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Introduction

The perceived effect of no-tillage on soil temperature, soil moisture conditions, soil compaction, soil productivity, and nitrogen movement and availability has become a major concern among producers considering adopting this tillage system. No-tillage presents a unique challenge in poorly drained soils, in which certain surface soil properties are affected due to the absence of tillage as a corrective measure. Effective tillage systems create an ideal seedbed condition (i.e., soil moisture, temperature, and penetration resistance) for plant emergence, plant development, and unimpeded root growth.

Soil moisture and soil temperature conditions in the seedbed zone (top 6 inches) can promote or delay seed germination and plant emergence (Licht and Al-Kaisi, 2005; Schneider and Gupta, 1985). Therefore, healthy plant growth and development require soil conditions that have adequate soil moisture and minimal root penetration resistance (Phillips and Kirkham, 1962). Soil temperature can be affected by surface residue cover, causing cooler surface soil temperature and slower soil drying in the spring (Fortin, 1993) in spite of reducing soil erosion and surface runoff (Cruse et al., 2001). Removal of residue from the row can reduce in-row soil moisture content in the seedbed, while conserving inter-row soil moisture. Unlike soil moisture, soil temperature has an inverse relationship with the amount of residue cover.

Soil management and tillage decisions

Soil management and tillage decision is one of several decisions farmers have to make every fall. However, there are many other factors that need to be considered when selecting a tillage system for any given field, or region within the state. Those factors are soil conditions, which include soil slope, soil drainage, topsoil depth or the A-horizon depth. Other equally important factors that need to be considered are hybrid selection, crop rotation, and management factors, such as residue cover, type of residue (corn or soybean), soil moisture condition at the time of making the decision, timing of tillage operation, fertilizer management in conjunction with tillage operation, type of residue management equipment, planting and harvesting equipment, compliance with conservation plans, and above all, the economic return and benefits for selecting the tillage system (Al-Kaisi and Yin, 2004).

The variability in soil conditions will be a key factor in selecting a tillage system that will ultimately influence crop response and yield expectations (Al-Kaisi, 2005). However, crop response to tillage systems has been demonstrated to be different for the same tillage system in different parts of the state or regions elsewhere. Different tillage systems affect soil temperature, soil moisture conditions, soil compaction, soil productivity, and nitrogen movement and N availability differently. These effects will be indicated in crop response to different tillage systems, where soil temperature plays a significant role in early seed germination, organic N mineralization, nutrient and residue incorporation, and weed and pest control.

Understanding site specific effect of tillage can significantly help in reducing input cost and also reduce the negative impact of tillage on water, air, and soil quality. Conservation tillage systems continue to be a very important component of crop production systems in terms of economic return and environmental benefits. However, the challenges in managing such systems, notably, no-tillage, are related to proper management practices that are associated with drainage in poorly drained soils, the use of residue management attachments, seeding depth, and fertilizer management. Also, the timing of field operations including N application, manure injection, etc., has to be done when the soil moisture condition is below field capacity to avoid any serious soil compaction problems.

Soil moisture and soil temperature conditions in the seedbed zone (top 2-6 inches) can promote or delay seed germination and plant emergence. Therefore, healthy plant growth and development require soil conditions with adequate soil moisture and minimal root penetration resistance. Soil temperature can be affected by surface residue cover, which causes cooler soil surface temperatures and slower soil drying in the spring despite reducing soil erosion and surface runoff. Removal of residue from the row can reduce in-row soil moisture content in the seedbed, while conserving inter-row soil moisture. Unlike soil moisture, soil temperature has an inverse relationship with the amount of residue cover. Furthermore, tillage systems and residue management have a significant effect on N dynamics by affecting C and N pools in the soil system. Soil disturbance during the tillage process and the incorporation of surface residue increases soil aeration, which further increases the rate of residue decomposition (McCarthy et al., 1995). This process impacts soil organic C and N mineralization and the readily available N for plant use (Dinnes et al., 2002). The type of tillage system adopted can influence the amount of N losses in the soil profile, and deep accumulation of $NO_{3-}N$ in the soil profile represents a potential for $NO_{3-}N$ leaching into shallow water tables (Keeney and Follett, 1991).

Concept of strip-tillage

Strip-tillage, which creates a soil environment that enhances seed germination, is an alternative to conventional tillage in areas, where poorly drained soils are dominant. In areas where soil moisture conditions are suitable for tillage operation, strip-tillage creates narrow-width tilled strips, traditionally in the fall, to increase early spring soil evaporation and soil temperature warm up in the top 2 inches. This is particularly effective in poorly drained wet soils, where slightly raised soil strips are normally created by available farm equipment such as anhydrous knives, discs, coulters, and residue cleaners on tool bars or manure injection equipment. Both fertilizer application and strip-tillage can be done in one operation.

The basic requirements for strip-tillage to be effective are accuracy in matching tillage equipment on the tool bar with the planter and placement of seeds in the tilled zones.

Traditionally, anhydrous ammonia injection knives, fluted coulters, residue cleaners and other tool attachments are used in the fall, to create residue-free strips and tilled zones that are approximately 6-8 inches wide and 6 to 8 inches deep. In the spring, seeds are planted directly in the same strips. Fertilizers may be incorporated while tilling these strips.

Strip-tillage is similar to zone-till with one exception. In the zone-till system, multiple fluted coulters create a zone that is approximately 1 to 2 inches deep and 8 inches wide and free of residue. These coulters operate at shallow depths to avoid creating void pockets below the seed. Another variation involves making a deep vertical slit with a thin profile knife centered in the 8-inch tilled zone. Zone-till can be achieved by using a planter equipped with fluted coulters. Coulters may be operated 2 or 3 inches to 6 inches deep if the soil is dry. Farmers in southeastern states with particularly compacted soils have used in-row sub-soiling with planter-mounted shanks in each row to create a tilled zone 12 inches deep. Seeds are then planted in the disturbed zone directly behind the shanks. This system is different from the above two systems in that it is often used with the full width conventional tillage system.

Studies have shown corn is more susceptible to delayed germination or disease in cool soil temperatures when soil is poorly drained and there is high no-till residue cover. Other studies show that by removing residue over the row or disturbing a narrow zone (6 to 8 inches wide) the seedbed warms up more rapidly. This can help with corn germination and seedling establishment in the early part of the growing season. In some cases, corn grain yield improved over no-till simply due to improved soil temperature. Recently it was found that removing residue or strip-tilling to create a residue free zone improves corn germination due to increased soil temperature at the top 2 inches. Many farmers are currently using planter attachments that move no-till residue away from the row during planting. This assists in more rapid warming of the soil and combats slow germination caused by cold and residue-covered soils. Topography is important to consider before using strip-tillage. In areas where the soil slope is steep or on highly erodible land (HEL), strip-tillage may not be the best choice. The disturbance of soil and removal of crop residue can create a significant water erosion problem in the row on steep slopes. It is recommended that after soybeans, at least 70 percent residue should be on the surface before strip-tilling. Strip-tillage is recommended on relatively flat land with poorly drained soils, where soil temperatures tend to be cold.

Results and discussion

Tillage system effects on soil temperature

In general, tillage significantly affects soil environment by altering the soil physical properties such as soil structure, compaction, aggregate stability, hydraulic properties, and thermal properties. The degree to which tillage affects or improves these properties depends on the intensity of the tillage system. The changes in soil properties will cause changes in the soil environment where crop production can be used as an indicator. Allowing soil to dry in the tilled zone before planting helps the planter's soil-engaging components (seed opener, depth wheels, closing wheels) establish proper seed depth without excessively compacting soil. Strip-tillage can have a significant impact on soil temperature, particularly in poorly drained soils and when soil moisture conditions remain relatively near field capacity. The improvement in soil temperature can be limited by excessive wet weather conditions. Studies show that strip-tillage improved soil temperature in the top 2 inches by more than 2° F over no-till in central Iowa.

Strip-tillage warms soils in the seed zone or bed quickly and promotes faster germination and growth of seedlings, reducing disease risk.

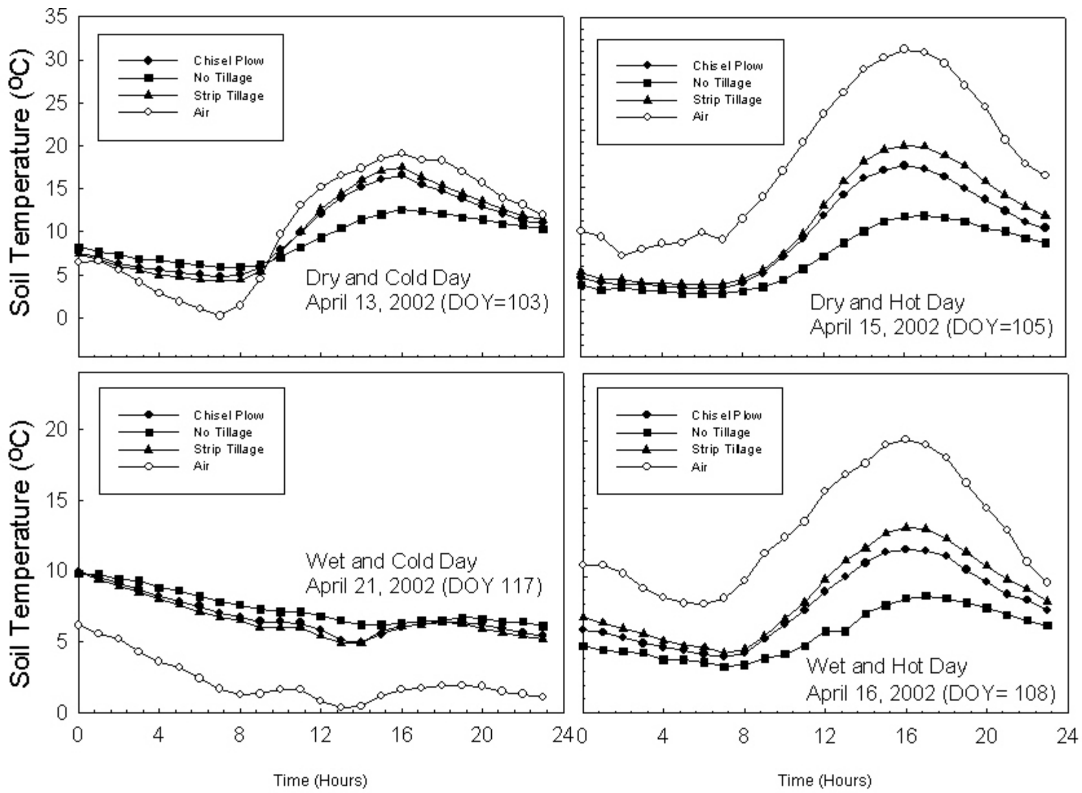

Figure 1. Tillage effect on soil temperature at the top 2 inches (No-tillage, Strip-tillage, and Chisel-plow).

Tillage effects on soil moisture

Conservations tillage systems such as no-till and strip-tillage increase water infiltration (Figure 2). In combination with high organic matter content, no-till and strip-tillage soils increase soil water storage. Typically, no-till surface soils (0-8 in) have greater water content at planting than plowed and residue tilled soils. Generally, no-till and strip-tillage increased water recharge in the subsoil profile by 25-30% over conventional tillage system (Figure 2). This is attributed to differences in surface residue cover as tilling prior to planting destroys soil structure, increases surface runoff and soil moisture evaporation. Studies in many parts of the country and elsewhere show that full width tillage is not the best solution for improving productivity, soil quality, energy use, labor, and time. Many conservation systems, such as strip-tillage, where tilled zone of 8 inches wide and 6 inches deep is done, can work as good as full width tillage. This system is very efficient and effective in nutrient placement, where tillage and nutrients application are coupled in a single operation.

Crop residues play significant role at several levels of soil sustainability. Primarily, crop residue physically protects the soil from potential erosion during heavy rain events. Crop residue reduces the impact of rain drops by absorbing the kinetic energy of rain drops to create a gentle infiltration and slow movement of water in the soil. Thus, reducing soil erosion and increasing the time opportunity for water to percolate the soil for better water recharge of the subsoil to save crop yield during drought (Figure 2). The effectiveness of residue in achieving these goals depends on how it is managed, which starts during harvest by cutting corn at a minimum height of 12 inches above the ground.

The upright residue can be very effective in trapping soil moisture in terms of snow and slow water movement. Residue should be kept intact to increase its effeteness. Shredding or chopping residue can create a lot of problems in terms of its ability to reduce soil erosion and potential washout during high intensity rain events.

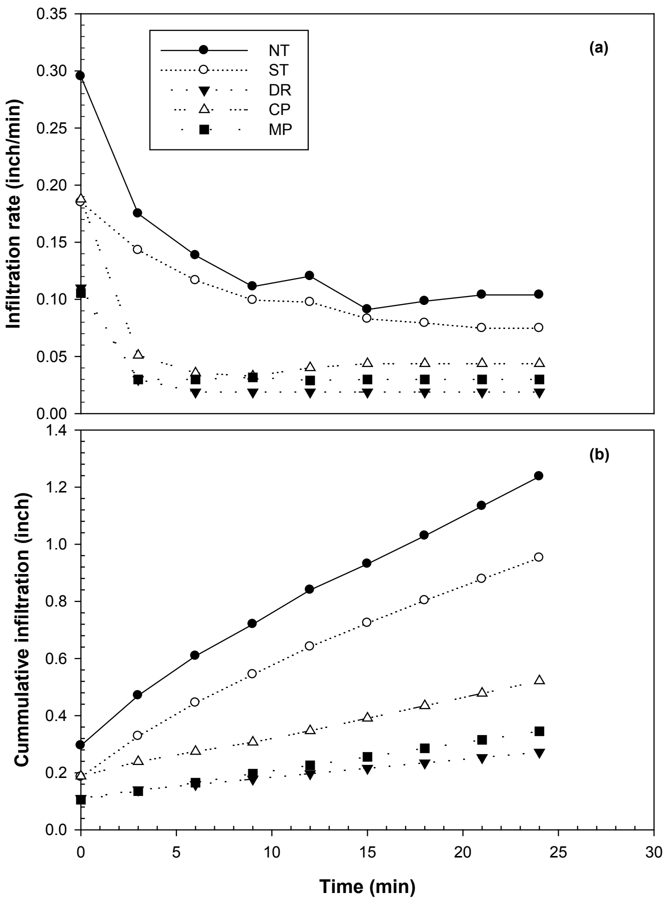

Figure 2. (a) infiltration rate and (b) cummulative infiltration under five tillage systems. (NT=no-till; ST=strip-tillage; CP=chisel plow; DR=deep rip; MP=moldboard plow).

Corn yield response to tillage system

Corn yields associated with conventional tillage systems (CP, DR, and MP) at all sites were not significantly different from those with ST, but all were significantly different from NT yields (Figure 3). The NT and ST systems yielded on average 5.6% and 8.7% less compared to conventional tillage systems. The only exception was a significant difference in yield between conventional tillage systems and NT or ST at sites in NW, NC, and SW. This suggests that the use of conventional tillage systems with aggressive soil disturbance is as effective as the minimum tillage system (ST), or in some sites (NT) regardless of the location in the state. Generally, the NT system resulted in lower yields compared to conventional systems. That was more evident in the northern sites (11.6% yield decline) than in the southern sites (6.9% yield decline). The observed yield decline in the NT system is most likely attributed to early spring wet and cold soil temperature conditions in the northern part of the state. A cooler spring soil temperature as a result of residue cover under NT is associated with slow early spring corn development. These conditions are more dominant in the northern sites in Iowa, where poorly-drained soils and cold soil temperature exists. For instance, at the northeast site (Nashua), the difference between NT and conventional tillage systems was significant in most years.

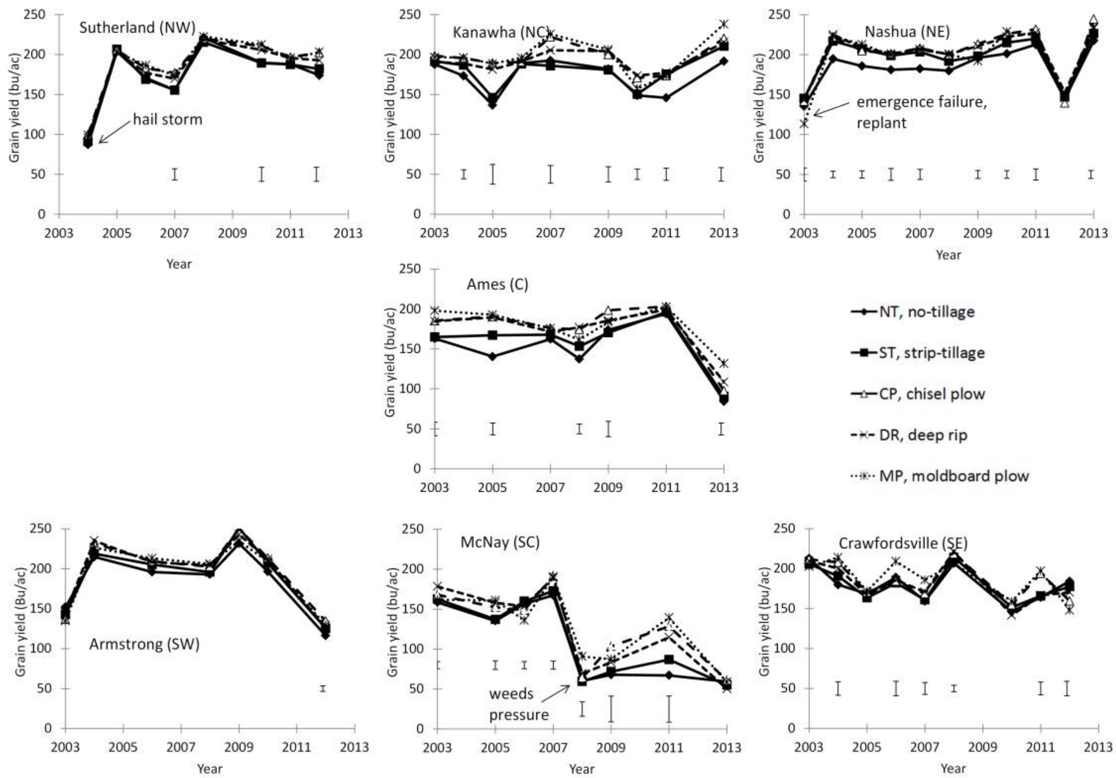

Figure 3. Corn yield response to different tillage systems in a corn-soybean rotation of long-term study across Iowa.

Summary

A few things we need to keep in mind in deciding on soil tillage: 1) tillage will destroy soil structure and during rain events will lead to sealing of the soil surface and a significant amount of soil erosion and surface runoff, and 2) tillage will compromise any chance for recharging the subsoil that is needed to make up for the water depletion during the growing season. These two effects by tillage are results of lack of adequate residue cover on the soil surface.

Keep crop residue on the soil surface. Crop residue plays a significant role in soil sustainability. First and foremost it is the physical protection of soil from potential erosion during heavy rain events. Residue can reduce the impact of rain drops by absorbing and reducing the magnitude of kinetic energy of rain drops to create a slow water movement, thus reducing soil erosion and increasing the time opportunity for water to penetrate the soil leading to a better water recharge to the subsoil, where this becomes a yield saver during the growing season. The effectiveness of residue in achieving those things depends on how it will be managed. This starts during harvest by cutting corn at 12 inches at least above the ground. The upright residue can be very effective in trapping soil moisture in terms of snow and slow water movement. Residue should be kept intact to increase its effeteness. Shredding or chopping residue can create a lot of problems in terms its ability to reduce soil erosion and potential washout during high intensity rain events.

To achieve the above, conservation tillage systems such as no-till and strip-tillage must be implemented. Studies in many parts of the country and elsewhere show that full-width tillage is not the best solution for improving productivity, soil quality, energy use, labor, and time. Many conservation systems such as strip-tillage, where a tilled zone of 8 inches wide and 6-8 inches deep is done can work as good as full width tillage. This system is very efficient and effective in nutrient placement, where tillage and nutrients application can be done in one trip. To have an effective strip-tillage system the following needs to be consider or implemented:

- Right-Time: Fall is the preferred time-immediately after harvest.
- Right-Moisture: reasonably dry soil after harvest.
- Right-depth: 6-8 inches is as effective as deeper depths.
- Right-Attachments: include cover discs, shallow knives, and residue cleaners.
- Right-Site: Avoid use of ST on sloped fields.

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