants m^{-2}. At 150% ET irrigation, green foxtail was not affected by N rate in DS. However, CT had an unexplained increase in density to 51 plants m^{-2} at 80% N, while the other N rates in CT were statistically the same and averaged 15 plants m^{-2}. Similarly, green foxtail density at 100% N in ST spiked to 52 plants m^{-2} while the 80 and 120% N rates averaged 14 plants m^{-2}.

Within-Row Counts. 2LSB green foxtail density within-row had the same tillage by irrigation interaction as between-row emergence (Table 8). Green foxtail density decreased in CT and ST as irrigation amounts increased from 50 to 150%. In DS, green foxtail density decreased 97 to 44 plants m^{-2} from 50 to 100% ET irrigation rates, respectively. However, the density unexpectedly increased to 79 plants m^{-2} from 100 to 150% ET. Green foxtail density did not differ from 50 to 150% ET.

There was no significant affect due to treatments at 6LSB for in-row green foxtail density (Table 8).

12LSB green foxtail density within-row had a three-way tillage by irrigation by N rate interaction (Table 8). At the 50% ET irrigation rate, green foxtail density in all of the tillage treatments responded the same to the increasing N rates, and averaged 10 plants m^{-2} (Table 10). Similar to 50% ET irrigation, green foxtail densities in the 100% ET treatment were not influenced by N rates with the exception of CT at 100% N which had a higher density than CT at 60% N, DS at 100% N, and CT and DS at 120% N. At 150% ET, green foxtail density in DS did not respond to increasing N rates, and averaged 15 plants m^{-2}. CT and ST had higher densities at 80 and 100% compared to the other N rates at 150% ET irrigation, respectively; other than those two unexplainable increases, there did not appear to have a trend in response to N rate at 150% ET.

Similar to the common lambsquarters densities, green foxtail density did not clearly respond to increasing irrigation rates or N rates. Green foxtail density was generally the same, with a few exceptions across the three tillage treatments. At the 100% ET irrigation rate and 100% N rate, there were no differences in green foxtail density among the three tillage treatments. Like common lambsquarters, the green foxtail response indicates that at optimum irrigation and N rate, the level of green foxtail control will be the same among CT, ST, and DS with the weed control regime that was used.

Total Weeds

Between-Row Counts. When all 13 weed species were combined, total weed densities between-row early in the spray season responded only to tillage (Table 11). Total weed density was lower in ST, averaging 180 plants m^{-2}, compared to CT and DS which were the same, and averaged 272 plants m^{-2} (Table 12). No other treatment besides tillage was affected. By 6LSB there was a tillage by N rate interaction and an irrigation rate by N rate interaction (Table 13). Total weeds in CT and ST did not respond to increasing N rates but DS density decreased from 54 to 29 plants m^{-2} between the 60 and 120% N rates, respectively. For the irrigation rate by N rate interaction, total weed densities were not affected by increasing N rates in the 50% and 100% ET irrigation rates. At the 150% ET irrigation, total weed densities decreased from 60 to 30 plants m^{-2} in the 80 to 120% N rates. By 12LSB, total weed density between-row was affected by tillage, irrigation, and N rate as main effects (Table 11). As was observed at the 2LSB, there were fewer weeds in the ST, which averaged 57 plants m^{-2} compared to the total weed density in CT and DS, which did not differ from each other and averaged 80 plants m^{-2} (Table 12). Furthermore, total weed density was greater in the 100% and 150% ET irrigation rates, averaging 89 plants m^{-2} compared to 50 plants m^{-2} in the 50% ET irrigation rate. Total weed density was lowest at the 120% N rate compared to the 60, 80, and 100% N rates, which were statistically equal and averaged 80 plants m^{-2} (Table 12).

Within-Row Counts. Total weed densities during the 2LSB were affected only by irrigation rates (Table 11), with 100% ET irrigation having a 28% lower weed density than

150% ET (Table 12). However, there was no difference in total weed density between 50 and 150% ET irrigation rates. At 6LSB, total weed densities were affected by tillage and N rates as main effects. CT and ST had the same amount of total weeds, averaging 48 plants m^{-2} while DS had 38 plants m^{-2} compared with the other tillage systems. The highest total weed density in response to N rates was the 80% N, although it was not significantly different from the 60% N rate. Compared to the 100 and 120% N rates, total weed density at 80% N was 19 and 33% greater, respectively. By 12LSB a tillage by irrigation interaction influenced total weed density (Table 11). CT was not affected by irrigation rates and averaged 57 plants m^{-2}; however, DS and ST weed densities increased 70 and 55%, respectively from 50 to 150% ET (Table 12). In response to increasing N rate, 12LSB total weed emergence had a similar response to N rate as observed during the 6LSB with 100 and 120% N having the lowest density.

In general, total weed populations were higher in disturbed soil than in undisturbed soil, which gives an advantage to managing weeds in untilled soil compared to tilled soil. This was also observed with common lambsquarters, which may have influenced the total weed density results since it was one of the predominant species. It is interesting that fewer total weeds are found at higher N rates than the lower N rates. Exactly why there are fewer total weeds in the higher N rate is not clear. As was observed with common lambsquarters and green foxtail, when there was an interaction among tillage and irrigation rate or N rate the total weed densities in DS and ST at the 100% ET irrigation and 100% N rate were equal to or lower than CT. Thus, from a weed management standpoint, controlling weeds in ST or DS does appear to be any more challenging than it is in CT.

Insects

Sugar beet root aphid infestation was not affected by tillage treatment or N rate in either 2013 or 2014. With an average rating of 0.62 and 1.82 in 2013 and 2014 respectively, sugar beet root aphid ratings did not differ among tillage treatments (Figure 3).

Leafminer egg counts at the first counting date in 2013 were significantly greater in CT than ST and DS (Table 14), averaging 0.29 eggs plant^{-1} (Figure 4). There was an increase in leafminer eggs between the first and second counting date. By the second counting date, CT had the greatest number of leafminer eggs at 1.8 eggs plant^{-1} followed by ST with 1.1 eggs plant^{-1}, which was statistically greater than DS with 0.64 eggs plant^{-1} (Figure 4). Although there were differences in leafminer egg density in response to tillage at both sampling dates in 2013, no such response was not observed in 2014 (Table 14). At the first sampling date in 2014, the sugar beets averaged 0.52 eggs plant^{-1} in all three tillage treatments. However, by the second counting date, there was a significant tillage by fertilizer interaction for leafminer egg density (Table 14). Leafminer egg density were not affected by N rates in the CT and ST treatments; whereas, DS was not affected at the 80 and 100% N rates averaging 0.31 eggs plant^{-1}, but were statistically more abundant at the 120% N rate, which had 0.94 eggs plant^{-1}.

Leafminer larvae were significantly affected only by tillage treatment in 2013. Similar to the leafminer egg counts, CT had 2.5 larvae plant^{-1} followed by ST and DS with 1.7 and 0.9 larvae plant^{-1}, respectively. By the second counting date in 2013, ST had a greater larvae density than DS. None of the 2014 counting dates for leafminer larvae were significantly impacted by treatments.

Bean aphid densities did not differ due to treatment in 2013 (Table 15). In 2014 bean aphid counts were initially affected by N rate (p = 0.0505) with the greatest density of bean aphids occurring in the highest N rate of 120% recommended N. For the last two counts, bean aphid densities had a tillage by N rate interaction (Table 15). Although there was an interaction, no distinguishable relationship was observed.

In 2014, a wireworm infestation in the field was suspected. Wireworm infestation had no relationship with tillage treatment. Wireworm was expected to favor strip tillage or direct seeding due to reduced disturbance of soil that would favor wireworm soil-dwelling habitat; however, this was not observed.

There were no indications that the sugar beet insect pests that were evaluated in this study were any more or less of a problem in ST and DS compared to CT. No distinguishable trends were observed between insect pests and N rates in this study. It was expected that insect pests would have responded positively to increased N fertilizer rates due to a greater N source for feeding.

Disease

In 2013 and 2014, several beets exhibiting Aphanomyces and Rhizoctonia symptoms were found throughout the field; however, overall disease incidence was low and there was no apparent relationship with tillage treatment, irrigation rate, or N rate and disease severity (O.T. Neher, personal communication). Thus, no data were analyzed to statistically compare treatments.

Yield and Quality

Combined over both years, sugar beet root yield responded to tillage, with no effects due to irrigation or N rate (Table 16). Conventional tillage and ST had comparable root yields of 94 and 92 Mg ha^{-1}, respectively, in contrast to the lower yielding DS at 85 Mg ha^{-1} (Table 17). The 8% reduction in DS root yield might have been due to differences in soil properties between the untilled DS treatments and the tilled soil in the CT and ST treatments. There was a reduced stand in 2013 in DS relative to CT and ST, but not in 2014. There also may have been some other soil characteristics, such as bulk density that were not measured that could have impacted root yield in the DS treatment. There was a lack of yield response to N possibly due to the unknown mineralization processes in the soil.

Unlike the root yield response, there was no difference in ERS yield between tillage treatments averaged over years (Table 16). However, the main effects of irrigation and N rate on ERS yield were significant when combined over years. The 150% ET irrigation rate had a higher ERS yield than 50% ET irrigation, however 100% ET irrigation was not different between 50 and 150% ET. ERS yield also had a significant response to applied N rates (Table 17). Interestingly, ERS yield at 120% N did not differ with 60 and 80% N rates and significantly higher than the 100% N rate. Although there was a difference in root yield between tillage treatments, ERS was not affected by tillage treatment. Additionally, ERS was impacted by N rate however root yield was not. More N does not necessarily increase root yield because more N may result in growing more tops and less sugar in those root yields.

Sucrose content responded to irrigation rate (Table 17). At 150% ET irrigation, sugar beet had a 14.1% sucrose content compared to 12.5% in the 50% ET irrigation rate. Sucrose content in the 100% ET irrigation sugar beet was not different between the 50 or 150% ET irrigation rates. The presumed water stress in the 50% ET irrigation may have reduced the sugar beet’s ability to recover from midday wilting, from personal observation, resulting in reduced photosynthetic rates and consequently sucrose synthesis (Berry and Björkman, 1980). Sucrose content was very low for each year of the study. Both growing season were extremely warm, which may have contributed to the low sucrose content. There were skips within the rows that in combination with the extremely warm weather reduced the sucrose content. Since brei nitrate levels were high, invariably the sucrose content decreased (Amalgamated Sugar Company, 2015).

Irrigation rate had a significant effect on brei nitrate levels over both years (Table 17). The 150% ET irrigation rate had the lowest nitrate level at 244 mg kg^{-1}. The nitrate levels in the 50 and 100% ET irrigation were 440 and 355 mg kg^{-1}. With increasing irrigation rate, the likelihood of N leaching increases and can contribute to the lower nitrate level in the over-irrigated sugar beet (Winter, 1980). As expected, N fertilizer rate significantly influenced nitrate content. The 60 and 80% N rates had lower nitrate levels of 309 and 314 mg kg^{-1}, respectively. Although nitrate levels were above 200 mg kg^{-1}, which can indicate over fertilization, all N treatments were high suggesting mineralization processes may have contributed to the elevated nitrate levels.

Irrigation rate was the only treatment with a significant effect on conductivity (Table 16). Conductivity in the 100 and 150% ET irrigation were statistically the same at 0.81 and 0.76 mmhos cm^{-1}, which was significantly less than the 50% ET irrigation at 0.87 mmhos cm^{-1} (Table 17). This is similar to the sugar beet nitrate levels, in which there were fewer salts in the higher irrigation rates. The 50% ET irrigation presumably did not receive enough water to leach salts in the soil profile, and apparently accumulated in the sugar beet to make sugar extraction less efficient.

Although an economic analysis of the treatments in this study was not conducted, it has been well documented that input costs for reduced tillage are lower than for conventional tillage (Overstreet, 2009; Tarkalson et al., 2012). Thus, the higher inputs costs of CT compared to ST and DS used in this study would result in a lower net return with CT compared to ST and NT based on similar ERS yield among the three tillage treatments compared.

Based on the results of this study, growing sugar beets with less tillage is a viable option to sugar beet farmers. There are some questions that still need to be addressed related to N management and response of other weed species not evaluated in this study. At the initiation of this study, it was thought that weed emergence and densities might be different between tilled and untilled soil. The same was assumed for insect pests. However, it appears that there are not great differences in water and N requirements or insect and weed management strategies among the three tillage systems.

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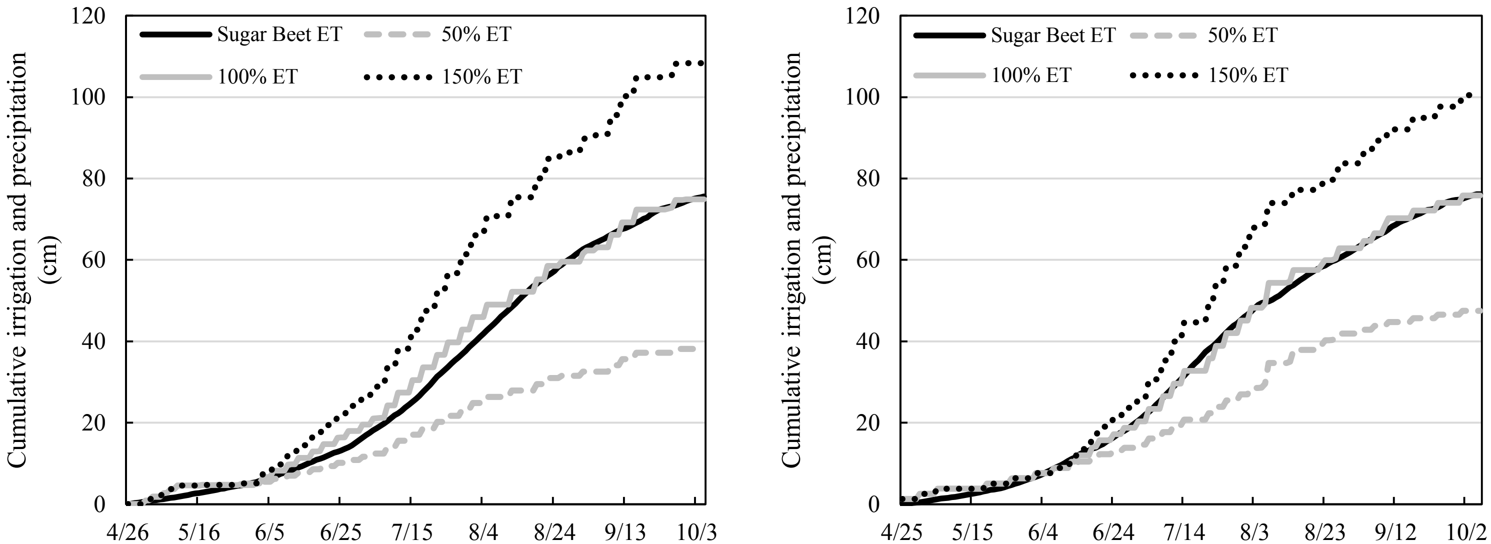

Figure 1. Cumulative irrigation and precipitation for the 50, 100 and 150% ET irrigation rates in 2014 field study.

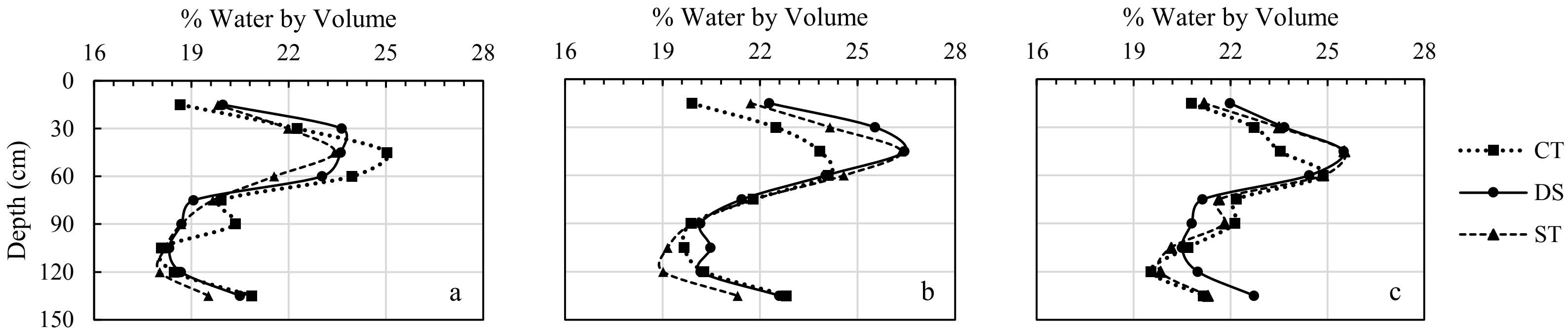

Figure 2. Volumetric soil moisture content in a 135 cm soil profile as affected by tillage system for each irrigation treatment in 2014. Soil moisture values are means across four sampling dates. Tillage systems were conventional tillage (CT), direct seed (DS), and strip tillage (ST). Figure 1a, 1b, and 1c represent the 50% 100% and 150% ET irrigation rates, respectively.

Table 1. Soil temperature at 2.5 cm depth compared among tillage systems. Different letters within a row and temperature range (mean, maximum and minimum) are significantly different at α=0.05 using least squared means. Tillage systems were conventional tillage (CT), direct seed (DS), and strip tillage (ST).

	Mean temperature (C)			Maximum temperature (C)			Minimum temperature (C)		
Days before/after planting	CT	DS	ST	CT	DS	ST	CT	DS	ST
-28	5.0 a	4.0 b	4.3 b	9.8 a	9.3 a	11.7 a	3.4 a	0.7 a	0.1 a
-21	8.3 a	7.2 c	7.6 b	9.7 a	9.3 a	10.4 a	7.1 a	5.2 a	4.9 a
-14	4.2 b	4.6 a	4.2 b	6.7 a	8.1 a	8.5 a	3.4 a	2.6 a	1.7 a
-7	13.2 a	11.5 c	12.2 b	16.4 a	16.2 a	18.0 a	10.9 a	7.5 a	7.2 a
0	8.3 a	8.0 a	7.7 a	8.6 a	5.4 a	4.9 a	15.1 a	18.5 a	18.0 a
7	8.6 a	8.5 a	8.5 a	15.2 a	13.6 a	14.0 a	3.7 a	4.1 a	3.9 a
14	14.9 a	13.9 a	13.8 a	24.8 a	21.8 a	21.1 a	8.3 a	7.1 a	7.2 a
21	12.3 a	12.2 a	12.3 a	18.4 a	16.8 a	17.0 a	9.8 a	9.0 a	9.0 a
28	14.7 a	13.9 a	14.0 a	24.6 a	21.7 a	22.2 a	8.0 a	6.9 a	6.6 a

Table 2. Soil temperature at 15 cm depth compared among tillage systems. Different letters within a row and temperature range (mean, maximum and minimum) are significantly different at $\alpha=0.05$ using least squared means. Tillage systems were conventional tillage (CT), direct seed (DS), and strip tillage (ST).

Days before/after planting	Mean temperature (C)			Maximum temperature (C)			Minimum temperature† (C)		
	CT	DS	ST	CT	DS	ST	CT	DS	ST
-28	5.0 a	4.4 b	4.5 b	4.0 a	2.9 a	2.9 a	6.7 a	6.4 a	6.7 a
-21	8.3 a	7.2 b	7.4 b	7.9 a	6.6 b	6.7 b	9.2 a	8.2 a	8.5 a
-14	4.6 b	4.9 a	4.6 b	4.0 a	4.0 a	3.6 a	5.5 a	6.0 a	5.7 a
-7	11.7 a	10.4 b	10.7 b	10.5 a	8.8 a	9.0 a	12.9 a	12.1 a	12.4 a
0	10.2 a	9.7 b	9.6 b	10.6 a	7.6 a	7.6 a	16.1 a	19.3 a	18.7 a
7	9.4 a	9.1 a	9.1 a	13.7 a	10.8 a	11.0 a	6.0 a	7.4 a	7.2 a
14	13.4 a	12.3 a	12.5 a	18.2 a	15.4 a	15.7 a	—	—	—
21	12.6 a	12.3 a	12.3 a	15.0 a	13.6 a	13.8 a	10.6 a	11.0 a	10.7 a
28	14.0 a	13.0 b	13.1 b	18.3 a	15.8 a	16.3 a	10.0 a	10.4 a	10.1 a

†Missing values represent an error from the temperature sensors.

Table 3. Sugar beet stand counts compared among tillage treatments in 2013 and 2014. Emergence data are presented separately by year due to differences in accumulated GDD and number of counting dates between years. Treatment means followed by the same letter within a column are not significantly different at α=0.05 based on least square means.

	Cumulative growing degree days†								
	2013					2014			
Tillage	435	575	750	895	1175	550	675	1110	1145
	--plants 30 m^{-1} row---------------------------------------								
CT	157 a	179 a	180 a	174 a	151 a	126 a	142 a	159 a	128 a
DS	112 b	145 b	160 b	151 b	132 b	108 a	134 a	152 a	123 a
ST	157 a	183 a	185 a	189 c	164 a	118 a	134 a	149 a	118 a

† $GDD = \frac{(T_{max}+T_{min})}{2} - 34$

Table 4. Analysis of variance of common lambsquarters emergence in response to tillage system, irrigation rate and nitrogen rate at three different counting periods during the spraying season. 2013 and 2014 data are combined due to no year effect.

	2LSB		6LSB		12LSB	
Source	between-row	within-row	between-row	within-row	between-row	within-row
Tillage (T)	**< 0.0001**	0.176	**< 0.0001**	**< 0.0001**	**0.003**	**0.018**
Irrigation (I)	0.140	**0.001**	0.101	0.624	**0.001**	**0.035**
T x I	**0.008**	0.821	**0.035**	0.520	**0.020**	0.425
N Rate (N)	—	—	**< 0.0001**	**< 0.0001**	**0.001**	**0.016**
T x N	—	—	0.322	0.407	0.315	0.566
I x N	—	—	**< 0.0001**	0.074	**0.001**	0.803
T x I x N	—	—	**0.043**	0.097	0.924	0.608

*2LSB had not yet received N treatments.

Table 5. Common lambsquarters density between-rows at three counting periods (2LSB, 6LSB, and 12LSB) pooled across years in response to interactions of tillage treatment†, irrigation rate‡ and nitrogen (N) rate§. 2LSB counts had a tillage by irrigation rate interaction. 6LSB counts had a tillage by irrigation rate by N rate interaction. 12LSB counts had a tillage by irrigation interaction. Means followed by the same letter within a column and treatment are not significantly different α=0.05 using least squared means.

Irrigation	2LSB				6LSB			12LSB		
rate	CT	DS	ST	N rate	CT	DS	ST	CT	DS	ST
%ET	plants m^{-2}			%	plants m^{-2}					
50	81 ab	45 de	36 e	60	27 c-h	21 e-j	13 ij	31 b	29 b	15 c
				80	41 a-c	37 a-d	16 g-j			
				100	41 a-c	16 g-j	15 ij			
				120	37 a-d	13 ij	15 h-j			
100	58 bcd	75 abc	49 de	60	19 e-j	13 ij	17 f-j	30 b	32 b	33 ab
				80	43 a-c	21 e-j	32 a-e			
				100	28 b-g	28 a-g	30 a-f			
				120	38 a-c	20 e-k	19 e-j			
150	87 a	54 cd	50 de	60	45 a-b	47 a	30 a-f	37 ab	47 a	28 b
				80	47 a	22 d-i	41 a-c			
				100	32 a-e	18 f-j	15 ij			
				120	27 b-h	15 h-j	12 j			

†Tillage treatments were conventional tillage (CT), direct seed (DS) and strip tillage (ST).
‡Irrigation rate was based on the amount of water needed to meet 50, 100, and 150% evapotranspiration (ET) based on the Penman-Monteith model for CT sugar beets.
§Nitrogen rate was relative and the 100% rate was based on the recommended rate to achieve a 78 Mg ha^{-1} yield goal.

Table 6. Common lambsquarters density between-rows in response to an irrigation rate† by nitrogen (N) rate‡ interaction at 12LSB pooled across 2013 and 2014. Means followed by the same letter within a column and treatment are not significantly different α=0.05 using least squared means.

Irrigation rate	N Rate (%)			
%ET	60	80	100	120
50	20 f	31 cde	24 def	22 ef
100	22 ef	39 abc	32 cde	36 bcd
150	53 ab	54 a	27 c-f	23 ef

†Irrigation rate was based on the amount of water needed to meet 50, 100, and 150% evapotranspiration (ET) based on the Penman-Monteith model for CT sugar beets.
‡Nitrogen rate was relative and the 100% rate was based on the recommended rate to achieve a 78 Mg ha^{-1} yield goal.

Table 7. Common lambsquarters density within-rows at three counting periods (2LSB, 6LSB, and 12LSB) pooled across years in response to tillage treatment†, irrigation rate‡ and nitrogen (N) rate§. Means followed by the same letter within a column and treatment are not significantly different α=0.05 using least squared means.

Tillage	2LSB¶	6LSB	12LSB
		------------------------------------plants m^{-2}------------------------------------	
CT	82 a	40 a	36 a
DS	68 a	27 b	26 b
ST	80 a	37 a	30 ab
Irrigation rate			
%ET			
50	67 b	34 a	27 b
100	68 b	33 a	29 b
150	97 a	36 a	36 a
N rate			
%			
60	—	39 a	35 a
80	—	42 a	36 a
100	—	30 b	26 b
120	—	28 b	26 b

†Tillage treatments were conventional tillage (CT), direct seed (DS) and strip tillage (ST).
‡Irrigation rate was based on the amount of water needed to meet 50, 100, and 150% evapotranspiration (ET) based on the Penman-Monteith model for CT sugar beets.
§Nitrogen rate was relative and the 100% rate was based on the recommended rate to achieve a 78 Mg ha^{-1} yield goal.
¶Missing values in response to N rate at the 2LSB counts was because the N had not yet been applied.

Table 8. Analysis of variance of green foxtail emergence in response to tillage system, irrigation rate and nitrogen rate at three different counting periods (2LSB, 6LSB and 12LSB) during the spraying season. 2013 and 2014 data are combined due to no year effect.

	2LSB		6LSB		12LSB	
Source	between-row	within-row	between-row	within-row	between-row	within-row
Tillage (T)	0.199	0.157	0.273	0.689	0.675	0.481
Irrigation (I)	**0.014**	**0.002**	**0.031**	0.059	**0.005**	**0.043**
T x I	**< 0.0001**	**0.039**	0.399	0.845	**0.052**	0.990
N Rate (N)	—	—	**0.018**	0.480	0.143	0.319
T x N	—	—	**< 0.0001**	0.529	**0.002**	0.144
I x N	—	—	0.402	0.893	0.248	0.552
T x I x N	—	—	**0.049**	0.080	**0.019**	**0.036**

*2LSB had not yet received N treatments.

Table 9. Green foxtail density between-rows at three counting periods (2LSB, 4LSB, and 12LSB) pooled across years in response to interactions of tillage treatment†, irrigation rate‡ and nitrogen (N) rate§. 2LSB counts had a tillage by irrigation rate interaction. Mid and 12LSB counts had a tillage by irrigation rate by N rate interaction. Means followed by the same letter within a column and treatment are not significantly different α=0.05 using least squared means.

	2LSB				6LSB			12LSB		
Irrigation rate	CT	DS	ST	N rate	CT	DS	ST	CT	DS	ST
%ET	---plants m^{-2}---			%	---plants m^{-2}---					
50	48 c	93 a	80 ab	60	12 c-h	24 ab	19 bc	14 e-i	31 a-d	16 d-i
				80	12 c-h	14 c-h	16 b-h	12 g-i	37 a-c	13 f-i
				100	9 gh	11 d-h	17 b-e	10 hi	12 g-i	17 d-i
				120	12 c-h	13 c-h	11 d-h	15 d-i	15 d-i	11 hi
100	83 a	29 d	50 bc	60	12 c-h	17 b-g	9 h	9 i	11 hi	17 d-i
				80	17 b-g	10 gh	13 c-h	25 c-g	17 d-i	18 d-i
				100	10 e-h	10 f-h	14 c-h	15 d-i	12 g-i	15 d-i
				120	10 e-h	11 d-h	10 f-h	18 d-i	11 hi	19 c-i
150	32 cd	101 a	37 cd	60	12 c-g	13 c-h	18 b-d	16 d-i	27 b-f	29 a-e
				80	24 ab	17 b-f	10 e-h	51 ab	19 d-i	13 f-i
				100	10 gh	12 c-h	32 a	17 d-i	15 e-i	52 a
				120	12 c-h	12 c-h	10 f-h	13 f-i	23 c-h	14 e-i

†Tillage treatments were conventional tillage (CT), direct seed (DS) and strip tillage (ST).

‡Irrigation rate was based on the amount of water needed to meet 50, 100, and 150% evapotranspiration (ET) based on the Penman-Monteith model for CT sugar beets.

§Nitrogen rate was relative and the 100% rate was based on the recommended rate to achieve a 78 Mg ha^{-1} yield goal.

Table 10. Green foxtail density within-rows at three counting periods (2LSB, 6LSB, and 12LSB) pooled across years in response to interactions of tillage treatment†, irrigation rate‡ and nitrogen (N) rate§. Early and 6LSB counts had a tillage by irrigation rate interaction. 12LSB counts had a tillage by irrigation rate by N rate interaction. Means followed by the same letter within a column and treatment are not significantly different α=0.05 using least squared means.

Irrigation	2LSB			6LSB				12LSB		
rate	CT	DS	ST	CT	DS	ST	N Rate	CT	DS	ST
%ET	plants m^{-2}						%	plants m^{-2}		
50	69 a-d	97 ab	103 a	9 a	10 a	11 a	60	9 cd	11 bcd	12 bcd
							80	11 bcd	15 a-d	12 bcd
							100	8 d	8 d	9 d
							120	11 bcd	10 bcd	9 cd
100	64 b-e	44 de	68 a-d	9 a	9 a	9 a	60	9 cd	15 a-d	15 a-d
							80	10 bcd	15 a-d	11 bcd
							100	20 ab	9 cd	11 bcd
							120	9 cd	9 cd	13 bcd
150	42 e	79 a-c	57 c-e	11 a	11 a	11 a	60	9 cd	16 a-d	9 cd
							80	27 a	18 abc	9 cd
							100	10 cd	11 bcd	26 a
							120	9 cd	15 a-d	15 a-d

†Tillage treatments were conventional tillage (CT), direct seed (DS) and strip tillage (ST).
‡Irrigation rate was based on the amount of water needed to meet 50, 100, and 150% evapotranspiration (ET) based on the Penman-Monteith model for CT sugar beets.
§Nitrogen rate was relative and the 100% rate was based on the recommended rate to achieve a 78 Mg ha^{-1} yield goal.

Table 11. Analysis of variance of total weed (13 species†) emergence in response to tillage system, irrigation rate and nitrogen rate at three different counting periods (2LSB, 6LSB, and 12LSB) during the spraying season. 2013 and 2014 data are combined due to no year effect.

	2LSB		6LSB		12LSB	
Source	between-row	within-row	between-row	within-row	between-row	within-row
Tillage (T)	**0.0002**	0.452	**< 0.0001**	**0.006**	**0.003**	0.224
Irrigation (I)	0.403	**0.010**	0.105	0.348	**< 0.0001**	**< 0.0001**
T x I	0.690	0.932	0.272	0.722	0.601	**0.007**
N Rate (N)	—	—	**< 0.0001**	**0.0001**	**0.0013**	**0.012**
T x N	—	—	**0.015**	0.760	0.177	0.738
I x N	—	—	**0.032**	0.094	0.086	0.727
T x I x N	—	—	0.425	0.064	0.437	0.554

†The weed species were common lambsquarters, green foxtail, redroot pigweed, kochia, common mallow, hairy nightshade, Russian thistle, flixweed, annual sowthistle, common purselane, prickly lettuce, shepherd’s-purse, and barnyardgrass.

Table 12. Total weed density within-rows at three counting periods (2LSB, 6LSB, and 12LSB) pooled across years in response to tillage treatment†, irrigation rate‡ and nitrogen (N) rate§. Early and 6LSB counts had a tillage by irrigation rate interaction. 12LSB counts had a tillage by irrigation rate by N rate interaction. Means followed by the same letter within a column and treatment are not significantly different α=0.05 using least squared means. Means without letters within a column and treatment have significant higher order interactions and the data are presented on Table 13.

	2LSB		6LSB		12LSB	
Tillage	between-row	within-row	between-row	within-row	between-row	within-row
CT	284 a	262 a	58	50 a	76 a	56 a
DS	260 a	277 a	40	38 b	83 a	53 a
ST	180 b	241 a	39	45 a	57 b	46 a
Irrigation rate						
%ET						
50	228 a	253 ab	42 a	43 a	50 b	36
100	225 a	223 b	44 a	42 a	80 a	50
150	259 a	310 a	49 a	47 a	98 a	78
N rate						
%						
60	—	—	47	49 ab	80 a	62 a
80	—	—	54	52 a	84 a	58 a
100	—	—	46	42 bc	75 a	48 ab
120	—	—	35	35 c	51 b	42 b

†Tillage treatments were conventional tillage (CT), direct seed (DS) and strip tillage (ST).
‡Irrigation rate was based on the amount of water needed to meet 50, 100, and 150% evapotranspiration (ET) based on the Penman-Monteith model for CT sugar beets.
§Nitrogen rate was relative and the 100% rate was based on the recommended rate to achieve a 78 Mg ha^{-1} yield goal.

Table 13. Total weed density within-rows at two counting periods (6LSB and 12LSB) pooled across years in response to tillage treatment†, irrigation rate‡ and nitrogen (N) rate§. 6LSB counts had a tillage by nitrogen (N) rate interaction. 12LSB counts had a tillage by irrigation rate interaction. Means followed by the same letter within a column and treatment are not significantly different α=0.05 using least squared means.

			6LSB within-row						12LSB between-row	
N rate	CT	DS	ST	50	100	150	Irrigation rate	CT	DS	ST
%	----	----	----	plants m^{-2}	----	----	%ET	----	plant m^{-2}	----
60	54 ab	54 ab	36 dc	43 bcd	39 cde	64 a	50	46 cd	31 e	33 de
80	70 a	46 bc	49 bc	52 ab	50 abc	60 a	100	64 bc	47 cd	41 de
100	55 ab	37 dc	48 bc	40 b-e	49 abc	50 abc	150	61 bc	104 a	74 ab
120	53 ab	29 d	28 d	36 de	38 cde	31 e				

†Tillage treatments were conventional tillage (CT), direct seed (DS) and strip tillage (ST).
‡Irrigation rate was based on the amount of water needed to meet 50, 100, and 150% evapotranspiration (ET) based on the Penman-Monteith model for CT sugar beets.
§Nitrogen rate was relative and the 100% rate was based on the recommended rate to achieve a 78 Mg ha^{-1} yield goal.

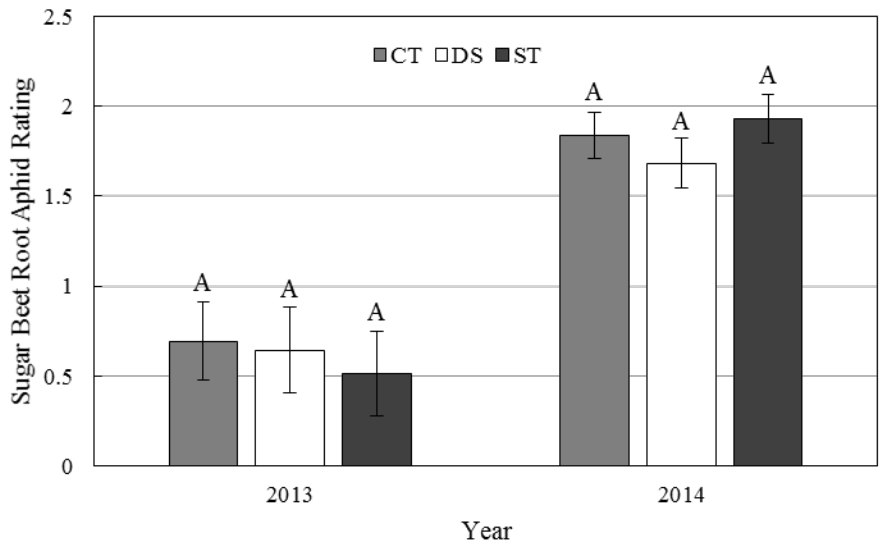

Figure 3. Mean ± SEM sugar beet root aphid rating. Rating scale is based on Hutchison and Campbell (1994). Means that share the same letter are not significantly different. Tillage treatments were conventional tillage (CT), direct seed (DS) and strip tillage (ST).

Table 14. Analysis of variance of leafminer egg and larvae counts in response to tillage system and nitrogen rate at two counting dates in 2013 and 2014.

Source	31 May 2013		12 June 2013		6 June 2014		16 June 2014	
	Eggs	Larvae	Eggs	Larvae	Eggs	Larvae	Eggs	Larvae
Tillage	**0.026***	**< 0.0001***	**0.003***	0.064	0.730	0.918	0.109	0.426
N Rate	0.134	0.808	0.942	0.466	0.581	0.107	0.980	0.566
Tillage x N Rate	0.173	0.352	0.133	0.296	0.931	0.296	**0.016***	0.637

*Indicates significance at 0.05 probability

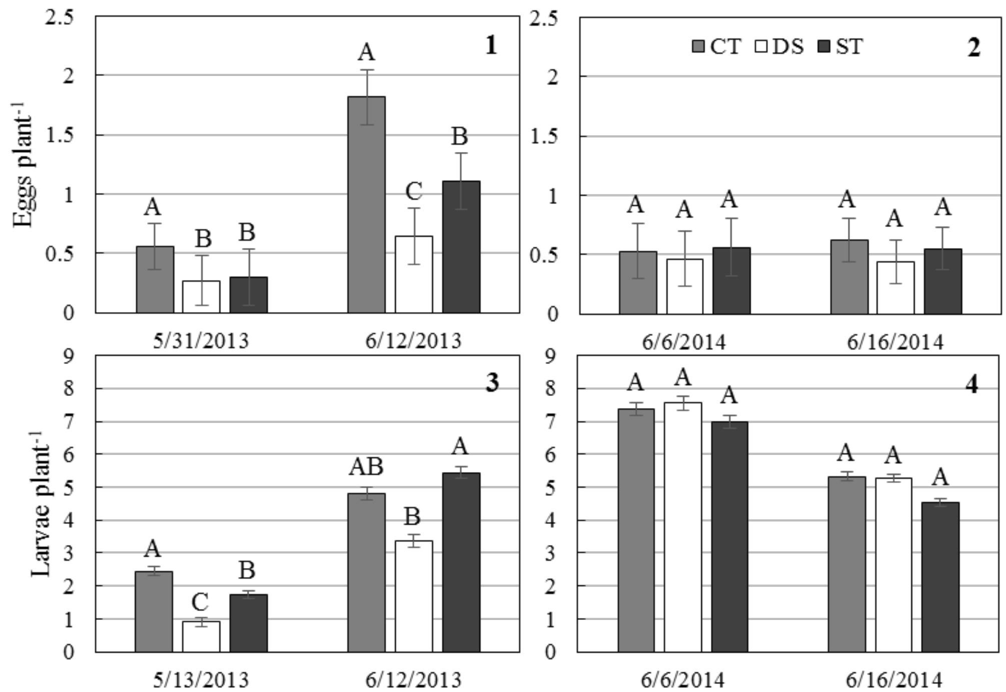

Figure 4. Mean ± SE number of leafminers per plant compared among tillage treatments for 2013 and 2014. Means that share the same letter are not significantly different. Panel 1 and 2 represent leafminer eggs for 2013 and 2014, respectively. Panel 3 and 4 represent leafminer larvae for 2013 and 2014, respectively.

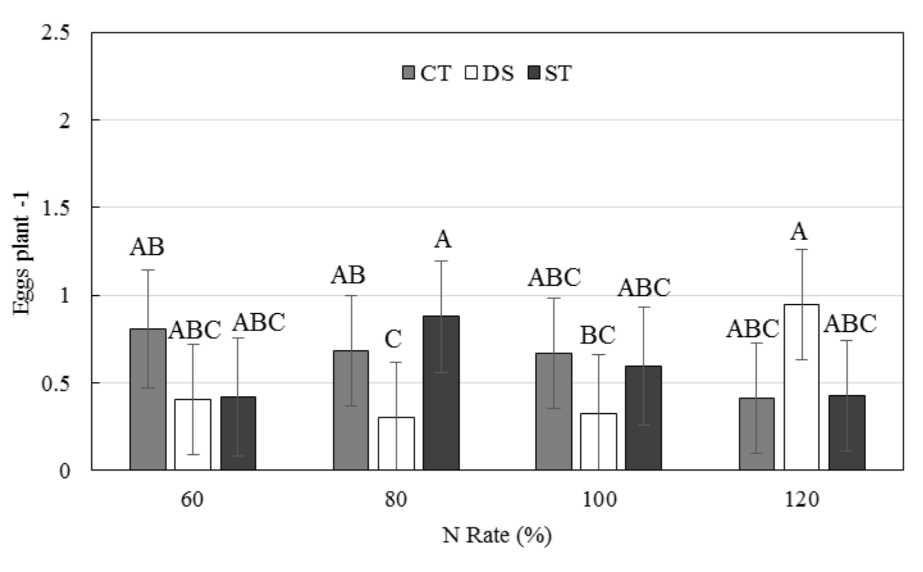

Figure 5. Mean ± SE number of leafminer eggs per plant compared among tillage and nitrogen treatments on 16 June 2014. Means that share the same letter are not significantly different.

Table 15. Analysis of variance of bean aphid in response to tillage system and nitrogen rate at two counting dates in 2013 and 2014.

Source	7/22/2013	8/7/2013†	7/8/2014	7/21/2014	8/14/2014
Tillage	0.2224	0.2299	0.1785	0.6482	0.7677
N Rate	0.0864	0.8409	**0.0505***	0.6262	0.1278
Tillage x N	0.4183	—	0.4929	**0.0388***	0.0553

*Indicates significance at 0.05 probability.
†No interaction due to Kruskal-Wallis analysis.

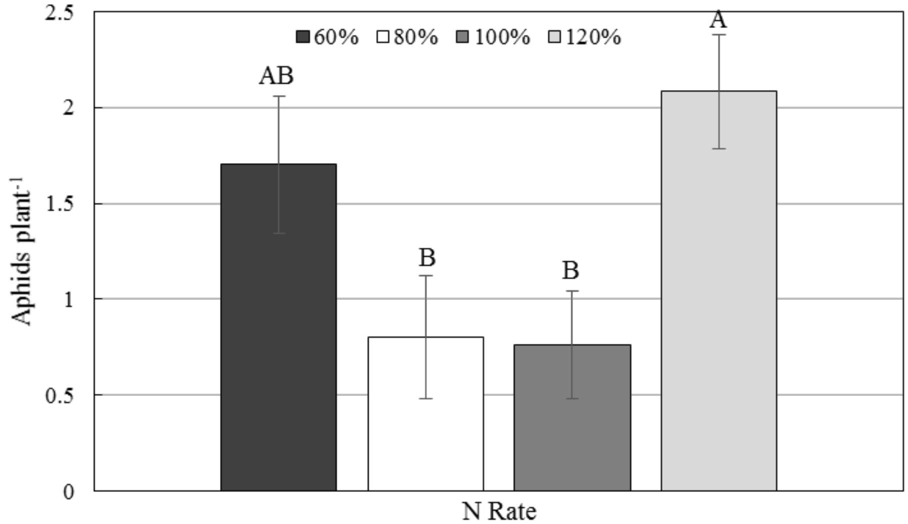

Figure 6. Bean aphid mean ± SE among nitrogen treatments on 8 July 2014. Means that share the same letter are not significantly different.

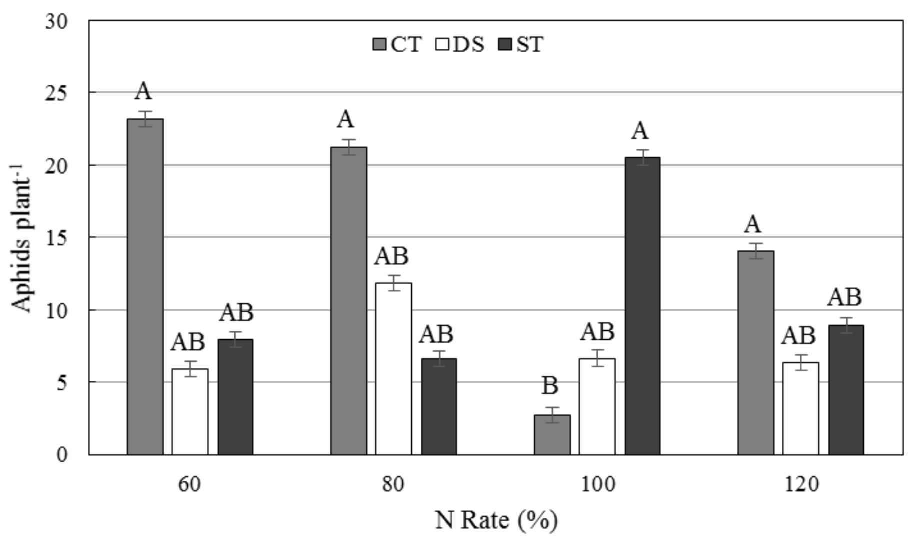

Figure 7. Bean aphid mean ± SE among tillage and nitrogen treatments on 21 July 2014. Means that share the same letter are not significantly different.

Table 16. Analysis of variance of sugar beet root and estimated recoverable sucrose yield and sugar quality parameters for 2013 and 2014.

Effect	Root Yield	ERS	% Sucrose	Nitrates	Conductivity
Year (Y)	0.167	**0.001***	**0.0001***	0.063	**<0.0001***
Tillage (T)	**0.002***	0.200	0.235	0.190	0.333
Irrigation (I)	0.161	**0.032***	**0.006***	**<0.0001***	**0.002***
Nitrogen (N)	**0.371**	**0.030***	**0.135**	**0.003***	**0.122**
Y x T	0.186	0.238	0.386	0.658	0.503
Y x I	0.655	0.867	0.973	0.983	0.911
Y x N	0.730	0.840	0.328	0.590	0.753
T x I	0.339	0.194	0.207	0.741	0.715
T x N	0.156	0.385	0.466	0.746	0.660
I x N	0.172	0.268	0.794	0.454	0.708
Y x T x I	0.189	0.261	0.207	0.373	0.230
Y x T x N	0.360	0.464	0.957	0.800	0.964
Y x I x N	0.813	0.390	0.077	0.104	0.177
T x I x N	0.770	0.835	0.179	0.149	0.275
Y x T x I x N	0.091	0.592	0.126	**0.001***	**0.004***

*Indicates significance at 0.05 probability.

Table 17. Sugar beet root and estimated recoverable sucrose yield and sugar quality in response to tillage treatment†, irrigation rate‡ and nitrogen (N) rate§ main effects pooled across years. Means followed by the same letter within a column and treatment are not significantly different α=0.05 using least squared means.

Treatment	Root Yield	ERS+	Sucrose	Nitrates	Conductivity
Tillage	Mg ha^{-1}	kg ha^{-1}	%	mg kg^{-1}	mmhos cm^{-1}
CT†	93.7 a	10902	13.25	354.32	0.8138
DS	85.0 b	10215	13.50	319.67	0.7974
ST	91.7 a	10564	13.15	336.94	0.8180
Irrigation rate					
%ET					
50	86.5	9413.2 b	12.49 a	440.23 a	0.8682 a
100	92.6	10755 ab	13.25 ab	355.35 b	0.8086 b
150	91.2	11512 a	14.16 b	243.96 c	0.7561 b
Nitrogen Rate					
%					
60	88.7	10551 ab	13.32	309.36 a	0.8151
80	89.8	10747 a	13.44	314.16 a	0.7894
100	91.0	10167 b	13.11	371.93 b	0.8265
120	91.1	10776 a	13.34	355.49 b	0.8080

†Tillage treatments were conventional tillage (CT), direct seed (DS) and strip tillage (ST).
‡Irrigation rate was based on the amount of water needed to meet 50, 100, and 150% evapotranspiration (ET) based on the Penman-Monteith model for CT sugar beets.
§Nitrogen rate was relative and the 100% rate was based on the recommended rate to achieve a 78 Mg ha^{-1} yield goal.

CHAPTER 3. STRIP TILLAGE AND DIRECT-SEEDING IN SUGAR BEET PRODUCTION

Introduction

Reduced tillage has many benefits including reduced tillage costs, enhanced stored soil moisture, and reduced soil erosion. No till, or direct seed (DS) and strip tillage (ST) are examples of reduced tillage systems. Strip tillage is a method of conservation tillage in which crops are grown in narrow, tilled strips of previously undisturbed soil, and no more than a third of the surface residue is disturbed and the crop residues are maintained on the soil surface year-round (ASABE Standards, 2013). Strip tillage alternates between properties of no-till in the inter-row while forming a seedbed similar to conventional tillage in the row (Overstreet, 2009), this method tills a strip (6 to 12 in wide and ≤ 3 in deep) into existing crop residue. Although ST is described as tilling ≤ 3 inches deep, the ST conducted at the Kimberly Research and Extension Center was 6 inches deep. Strip tillage generally consists of a two-pass operation with the first pass tilling strips into the previous crops residue and the second pass for planting.

Tillage Effects in Sugar Beets

In 2013 and 2014, a field study was conducted at the University of Idaho Kimberly Research and Extension Center to evaluate the effects of tillage system, irrigation amount, and nitrogen (N) rate on sugar beets. Three tillage treatments were compared: conventional tillage (CT), strip tillage (ST), and direct seed (DS). Irrigation treatments were based on the sugar beet evapotranspiration (ET) model and were 50, 100, and 150% of ET for conventionally tilled sugar beets. Four N fertility rates were applied: 60, 80, 100, and 120%

of recommended rates for CT sugar beets. The overall objectives of this study was to examine effect of nitrogen fertilizer rates, irrigation amounts, and tillage type on:

1. Moisture content and temperature within the soil profile
2. Emergence and stand establishment of the sugar beet crop
3. Weed emergence and control
4. Abundance of insect pests and severity of associated crop damage
5. Onset, development, and severity of disease
6. Root yield, sugar content, and estimated recoverable sucrose

Effect on Soil Properties and Erosion

Reduced tillage has been shown to conserve soil moisture due to increased water infiltration, decreased runoff or loss due to evaporation, and trap snow which increases soil moisture supply (Deibert, 1983; Hatfield et al., 2001). Soil moisture in the germination zone (3 inches) has been shown to be significantly drier in CT than ST or DS during stand establishment (Sojka et al., 1980). Furthermore, reduced tillage tends to have cooler soil temperatures (Deibert and Giles, 1979) although some research has found no differences in soil temperature between conventional and reduced tillage (Halvorson and Hartman, 1984). More recent research at the University of Idaho showed average daily soil temperatures for CT averaged 1^{o}F greater than DS and ST at the 1- and 6-inch depths before planting (Table 1). However, after planting average daily soil temperatures did not differ between tillage treatments (Belmont et al., 2015).

Table 1. Soil temperature at 1 and 6 inch depth as affected by tillage system. Different letters within a row and depth are significantly different at p = 0.05 using least squared means. Tillage systems were conventional tillage (CT), direct seed (DS), and strip tillage (ST).

	Average Temperature at 1" (°F)			Average Temperature at 6" (°F)		
Days before/after planting	CT	DS	ST	CT	DS	ST
-28	**41 a**	**39 b**	**40 b**	**41 a**	**40 b**	**40 b**
-21	**47 a**	**45 c**	**46 b**	**47 a**	**45 b**	**45 b**
-14	**40 b**	**40 a**	**40 b**	**40 b**	**41 a**	**41 a**
-7	**56 a**	**53 c**	**54 b**	**53 a**	**51 b**	**51 b**
0	47	46	46	**50 a**	**49 b**	**49 b**
7	47	47	47	49	48	48
14	59	57	57	56	54	55
21	54	54	54	55	54	54
28	59	57	57	**57 a**	**55 b**	**56 b**

Soil erosion is reduced in reduced tillage systems because the crop residue protects the soil surface from wind and water erosion. Strip tillage reduces wind erosion by reducing wind velocity at the soil surface, binding soil to previous crop roots, and the standing stubble traps soil suspended in the wind (Overstreet, 2009). Sojka et al. (1980) reported maximum wind speeds were reduced by almost 50% in reduced tillage compared with conventional tillage when measure 2 inches above the soil surface. Sugar beet seedlings are susceptible to damage by wind due to the large leaves and delicate hypocotyl. Similarly, water erosion is reduced by reducing the velocity of moving water on the soil surface, allowing for greater infiltration of water and less runoff (Overstreet, 2009).

Soil Moisture

- 50% ET: no differences between tillage
- 100% ET: CT drier than ST and DS from 12 to 18 inch depth
- 150% ET: CT drier at 6 and 18 inch depth

Sugar Beet Emergence

Crop emergence differed between 2013 and 2014. In 2013, sugar beet emergence in DS was lower than CT and ST by an average of 20% (Table 2). Conventional tillage and ST stand counts did not differ by the final of the counting date and averaged 158 plants per 100 ft of row compared with DS averaging 132 plants per 100 ft. One reason why the stand in the DS was lower in 2013 was because there was 7507 pounds per acre of crop residue on the soil surface. In contrast, there were no differences in 2014 sugar beet emergence between the tillage treatments with a lighter crop residue level, which averaged 5186 pounds per acre. By the final stand count date in 2014 all three tillage treatments averaged 123 plants per 100 ft (Table 2).

Table 2. Sugar beet stand counts in response to tillage treatment in 2013 and 2014. Emergence data are presented separately by year due to differences in accumulated GDD and number of counting dates between years. Treatment means followed by the same letter within a column are not significantly different at p = 0.05 based on least square means.

	Cumulative growing degree days†								
	2013					2014			
Tillage	435	575	750	895	1175	550	675	1110	1145
	----plants 100 ft^{-1} row----								
CT	157 a	179 a	180 a	174 a	151 a	126 a	142 a	159 a	128 a
DS	112 b	145 b	160 b	151 b	132 b	108 a	134 a	152 a	123 a
ST	157 a	183 a	185 a	189 c	164 a	118 a	134 a	149 a	118 a

†$GDD = \frac{(T_{max}+T_{min})}{2} - 34$

Effect on Weed Management

Establishing a weed-free stand early in the growing season is necessary to prevent substantial yield loss (Scott and Wilcockson, 1976). Sugar beet slow canopy closure and low plant height makes the crop particularly vulnerable to weed competition (Scott and Wilcockson, 1976). Weed management is a major production cost, due to the complexity required for adequate weed control (Kniss et al., 2004). Weeds interfere with crop growth and development due to competition for nutrients, water, and light (Schweizer and May, 1993).

Tillage can kill weeds or prevent germination by burying weed seed deep enough to prevent emergence of seedlings. In reduced tillage systems, weed management timing is critical in order to prevent weeds from interfering with crop growth and development. Cultural practices such as diverse crop rotation, field sanitation, and fertility and irrigation management are non-herbicide options for weed control in reduced tillage systems. Effective herbicide accompanying cultural practices can reduce weed densities.

Residue on the soil surface affect weeds by blocking sunlight, decreasing temperatures, and providing an environment for insects to eat weed seeds. In reduced tillage, weed species can shift. Without tillage to bury seeds deeper in the soil, weed seeds remain on the soil surface, under crop residue. The environment under crop residue favors small seeded weeds more than large seeded weed species. Generally, grass weeds are more abundant in reduced tillage; however, small seeded broadleaf weeds such as common lambsquarters and redroot pigweed can remain a problem. Such weeds can be controlled with herbicides like glyphosate since sugar beet is glyphosate-resistant.

With the immediate adoption of glyphosate-resistant sugar beet, the flexibility and effectiveness of glyphosate enabled the potential for reduced tillage. Herbicides are relied on more heavily to control weeds without tillage. Glyphosate controls larger weeds than the previous postemergence sugar beet herbicides, offering more flexibility in application timing (Kemp et al., 2009).Split or sequential applications of herbicide allow for control for early and late germinating weeds. Tank mixing herbicides with residual soil-activity can control later germinating summer annual weeds and reduce selection pressure for herbicide resistant weeds.

The weeds in this study were counted within the rows and between the rows to see how tillage might influence weed densities. The growth of all the weeds did not show a consistent difference in their response to the tillage, irrigation and N treatments. Common lambsquarters (*Chenopodium album* L.) was the most abundant broadleaf weed and green foxtail (*Setaria viridis* (L.) Beauv) was the most abundant grass weed for both years. Within-row, more common lambsquarters were counted in the CT and ST compared to DS after the 2-leaf sugar beet growth stage, which indicates that common lambsquarters emerges better in disturbed soil than in non-disturbed soil. In response to tillage, irrigation and N rate, there was no difference in common lambsquarters density between-rows at the 100% ET irrigation rate and 100% N rate between tillage treatments. Within-row, common lambsquarters density in the DS was lower than in the CT and ST, regardless of irrigation and N rate. This indicates that at optimum irrigation and N rate, the level of common lambsquarters control will be the same between CT, ST, and DS.

Similar to the common lambsquarters densities, green foxtail density did not clearly respond to increasing irrigation rates or N rates. Green foxtail density was generally the same, with a few exceptions, across the three tillage treatments. At the 100% ET irrigation rate and 100% N rate, there were no differences in green foxtail density among the three tillage treatments. Like common lambsquarters, the green foxtail response indicates that at optimum irrigation and N rate, the level of green foxtail control will be the same between CT, ST, and DS with the weed control regime that was studied.

In general, total weed populations were higher in disturbed soil than in undisturbed soil, which gives an advantage to managing weeds in untilled soil compared to tilled soil (Table 3). This was also observed with common lambsquarters, which may have influenced the total weed density results since it was one of the predominant weeds in the study. It is interesting that fewer total weeds are found at higher N rates than the lower N rates. Exactly why there were fewer total weeds in the higher N rate is not clear. As was observed with common lambsquarters and green foxtail, when there was an interaction between tillage and irrigation rate or N rate the total weed densities in DS and ST at the 100% ET irrigation and 100% N rate were equal to or lower than CT. Thus, from a weed management standpoint, controlling weeds in ST or DS does not appear to be any more challenging than it is in CT.

Table 3. Total weed density within-rows at three counting periods (2 leaf sugar beet, 6 leaf sugar beet, and 12 leaf sugar beet) pooled across years in response to tillage treatment[1], irrigation rate[2] and nitrogen (N) rate[3]. Means followed by the same letter within a column and treatment are not significantly different p = 0.05 using least squared means.

	2-leaf sugar beet		4-leaf sugar beet		4 weeks after last application	
Tillage	between-row	within-row	between-row	within-row	between-row	within-row
CT	26 a	24 a	5 a	5 a	7 a	5 a
DS	24 a	26 a	5 a	3 b	8 a	5 a
ST	17 b	22 a	4 b	4 a	5 b	4 a
Irrigation rate						
%ET						
50	21 a	24 ab	4 a	4 a	5 b	3 c
100	21 a	21 b	4 a	4 a	8 a	5 b
150	24 a	29 a	5 a	4 a	9 a	7 a
N rate						
%						
60	—	—	4 a	5 ab	8 a	6 a
80	—	—	5 a	5 a	8 a	5 a
100	—	—	4 a	4 bc	7 a	4 ab
120	—	—	3 b	3 c	5 b	4 b

[1]Tillage treatments were conventional tillage (CT), direct seed (DS) and strip tillage (ST).
[2]Irrigation rate was based on the amount of water needed to meet 50, 100, and 150% evapotranspiration (ET) based on the Penman-Monteith model for CT sugar beets.

[3]Nitrogen rate was relative and the 100% rate was based on the recommended rate to achieve a 35 ton per acre yield goal

Effect on Insect Management

Insects that overwinter in the soil or crop residue can interfere with crop growth and development. The cooler temperatures of reduced tillage may delay insect emergence relative to conventional tillage, but are more abundant because they were not disturbed or eliminated through tillage. Reduced tillage may increase beneficial insects such as ground beetles, rove beetles, and spiders.

Winged aphids prefer bare-ground rather than residue-covered ground, and this can limit infestations in reduced tillage. Wireworm numbers have increased in general in the past few years, with some research suggesting a link to reduced tillage (Gregory and Musick, 1976), but other research finding no relationship between wireworm infestation and tillage system (Belcher, 1989). Wireworms are most likely to increase and cause damage after grassy weed infestations, with reduced soil disturbance, and where cool soils delay germination.

Differences between conventional and reduced tillage may indirectly affect pestiferous arthropods. The effects of reduced tillage on soil temperature, moisture, and soil properties (Overstreet, 2009) can affect crop physiology (Stinner and House, 1990) and indirectly affect crop susceptibility to pests.

Tillage can kill soil and surface dwelling insects by exposure to the elements and disturbance of habitat (Gregory and Musick, 1976). By reducing tillage, there is a reduction in soil disturbance and favors a more stable environment for arthropods in soil and on standing residue (Stinner and House, 1990). Increased residue in reduced tillage systems may reduce feeding damage to sugar beet seedlings by providing an alternative food source (Heimbach and Garbe, 1996).

Insects

- Leafminers were affected by tillage treatment in 2013, but not in 2014.
    - Leafminer eggs and juveniles occurred most in CT treatments.
- Black bean aphid responded to N rates in 2014, but not in 2013.
    - At 80 and 100% N, black bean aphids were not as dense.
- Sugar beet root aphid was not affected by tillage or N rates in either year.

Effect on Disease Management

Reduced tillage has variable effects on disease pressure, which depend on the presence of the plant pathogen, environment, and host. Foliar disease pressure may increase whereas soilborne disease pressure may decrease due to increased activity of beneficial microorganisms in reduced tillage (Bockus and Shroyer, 1998). Pathogens that favor cool, wet soil may become problematic in reduced tillage compared with pathogens that thrive in warm, drier soils.

Crop rotation can limit a pathogen's ability to survive and increase in the soil. Diverse crop rotation is one strategy to reduce disease; however, weather can favor disease incidence. In such cases, appropriate cultural, chemical, and biological controls need to be taken.

Diseases

- No relationship between Aphonomyces or Rhizoctonia and tillage, irrigation rate, or N rate treatments in this study. However, the study site in both years did not have a history of either plant pathogen.

Irrigation Effects in Sugar Beets

Because of limiting water supplies for irrigation, sugar beets grown in the Magic Valley of southern Idaho can be subjected to periods of water stress. Sugar beets have some tolerance to mid and late-season plant water stress (Carter et al., 1980; Winter, 1980). Late season water stress reduces fresh root weight though sucrose concentration has been shown to increase (Carter et al. 1980). The deep taproot of sugar beet effectively extracts water from the soil profile at depths of 3 to 4 ft in soils with no restrictive horizons (Neibling and Gallian, 1997).

Jabro et al. (2014) observed ST system used 2.5 and 16 gallons less irrigation water than CT system to produce 2.2 lb of sugar beet root 2.2 lb of sucrose, respectively**.** Deibert and Giles (1979) observed a 4% greater estimated recoverable sucrose from ST relative to CT in a particularly dry year. Reduced tillage has shown an increase in water storage within the soil profile because of reduced evaporation losses (Aase and Pikul, 1995). “The inter-row area of ST is a reservoir for water, generally displaying greater plant-available moisture content than that of the stripped area (Gegner et al., 2008). Improved water infiltration and reduced evaporation in ST can be a major advantage in arid environments and on well-drained soils particularly sandy soils (Overstreet, 2009). Furthermore, no tillage improves crop water productivity and soil health across soils, cropping systems, and climates (Hobbs, 2007).

N Management Effects in Sugar Beets

Adequate fertilization is a concern in reduced tillage since fertilizers are often broadcast on to the soil surface and incorporated by irrigation or rainfall in order to become available to the sugar beet. Loss of N to volatilization when applied broadcast can result in losses of N, particularly with urea (Fenn and Hossner, 1985). In addition, if reduced till soils have cooler soil temperatures biological activity can be reduced resulting in reduced N mineralization from organic matter (Deibert and Giles, 1979). As mentioned previously however, the soil temperature in DS was equal to CT and ST in the study conducted at Kimberly.

There has been much research on N management in sugar beet; however, few studies have evaluated N needs under different tillage and irrigation amounts. Tarkalson et al. (2012) observed no differences in N response between CT and ST systems. Similarly, Khan and McVay, 2014 detected no tillage by N rate, suggesting fertilizer N recommendations require no adjustments for tillage. Irrigation method affects optimum N management since irrigation water has the potential to move N in the soil profile (Spalding et al., 2001). Nitrogen requirements were not affected by irrigation systems such as flood or sprinkler irrigation (Khan and McVay, 2014).

Effect of Yield

- Root yield. DS was 8% lower than CT and ST averaged over both years. No response to irrigation rate or N rate.
- Estimated Recoverable Sucrose (ERS). DS and ST were equal to CT averaged over both years. The 50% ET irrigation rate had lowest ERS apparently because it did not move the salts down the soil profile

- Sucrose content. Lowest at the 50% ET irrigation rate.
    - o Water stress may have reduced the ability for sugar beet to recover from midday wilting and reduced photosynthetic rates.
- Nitrate levels. Greatest in the 50% ET treatments, which contributed to lower ERS. Greatest at the 100 and 120% N rates.
- Conductivity. Greatest in the low irrigation rate of 50% ET.

Table 4. Sugar beet root and estimated recoverable sucrose yield and sugar quality in response to tillage treatment[1], irrigation rate[2] and nitrogen (N) rate[3] main effects pooled across years. Means followed by the same letter within a column and treatment are not significantly different p = 0.05 using least squared means.

Treatment	Root Yield	ERS+	Sucrose	Nitrates	Conductivity
Tillage	ton/A	lb/A	%	ppm	mmhos/cm
CT[1]	42 a*	9,734 a	13.25 a	354 a	0.8138 a
DS	38 b	9,121 a	13.50 a	320 a	0.7974 a
ST	41 a	9,432 a	13.15 a	337 a	0.8180 a
Irrigation rate					
%ET					
50	39 a	8405 b	12.49 a	440a	0.8682 a
100	41 a	9603 ab	13.25 ab	355b	0.8086 b
150	41 a	10279 a	14.16 b	244 c	0.7561 b
Nitrogen Rate					
%					
60	40 a	9421 ab	13.32 a	309 a	0.8151 a
80	41 a	9596 a	13.44 a	314 a	0.7894 a
100	40 a	9078 b	13.11 a	372 b	0.8265 a
120	41 a	9622 a	13.34 a	355 b	0.8080 a

[1]Tillage treatments were conventional tillage (CT), direct seed (DS) and strip tillage (ST).
[2]Irrigation rate was based on the amount of water needed to meet 50, 100, and 150% evapotranspiration (ET) based on the Penman-Monteith model for CT sugar beets.
[3]Nitrogen rate was relative and the 100% rate was based on the recommended rate to achieve a 35 tons per acre yield goal.

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