IMPACT OF CONSERVATION TILLAGE PRACTICES ON WEED MANAGEMENT, SOIL PROPERTIES, AND SWEET CORN AND DRY BEAN YIELD AND QUALITY

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ABSTRACT

Zone and deep zone tillage are both types of conservation tillage that have been studied in agronomic cropping systems. There has been little research on the use of these types of conservation tillage in vegetable production systems. The objectives of this research were to examine the effects of conservation tillage systems on crop yield and quality, weed management, and soil properties in a vegetable production system. If crop yield and quality is similar between conventional tillage (CT) and zone (ZT) or deep zone tillage (DZT), then there is an increased incentive for growers to adopt a system of tillage that saves time, fuel, and has the potential to improve soil quality.

Tillage and weed control plots were established in 2004 to evaluate the long term effects of conservation tillage on crop yield and quality, weed management, and soil properties in sweet corn and dry beans. The experiment made use of a randomized complete block split-split plot design and contained four replicates. The main plot was three tillage treatments CT, DZT and ZT which were assigned randomly. The first split was by weed control. Three methods of weed control were used conventional full width (CFH), banded plus cultivation (BH), and cultivation only (CUL). The second split was by cultivar, early and late cultivars of both crops were assigned to each tillage treatment.

Tillage affected soil penetration resistance in both crops in 2006 and in 2007. Between and in row penetration resistance in sweet corn in the ZT treatment was higher than in the CT treatment at all depths in 2007. Compared to the CT treatment penetration resistance between-row for dry beans was higher in the ZT treatment at the 12.5 to 20 cm depth in both years. While tillage affected soil nitrogen mineralization

in sweet corn and dry beans in 2006, the magnitude of the measured differences was small and would not likely have practical impact on crop yields.

Dry weed biomass in-row was not significant across tillage treatments in sweet corn in both years. Tillage had a significant effect on in row dry weed biomass in dry beans in 2006 but not in 2007. In- row dry weed biomass in dry beans was not affected by tillage in 2007. The use of full width herbicides (CFH) resulted in lower weed biomass in-row than the CUL treatments, in both years.

While other sweet corn yield and quality parameters were affected by tillage, marketable yield ($kg \cdot ha^{-1}$) of sweet corn was similar in the CT, DZT, ZT treatments in 2006 and in 2007. With the exception of plant number per hectare in 2006, tillage did not have an affect on dry bean yield and quality in 2006 or in 2007. These results indicate that deep zone and zone tillage may be a viable alternative to conventional tillage in the Northeastern United States.

BIOGRAPHICAL SKETCH

The author's interest in agriculture grew from being raised on a family farm and from a summer course in sustainable agriculture at Northland College in Ashland Wisconsin. His interest in weed management began at very early age and was due in part to the countless hours spent pulling weeds by hand in the family garden. Matt's experience in agriculture lead to the pursuit of a B.S. in horticulture at the University of Wisconsin River Falls, which he completed in 2006. Instead of a summer job, the author grew and sold produce to local restaurants to help fund his undergraduate education. Apart from vegetables and weeds some of the author's additional interests include cycling, photography, reading, baking bread, snowboarding and cross country skiing.

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The History of Tillage

Reasons for tillage are often as varied as the tillage practices themselves. Weed control, seed bed preparation, soil aeration, aesthetics, and burial of surface residues comprise a few of the numerous reasons given for tillage (Hobbs, 2007; Phillips, 1984). The development of plow-based tillage systems began in Northern Europe during the early middle ages (Mazoyer and Roudart, 2006). Plows replaced hand labor and an older piece of tillage equipment, the ard, for soil preparation. The advantage of early plows was that they buried surface residues and allowed for thorough incorporation of animal manure (Mazoyer and Roudart, 2006).

Despite their long history, plows were scarce in the early American colonies and tillage was often accomplished using manual labor. The plows that did exist were made of wood and metal and built by farmers or blacksmiths; the differences in plow design and construction produced inconsistent tillage results. These problems were observed by Thomas Jefferson who thought that plow performance could be standardized by using mathematics to design and metal to construct plows (Hurt, 1994).

The first plow made entirely of metal was a one piece cast iron plow patented by Charles Newbold in the late 1700’s. The major disadvantage of this plow was that since it was cast in a single piece, a broken part rendered it useless. Improvements on this design were made by other inventors such as David Peacock, who in the early 1800’s, patented a plow made of separate parts that could be individually replaced. Jethro Wood of Scipio, New York, also patented a plow with replaceable parts in

1814. As a result of successful marketing, Wood is usually credited with the invention of standardized replaceable parts for agricultural implements. Even with these improvements, early cast iron plows were almost useless on prairie soils, which stuck to the moldboard and thus increased the time required for plowing (Hurt, 1994).

An Illinois blacksmith named John Lane realized that a moldboard made of steel could be highly polished and would not clog. By attaching strips of steel to a wood moldboard and share, Lane created a plow superior to those previously used to till the prairie soil. This design was not patented and Lane did not produce a large number of his plows. Another blacksmith, John Deere, made use of Lane's ideas by incorporating steel parts into his plows and by the mid 1800's, Deere was constructing numerous steel plows (Hurt, 1994). The performance of these plows was limited in that they only turned the soil in one direction and often required two operators, these problems were solved by the Brabant plow which was developed in France. The Brabant plow was a reversible plow, the major component being two plows affixed to an axle that could be rotated allowing for soil to be thrown left or right. The design of this plow also allowed for one operator since it did not require direct operator control (Mazoyer and Roudart, 2006).

The scale of agricultural operations in the early twentieth century was limited by the amount of animal draft power available to the farmer. This began to change with the adoption of steam and gasoline powered tractors. The use of steam tractors was constrained by their high cost and limited maneuverability and they were eventually replaced by gasoline powered tractors. In comparison to draft animal power, the amount of area that could be tilled, planted, and harvested using tractor power was significantly higher. As a result of these factors, the amount of area in production expanded, and the improved production created a surplus of agricultural products, resulting in low prices while costs of farming increased. The plight of

American farmers was worsened by the stock market crash of 1929 and the economic depression that followed. These events, coupled with a drought in the Great Plains region of the U.S., resulted in dust storms, or wind erosion on a massive scale. An estimated 300 million tons of soil was lost in one storm alone, this and other storms lead to use of the term “Dust Bowl” in reference to the great plains (Hurt, 1994).

The ecological disaster of the Dust Bowl lead to a renewed interest in soil conservation practices, many of which were augmented by pesticides developed after World War II. No-till farming became increasingly prevalent in the early 1950’s as an alternative method to conventional crop production. Numerous advantages of no-till production, including increased erosion control, increased land use, reduced fuel use, and lower labor requirements, have been documented (Phillips, 1984).

Labor shortages and high crop prices during World War II facilitated the adoption of mechanical draft power by farmers. After the second world war the replacement of animal draft power by tractors continued, and by the mid 1950’s, more tractors were used for farm operations than horses (Hurt, 1994). The size, power, and weight of farm tractors also continued to increase from the 10 to 50 horsepower two-wheel drive tractors seen in the first half of the twentieth century (Mazoyer and Roudart, 2006) to the four-wheel drive tractors seen today which produce over 500 horsepower (AGCO, 2008; CNH, 2008; Deere & Company, 2008). The increased weight of agricultural equipment has resulted in higher levels of subsoil compaction, which can persist for over five years depending on the soil type (Lowery and Schuler, 1991). Soil compaction levels in vegetable production are further increased due to fixed production schedules which are not based upon soil conditions or moisture. As a consequence, field operations often take place before the soil has had sufficient time to dry after a rain event (Hamza and Anderson, 2005; Wolfe et al., 1995). Vegetable crops, such as dry beans and sweet corn, are susceptible to soil compaction and when grown in compacted soil, crop growth and yield reductions have been observed (Buttery et al., 1998; Wolfe et al., 1995).

Definition of Tillage Systems

One method to describe tillage systems is by the amount of residue left on the soil surface after tillage has been completed (Magdoff and van Es, 2000). The amount of surface residue left of the soil surface can be used to categorize methods of tillage along a continuum from the greatest amount of disturbance to the least. Tillage practices that create the most disturbance and leave most of the soil surface barren and exposed are defined as conventional tillage. No tillage, a system where little or no soil disturbance occurs prior to planting (SSSA, 2008), can be placed furthest from conventional tillage on the continuum. In between these two extremes is conservation tillage, a method of soil preparation that leaves some residue present on the soil surface and disturbs the least amount of soil (SSSA, 2008).

Conventional tillage is defined by the Soil Science Society of America (2008) as forms of primary and secondary tillage typically performed in a given geographic area that leave less than 30% of previous plant biomass on the soil surface. Tillage operations, or passes, that function to loosen the soil, incorporate or mix surface residue, and decrease soil strength are classified as primary tillage. Moldboard plows, disk harrows, and chisel plows are some examples of primary tillage implements. Finishing disks, spring or spike tooth harrows, rollers, rotary hoes, and powered rotary tillers are examples of equipment used for secondary tillage. Secondary tillage further pulverizes, levels, and firms the soil to create a seedbed for the crop (ASABE, 2006a; Magdoff and van Es, 2000).

For a practice to be considered conservation tillage, a minimum of 30% crop residue must be present on the soil surface. Reduced tillage is another term that has been used as a synonym (Roberts et al., 1999) or considered to be a variation of conservation tillage (Rapp et al., 2004). Reduced tillage is defined as "a tillage system in which the total number of tillage operations preparatory for seed planting is reduced from that normally used on that particular field or soil (SSSA, 2008)." Many methods of conservation tillage fit into this definition, given that they typically require fewer tillage events prior to sowing.

Within conservation tillage systems, the amount and method of soil disturbance varies. Some conservation tillage systems, called strip tillage, use rotary tillers (Hoyt, 1999; Licht and Al-Kaisi, 2005; McKeown et al., 1988) to pulverize the soil and prepare a seedbed. Zone tillage, also a form of conservation tillage, uses a series of disks or coulters to chop residue and loosen the soil. A zone tillage system may also be modified by using subsoiler shanks to fracture the soil profile. The depth of tillage may vary, but on the surface only a small portion of the soil is left barren and exposed (Hendrix et al., 2004; Mochizuki et al., 2007; Swanton et al., 2004; Thomas et al., 2001; Vetsch et al., 2007; Wilhoit et al., 1990).

No-till systems are sometimes classified as a form of conservation tillage (Jasa et al., 2000b; Licht and Al-Kaisi, 2005; Mochizuki et al., 2007; Roberts et al., 1999). This system of conservation tillage warrants further explanation since it is quite different than the methods of conservation tillage explained previously. The term "no-till" is somewhat misleading since it implies that no soil disturbance occurs. Some disruption of the soil is required to plant the crop, but the amount of disturbance is minimal compared to conventional tillage. The disturbance is caused by a coulter preceding the planter and is typically confined to a very narrow area near the seed. The coulter serves to chop residues and loosen the soil (ASABE, 2006a; Magdoff and van Es, 2000; SSSA, 2008).

The use of no-till systems in agronomic crops, such as field corn (*Zea mays* L.), soybean (*Glycine max* (L.) Merr.) grain sorghum (*Sorghum bicolor* (L.) Moench), and wheat (*Triticum aestivum* L.) is well represented in the literature (Lafond et al., 2006; Licht and Al-Kaisi, 2005; Niehues et al., 2004; Vetsch and Randall, 2002; Vetsch et al., 2007; Webber et al., 1987; Wortmann et al., 2006). In some situations no-till systems have proved a viable alternative to conventional tillage. Soils in no-till systems are less susceptible to erosion, temperature extremes, and water loss. No-till systems typically require less labor and fuel inputs (Jasa et al., 2000a; Magdoff and van Es, 2000) and have been used for vegetable production and been successful in some southern regions (Mascianica et al., 1986; Morse, 1999; Sandoval-Avila et al., 1994). The success of a no-till system is dependent on factors such as soil type and climate (Jasa et al., 2000a; Magdoff and van Es, 2000). Soils in no-till systems are often cooler and retain more soil moisture (Cox et al., 1990; Hendrix et al., 2004; Vetsch and Randall, 2002; Webber et al., 1987). These characteristics can slow the early season establishment of vegetable crops in northern areas.

Another problem associated with no-till production is increased soil compaction (Cox et al., 1990; Hill, 1990). High levels of soil compaction have negative physiological effects, such as poor root growth and decreased yield (Lowery and Schuler, 1991; Wolfe et al., 1995). Under field conditions, high compaction levels can decrease nutrient availability or uptake and increase risk to pest damage (Wolfe et al., 1995). As a consequence of poor root growth, water use efficiency also decreases (Amato and Ritchie, 2002), causing the effects of soil compaction to become most apparent during soil moisture extremes such as drought (Buttery et al., 1998).

The use of zone and strip tillage has the potential to alleviate some of the negative effects associated with no till systems while maintaining some of the benefits

(Hendrix et al., 2004; Janovicek et al., 2006; Licht and Al-Kaisi, 2005). In some cases, strip and zone tillage are classified as modified no till practices (Vetsch and Randall, 2002) and may also be known as row or band tillage (Morrison, 2002). These methods of tillage typically disturb a narrow band of soil in preparation for planting, leaving a percentage of the surface biomass in place. Zone and strip tillage create an area of soil that warms and dries more quickly than the surrounding area, providing better conditions for plant growth than a no-till system (Hendrix et al., 2004).

Zone and strip tillage should not be confused with ridge tillage, another form of reduced tillage that maintains a high level of surface residue while minimizing the amount of soil disturbance. In this type of tillage system, crops are planted into ridges that were formed by cultivation of the previous year's crop. Planting causes the ridges to break down. As a result, post planting cultivation is required to reconstruct the ridges (ASABE, 2006b; Jasa et al., 2000a).

Definitions of zone and strip tillage can vary, and at times, the terms are used interchangeably. References to strip and zone tillage in the literature can be confusing if the strict definition of these tillage practices is followed. For example the term zone tillage is sometimes used to describe a method of tillage that fits the definition of strip tillage presented by others (Lonsbary et al., 2004; Swanton et al., 2004; Thomas et al., 2001).

Zone and strip tillage can be segregated based on the method and depth of disturbance. The shallowest disturbance is found in zone till systems which use a series of fluted coulters to disrupt the soil (Magdoff and van Es, 2000; Randall and Hill, 2000). These coulters may be positioned a toolbar as part of a planter (Magdoff and van Es, 2000) or used as an independent implement (Swanton et al., 2004). The coulters disturb an area of soil approximately 10-20 cm deep and 15 cm wide

(Magdoff and van Es, 2000; Randall and Hill, 2000). The coulters can be positioned in an offset manner to create a grinding action of disturbed soil while they cut through any existing crop residue.

Depth of disturbance under strip tillage systems is slightly greater than zone tillage (Randall and Hill, 2000) and may employ a rotary tiller (Hoyt, 1999; Loy et al., 1987; Petersen et al., 1986) or a shank (Licht and Al-Kaisi, 2005; Luna and Staben, 2002) to prepare the soil. Methods of strip tillage that use rotary tillers for seedbed preparation have been defined as rotary strip tillage (Throckmorton, 1986) and will be referred to as such in this review. The term strip tillage will be used in reference to the systems that use a shank or ripper to disturb the soil profile.

Strip tillage has been defined as a type of tillage that disturbs the soil in an area that is approximately 10-30 cm deep and 15 cm wide (Randall and Hill, 2000). Configuration of strip tillage equipment can vary, but most strip tillage implements consist of the following components: a coulter which serves to cut through crop residue, a shank, and a pair of coulters positioned after the shank which act to break up soil clods and can be angled to form the soil into a mound. Rolling baskets often follow the pair of coulters to break up clods and further smooth the seedbed.

Deep zone tillage systems make use of a shank for soil disturbance, however the depth of disturbance is greater than that of strip or zone tillage. This method of soil preparation disturbs the soil in a band that is approximately 15 to 30 cm but the depth of disturbance is greater than 30 cm. The components of the tillage equipment used are similar to those described above for strip tillage. This type of tillage has also been described as zone tillage (Janovicek et al., 2006; Vetsch et al., 2007) or *Rawson* tillage (Vetsch and Randall, 2002).

Yields in Rotary Strip Tillage Systems

Crop yields in rotary strip tillage systems vary depending on the crop. Yield of snap beans (*Phaseolus vulgaris* L.) grown in a rotary strip tillage system were comparable to those of conventional tillage (Hoyt, 1999). The snap beans developed more quickly in the conventional tillage treatment and had more mature beans at the first harvest. After 15 days, however, the yield between the two tillage systems was similar (Hoyt, 1999).

Sweet corn (*Zea mays*) yield in a rotary strip tillage system was greater than that of conventional tillage (Luna and Staben, 2002). Tillage did not significantly impact crop quality or grade. Rotary strip tillage decreased tillage costs in comparison to conventional tillage, while maintaining the benefits of conservation tillage. This more recent work contrasts with an earlier study which found lower sweet corn yields under rotary strip tillage in comparison to conventional tillage in one of two years (Petersen et al., 1986).

Tomatoes (*Lycopersicon esculentum* L.) grown under rotary strip tillage yielded similar to those of conventional tillage in two of three years (McKeown et al., 1988). Yield differences in one year were attributed to poor transplant vigor and low-temperature injury. The tilled areas were approximately 60 cm wide and 15 cm deep, Hoyt (1999) reported greater yields of tomatoes grown using rotary strip tillage in comparison to conventional tillage. In this case, the strip tilled area was 20-30 cm wide and 30 cm deep, twice the depth of the McKeown study et al. (1988).

Yields of winter squash (*Cucurbita maxima* Duchesne) grown in rotary tilled strips approximately 20-30 cm wide and 30 cm deep were similar to those of conventional tillage (Hoyt, 1999). In the northeastern United States pumpkin (*Cucurbita pepo* L.) yields in conventional and rotary strip tillage systems were not significantly different (Rapp et al., 2004).

Yields in Strip (shank) and Deep Zone Tillage Systems

Cabbage yields were similar between strip and conventional tillage in one of two years (Wilhoit et al., 1990). During both years, areas 15-20 cm and 20-25 cm wide were strip tilled into a rye cover crop that had been either removed (leaving stubble) or left in place. In the first year of the experiment which had extreme drought conditions, water conservation by the mulch resulted in a significant increase in yield over the non-mulched plots. These differences indicated that "strip tillage appears to offer greater yield stability than either conventional or no-tillage" (Wilhoit et al., 1990).

Cabbage yields in strip and deep zone tillage are similar to conventional tillage in some instances. The success of these two systems may be dependent on depth of tillage and volume of disturbance (Mochizuki et al., 2007). Cabbage was grown in plots tilled 15 or 30 cm wide and 10 or 30 cm deep. Yields of reduced tillage were equal to those of conventional tillage when the volume of the tilled area reached 450 cm^3 per plant. Increasing the depth of tillage had a greater impact on yield than increasing the width of the disturbed area. Tilling the soil at a depth of 30 cm served to alleviate compaction, which was considered primary cause for decreased yield (Mochizuki et al., 2007).

Strip tillage can also serve as an acceptable option to conventional and other reduced tillage practices for cucumber (*Cucumis sativus* L.) production. (Lonsbary et al., 2004) evaluated the effects of strip tillage, no-till and disked tillage on yield of processing cucumbers. The strip tilled areas were 15 cm deep and 23 cm wide. Yields were similar among the treatments (Lonsbary et al., 2004).

Small seeded crops such as carrots (*Daucus carota* L. var. *sativus*) and onions (*Allium cepa* L.) have performed well when grown in muck soils using zone and strip tillage (Swanton et al., 2004). The onions were grown in soil prepared using zone tillage, which consisted of soil disturbance by two wavy coulters per row that were spaced 5 cm apart and set to run at a depth of 5 to 10 cm. Onions grown using zone tillage yielded more than those in conventional systems. The conventional tillage system did produce higher yields of large onions while the zone tillage increased the yield of medium sized onions. This difference in size categories was not considered problematic since onion prices in the region, Ontario Canada, were not subject to variation based on size. Carrots grown in the same region using strip tillage produced yields comparable to conventional tillage. Soil preparation was conventionally tilled or strip tilled approximately 25 cm deep. The soil was then left flat or formed into raised beds which are typically used in carrot production (Swanton et al., 2004).

Yield of tomatoes grown in strip or disk tilled systems were similar to conventional tillage (Thomas et al., 2001). The no till system, however, showed a decline in yield that may have been a result of delayed crop maturity.

Farm trials located in western Oregon have indicated sweet corn yields do not differ significantly between conventional and deep zone tillage treatments. The method of deep zone tillage used did not produce a satisfactory seedbed in some cases, and in the second year of the experiment an additional tillage pass was required on some of the fields. The most apparent effect of a second tillage operation was an increased cost of production per hectare for deep zone tillage (Luna and Staben, 2002).

Strip and deep zone tillage are a viable option to conventional and no tillage for agronomic crops. Field corn (*Zea mays*) yields were higher under strip tillage and deep zone tillage when compared to no-till (Vetsch et al., 2007). In a two year study by Licht and Al-Kaisi (2005), yields of field corn grown under strip tillage were similar to conventional and no tillage during the first year of the experiment, but in the second year, strip and conventional tillage yields were significantly higher than no-till yields (Licht and Al-Kaisi, 2005). Use of deep zone tillage and strip tillage resulted in field corn yields that were equivalent or slightly less than those of conventional tillage

(Vetsch and Randall, 2002). In southern Illinois, yields of corn grown in a strip tillage system were higher in one year but lower in the second year compared with conventional tillage (Hendrix et al., 2004). The authors concluded that optimal soil temperature and crop germination were necessary for competitive corn growth and yield in a strip tillage system. Strip tillage has been used in the cultivation of other crops such as sugar beet (*Beta vulgaris* L.) (Morris et al., 2007) and cotton (*Gossypium hirsutum* L.) (Schomberg et al., 2006).

The success of conservation tillage systems is dependent on a variety of factors such as climate, soil type, prior soil compaction, cropping history, and surface residue (Coolman and Hoyt, 1993; Lopez-Fando et al., 2007; Luna and Staben, 2002). It is possible that yields may be more dependent on the cultivar rather than the method of tillage (Sandoval-Avila et al., 1994). In many cases, the yields of reduced tillage systems are compared to those of a conventional cropping system where high short term yield and profit often take precedence. Other factors such as ecosystem health and lasting soil preservation in conventional and conservation tillage systems are difficult to measure in monetary terms. If factors such as these are taken into account they may substantially influence the sustainability associated with different tillage systems (Roberts et al., 1999).

Weed Management in Conservation Tillage Systems

Weeds are seen by growers as the largest obstacle to the adoption of conservation tillage (Hall et al., 2000). Tillage is one management strategy that can impact the diversity of weed species present. The type of tillage practiced can affect crop and weed development (Hendrix et al., 2004; Teasdale et al., 1991). Intensive tillage can be an effective weed management tool but may contribute to a decline in soil quality (Gallandt, 2006; Hobbs, 2007; Magdoff and van Es, 2000; Rutledge, 1999). Germination of weed seeds can be promoted or diminished by tillage events (Burnside et al., 1996; Mohler, 1991). For example, shallow tillage promoted the emergence of four broadleaf species, reduced the germination of a grass, and did not affect the emergence of three other broadleaf species (Ogg and Dawson, 1984).

When compared to other forms of tillage (disk, rotary tiller and chisel plow) moldboard plowing had a greater tendency to bring weed seeds to the soil surface as well as to bury weed seeds present on the soil surface. For this reason, moldboard plowing could serve as a useful method for the control of weed species with a short survival time in the soil (Mohler et al., 2006). There is a tendency for a shift to biennial and perennial weed species under reduced tillage systems (Swanton et al., 1993). The shifts in weed populations under reduced tillage populations are a form of natural succession (Murphy et al., 2006; Swanton et al., 1993). Species diversity can also be influenced by tillage, no-till tends to promote the highest species diversity and moldboard plow the lowest. The weed species diversity seen in the chisel plow treatments was intermediate to that of conventional and no-tillage. (Murphy et al., 2006).

Annual weed species present may vary depending on the type of tillage used. A 1990 Buhler and Oplinger study which monitored the presence of different weed species in conventional, chisel plow, and no tillage systems found that the density of common lambsquarters (*Chenopodium album*) was not drastically altered by tillage system. Velvet leaf (*Abutilon theophrasti* Medicus) densities were higher in the conventional tillage system, this difference was attributed to seed burial by this form of tillage. For dormancy of velvet leaf seeds to be overcome, the hard impermeable seed coat must be broken. This requirement is most likely met if the seeds are buried instead of being left on the soil surface. Densities of giant foxtail (*Setaria faberi* Herrm.) were higher in the no till system, which might have provided appropriate conditions for seed germination (Buhler and Oplinger, 1990). Other weed species such as common lambsquarters and *Amaranthus* species that have hard seed coats and populations tend to increase in the weed seed bank. The importance of these two species in the seedbank may not be greatly affected by management systems (Swanton et al., 2006).

Cover Crops in Conservation Tillage Systems

Cover crops can be incorporated into weed management systems in several ways. Actively growing cover crops compete with weeds for space and other critical resources such as light, water, and nutrients (Gallandt, 2006). The use of cover crops in combination with different methods of tillage can “influence weed population levels, the rate of population growth, and species composition” (Teasdale et al., 1991). Cover crops such as winter rye (*Secale cereale* L.), winter wheat (*Triticum aestivum*), and barley (*Hordeum vulgare* L.) produce allelopathic chemicals that can serve as an effective method of weed control (Barnes and Putnam, 1983; Liebman and Dyck, 1993).

Cover crops can be killed mechanically or chemically prior to planting of agronomic or horticultural crops. The effect of cover crops on weed pressure can vary and cover crops may be used alone or with herbicides. In the absence of herbicides weed densities were lower in no till sweet corn planted into a vetch (*Vicia villosa* Roth) or a rye-vetch mixture than in bare soil (Carrera et al., 2004). Use of an oat cover crop in no-till and rotary strip tillage cucumber systems allowed for a 50% reduction in herbicide use while maintaining weed control similar to a full rate of herbicide (Wang and Ngouajio, 2008). In pumpkins the best weed control was achieved through the use of herbicides and a rye cover crop (Rapp et al., 2004). Rye and crimson clover (*Trifolium incarnatum* L.) cover crops did not eliminate the need for herbicides in no-till and conventional till soybean production systems, acceptable weed control was achieved when pre or post emergent herbicides were used (Reddy et al., 2003).

Cover crops have the added benefit of decreasing wind and water erosion when planted post harvest (Hall et al., 2000). Soil temperature and moisture loss are typically lower when cover crops are used (Morse, 1993; Rapp et al., 2004; Wilhoit et al., 1990), these factors may decrease, slow, or promote weed germination and growth. The increased moisture conservation by cover crop residues may inhibit weed germination in saturated soils or promote germination in drier conditions (Teasdale and Mohler, 1993). There are several disadvantages associated with planting cover crops, especially those with allelopathic effects such as winter rye. The allelopathic effect of the cover crop may suppress the growth of the cash crop (Bond, 2002; Roberts et al., 1999). Planting and management of a cover crop can be time consuming and costly (Morse, 1999). Cover crop residue can also contribute to lower soil temperatures which in turn may result in yield reduction (Hoyt and Walgenbach, 1995; Mwaja et al., 1996; Walters et al., 2007).

Soil Compaction and Temperature

Soil compaction is defined as “a process of densification in which porosity and permeability are reduced, strength is increased and many changes are induced in the soil fabric and in various behavior characteristics (Soane and van Ouwerkerk, 1994).” Soil compaction is a problem on agricultural land throughout the world due to increased mechanization and machinery weight (Gregory et al., 2007; Lowery and Schuler, 1991). Compaction of soil by wheel traffic from farm operations such as tillage, pesticide and fertilizer application, and harvest is caused by a reduction in porosity in the area below the wheel (Hamza and Anderson, 2005). Use of low tire pressure, dual wheels, or tracks on equipment can reduce the amount of compaction caused (Larson et al., 1994; Sidhu and Duiker, 2006).

Water content of the soil can influence its weight bearing capacity, wetter soils generally tend to be more susceptible to compaction. The amount soil compaction caused by a specific piece of equipment on a field is related to its weight and the soil moisture. As soil moisture increases the weight bearing capacity of the soil is diminished under high moisture levels, effects of traffic are more severe. This holds true until the optimum moisture content of the soil is reached, at this point compaction is reduced due to higher soil plasticity and incompressibility (Hamza and Anderson, 2005).

Soil type and crop growth can help alleviate soil compaction. For example, results in a 2007 study by Gregory et al. indicated that resilience of a soil may be affected by soil type and crop presence. The differences in resilience across the soil types was attributed in part to the higher pore water in the clay soil which created improved the resilient qualities of the clay soil. The primary difference in soil resiliency was credited to the variation in root growth caused by moisture availability in the different soil types. Both the sandy loam and sandy clay loam soils did not supply adequate moisture, thus limiting root growth. The clay soil had a higher moisture content and allowed for more root growth which served to fracture the soil and alleviate compaction (Gregory et al., 2007).

The amount of organic matter present in a soil can affect its susceptibility to compaction, soils with lower levels of organic matter tend to be more susceptible to compaction (Larson et al., 1994). Levels of organic matter are influenced by environmental factors which include, precipitation, temperature, drainage, vegetation, and soil pH. A variety of anthropogenic factors also such as, loss of topsoil due to erosion, tillage, and type of cropping system also contribute to loss of organic matter.

An excellent of example of how tillage causes a loss of organic matter is given by Magdoff and van Es (2000) who compare the loss of organic matter to opening the damper on a wood stove. By increasing the amount of oxygen available the fire burns hotter and consumes more fuel. Tillage acts in a similar manner; it increases the amount of oxygen in the soil which escalates the breakdown of organic matter by microorganisms. Organic matter levels tend to decrease in annual cropping systems that rely of conventional tillage. Practices such as cover cropping, crop rotation, and organic amendments can be used to increase the amount of organic matter in a soil (Larson et al., 1994; Magdoff and van Es, 2000).

Mechanical methods such as deep tillage or subsoiling can also be used to alleviate soil compaction (Mochizuki et al., 2007). The time required between deep tillage events can be influenced by traffic patterns. If traffic patterns are reduced or controlled the benefits of subsoiling may last for several years, or as little as 1-2 years if traffic is not managed (Larson et al., 1994; Sidhu and Duiker, 2006).

Diseases and Insects

Lack of aggressive tillage, surface residues, cooler soil temperatures, and higher levels of soil moisture can increase the risk of certain diseases in conservation tillage systems (Bockus and Shroyer, 1998). Higher rates of *Alternaria brassicae* (Berk.) infection were observed in cabbage grown using strip tillage (Hoyt and Walgenbach, 1995). Tillage practices such as moldboard plowing decrease the persistence of plant pathogens through burial. An example of this is seen in a study which evaluated the effects of moldboard plowing on the survival and diversity of *Fusarium* species. In comparison to chisel plowing and rotary tillage moldboard plowing decreased the population and number of pathogenic *Fusarium* species present in the soil (Steinkellner and Langer, 2004).

The use of reduced tillage practices can also result in decreased disease pressure. A decline in white mold was seen in dry beans grown in strip and no tillage systems that had winter rye mulch. Lower rates of white mold (*Sclerotina sclerotiorum* (Lib.) deBary) were ascribed to the presence of the rye mulch which limited the spread of the pathogen by soil splashing (Bottenberg et al., 1999). Decreased intensity of tillage can also contribute to the demise of pathogens such as *Pseudocercosporella herpotrichoides* (Fron) Deighton, which causes eye spot in winter wheat (Anken et al., 2004; Bockus and Shroyer, 1998).

Levels of insect pests in conservation tillage systems tend to be lower or equivalent to populations in conventional tillage systems. Lepidopterous pest damage in cabbage did not differ between conventional and strip tillage (Hoyt and Walgenbach, 1995).

No change in insect pest population across twenty paired tillage treatments was reported by Luna and Staben in a 2002 study, with one exception. In one year of the study crop damage occurred at two of the experiment sites as result of an increase in the garden symphylan (*Scutigerella immaculata* Newport) population. Potato leaf hopper (*Empoasca fabae* Harris) populations in strip tilled snapbeans were not significantly different from those found in conventional tillage (Bottenberg et al., 1999).

Chapter 2

Impact of conservation tillage practices on weed management, soil properties, and sweet corn and dry bean yield and quality

Zone and deep zone tillage are both types of conservation tillage that have been studied in agronomic cropping systems. There has been little research on the use of these types of conservation tillage in vegetable production systems. The objectives of this research were to examine the effects of conservation tillage systems on crop yield and quality, weed management, and soil properties in a vegetable production system. If crop yield and quality is similar between conventional tillage (CT) and zone (ZT) or deep zone tillage (DZT), then there is an increased incentive for growers to adopt a system of tillage that saves time, fuel and has the potential to improve soil quality. Conservation tillage presents a set of weed management challenges different from conventional tillage practices. Of the three methods of weed management, it was expected that the conventional full width herbicide and the banded application would likely present the best weed control. Mechanical cultivation was used as the third type of weed control. Greater weed biomass was expected in the cultivation only treatments since it is difficult to target weeds in the crop row.

Formation of a hard pan or plow pan is one of the disadvantages associated with conventional tillage. The two types of tillage, zone and deep zone, disturb the soil profile by fracturing rather than inverting it. Decreasing the amount of soil compaction has advantages such as improved drainage and root growth.

If conservation tillage systems do not compromise yield or present undue weed management challenges while maintaining soil quality, zone and deep zone tillage could provide an alternative to conventional tillage in vegetable production systems.

The goal of this experiment was to test three main hypotheses in relation to tillage. First, yields of conservation tillage systems will be similar to those of conventional systems. Second weed pressure in conservation and conventional tillage systems will be similar. Lastly compaction levels of conservation tillage treatments will be less than conventional tillage treatments.

Materials and methods

Experimental design

To evaluate the long term effects of conservation tillage on crop growth, weed management and soil quality, tillage and weed control treatments were established in 2004 at the Homer C. Thompson Vegetable Research Farm in Freeville, N.Y. (42°31'16.12"N, 76°19'47.58"W). The soil types present at the experimental site were a Howard gravelly loam (Loamy-skeletal, mixed, active, mesic Glossoboric Hapludalfs, 1.25% organic matter [OM], pH 5.8) and a Phelps gravelly silt loam (Fine-loamy over sandy or sandy-skeletal, mixed, active, mesic Glossoboric Hapludalfs, 1.25 % OM, pH 7.2). The experiment contained four replicates and made use of a randomized complete block split-split plot design. Blocking was based upon the two soil types. The first treatment split plot was by tillage. Three forms of tillage were tested and included conventional, deep zone, and zone, which were assigned randomly to sections approximately 48.8 m in length and 7.6 or 6.1 m wide. A description of the three types of tillage used is given on pages 20 and 21. The second split plot was by cultivar. Each tillage plot contained eight or ten crop rows spaced 76 cm apart. Plots containing eight rows were divided into four rows of each cultivar. To minimize edge effects ten row plots were divided into six rows of one cultivar and four of the other.

Three methods of weed control were then imposed at random on each tillage section. The three weed control treatments included broadcast herbicide application, banded herbicide application plus cultivation, and cultivation only. A detailed description of the weed control methods is provided below. The weed control strategies divided the tillage treatments into three subplots (weed control plots).

Tillage

Deep zone tillage. A two row Zone Builder (Model 130, Unverferth Manufacturing Co. Inc, Kalida, OH) was used to prepare the deep zone tillage treatments for both crops. Each gang consisted of the following components, one ripple coulter, a straight shank with a 4.45 cm point, two fluted coulters (13 wave), and a rolling basket. The two shanks were spaced approximately 76 cm apart and set to run at a depth of approximately 35 cm. The width of the tilled area was approximately 15-20 cm. The timing of deep zone tillage is listed in Table 1.

Table 1. Tillage treatments used for seedbed preparation prior to dry bean and sweet corn planting in 2006 and 2007 at Freeville, NY.

Tillage	2006	2007
Deep zone tillage	31 May	30 May
Zone tillage		
Subsoil	31 May	1 June
Coulters	31 May	8 June
Conventional tillage		
Plow	17 May	25 May
Disk	31 May	31 May

Zone tillage. Preparation of the zone tillage treatments consisted of two operations, vertical tillage with a subsoiling implement (Monroe Tufline, Columbus, MS) with a 6 cm point set to run at approximately 10-15 cm deep. Vertical tillage was followed by a single pass over the tilled area with an implement that consisted of two gangs with three eight wave coulters (Rawson Coulters Inc., Farwell, MI) mounted on a tool bar. This implement was constructed on site and is referred to as the “Rawson coulter set-up.” The second tillage pass with the Rawson coulter set-up created a seed bed approximately 15-20 cm wide.

In 2007 soil in zone tillage plots was disturbed to a depth of approximately 11-13 cm with the same Tufline subsoiling implement used in 2006. After vertical tillage a second tillage pass was performed with the Rawson coulter set-up. The configuration of the Rawson coulter set-up was modified in 2007 by adding cultipacker wheels to each gang. The timing of vertical tillage and the second tillage pass with the Rawson coulter set-up is listed in Table 1.

Conventional tillage. Conventional tillage treatments were tilled using a two way plow (Model 975, John Deere, Moline, IL) followed by disking to prepare the seed bed. The timing of conventional tillage practices is listed in Table 1.

Soil measurements

Compaction. Soil compaction was measured at 2.5 cm intervals to a depth of 30 cm using a Rimik CP20 recording cone-tip penetrometer (Agridry, Toowoomba, Australia). Two in-row and two between-row readings were taken from each tillage treatment and averaged. Readings were sorted into three categories based on depth, 0-10 cm, 12.5-20 cm, and 22.5- 30 cm. Readings were taken at sweet corn and dry bean harvest in 2006. In 2007 penetrometer readings were taken at or before sweet corn and dry bean planting. Penetrometer data at harvest in 2007 were not recorded due to equipment malfunction. Soil water content at planting ranged from 0.10 to 0.24 kg water per 1 kg dry soil^{-1}.

Temperature. Soil temperature in all tillage treatments was recorded hourly using WatchDog 100 series button loggers (Spectrum Technologies, Plainfield, IL).

To avoid damage from cultivation and other field operations, data loggers were placed in the crop rows. Data loggers were installed in dry bean plots 5 DAP in 2006 and 14 DAP in 2007 and in sweet corn plots 7 DAP in 2006 and 9 DAP in 2007.

Cultural practices

Planting and fertility. Two dry bean cultivars ‘California Early Light Red Kidney’ and ‘RedKanner,’ both classified as light red kidney beans were sown on a 76 cm between-row spacing and a 5 cm in-row spacing, using a two row disk planter (John Deere, Moline, IL). Dry bean seed was treated with Dry bean seed was treated with the fungicide fludioxonilmefenoxam, to prevent damping off and chlorpyrifos to protect from seed corn maggot (*Delia platura* Meigen). The dry beans were planted on 14 June 2006 with 24 kg N, 71 kg P_20_5, and 47 kg $K_20{\cdot}ha^{-1}$. Disulfoton was also applied (2.19 kg $ai{\cdot}ha^{-1}$) at planting in 2006 for leaf hopper control. Dry beans were planted on 12 June 2007 with 27 kg N, 82 kg P_20_5, and 55 kg $K_20{\cdot}ha^{-1}$.

The two sweet corn cultivars, ‘Precious Gem’ and ‘Temptation,’ were sown using a two row vacuum planter (Monosem Inc., Lenexa, KS) at a 76 cm between-row spacing and 23 cm in-row spacing. In 2006, sweet corn was planted on 12 June with fertilizer banded at a rate of 45 kg $N{\cdot}ha^{-1}$, 22 kg $P_20_5{\cdot}ha^{-1}$, 22 kg $K_20{\cdot}ha^{-1}$. Sweet corn was planted on 18 June in 2007 with a banded fertilizer rate of 90 kg $N{\cdot}ha^{-1}$, 45 kg $P_20_5{\cdot}ha^{-1}$, 45 kg $K_20{\cdot}ha^{-1}$. Additional fertilizer was side dressed in the sweet corn 33 DAP in 2006 (67 kg $N{\cdot}ha^{-1}$) and 37 DAP in 2007 (95 kg $N{\cdot}ha^{-1}$).

Weed control. The three weed management strategies for each crop were broadcast herbicide application, banded herbicide application plus cultivation, and cultivation only. Broadcast herbicide application was achieved with an Allis Chalmers G tractor modified to accommodate a belly mounted spray boom. Herbicides in the banded treatments were applied using a backpack sprayer in 2006.

In 2007, banded herbicides were applied using an Allis Chalmers G with a modified belly mounted boom that applied herbicide in four 25 cm wide bands approximately 76 cm apart.

All herbicides were applied based on the Integrated Crop and Pest Management Guidelines for Commercial Vegetable Production (Reiners and Petzoldt, 2008). Tables 2 and 3 list herbicides used, kilograms of active ingredient applied per hectare, and time of application in dry bean and sweet corn plots respectively.

Table 2. Herbicides used and time of application in dry beans during the 2006 and 2007 seasons at Freeville, NY.

		2006		2007	
Method of application	Herbicide	kg ai·ha^{-1}	DAP^{z}	kg ai·ha^{-1}	DAP
Broadcast	metolachlor	1.1	2	1.1	2
	bentazon	0.28	16	1.1	20
	fomesafen	0.34	16	0.14	20
Banded	metolachlor			1.1	3
	bentazon	0.28	16	1.1	21
	fomesafen	0.35	16	0.28	21

^{z}Days after planting.

Table 3. Herbicides used and time of application in sweet corn during the 2006 and 2007 seasons at Freeville, NY.

		2006		2007	
Method of application	Herbicide	kg ai·ha^{-1}	DAP^{z}	kg ai·ha^{-1}	DAP
Broadcast	metolachlor	0.72	1	1.1	7
	atrazine	0.91	1	1.0	7
	bentazon	0.28	18	1.1	14
Banded	metolachlor	0.72	1	1.1	7
	atrazine	0.91	1	1.0	7
	bentazon		18	1.1	15

^{z}Days after planting.

The timing of mechanical weed control practices for dry beans and sweet corn is listed in Table 4. Different cultivation implements were used for mechanical weed control in 2006 and 2007. With the exception of the second dry bean cultivation in 2007 both cultivation implements were mounted on the three point hitch of a tractor (Model 5220, John Deere, Moline, IL). A Taylor-Way (Pittsburgh Forgings Company, Athens, TN) cultivator was used for mechanical weed control of dry bean and sweet corn plots in 2006. This implement had three gangs and cultivated two crop rows in a single pass. The outside two gangs consisted of: a 36 cm disk hiller, a 50 cm tracking disk, a 50 cm disk hiller, and a 25 cm half sweep. The middle gang consisted of: two 36 cm disk hillers, a 50 cm tracking disk, and a 50 cm sweep. Weed control with this cultivator was not satisfactory due to the large sweep size and for this reason a different cultivator was used in 2007. The cultivator used in 2007 had three gangs and cultivated two crop rows in a single pass. The outside two gangs contained a 30 cm disk hiller, and two 19 cm sweeps. The middle gang contained two 30 cm disk hillers and three 19 cm sweeps. This cultivator was used for both sweet corn cultivations and one dry bean cultivation in 2007. The second dry bean cultivation was delayed because of high soil moisture levels. Weed control was still deemed necessary and a smaller tractor (Saukville Tractor Corp., Saukville, WI) with a belly mounted implement was used for the second cultivation.

Table 4. Implement used and time of application for mechanical weed control in dry beans and sweet corn in 2006 and 2007 at Freeville, NY.

	DAP[z]			
	Dry beans		Sweet corn	
Implement	2006	2007	2006	2007
Taylor-Way	7, 23		9, 25	
Allis Chalmers		17		11, 21
Saukville		29		

[z]Days after planting.

Insects and plant pathogens. Scouting indicated that potato leaf hopper (*Empoasca fabae*) populations were high enough in the dry beans to require control in 2006 and 2007. Levels of common bacterial blight (*Xanthomonas campestris pv. phaseoli*) in the dry beans were sufficient to require control in 2007. Control measures for insects and plant pathogens were segregated by crop but applied regardless of tillage treatment and weed control (Table 5). Insect and plant disease levels in the sweet corn were not high enough to warrant control in both years of the experiment.

Table 5. Disease and insect pest control in dry beans for the 2006 and 2007 seasons at Freeville, NY.

			DAP[z]	
Target organism	Pesticide	kg ai·ha^{-1}	2006	2007
Potato leaf hopper	acephate	1.1	36	
(*E. fabae*)	esfenvalerate	0.04		16
	bifenthrin	0.11		28
Common bacterial blight (*X. campestris pv. phaseoli*)	copper hydroxide	1.3		57

[z]Days after planting.

Cover crops. The cover crop seeded the previous fall was killed by applying glyphosate to the entire field. To minimize the effects of herbicide application on the cultivation-only weed control plots, plots were flail mowed prior to herbicide application. The remaining plots were flail mowed after the herbicide had killed the rye cover crop.

After harvest, plots were flail mowed and then planted to a winter rye cover crop using a no-till drill (Great Plains Mfg, Inc., Salina, KS). Due to high weed pressure in 2007, glyphosate (1.2 kg ai·ha^{-1}) was applied to all plots prior to seeding the winter rye cover crop.

Plant measurements

Midseason biomass. Crop plants harvested for biomass samples were taken from sections of row that had a similar plant population to the data area and where effects of the sampling would not influence the areas for yield measurements. Plants in approximately 90 cm of dry bean row and 150 cm of sweet corn row were first counted then cut at the soil line. After cutting they were weighed and then placed in a greenhouse for initial drying. Drying was finished in a drying oven set at approximately 71º C. Dry weights of the biomass samples were taken when sample material had reached a constant weight in the drying oven. Crop biomass samples were taken from dry bean plots 27 DAP in 2006 and 38 DAP in 2007 and from sweet corn plots 29 DAP in 2006 and 28 DAP in 2007.

Sweet corn harvest. The primary ears from 4.6 m of two data rows of each sweet corn cultivar were harvested by hand from all plots. Plant population within the data section was recorded. The harvested ears were then counted, weighed and graded based on size. Ears that measured less than 17.8 cm were classified as culls and weighed separately. The cull weight was then subtracted from the overall weight to obtain the marketable yield of the area harvested. Ten marketable ears were weighed, husked, and weighed again. The amount of kernel development in relation to the length of the ear (tip-fill) was used to measure maturity. Tip-fill measurements of five husked ears were taken by recording the total length of the ear followed length of the ear occupied by fully developed kernels.

Final Sweet corn biomass. Biomass samples of sweet corn cultivars grown in the weed management plots were taken after harvest in 2006 and at harvest in 2007. Five corn plants similar to those within, but outside, the marked data rows were selected for sampling. These samples were taken by cutting the corn plants at the soil level and separating the primary ears and ear leaves from the corn plant. Fresh and dry biomass (g) was recorded for the corn plant, primary ears, and ear leaves.

Dry bean harvest. Two 3.1 m areas from data rows were harvested when approximately 90% of the pods had dried. Bean plants were pulled by hand and placed into burlap sacks for further drying in a greenhouse. The number of plants in the harvested area was also recorded at this time. Beans were then threshed at approximately 12% moisture. After threshing, weight of 100 seeds (seed size) and percent moisture was recorded.

Weed biomass

Sampling procedure 2006. Aboveground weed biomass samples were taken after harvest of both crops, 106 DAP in sweet corn and 114 DAP in dry beans. Samples were taken by randomly placing a meter stick in or between the crop rows and then harvesting at soil level the weeds in band approximately 7.6 cm wide on each side of the meter stick. Two in and two between row samples were taken and the total area sampled was 0.56 m^2 per cultivar. The weed biomass samples were first dried in a greenhouse and final drying completed in an oven set at 71°C.

Sampling procedure 2007. A visual survey to identify the most prevalent weed species (Table 6) was conducted approximately five days prior to biomass sampling. The size of the field and availability of labor limited the number of samples that could be identified. Weed biomass sampling was carried out in late August when the majority of weed species present were at or near reproductive maturity. Two in and two between row samples per cultivar were taken in the weed control plots using 66 x 76 cm (0.5 m^2) quadrat. Weed biomass samples were placed in a greenhouse to dry and drying completed in an oven set at 71°C.

Table 6. Most abundant weed species in dry beans and sweet corn at Freeville NY, 2007.

Genus	Species
Amaranthus	*powellii* S. Wats.
	retroflexus L.
Chenopodium	*album* L.
Panicum	*capillare* L.
	dichotomiflorum Michx.
Digitaria	*ischaemum* Schred. *ex* Muhl.
	sanguinalis (L.) Scop.

Statistical Analysis

Data were analyzed using the Proc mixed procedure in SAS version 9.1 (SAS Institute, 2003). Comparisons of two means were conducted using the Student's *t* test. The Tukey-Kramer test was used to control for error across multiple comparisons.

Results and discussion

Soil measurements

Soil penetration resistance. Plant growth can be limited when penetration resistance measurements exceed 3.0 MPa in sandy (Laboski et al., 1998), sandy loam, and sandy clay loam soils (Gregory et al., 2007). In this study, several penetration resistance readings were higher than the 3.0 MPa threshold (Fig. 1-4). The 3.0 MPa threshold is included as a point of reference in Figures 1-4. Some of these high readings may be a result of the soil type and stones at the study site. In other cases, however, the results reflect the management systems that have been in place for several years. Overall, ZT had higher penetrometer resistance than CT at the shallow soil depths of 2.5 to 10 cm, for both crops, both years and for both between and in-row locations (Figure 1-4). The effect of the DZT treatment varied based upon crop and year.

Soil penetration resistance in sweet corn. Tillage affected the between and in-row soil penetration resistance in 2006 and 2007. Soil penetration resistance between-row at the 22.5 to 30 cm depth in the DZT treatment was lower than the CT treatment in 2006 (P<0.10; Fig. 1A), but not in 2007. Between-row soil penetration resistance in the ZT treatment was higher than in the CT treatment from 2.5 to 30 cm in 2007 (P<0.05; Fig. 1B). These differences in penetration resistance between-row may reflect the previous year's management. Each year, the DZT and ZT strips were formed between the previous year's strips (offset by 38 cm).

In-row soil penetration resistance in the ZT treatment was higher than the CT treatment at the 2.5 to 10 cm soil depth for both years (P<0.05; Fig. 2). In 2007, the ZT treatment had higher in-row penetration resistance than the CT and DZT treatments at 12.5 to 20 cm and 22.5 to 30 cm depths (P<0.05; Fig. 2B). The DZT treatment had lower in-row soil penetration resistance that the CT treatment, in the

12.5 to 20 cm depth in both years (*P*<0.05; Fig. 2). At the 22.5 to 30 cm depth, in-row soil penetration resistance in the DZT treatment was lower than the CT treatment in 2007 (*P*<0.05; Fig. 2B).

Soil penetration resistance in dry beans. Tillage had an effect on soil penetration resistance in and between row in 2006 and in 2007. The DZT and ZT treatments had a higher level of between row soil penetration resistance in the 2.5 to 10 cm range than the CT treatment in 2007 (*P*<0.05; Fig. 3B). Deeper in the soil, at the 12.5 to 20 cm depth, penetration resistance between-rows in the ZT treatment was higher than in the CT treatment in both years (*P*<0.05; Fig. 3B). Both DZT and ZT treatments had higher levels of between-row soil penetration resistance than the CT treatment at the 22.5 to 30 cm depth in 2007 (*P*<0.05; Fig. 3B).

In-row soil penetration resistance in the ZT treatment was higher than the CT treatment in 2006 at the 2.5 to 10 cm depth and the 12.5 to 20 cm (*P*<0.05; Fig. 4A). In row soil penetration resistance at the 12.5 to 20 cm depth in the DZT treatment was lower than in the CT treatment in 2006 (*P*<0.05; Fig. 4A).

Soil temperature. Soil temperature in sweet corn and dry beans was not affected by tillage in both 2006 and 2007 (Figs. 5 and 6).

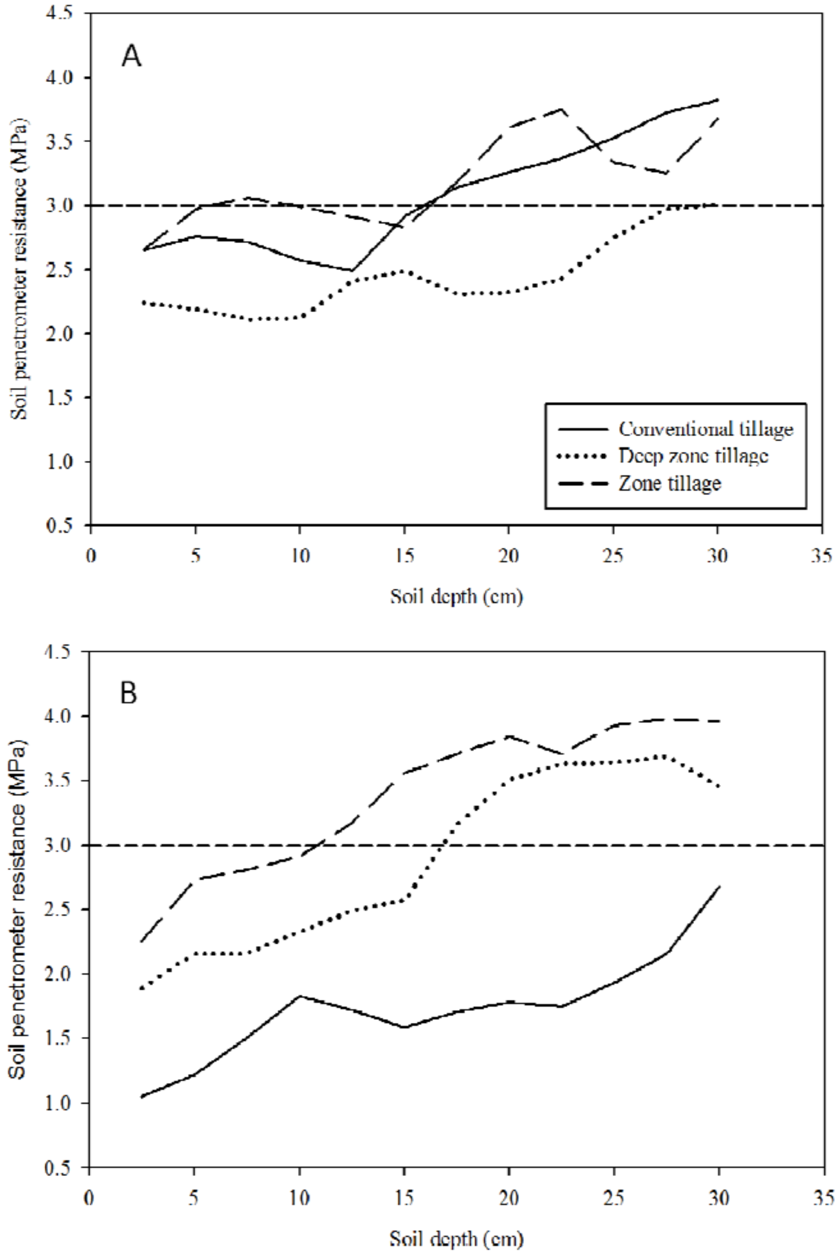


Figure 1. Effect of tillage on soil penetrometer resistance (MPa) between rows of sweet corn in 2006 (A) and in 2007 (B). The dashed line at 3.0 MPa indicates the level of soil compaction where plant growth may be limited.

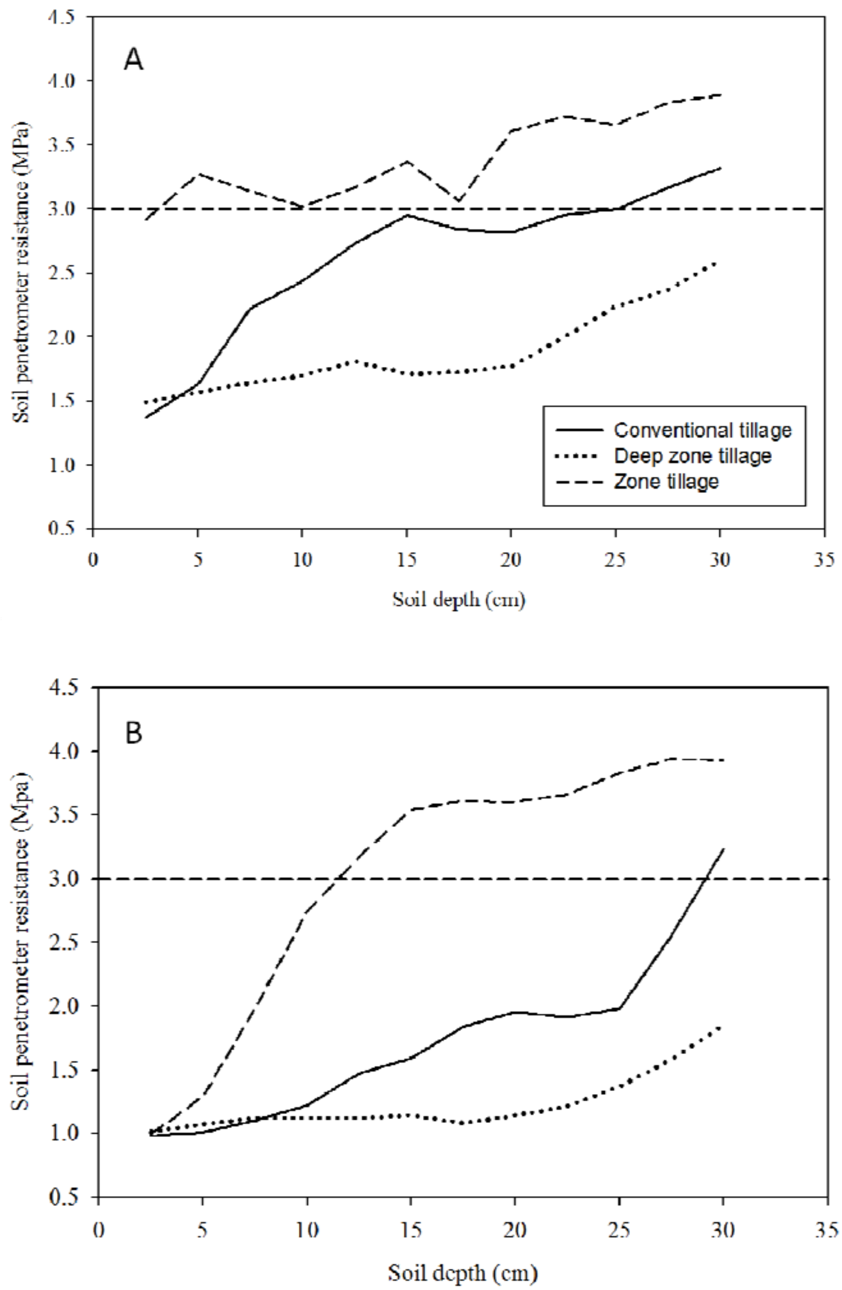


Figure 2. Effect of tillage on in-row soil penetrometer resistance (MPa) in sweet corn, 2006 (A) and in 2007 (B). The dashed line at 3.0 MPa indicates the level of soil compaction where plant growth may be limited.

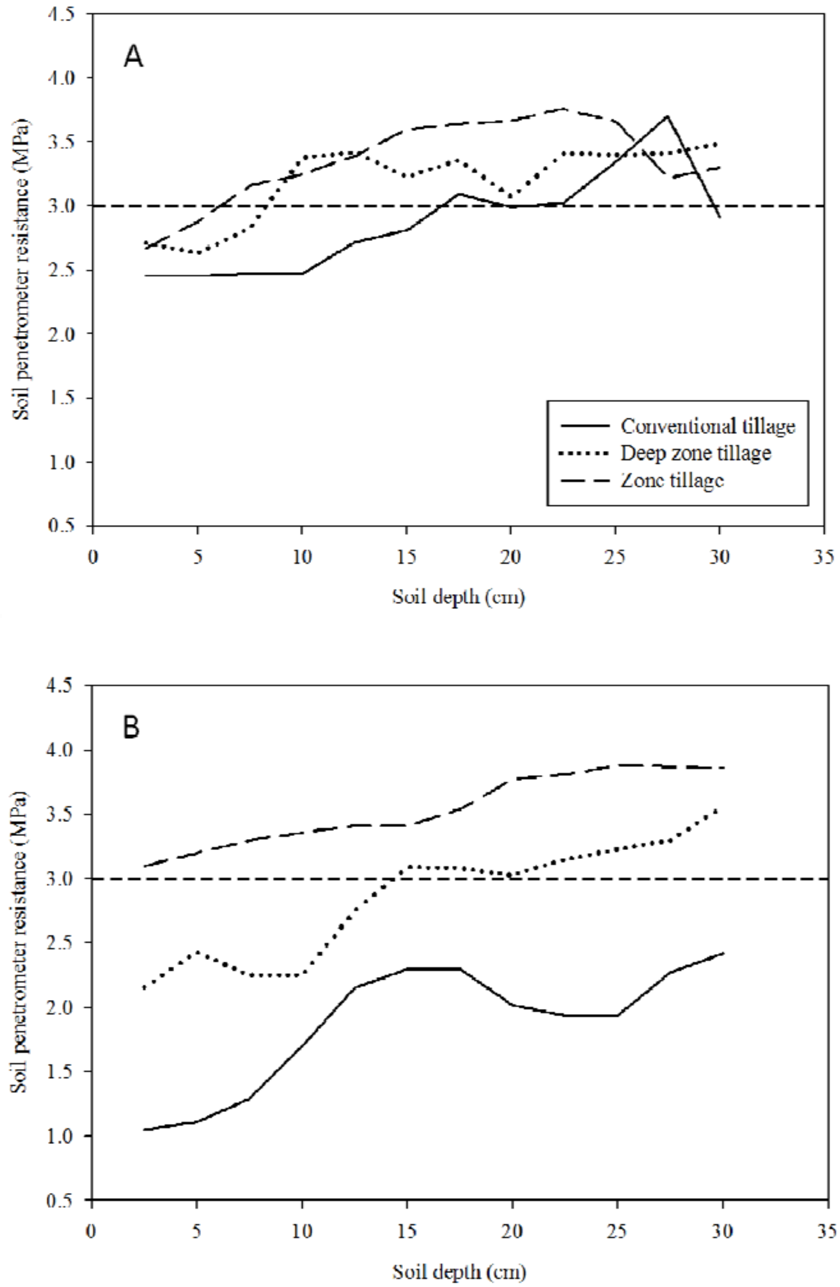


Figure 3. Effect of tillage on soil penetrometer resistance in dry beans between row in 2006 (A) and in 2007 (B). The dashed line at 3.0 MPa indicates the level of soil compaction where plant growth may be limited.

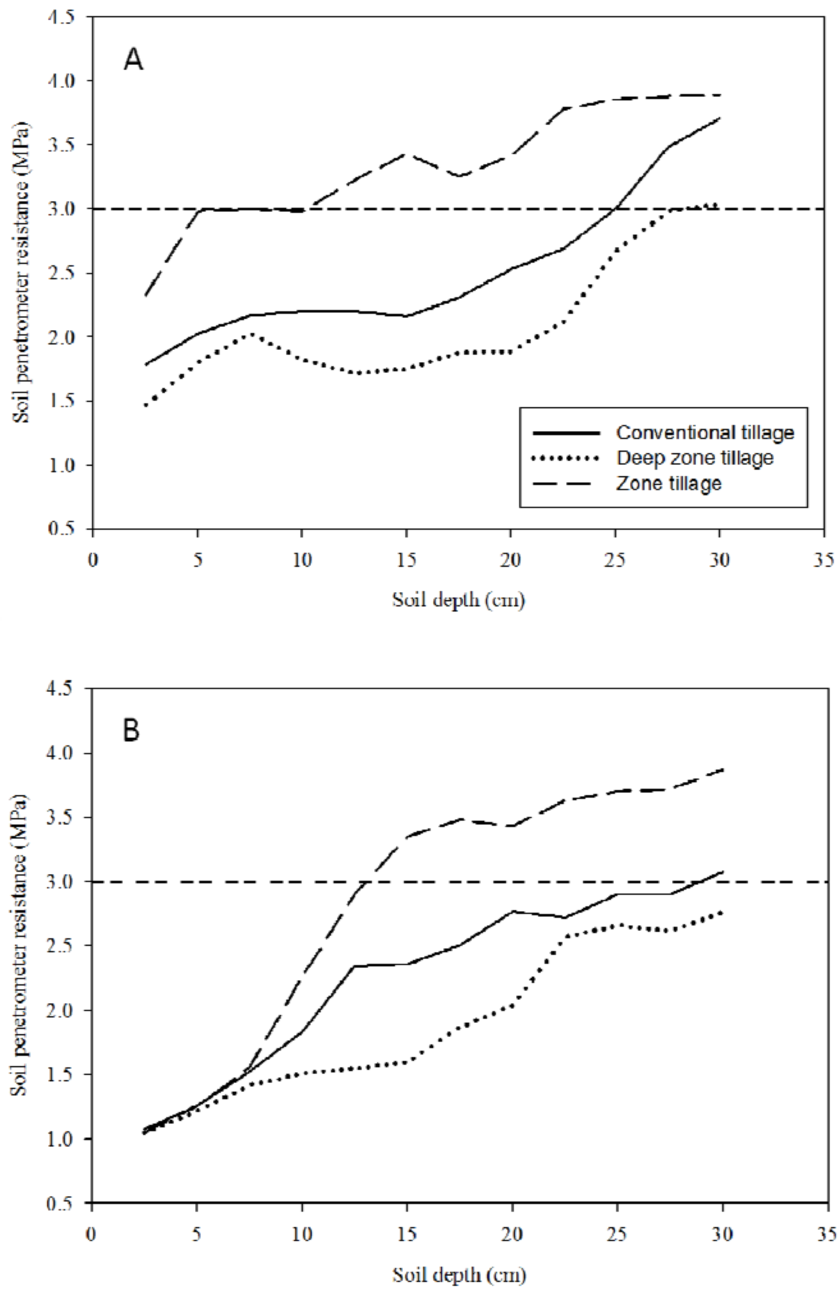


Figure 4. Effect of tillage on soil penetrometer resistance in dry beans in row in 2006 (A) and in 2007 (B). The dashed line at 3.0 MPa indicates the level of soil compaction where plant growth may be limited.

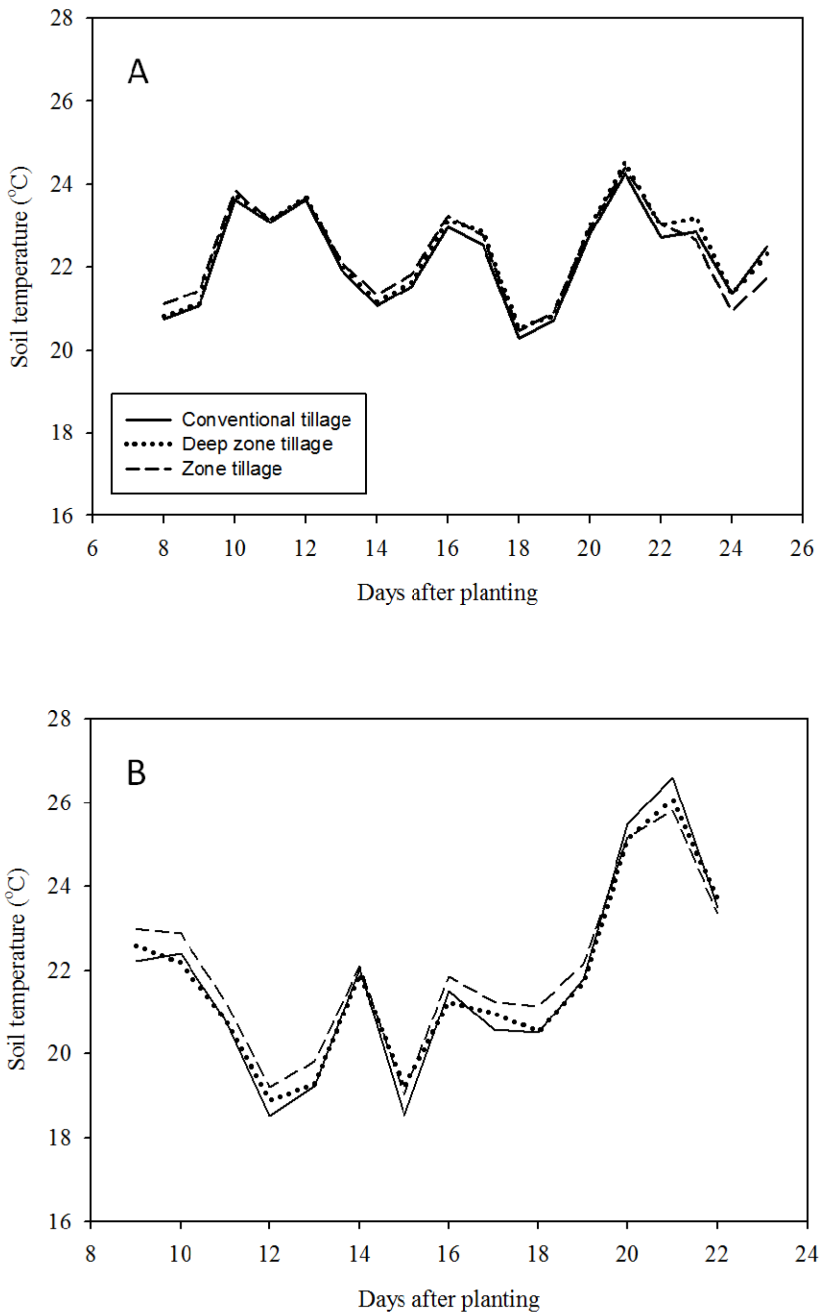


Figure 5. Effect of tillage on mean daily soil temperature in sweet corn 8 to 25 d after planting (DAP) in 2006 (A) and 9 to 22 DAP in 2007 (B).

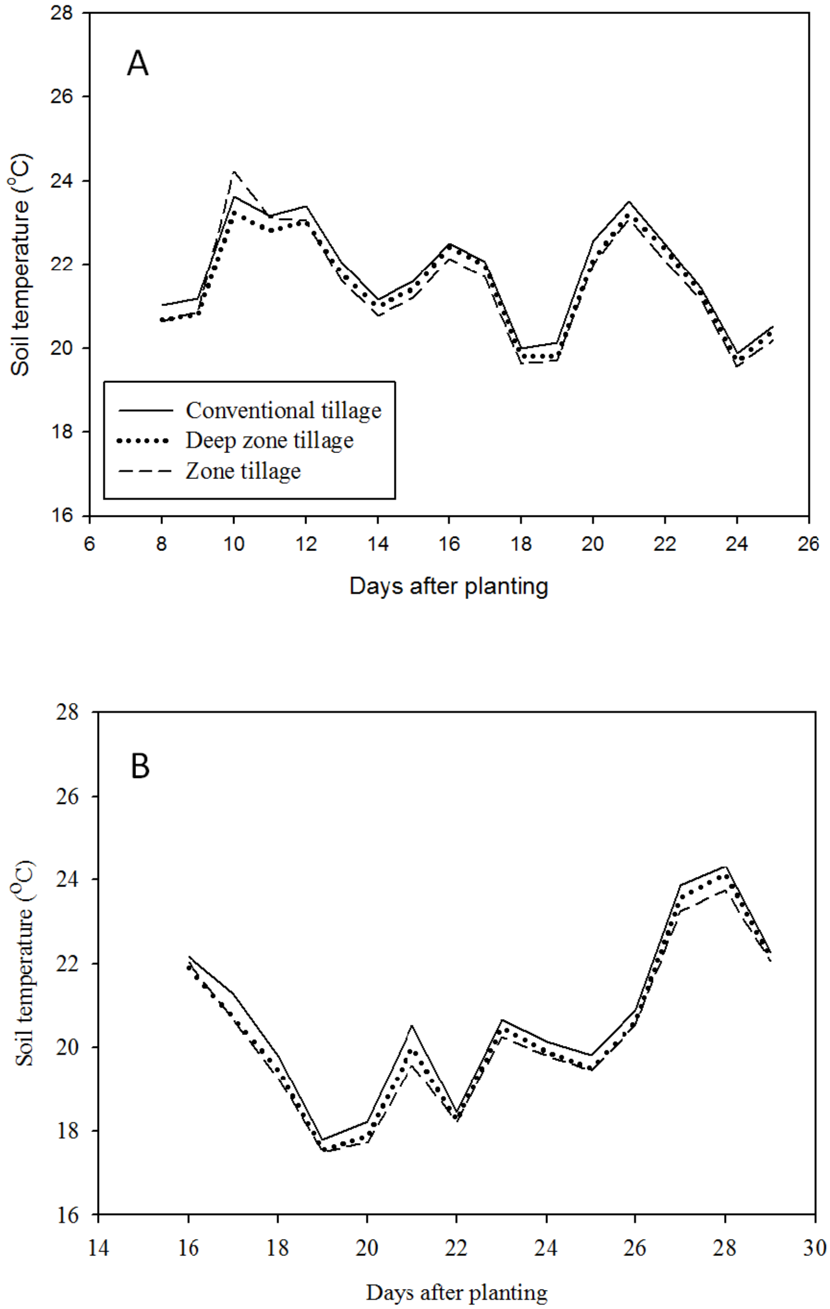


Figure 6. Effect of tillage on mean daily soil temperature in dry beans 8 to 25 d after planting (DAP) in 2006 (A) and 16 to 29 DAP in 2007 (B).

Soil nitrogen in sweet corn. Tillage had an effect on soil nitrogen mineralization potential (N min) at midseason and at harvest in 2006 (P <0.10 and <0.05 respectively; Table 7). Soil N mineralization potential was higher in the ZT treatment at midseason and at harvest (P<0.10 and P<0.05 respectively; Table 7). The samples taken both indicate that N min was significantly higher in the ZT treatment, however it is impossible to determine a trend based on the data from one growing season. While significant, the magnitude of these differences was small and not likely to have a practical impact. There was a significant T x WM interaction for soluble N in sweet corn at midseason in 2007 (P <0.10; Table 8). Soluble N in the CT treatments varied widely between the CFH and CUL sub plots (Fig. 7). There was very little difference in soluble N levels between the CFH and CUL weed control sub plots in the DZT treatment (Fig 7). In the ZT treatment soluble N levels in the CFH sub plots were higher than in the CUL plots, this difference was not as extreme as in the CT treatment (Fig 7). The slight differences in soluble N in the CFH and CUL weed control sub plots located in the DZT and ZT treatments makes it difficult to attribute the variation in the CT treatment to weed management strategy.

Table 7. Effect of tillage and weed management on soil nitrogen in sweet corn midseason and post harvest in 2006[z] at Freeville, NY.

	Soil NO_3-N + NH_4-N ($mg \cdot kg^{-1}$)[y]		Soil N mineralization potential ($mg \cdot kg \cdot wk^{-1}$)	
Parameter	midseason	post harvest	midseason	post harvest
Tillage (T)				
Conventional (CT)	16.2	3.9	2.1 b[x]	3.0 b
Deep zone (DZT)	19.5	4.7	3.6 ab	2.9 b
Zone (ZT)	35.8	5.1	5.5 a	4.6 a
	NS	NS	*	**
Weed management (WM)				
Conventional full width (CFH)	20.0	4.4	5.2	3.7
Banded + cultivation (BH)	23.5	4.2	3.7	3.1
Cultivation (CUL)	27.9	5.0	2.3	3.6
	NS	NS	NS	NS
T x WM	NS	NS	NS	NS

[z]Midseason soil samples were taken on 17 July 2006 (35 days after planting [DAP]), post harvest samples on 9 Oct. 2006 (119 DAP).
[y]Data log transformed, non-transformed least squared means presented.
[x]Same letter within columns indicates no significant difference.
*,**Significant at *P* <0.10 and <0.05 respectively.

Table 8. Effect of tillage and weed management on soil nitrogen in sweet corn midseason in 2007[z] at Freeville, NY.

	Soil NO_3-N + NH4-N ($mg \cdot kg^{-1}$)[y]
Parameter	midseason
Tillage (T)	
Conventional (CT)	90.0 ab[x]
Deep zone (DZT)	37.4 b
Zone (ZT)	134.8 a
	**
Weed management (WM)	
Conventional full width (CFH)	112.6 a
Cultivation (CUL)	62.2 b
	*
T x WM	*

[z]Midseason soil samples were taken on 11 July 2007 (23 days after planting).
[y]Data log transformed, non-transformed least squared means presented.
[x]Same letter within columns indicates no significant difference.
*,**Significant at *P* <0.10 and <0.05 respectively.

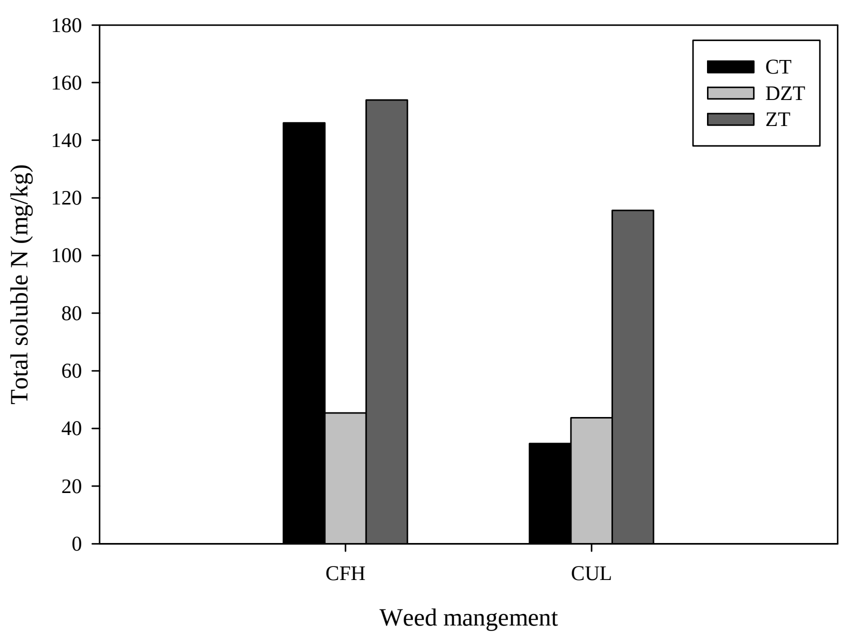


Figure 7. Tillage x weed management interaction for soil NO_3-N +NH_4-N ($mg \cdot kg^{-1}$) in sweet corn midseason in 2007 at Freeville, NY.

Soil nitrogen in dry beans. There was a significant T x WM interaction for soluble N post harvest in 2006 (P<0.10; Table 9). Differences in soluble N while significant were small and given the size of this experiment not applicable from a practical standpoint. N min was higher in the ZT treatment midseason and post harvest (P<0.05; Table 9). These differences were slight but highly significant, however it is difficult to determine a trend based on two samples taken during the 2006 growing season.

Table 9. Effect of tillage and weed management on soil nitrogen in dry beans midseason and post harvest in 2006[z] at Freeville, NY.

	Soil NO_3-N + NH_4-N ($mg \cdot kg^{-1}$)		Soil N mineralization potential ($mg \cdot kg \cdot wk^{-1}$)	
Parameter	midseason	post harvest	midseason	post harvest
Tillage (T)				
Conventional (CT)	8.7	4.7 b[y]	2.0 c	2.6 b
Deep zone (DZT)	11.5	5.8 ab	3.7 b	4.0 ab
Zone (ZT)	10.4	7.0 a	6.0 a	6.4 a
	NS	*	**	**
Weed management (WM)				
Conventional full width (CFH)	10.2	5.9	3.7 ab	4.4
Banded + cultivation (BH)	11.1	6.1	4.5 a	4.4
Cultivation (CUL)	9.4	5.4	3.4 b	4.3
	NS	NS	*	NS
T x WM	NS	**	NS	NS

[z]Midseason soil samples were taken on 17 July 2006 (33 days after planting [DAP]), post harvest samples on 9 Oct. 2006 (117 DAP).
[y]Same letter within columns indicates no significant difference.
*,**Significant at P <0.10 and <0.05 respectively.

Dry weed biomass

Sweet corn. The sweet corn cultivars ‘Temptation’ (T) and ‘Precious Gem’ (PG) were selected because of their different maturity dates. ‘Temptation’ is a 72 d sweet corn (Seminis Seeds, 2008), while ‘PG’ has a later (80 d) maturity date (Harris Seeds, 2008). In general, later sweet corn varieties have a larger plant architecture and slower growth.

In both years the cv. x T x WM terms were significant for dry weed biomass between rows (P<0.05; Table 10), but no discernable relationship was observed. Efforts were made to harvest a representative sample from each weed control subplot by using a randomized sampling pattern. Yet, in some plots, one or two large weeds could have resulted in high weed biomass values compared with the plot average, and contributed to the cv. x T x WM interaction. In row dry weed biomass for the CUL treatments was higher than in the CFH treatments in both years (P<0.05; Table 10). The in row BH treatment was similar to the CFH in 2006, but had significantly higher weed biomass in 2007 (P<0.05; Table 10). In 2007, the method of herbicide application in the BH treatment may have affected the in row weed population. The sweet corn was planted using a two-row planter but the boom sprayer that banded herbicide was for four rows. Although attempts were made to center the sprayer on the data rows, poor alignment may have contributed to the high level of in row weeds in 2007. Cultivar did not have an effect on in-row dry weed biomass in 2006 or in 2007 (Table 10).

Dry beans. The dry bean cultivars ‘California Early Light Red Kidney’ (CELRK) and ‘RedKanner’ (RK) were selected for their different maturity dates and growth habits. ‘California Early Light Red Kidney’ is an early (88 d) cultivar and has an upright growth habit, ‘RK’ is a 105 d dry bean cultivar that develops a larger canopy. The difference in maturity dates, early season growth, and canopy architecture affects the competitive ability and yield of ‘RK’ and ‘CELRK.’

There was a significant cv. x T x WM interaction between row in 2006 (*P*<0.10; Table 11). Examination of the individual means suggested that the two cultivars varied in their response to the systems. The different growth habits of the two dry bean cultivars may have contributed to lower weed biomass in the ‘RK’ than in the ‘CELRK’ plots (*P*<0.05; Table 11). In 2007 the WC x T interaction between row was significant (*P*<0.10; Table 11). Since this experiment has been conducted since 2004, a poor weed control strategy in one year could contribute to long term changes in weed biomass. Inadequate weed control in a few zone tillage plots in 2006, indicated by high weed biomass (Table 10) probably contributed to increased early season weed pressure and this significant interaction in 2007.

In row weed biomass was not affected by tillage in 2007 (Table 11). In row dry weed biomass in the CUL treatment was higher than the CFH treatment in 2006 (*P*<0.05; Table 11). The CUL treatment had an in row weed biomass that was higher than the BH and CFH treatments in 2007 (*P*<0.05; Table 11). In row weed biomass in the BH treatment was higher than the CFH treatment in 2007 (*P*<0.05; Table 11). Cultivar did not have a significant effect on in row biomass in 2007 (Table 11).

Table 10. Effect of tillage, weed management, and sweet corn cultivar on dry weed biomass in (IN) and between (BT) crop rows in 2006[z] and 2007[y] at Freeville, NY.

	Dry wt. ($g \cdot m^{-2}$)[x]			
	2006		2007	
Parameter	BT	IN	BT	IN
Tillage (T)				
Conventional (CT)	156	346	50	249
Deep zone (DZT)	209	461	52	213
Zone (ZT)	222	298	73	203
	NS	NS	NS	NS
Weed management (WM)				
Conventional full width (CFH)	157	110 b[w]	28 b	49 b
Banded + cultivation (BH)	197	288 ab	64 ab	259 a
Cultivation (CUL)	234	707 a	84 a	376 a
	NS	**	**	**
Cultivar (cv.)				
Precious Gem (PG)	230	388	52	269
Temptation (T)	161	349	65	174
	NS	NS	NS	NS
T x WM	NS	NS	NS	NS
cv. x WM	NS	NS	NS	NS
cv. x T	**	NS	NS	NS
cv. x T x WM	**	NS	**	NS

[z]Weed biomass samples were taken after harvest of both sweet corn cultivars in 2006 (106 DAP).

[y]Biomass samples were taken when weeds were at or near reproductive maturity in 2007, approximately 62 DAP.

[x]Data log transformed(+1), non transformed least squared means are reported.

[w]Same letter within columns indicates no significant difference.

**Significant at P <0.05.

Table 11. Effect of tillage, weed management, and dry bean cultivar on between (BT) and in (IN) row dry weed biomass in 2006[z] and 2007[y] at Freeville, NY.

	Dry wt ($g \cdot m^{-2}$)[x]			
	2006		2007	
Parameter	BT	IN	BT	IN
Tillage (T)				
Conventional (CT)	99	50 ab	76 b	81
Deep zone (DZT)	128	38 b	91 ab	135
Zone (ZT)	96	114 a	101 a	109
	NS	*	*	NS
Weed management (WM)				
Conventional full width (CFH)	134 ab[w]	43 b	42 b	11 c
Banded + cultivation (CH)	44 b	49 ab	105 a	126 b
Cultivation (CUL)	144 a	111 a	122 a	188 a
	**	**	**	**
Cultivar (cv.)				
California Early (CELRK)	166 a	107 a	104	119
RedKanner (RK)	48 b	28 b	75	97
	**	**	NS	NS
T x WM	NS	NS	*	NS
cv. x WM	NS	NS	NS	NS
cv. x T	**	NS	NS	NS
cv. x T x WM	*	NS	NS	NS

[z]Weed biomass samples were taken after harvest of both dry bean cultivars in 2006 (114 DAP).
[y]Biomass samples were taken approximately 72 DAP when weeds were at or near reproductive maturity in 2007.
[x]Data log transformed(+1), non transformed least squared means are reported.
[w]Same letter within columns indicates no significant difference.
*,**Significant at P <0.10 and <0.05 respectively.

Dry above ground biomass

Sweet corn. Above ground dry biomass (g/plant) at midseason and at harvest were measured to determine differences in growth rate of 'Temptation' and 'Precious Gem' due to tillage and weed control treatments. In 2006, tillage did not affect above ground dry biomass at midseason or harvest (Table 12). In 2007, the zone tillage treatment had 56% and 25% more biomass than the CT treatment at midseason and harvest respectively ($P<0.05$; Table 12). The improved crop growth in the ZT treatments in 2007 cannot be explained by soil temperature (Figure 5), soil compaction (Figs. 1 and 2), or weed biomass (Table 10). However, the ZT treatments did have higher soil nitrate at the mid season sample (Table 7), which could explain the higher biomass in this treatment. While this soil N was not significantly different from the CT treatment at the sampling time, the actual soil N release dynamics may have been different for ZT treatment.

Sweet corn biomass varied by weed control strategy. The corn biomass in the banded treatment (BH) was 18% lower than the conventional full width herbicide (CFH) at midseason in 2006 ($P<0.05$; Table 12) but similar at harvest. In 2007, the CFH treatment had a higher midseason biomass ($P<0.05$; Table 12) than the BH and cultivation only (CUL) treatments. At harvest in 2007 sweet corn biomass was similar across all weed control treatments (Table 12).

Differences in biomass between sweet corn cultivars were observed at all sample dates. 'Temptation' biomass was significantly higher than 'PG' at 29 DAP in 2006 and in 2007 ($P<0.05$; Table 12), while 'PG' was higher at harvest in both years ($P<0.05$; Table 12).

Table 12. Effect of tillage, weed management, and cultivar on the dry above-ground biomass of sweet corn midseason[z] and at harvest[y] in 2006 and 2007 at Freeville, NY.

	Midseason (g per plant)		Harvest (g per plant)	
Parameter	2006	2007	2006	2007
Tillage (T)				
Conventional (CT)	3.9	2.5 b	70.2	76.1 b
Deep zone (DZT)	3.8	2.9 b	63.6	9.0 ab
Zone (ZT)	4.2	3.9 a	68.9	95.5 a
	NS	**	NS	**
Weed management (WM)				
Conventional full width (CFH)	4.4 a[x]	3.8 a	70.2	94.6
Banded + cultivation (BH)	3.6 b	3.1 b	68.6	83.1
Cultivation (cv.)	3.8 ab	2.4 c	63.9	82.8
	**	**	NS	NS
Cultivar (cv.)				
Precious Gem (PG)	3.3 b	2.6 b	73.4 a	104.8 a
Temptation (T)	4.6 a	3.6 a	61.7 b	68.9 b
	**	**	**	**
cv. x T	NS	NS	NS	NS
cv. x WM	NS	NS	NS	NS
T x WM	NS	NS	NS	NS
T x WM x cv.	NS	NS	NS	NS

[z]Midseason above ground dry biomass measurements were taken on 11 July 2006 (29 d after planting [DAP]) and on 17 July 2007 (29 DAP).
[y]At harvest above ground dry biomass measurements were taken on 22 (‘Temptation’) and 31 (‘Precious Gem’) Aug. 2006, (71 and 80 DAP respectively), and on 4 (‘Temptation’) and 11 (‘Precious Gem’) Sept. 2007 (78 and 85 DAP respectively).
[x]Same letter within columns indicates no significant difference.
**Significant at $P < 0.05$.

Dry beans. Midseason biomass of dry beans was not affected by tillage system in either year (Table 13). Only in 2006, did tillage affect biomass at harvest. Conventionally tilled treatments had significantly higher biomass than DZT tillage and ZT (P <0.05; Table 13).

The effect of weed management on dry bean above ground biomass was generally not significant. While there was a statistically significant difference in midseason biomass in 2006 among the weed management strategies (P<0.05; Table 13), the actual range of these differences was only 0.3 g dry wt. By harvest, there were no detectable differences in biomass by weed management. In 2007, the CFH treatment did have higher biomass than the cultivation only treatment. This may have been the result of crop injury from cultivation prior to midseason biomass sampling.

Differences in cultivar growth rate were observed at midseason in 2006 and 2007, the biomass of 'CELRK' was higher than that of 'RK' in both cases (P<0.05; Table 13). The above ground biomass of 'CELRK' and 'RK' was similar at harvest in 2006 and 2007 (Table 13).

Table 13. Effect of tillage, weed management, and cultivar on dry above ground biomass of dry beans midseason[z] and at harvest[y] in 2006 and 2007 at Freeville, NY.

	Midseason (g/plant)		Harvest (g/plant)	
Parameter	2006	2007	2006	2007
Tillage (T)				
Conventional (CT)	3.2	6.4 a	22.3 a	14.1
Deep zone (DZT)	3.3	6.5 a	19.4 b	13.9
Zone (ZT)	2.9	5.6 b	18.0 b	12.5
	NS	**	**	NS
Weed management (WM)				
Conventional full width (CFH)	3.1 ab[x]	6.1	19.5	15.2 a
Banded + cultivation (BH)	3.0 b	6.4	21.1	13.9 a
Cultivation (CUL)	3.4 a	6.0	19.1	11.4 b
	*	NS	NS	**
Cultivar (cv.)				
California Early (CELRK)	3.4 a	6.5 a	19.7	14.0
Red Kanner (RK)	2.9 b	5.8 b	20.1	13.0
	**	**	NS	NS
cv. x T	NS	NS	NS	NS
cv. x WM	NS	NS	NS	NS
T x WM	NS	NS	NS	NS
T x WM x cv.	NS	NS	NS	NS

[z]Midseason above ground dry biomass measurements were taken on 11 July 2006 (27 d after planting [DAP]) and on 20 July 2007 (38 DAP).

[y]At harvest above ground dry biomass measurements were taken on 26 Sept. and 5 Oct. 2006 (104 and 113 DAP), and on 5 and 16 Oct. 2007 (114 and 125 DAP).

[x]Same letter within columns indicates no significant difference.

*,**Significant at *P* <0.10 and <0.05 respectively.

Crop yield and quality

Sweet corn. Tillage did not affect total plant number, total ear number, total yield, or marketable yield in 2006 (Table 14). In 2006, the ZT treatment had 17% fewer marketable ears (no.) than the CT treatment (P<0.10; Table 14), however, marketable yield (kg) was similar. In 2006, the CT treatment had a higher percentage of marketable ears than the DZT treatment (P <0.10; Table 14).

In 2007, there were significant interactions in the plant no., ear no., and yield (kg) per hectare of sweet corn measurements. The T x WM x cv. interaction was significant for plant number per hectare (P<0.10; Table 15). High weed pressure early in the growing season and different growth rates of the cultivars T and PG probably contributed to this interaction. Cultivation only subplots had to be selectively hand weeded in order minimize crop damage during cultivation. Hand weeding of sweet corn plants is not a standard practice but was necessary to avoid complete crop failure in the CUL weed control sub plots. The performance of the cultivars T and PG was also affected by the high level of weed pressure early in the growing season. 'Temptation' is an earlier cultivar which compared to 'PG' grows faster early in the season. The higher early season growth rate of 'T' allowed it to better compete with surrounding weeds and likely contributed to a plant population that was higher than 'PG' (P<0.05; Table 15).

The cv. x WM interaction for ear no. and total yield per hectare was significant in 2007 (P<0.05, and <0.10 respectively; Table 15). Ear no. per hectare was lower in CUL treatment compared to the CFH and BH treatments (Table 15). 'Precious Gem' had a lower ear no. per hectare compared to the 'T' (Table 15). Total yield (kg) per hectare for the CUL treatment was lower than in the CFH and BH treatments (Table 15). With the exception of cultivar impacts on total yield per hectare, weed pressure and slower early season growth had likely had effects similar to those described in T x

WM x cv. interaction for plants per hectare. Total yield (kg per hectare) was higher for ‘PG’ this increase in yield was expected since later maturing cultivars tend to produce higher yields (Table 15). However, total yield in 2006 for ‘PG’ was higher (Table 14) compared to 2007 (Table 15).

There are few published studies comparing sweet corn performance among different conservation tillage systems. In one study from Oregon, sweet corn grown in a conservation tillage system yielded similarly to conventional tillage (Luna and Staben, 2002). A greater number of studies examine the effects of conservation tillage on field corn yield. There are numerous differences between sweet and field corn production, in particular sweet corn is harvested immature and at a high moisture level compared to field corn however, both crops have similar architecture and phenology. Results from field corn experiments have been mixed. In some studies, field corn yields were similar between conservation and conventional tillage systems (Beyaert et al., 2002; Opoku et al., 1997; Vetsch and Randall, 2002). Other studies found yields of conservation tillage treatments were lower than conventional tillage (Al-Kaisi and Licht, 2004; Hendrix et al., 2004; Perez-Bidegain et al., 2007).

Unlike tillage systems, weed management did affect sweet corn yield and quality in both years of this study. In 2006, yield measurements from the CUL treatment were significantly lower than the CFH treatment ($P<0.05$; Table 14). In 2007, weed management did not affect total plant, total ear, and marketable ear no. in sweet corn (Table 15), but total yield, marketable yield, and percent marketable yield of the CUL treatment was significantly lower than in the CFH and BH treatments ($P<0.05$; Table 15).

Table 14. Effect of tillage, weed management, and cultivar on the per hectare mean of total number of plants, total number of ears, total yield, number of marketable ears, marketable yield, and percent marketable ears of sweet corn at harvest in 2006[z] at Freeville, NY.

	Total (per ha)			Marketable (per ha)		
Parameter	Plant no.	Ear no.	Yield (kg)	Ear no.	Yield (kg)	Percent marketable ears
Tillage (T)						
Conventional (CT)	55,374	48,258	18,864	44,969 a	18,197	93 a
Deep zone (DZT)	55,568	48,383	18,040	42,981 ab	17,057	87 ab
Zone (ZT)	54,805	43,813	18,602	37,342 b	17,329	85 b
	NS	NS	NS	*	NS	*
Weed management						
Conventional full width (CFH)	58,245 a[x]	51,308 a	19,573 a	47,720 a	18,834 a	92 a
Banded + cultivation (BH)	53,999 b	45,986 b	18,639 ab	41,142 b	17,730 ab	89 ab
Cultivation (CUL)	53,504 b	43,160 b	17,293 b	36,431 b	16,019 b	83 b
	*	**	**	**	**	**
Cultivar (cv.)						
Precious gem (PG)	54,214	46,092	22,199 a	43,361	21,522 a	94 a
Temptation (T)	56,284	47,543	14,805 b	40,167	13,534 b	83 b
	NS	NS	**	NS	**	**
Significance of interactions						
cv. x T	NS	NS	NS	NS	NS	NS
cv. x WM	NS	NS	NS	NS	NS	NS
T x WM	NS	NS	NS	NS	NS	NS
T x WM x cv.	NS	NS	NS	NS	NS	NS

[z]Planting date was 12 June, harvested 22 (‘Temptation’) and 31 (‘Precious Gem’) Aug. (71 and 80 DAP respectively).
[x]Same letter within columns indicates nonsignificant (NS) comparison in columns by parameter.
*,**Significant at *P* <0.10 and <0.05 respectively.

Table 15. Effect of tillage, weed management, and cultivar on the per hectare mean of total number of plants, total number of ears, total yield, number of marketable ears, marketable yield, and percent marketable ears of sweet corn at harvest in 2007[z] at Freeville, NY.

	Total (per ha)			Marketable (per ha)		
Parameter	Plant no.	Ear no.	Yield (kg)	Ear no.	Yield (kg)	Percent marketable ears
Tillage (T)						
Conventional (CT)	53,550	50,471	14,581	42,362	13,073	85
Deep zone (DZT)	55,195	52,504	15,216	41,561	13,194	79
Zone (ZT)	54,776	51,368	14,938	41,381	13,037	82
	NS	NS	NS	NS	NS	NS
Weed management (WM)						
Conventional full width (CFH)	56,212 a[x]	52,265 a	16,046 a	44,371 a	14,398 a	85 a
Banded + cultivation (BH)	56,212 a	52,683 a	15,266 a	44,371 a	13,641 a	85 a
Cultivation (CUL)	51,098 b	49,394 b	13,423 b	36,562 b	11,265 b	75 b
	**	**	**	**	**	**
Cultivar (cv.)						
Precious gem (PG)	50,530 b	46,165 b	15,505 a	42,195	14,878 a	91 a
Temptation (T)	58,484 a	56,730 a	14,318 b	41,341	11,325 b	73 b
	**	**	**	NS	**	**
Significance of interactions						
cv. x T	NS	NS	NS	NS	NS	NS
cv. x WM	**	**	*	NS	NS	NS
T x WM	NS	NS	NS	NS	NS	NS
T x WM x cv.	*	NS	NS	NS	NS	NS

[z]Planting date was 19 June, harvested 4 (‘Temptation’) and 11 (‘Precious Gem’) Sept. (78 and 85 DAP respectively).
[x]Same letter within columns indicates nonsignificant (NS) comparison in columns by parameter.
*,**Significant at *P* <0.10 and <0.05 respectively.

In both years of this study, yields of 'Precious Gem' were significantly higher than those of 'Temptation' ($P<0.05$; Tables 14 and 15). Cultivar did not affect the total plant no. per ha or marketable ear no. per ha in either year. 'Temptation' had a lower percentage of marketable ears in both years (Tables 8 and 9). As there were no significant interactions among cultivar, tillage or weed control strategy in this experiment, the cultivar differences in yield were solely due to genetic background. Later maturing cultivars, such as 'PG' generally have higher yields than earlier maturing cultivars ('T').

Dry beans. There was a significant T x WM x cv. interaction for the number of dry bean plants per hectare in 2006 ($P<0.05$; Table 16). Weed management had an effect on plant population, however the largest differences were observed in the tillage and cultivar categories. The significantly higher plant populations in the ZT treatment and for the cultivar RK likely contributed to this interaction, but cannot be explained with the data in this study. Seed yield, harvest index, and seed size were not affected by tillage in 2006 (Table 16). In 2007 tillage did not affect plant population, seed yield, harvest index, or seed size (Table 17). There are few published studies that compare dry bean performance in conservation tillage systems. A greater number of studies examine the effects of conservation tillage on soybean (*Glycine max*) yield. While there are numerous differences between dry bean and soybean production, and soybeans are less sensitive to soil compaction (Smucker et al., 1991), both crops are legumes that are harvested at physiological maturity. Soybean yield has been similar in conservation and conventional tillage systems (Archer et al., 2007; Vyn et al., 1998).

Table 16. Effect of tillage, weed management , and dry bean cultivar on the per hectare mean of total number of plants, seed yield, harvest index, and seed size at harvest in 2006[z] at Freeville, NY.

Parameter	Plant no. (ha^{-1})	Seed yield (kg)[y] (ha^{-1})	Harvest index (%)	Seed size (seeds/kg^{-1})[x]
Tillage (T)				
Conventional (CT)	166,100 b[w]	3,518	48	1,912
Deep zone (DZT)	166,756 b	3,381	49	1,854
Zone (ZT)	190,424 a	3,521	51	1,921
	**	NS	NS	NS
Weed management				
Conventional full width (CFH)	182,921 a	3,667 a	49	1,870
Banded + cultivation (BH)	174,166 ab	3,657 a	49	1,903
Cultivation (cv.)	166,193 b	3,096 b	50	1,915
	*	*	NS	NS
Cultivar (cv.)				
California Early (CE)	154,325 b	3,249 b	52 a	1,866 b
Red Kanner (RK)	194,528 a	3,697 a	47 b	1,926 a
	**	*	**	**
cv. x T	NS	NS	NS	NS
cv. x WM	NS	NS	NS	NS
T x WM	NS	NS	NS	NS
T x WM x cv.	**	NS	NS	NS

[z]Planting date was 14 June, harvested 26 Sept. and 5 Oct. (104 and 113 d after planting).

[x]Seed yield was adjusted to 18% moisture.

[y]Seed size was adjusted to 12% moisture.

[w]Same letter within columns indicates nonsignificant (NS) comparison in columns by parameter.

*,**Significant at P <0.10 and <0.05 respectively.

Table 17. Effect of tillage, weed management, and dry bean cultivar on the per hectare mean of total number of plants, seed yield, harvest index, and seed size at harvest in 2007[z] at Freeville, NY.

Parameter	Plant no. (ha^{-1})	Seed yield (kg)[x] (ha^{-1})	Harvest Index (%)	Seed size ($seeds/kg^{-1}$)[y]
Tillage (T)				
Conventional (CT)	198,684	3,456	54	1,906
Deep zone (DZT)	192,853	3,236	53	1,912
Zone (ZT)	203,528	3,193	54	1,935
	NS	NS	NS	NS
Weed management (WM)				
Conventional full width (CFH)	203,169	3,820 a[w]	54	1,889
Banded + cultivation (BH)	191,059	3,166 b	54	1,924
Cultivation (CUL)	200,837	2,900 b	53	1,940
	NS	**	NS	NS
Cultivar (cv.)				
California Early (CE)	198,953	3,406	53	1,787 b
Red Kanner (RK)	197,757	3,184	54	2,048 a
	NS	*	NS	**
cv. x T	NS	NS	NS	NS
cv. x WM	NS	NS	NS	NS
T x WM	NS	NS	NS	NS
T x WM x cv.	NS	NS	NS	NS

[z]Planting date was 12 June, harvested 5 and 16 Oct. (114 and 125 d after planting).
[x]Seed yield was adjusted to 18% moisture.
[y]Seed size was adjusted to 12% moisture.
[w]Same letter within columns indicates nonsignificant (NS) comparison in columns by parameter.
*,**Significant at P <0.10 and <0.05 respectively.

Weed management did not affect dry bean plant number, harvest index, or seed size (Table 17). Dry bean seed yield in the BH and CUL treatments was lower than in the CFH treatment in 2007 (P<0.05; Table 17). Lower seed yield in the BH and CUL treatments was likely due to weed crop competition and damage to the bean plants from a second cultivation. The BH and CUL treatment had a greater in and between row weed biomass than the CFH treatment in 2007 ($P<0.05$; Table 17). The second cultivation of the BH and CUL plots had to be delayed due to high soil moisture in 2007 and took place 29 DAP. Cultivation of the BH and CUL treatments was not entirely successful due to weed and crop growth in the time between the first (17 DAP) and second (29 DAP) cultivations. Crop size and weed pressure were taken into consideration for the second cultivation in 2007. Weed pressure in the BH and CUL treatments was high enough to require a second cultivation which may have damaged the crop and contributed to the decrease in yield.

Cultivar did affect plant population, seed yield, harvest index, and seed size in 2006. ‘RedKanner’ had the highest population, seed size ($P<0.05$; Table 16) and yield ($P<0.10$; Table 16) in 2006. ‘California Early Light Red Kidney’ had the highest harvest index ($P<0.05$; Table 16). The increased yield observed in ‘RK’ was expected since yields of later cultivars are usually higher than those that mature earlier such as CELRK.

Summary

With the exception of dry bean plants per ha in 2006 and marketable ear no. per ha and percent marketable ears in sweet corn in 2006, tillage did not affect crop yield and quality in both years of the experiment. It was expected that the reduced amount of soil disturbance in the ZT treatments would not be sufficient to reduce soil compaction which would result in lower crop yield and quality. Soil penetration resistance measurements indicated that resistance was higher in some of the ZT treatments. The soils (Howard gravel loam) at the experiment site had a high stone content which likely had an impact on the accuracy of the penetrometer measurements. The 2006 and 2007 growing seasons had ideal rainfall (Table A1) eliminating the need for irrigation and hence optimal soil moisture may have masked the effects of soil compaction on root growth in this study. Root growth has been shown to be restricted by compacted soils (Wolfe et al., 1995), and decreased root growth can magnify the effects of low soil moisture (Buttery et al., 1998).

In 2006 there were significant differences in soil nitrogen across tillage and weed management treatments in both crops. Compared to the CT treatment, ZT had a higher soil N mineralization potential in sweet corn post harvest in 2006. In dry beans soil N mineralization in ZT was higher than the CT treatment midseason and at harvest in 2006. For soluble N measures, the magnitude of differences among treatments was small, and not likely to result in practical differences from a cultural practice standpoint. Soil N mineralization measured midseason and at harvest was significantly higher in the ZT treatment for sweet corn and dry beans in 2006. This suggests that the mechanical disturbance of soil by ZT may have created environmental factors such as improved soil aeration or better moisture availability, which are more favorable to N min. The effect of ZT on environmental factors was not measured and it is impossible to determine these factors were responsible for the increased in N min observed in the ZT treatments in 2006. Due to funding constraints N min potential was not measured in 2007. The lack of additional data on N min makes it impossible to determine a trend for the effect of ZT on N min potential in sweet corn and dry beans in 2006. To discern trends in soil nitrogen and N min future research should budget for multiple samples throughout the growing season or over the course of several years.

Data collected in this study on crop yield and quality parameters indicate that DZT and ZT are a viable alternative to CT. A dry growing season would be necessary for DZT and ZT to be completely tested as an alternative to conventional tillage in the Northeastern United States. Grower communication has suggested, however, that DZT had improved yield under dry conditions compared to CT.

The effect of tillage on dry weed biomass varied depending on the sampling location (in or between row) and year. Tillage did not affect in row weed biomass in sweet corn during both years or in 2007 for dry beans. In 2006 tillage had an effect on in row weed biomass in dry beans. Compared to ZT the DZT treatment had a lower in row weed biomass in dry beans in 2006, however the DZT and ZT treatments did not differ significantly from the CT treatment. The similarity of the DZT and ZT in row weed biomass measurements to the control treatment (CT) makes the effect of tillage on in row weed biomass in dry beans in 2006 difficult to interpret. The majority of the weed species at this experimental site were annuals. Decreased levels of soil disturbance such as those in conservation tillage systems tend to favor perennial weed populations. The DZT and ZT treatments were offset each year to till the between row area of the previous year and may have prevented a shift toward perennial weeds species.

Weed management had an effect on yield and quality of sweet corn and dry beans in both years. In 2006 the CFH treatment in sweet corn had the highest yield and quality. Sweet corn yield and quality in the BH treatment was variable in 2006. Compared to the CFH treatment sweet corn yield and quality was lowest in the CUL treatment in 2006. Total sweet corn yield and quality in 2007 was lowest in the CUL treatment, there were several significant interactions and it is difficult to determine if lower total yield and quality were due to cultivation or some other factor. Marketable yield and quality of sweet corn were lowest in the CUL treatment in 2007. Dry bean seed yield was lowest in the CUL treatment in both years. In 2006 weed management had an effect on plant no. per hectare, but there was no effect in 2007. Harvest index and seed size were not affected by weed management in both years.

While an analysis of the weed seed bank was not performed it is probable that the seed bank increased in years of poor weed control. Germination of weed seeds in the following years could reduce the effectiveness of control measures which lead to higher weed populations in plots with poor weed control in the previous year. Analysis of dry weed biomass and the weed seed bank over several years could provide insight into the impacts of weed management on dry weed biomass and crop quality in conservation tillage systems for vegetable production.

Of the three types of weed management dry weed biomass was typically highest in the CUL treatment in row for both crops in 2006 and 2007. In row dry weed biomass in the BH treatment varied depending on the year. Herbicide was broadcast or banded over the crop plants. Crops such as dry bean produce a large leafy canopy which likely reduced herbicide contact with in row weeds. In the banded treatment chemical weed control would have been more successful if drop nozzles where used instead of applying the herbicide in a band directly over the crop plants. Herbicides such as metolachlor and fomesafen are less effective if dry weather follows the application. There was little precipitation post application in both years of the experiment (Figures C1 and C2).

The seeds of many weeds at the experimental site such as *Amaranthus* spp., *Chenopodium album, Panicum* spp., and *Digitaria* spp. germinate relatively late (Uva et al., 1997) and as result may have emerged after both cultivations. To counteract this problem the crop could be planted early to give it a competitive advantage, or it could be planted later. A later planting would allow for a later cultivation which could serve to control late emerging weed species. Timing of mechanical and control could also be adjusted to correspond with the minimum amount of time weeds need to be suppressed, the critical period (Weaver, 1984) in conservation tillage systems. Establishment of the critical period in dry beans and sweet corn grown in DZT and ZT systems would likely improve crop yield.

The use of conservation tillage practices such as DZT and ZT have the potential to reduce input costs. Deep zone tillage and ZT practices likely conserve fuel since they involve fewer tillage passes than conventional tillage. Fuel usage in DZT and ZT systems compared to conventional tillage still needs to be quantified. Labor saved in DZT and ZT would be difficult to determine using a small plot design. Instead labor savings might be best estimated by on farm trials or through interviews with farmers who have transitioned from conventional tillage to DZT or ZT.

Deep zone and zone tillage are methods that fracture the soil, conventional plows partially or completely invert the soil surface. The high level of soil disturbance associated with conventional tillage can act as a weed management tool, and for this reason higher weed populations were expected in the DZT and ZT treatments. Tillage did affect weed management in some cases, but this effect was not as dramatic as expected. Weed pressure increased in the second year of the experiment, this increase was likely due to the weed management treatments and not tillage.

Methods of weed management that eliminate or reduce use of chemical controls should be examined before application in a production setting. The performance of the two cultivars used for weed control varied. Sweep size was the major drawback of the Taylor-Way (Pittsburgh Forgings Company, Athens, TN) cultivator used in 2006. The Taylor-Way cultivator had wide (25 cm or 50 cm) single sweeps per row which did not adequately penetrate the soil. In 2007 a cultivar with two to three 19 cm sweeps per row was used. The smaller 19 cm sweeps penetrated the soil effectively. The cultivator used in 2007 had seen substantial use in the past and due to normal wear precise cultivation was not possible. In future work mechanical weed control a multiple sweep cultivator in good working order should be used. Future work on fuel and labor inputs would provide an added benefit to growers interested in adopting conservation tillage.

Late season cultivars typically out yield those that mature earlier and this was the case for both crops. In general later cultivars have a slower early season growth rate, this was especially noticeable for the sweet corn cultivar PG. The slower growth rate increased the susceptibility of ‘PG’ to weed crop competition. The canopy architecture of the two dry bean cultivars was expected to play a role in weed suppression. In the first year weed biomass was lower in the cultivar RK which has a broader canopy and closes over the crop rows more rapidly than ‘CELRK’. The similarity in weed biomass between the two cultivars in 2007 was not expected and may have been a result of the overall increase in weed pressure.

The overall goal of this study was to evaluate if sweet corn and dry bean yield could be maintained in conservation tillage systems. Based on the depth of disturbance deep zone tillage was expected to be the best alternative to conventional tillage. The intermediate depth of soil disturbance (10-15 cm) in the ZT treatments was expected to be less effective at disrupting soil compaction caused conventional tillage than DZT which tilled 35 cm deep. The comparable crop yield and quality of the DZT and CT treatments to ZT was not expected. Compared to DZT, the ZT treatments required less draw bar horsepower to prepare. If yield and quality could be maintained under dry conditions, ZT could be adapted for use on small farms.

The results of this study indicate that DZT and ZT may be an alternative to conventional tillage in the Northeastern United States. Measurement of soil quality indicators such as percent organic matter, microbial activity, plant pathogens and crop pests would provide a valuable addition to the comparison of conventional and conservation tillage systems.

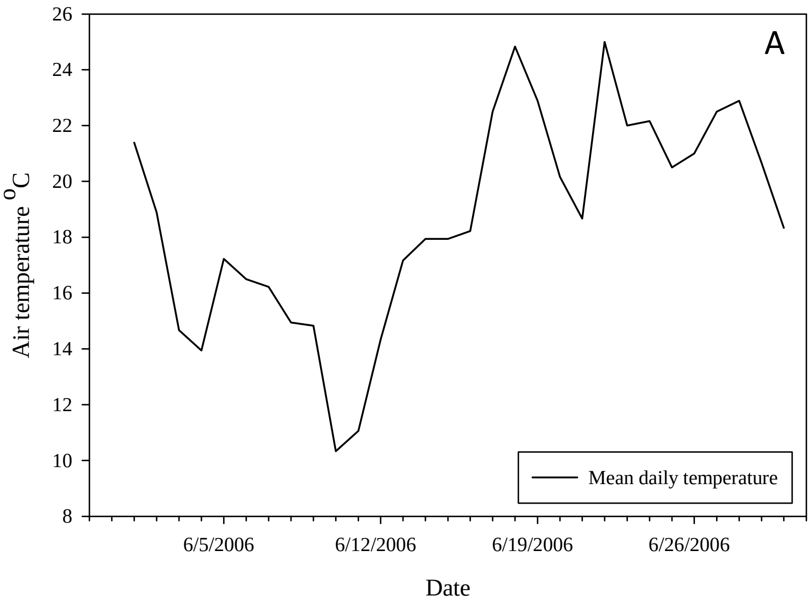
APPENDIX A: Monthly air temperature and precipitation

Table A1. Mean monthly air temperature and total precipitation in 2006 and 2007 at Freeville, NY.

	Mean air temperature (°C)		Total precipitation (mm)	
	2006	2007	2006	2007
Month				
May	14	14	51	33
June	19	19	173	88
July	23	20	166	118
August	20	21	113	61
September	15	17	45	104

Source: Freeville, NY weather station, Network for Environment and Weather Awareness, New York State Integrated Pest Management Program, Cornell University. 14 April 2009 http://newa.nysaes.cornell.edu

APPENDIX B: Air temperature for June and July of 2006 and 2007



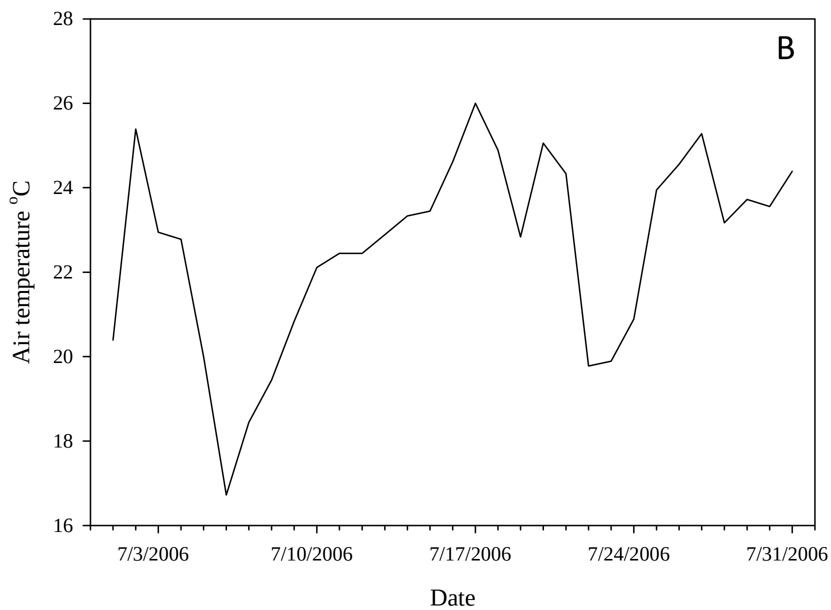
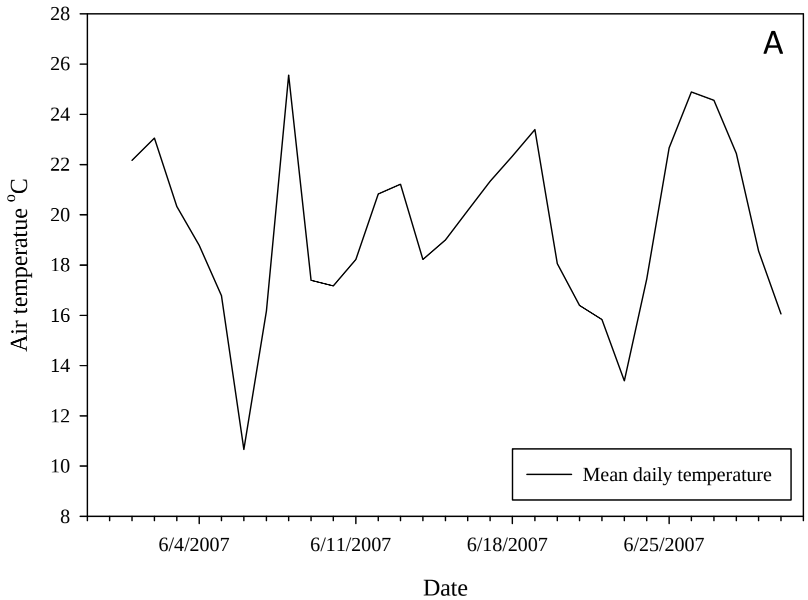


Figure B1. Mean daily air temperature for June (A) and July (B) 2006 at Freeville, NY. Source: Freeville, NY weather station, Network for Environment and Weather Awareness, New York State Integrated Pest Management Program, Cornell University. 14 April 2009 http://newa.nysaes.cornell.edu



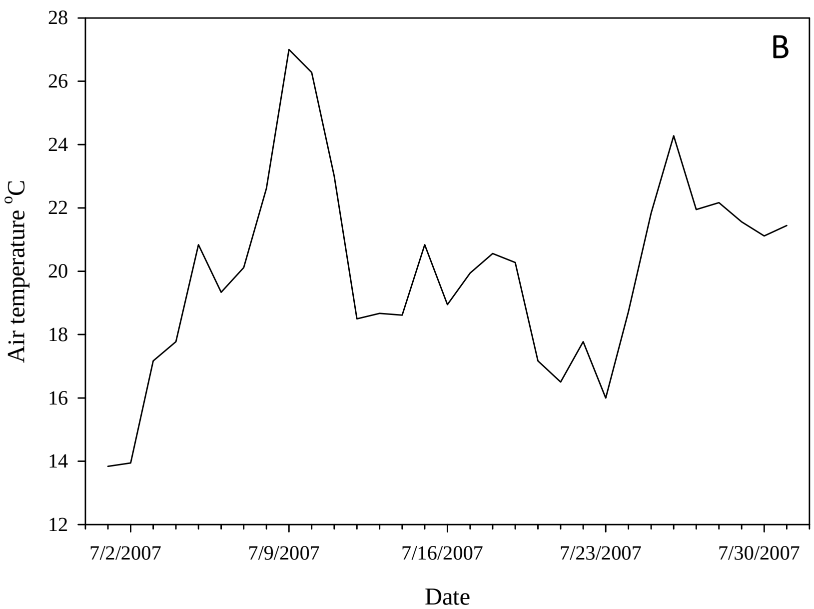
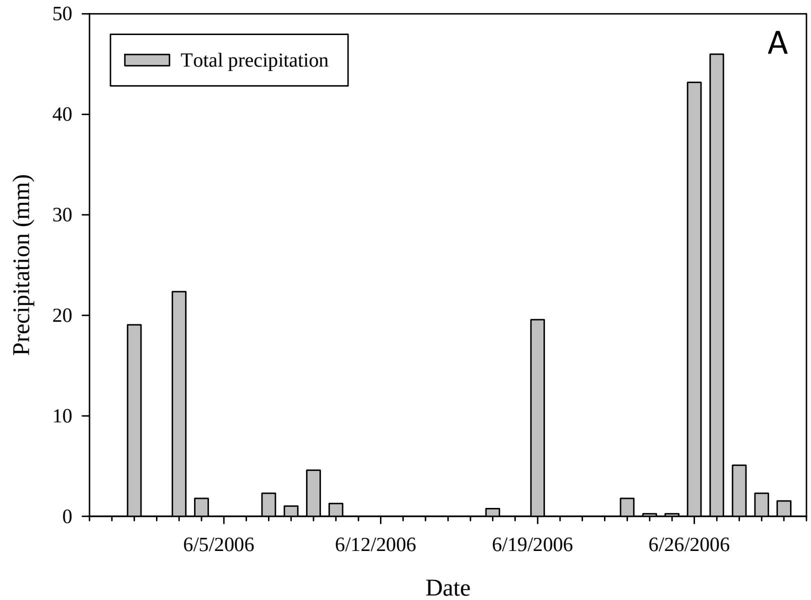


Figure B2. Mean daily air temperature for June (A) and July (B) 2007 at Freeville, NY. Source: Freeville, NY weather station, Network for Environment and Weather Awareness, New York State Integrated Pest Management Program, Cornell University. 14 April 2009 http://newa.nysaes.cornell.edu

APPENDIX C: Total precipitation for June and July of 2006 and 2007



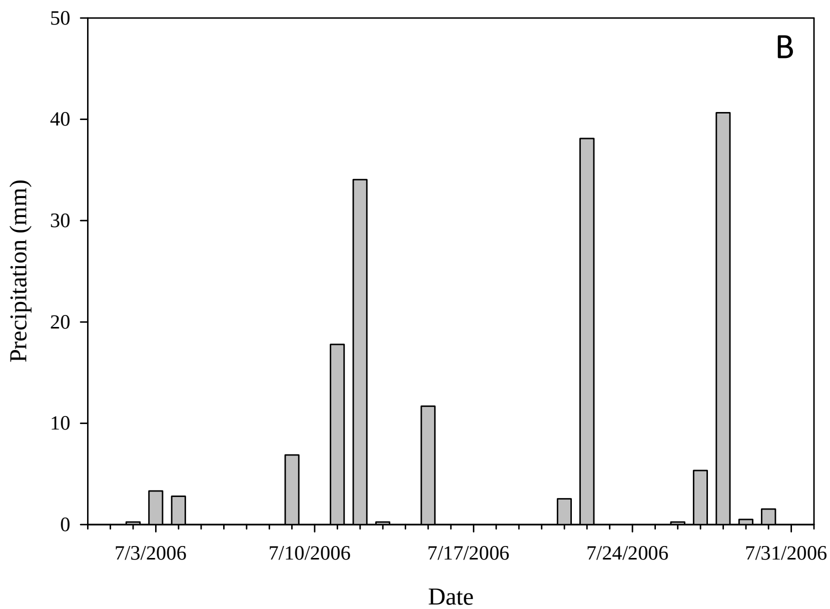


Figure C1. Total daily precipitation for June (A) and July (B) 2006 at Freeville, NY. Source: Freeville, NY weather station, Network for Environment and Weather Awareness, New York State Integrated Pest Management Program, Cornell University. 14 April 2009 http://newa.nysaes.cornell.edu

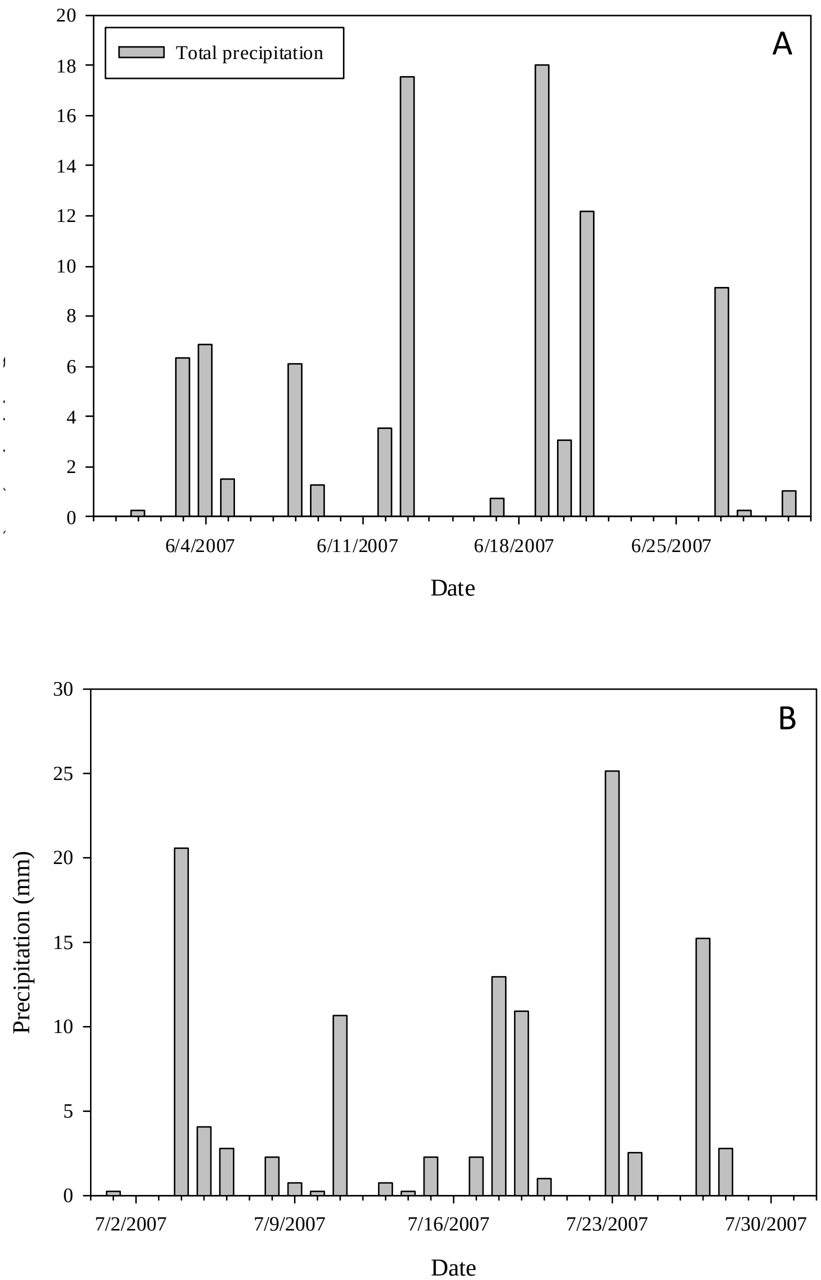


Figure C2. Total daily precipitation for June (A) and July (B) 2007 at Freeville, NY. Source: Freeville, NY weather station, Network for Environment and Weather Awareness, New York State Integrated Pest Management Program, Cornell University. 14 April 2009 http://newa.nysaes.cornell.edu

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