Nutrient Management { in No-till and Minimum Till Systems

photo courtesy of Dry Fork Ag at Ledger, Montana

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Nutrient availability can differ somewhat among no-till, minimum till and till systems. This guide explains how nutrients should be managed in no-till and minimum till systems to optimize crop yield and quality.

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Introduction

With increased acres of no-till and minimum till in Montana, it has become important to describe differences in nutrient availability and recommended fertilizer application practices between no-till, minimum till and conventional till systems. In addition, no-till practices have changed the surface layer which affects soil nutrients both at the surface and deeper in the soil profile. An understanding of nutrient availability differences among tillage systems should prove useful in optimizing fertilizer use and crop yields.

Conventional till is often considered to be tillage that inverts the soil and has become relatively rare in Montana over the past few decades. Minimum tillage systems leave crop residue on the field, providing 15 to 30 percent surface coverage and causing minor soil disturbance. Examples of minimum till systems include:

- stubble mulching (tillage that leaves stubble on the soil surface)
- fewer tillage passes
- sweep tillage
- strip tillage

In addition, surface residue coverage increases further as tillage intensity decreases (e.g. ridge till and mulch till), with maximum surface residue coverage in no-till systems.

In 2004, approximately 28 percent of Montana's cropland was no-till, whereas 22 percent was in minimum till (CTIC, 2004). The large conversion to either no-till or minimum till occurred because these systems offer several advantages over conventional till systems. For example, conversion to no-till and minimum till systems can increase crop yields, save on fuel costs, reduce soil erosion and decrease water runoff.

Research has shown that no-till and minimum till systems influence:

- water infiltration
- soil moisture
- soil temperature
- nutrient distribution (or 'stratification')
- soil aeration
- microbial populations and activity

These factors each affect soil nutrient availability. Information in this guide will help producers and their advisers optimize nutrient availability and crop yields in both no-till and minimum till systems.

Two nutrient cycling processes, nitrogen (N) "mineralization" and nutrient "stratification," appear to have the highest likelihood of being affected by the degree of tillage. This guide will focus on these two processes.

Differences in Nitrogen Mineralization

BACKGROUND

Soil organic matter (SOM) is composed of decomposing plant and animal residues, cells and tissues of soil organisms and well-decomposed substances. Though living organisms are not considered within this definition, their presence is critical to the formation of SOM. For example, crop residue is converted to stable SOM by the action of bacteria, fungi and larger organisms (e.g., rodents and earthworms). In breaking down both crop residue and SOM, organisms release plant available nitrogen (N) in a process called "mineralization." Tillage breaks up organic particles and soil aggregates (clumps of soil), thereby increasing surface area and aeration. This increases the rate of N mineralization, but often decreases SOM levels, which is the source of mineralizable N.

A major advantage of no-till systems in the northern Great Plains is that they generally maintain or increase SOM content (McConkey et al., 2002). Unfortunately, building SOM requires N. To gain 1 percent SOM in the upper 6 inches of soil, it takes approximately 1,000 pounds of N per acre (lb N/ac) above crop needs (assuming a 20:1 SOM:N ratio). That amount cannot be added all at once, but needs to be added over time, likely decades. If additional N is not added to no-till and minimum till systems, crop yields will often suffer due to inadequate amounts of available N. This, in turn, adds less roots and stubble to the soil system, lowering the amount of SOM accumulation, reducing N mineralization, and thus, reducing available N in future years. Finally, crop residue left on the surface, as a result of less tillage,

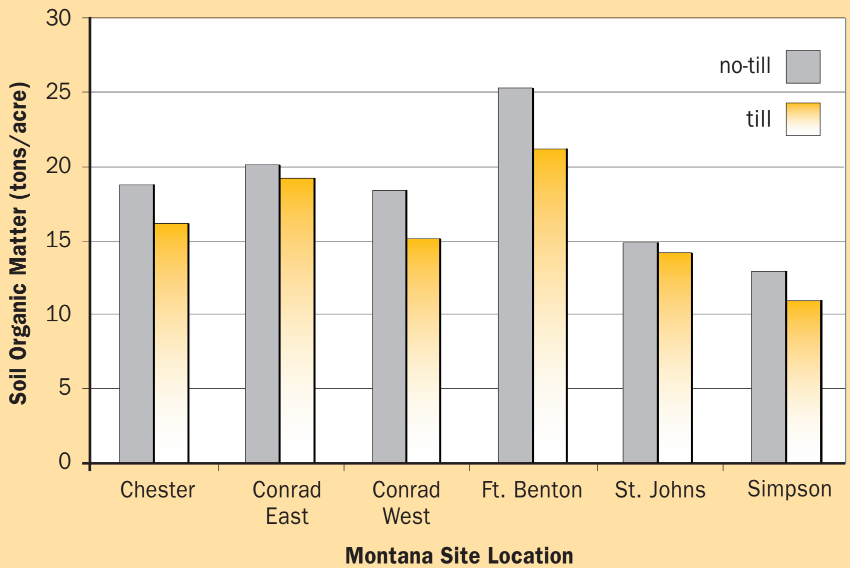

FIGURE 1. Soil organic matter in Montana in the 0 to 8 inch soil depth 6 to 10 years after the conversion to no-till (Bricklemyer et al., 2007). Soil organic matter does not include surface residue.

affects soil temperature and moisture content, which affects both N mineralization and the efficiency of N fertilizer use.

SUMMARY OF STUDIES

In no-till systems within Montana, SOM was generally higher in the top 8 inches of soil than in conventional till systems (Figure 1). In a wheat-fallow system in Western Nebraska, soil organic N (SON) over a 12-year period was reduced 3 percent and 19 percent in no-till and conventional till systems, respectively (Figure 2). The most practical approach to increase or conserve SOM and SON is by reducing tillage intensity and by maintaining more crop residue through conservation tillage and minimum tillage systems.

In sub-humid north-central Alberta, broadcast urea (60 lb N/ac) produced higher barley yield increases under conventional till compared to plots under 1 to 6 years no-till; however, in the same experiment when urea was banded, yield increases were similar between no-till and conventional till (Malhi and Nyborg, 1992). These results suggest that urea was either immobilized or lost to the atmosphere (ammonia volatilization). Ammonia volatilization refers to the loss of ammonia (NH_3) from the soil as a gas and is associated with soil pH greater than 7, warm soil temperatures, higher levels of surface residue and moist soil. Ammonia volatilization is more likely to occur in no-till systems because there is less incorporation of broadcast N into the soil. For more information on ammonia volatilization,

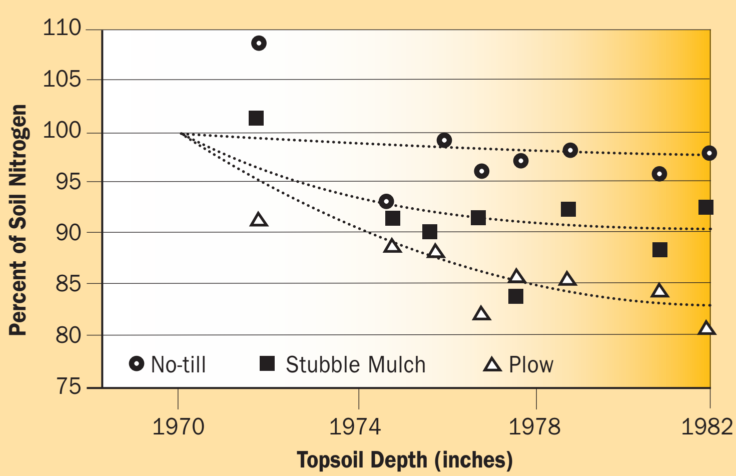

FIGURE 2. Soil nitrogen decreased approximately 19 percent, 8 percent and 3 percent in 12 years with conventional, stubble mulch and no tillage practices in wheat-fallow in western Nebraska (Lamb et al., 1985).

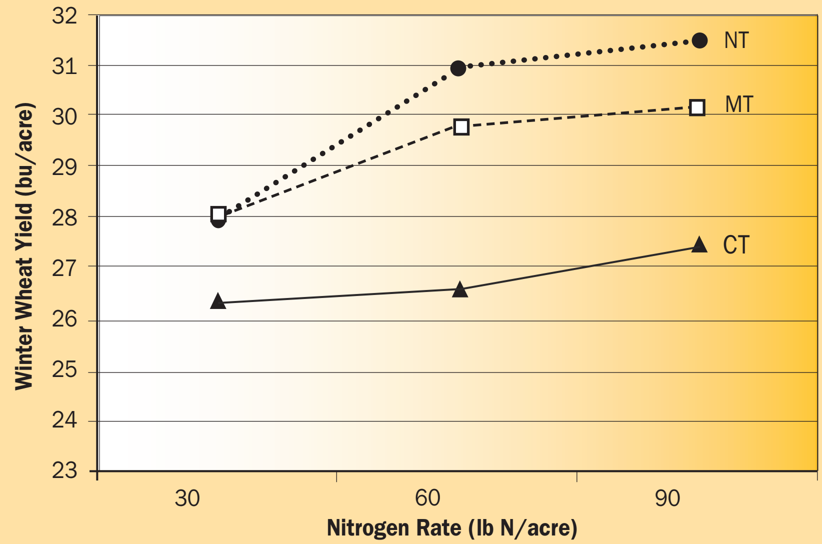

FIGURE 3. Grain yields (near Mandan, North Dakota) under no-till (NT), minimum till (MT) and conventional till (CT). Twelve year average for 30, 60 and 90 pounds of nitrogen per acre per year (lb N/ac/yr) applied as ammonium nitrate (Halvorson et al., 1999).

refer to *Management of Urea Fertilizer to Minimize Volatilization* (EB173). See "Extension Materials" at the back of this publication for the Web address and ordering information for all Extension documents referenced in this bulletin.

In a study at Moccasin, Montana, spring wheat yields following winter wheat after 9 years of no-till were slightly lower than in paired, minimum till fields (Chen and Jones, 2006). However, the N rates needed to optimize yields were nearly identical, suggesting similar rates of N mineralization between no-till and minimum till systems. In the Golden Triangle (an area of Montana from Cutbank to Havre to Great Falls), wheat yields following fallow averaged 13 percent higher in no-till than conventional till plots over a 3 year study (Bricklemyer and Miller, 2006). The differences strongly suggest that the degree of tillage, climate and/or even soil properties may be affecting relative yields. At Moccasin, only 1 tillage pass (3 inch, sweep) per year was used, whereas in the Golden Triangle, an average of 2.5 passes per year were used primarily with a chisel plow, which generally incorporates all surface residue into the soil (Bricklemyer, 2006). In addition, much shallower soils at Moccasin make no-till less important in storing water than in the Golden Triangle for crop growth.

Soil N availability in Saskatchewan was generally less under both fallow and continuous no-till than conventional till, even 8 to 12 years after conversion to no-till, and despite applying approximately 5 lb N/ac more each year to no-till than conventional till (McConkey et al., 2002). Grain yields and protein were generally less in no-till than conventional till in fine- and medium-textured soil, but often higher in no-till systems in coarse soils. The difference was attributed to less N mineralization in finer soils under no-till due to lower soil temperatures, protection of SOM within soil aggregates and/or from less oxygen movement and N mineralization in finer soils. The authors concluded that slightly more N would need to be applied in fine- and medium-textured no-till soils for up to 15 years after conversion to no-till to attain similar grain yields and protein levels as in conventional till systems.

In a 12 year study in North Dakota, no-till and minimum till systems made better use of medium to high N fertilizer rates than did conventional till systems, indicating a superior yield response to N in no-till systems (Figure 3).

Much less N was needed in 25 year no-till than short-term (3 years) no-till to achieve the same yield and protein (Figure 4). Part of the reason for these large differences may have been that the 3 year no-till was previously under conventional till for approximately 20 more years, likely depleting SOM prior to tillage management conversion. At the time of the study,

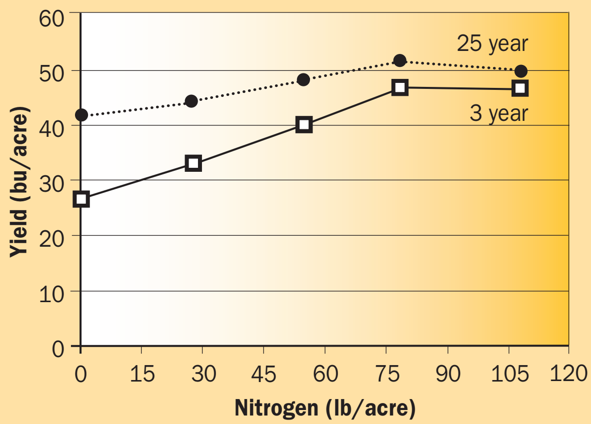

FIGURE 4. Spring wheat grain yield and protein response to fertilizer nitrogen (N) in long-term (25 year) vs. recently converted (3 year) no-till fields (Lafond et al., 2005).

SOM was 24 percent higher in the 25 year no-till than in the 3 year no-till (Lafond et al., 2005). In Alberta, the percentage of N mineralized from pea, canola and wheat crop residues over a one year period was the same for no-till as for conventional till 6 to 7 years after conversion (Lupwayi et al., 2006a). Therefore, the slightly lower N needs under conventional till in the short-term are likely due to faster and greater tillage-induced N release from existing SOM in conventional till systems opposed to prior year's crop residue in no-till systems. However, the higher N needs for no-till are short-term. For example, in Sidney, Montana, continuous spring wheat was either spring-tilled or no-till since 1972 (Eckhoff, unpublished data). April soil sampling in 1997 revealed that levels of nitrate-N were not different between spring-tilled and no-till in each of the top three 1 foot increments. Phosphorus (P), potassium (K) and sulfur (S) were also not different in the top 1 foot increments between tillage systems. Therefore, in very long-term no-till, fertilizer rates likely do not need to be adjusted compared to minimum till systems.

These studies show that N responses among tillage systems are not always consistent. This is apparently due to differences in soil texture, climate, time since conversion from conventional till and degree of tillage; therefore, there is not a "one size fits all" recommendation for each tillage system. However, some general N management recommendations can still be made based on the general findings that mineralization is less and water savings are somewhat more in no-till systems.

NITROGEN MANAGEMENT RECOMMENDATIONS

When possible, apply N below the soil surface to minimize immobilization and volatilization. When banding, place N about 2 inches beside and/or below the seed row. Because "2 x 2" seeders are not very common, an alternative approach is to put N with the seed using a wide opener (4 inches or greater) to minimize germination problems. In addition, consider injecting liquid solutions (such as anhydrous or urea ammonium nitrate [UAN]), incorporating granular fertilizer with irrigation (or rain) when possible, applying urea prior to seeding for partial incorporation with the seeding tool and/or applying urea during cool periods (Jones et al., 2007).

Although fertilizer practices and rates are relatively the same between no-till and conventional till systems, stubble decomposition in no-till tends to tie-up soil N and surface-applied N. Therefore, apply more N the first few years after conversion to no-till, especially when surface broadcasting N on fine- to medium-textured soils. The amount of additional broadcast N to apply in no-till systems is approximately 10 lb N/1000 lb stubble up to a

CALCULATION BOX. Nitrogen adjustments for remaining stubble.

Grain Weight Calculation:

Grain Weight = Last Year's Yield (bu/acre) x Test Weight[a] (lb grain/bu) = 50 bu/acre x 60 lb/bu = 3000 lb grain/acre

Stubble Weight Calculation:

Spring Wheat: Stubble Weight = 3000 lb grain/acre x 1.33 lb stubble/lb grain = 4000 lb stubble/acre

Winter Wheat: Stubble Weight = 3000 lb grain/acre x 1.67 lb stubble/lb grain = 5000 lb stubble/acre

Stubble Remaining Calculation (Spring Wheat Example):

Stubble Remaining = Stubble Weight (lb stubble/acre) - Stubble Baled/Removed (lb stubble/acre)
= 4000 lb/acre – 2000 lb/acre
= 2000 lb/acre

Nitrogen Adjustment for Stubble Remaining Calculation (Spring Wheat Example):

N adjustment for stubble remaining = 10 lb N/1000 lb Stubble x Stubble Remaining (lb/acre)
= 10 lb N/1000 lb x 2000 lb/acre
= 20 lb N/acre (add this to N rate, up to 40 lb N/acre[b])

NOTE: For crop-fallow systems, use ½ of the N amount calculated here to account for stubble decomposition over the fallow year.

[a] Table 21 from EB 161 or measured at grain elevator
[b] Montana research indicates that additional nitrogen is not needed

maximum of 40 lb N/acre (Calculation Box). If N is banded below the surface, apply slightly more N for no-till than conventional till in finer soils. On coarse, no-till soils, band similar N amounts as conventional till. In the long-term (greater than 5 to 15 years), less N will likely be needed to maximize yield and protein in no-till systems, especially if more N has been added in the short-term.

Apply starter N in recropped no-till systems due to cooler soil temperatures and generally low soil N on recrop. Cooler soil temperatures delay and reduce early season N mineralization, reducing N availability. Therefore, a starter N application at seeding followed by one (or more) in-season N applications should improve the efficiency of N fertilizer. Refer to Nutrient Management (NM) Module 11 (#4449-11) for more information on fertilizer placement and timing.

Sound N management is key to a successful fertilizer program in no-till and minimum till systems. Refer to *Developing Fertilizer Recommendations for Agriculture* (MT200703AG) for more information on N fertilizer recommendations.

Differences in Nutrient Stratification and Uptake

BACKGROUND

Stratification refers to the accumulation of soil nutrients in certain areas more than in others. Plants convert sunlight, water and nutrients into organic cells as they construct leaves, stems and seeds. Plant roots grow deep into the soil, scavenging for water and nutrients. As the plants mature, leaves senesce and drop back onto the soil surface where they begin to decay. As plant residues decompose, nutrients are released back into the soil, with greater levels at the soil surface. This cycle is repeated each season and is compounded by surface fertilization, creating a soil surface rich in nutrients, but depleted at depth. Certain fertilizers, such as P, are less mobile than others (e.g. N) and tend to accumulate in surface layers. Stratification, both vertical and horizontal, is expected to occur more in no-till and minimum till systems due to less soil mixing by tillage.

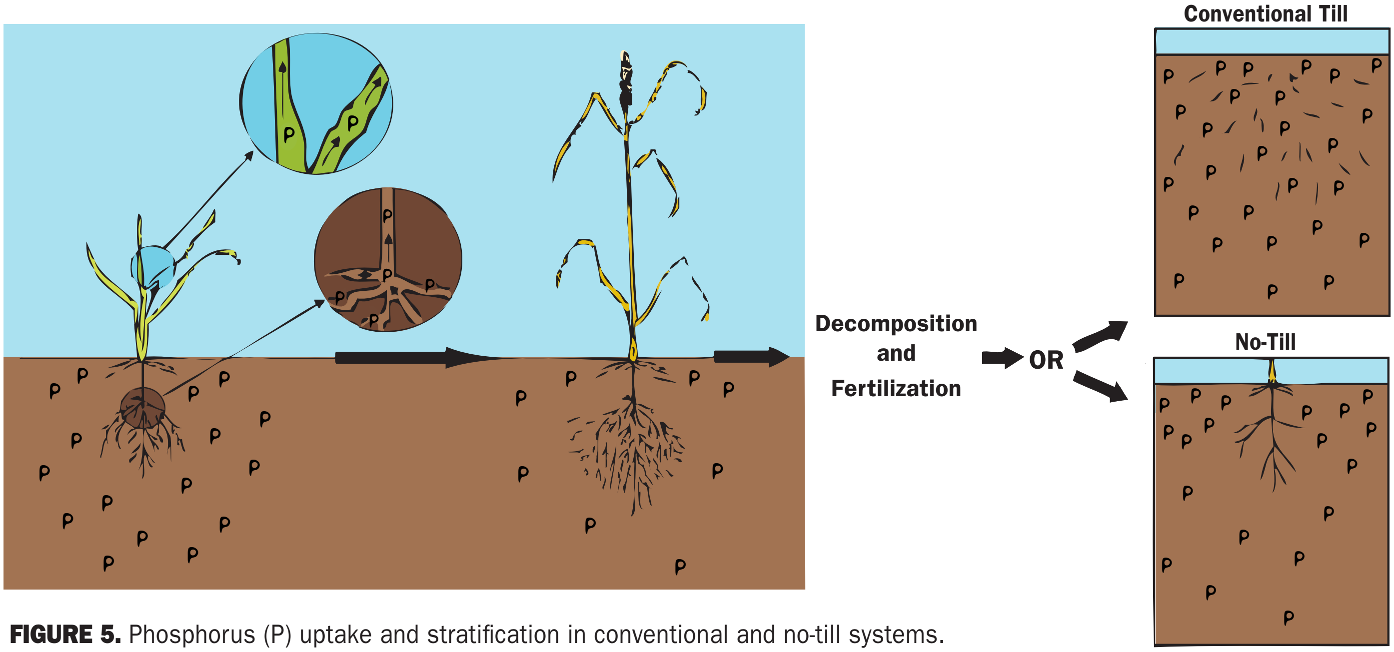

FIGURE 5. Phosphorus (P) uptake and stratification in conventional and no-till systems.

SUMMARY OF STUDIES

No-till and minimum till systems often result in greater stratification of soil nutrients than conventional till systems in both western Canada and Montana (Grant and Bailey, 1994; Lupwayi et al., 2006b; Jones and Chen, 2007). Specifically, no-till and minimum till systems coupled with broadcast and seed-placed P fertilizer applications have led to the accumulation of available P in the surface and a depletion of available P deeper in the soil profile (Figure 5). Although differences in soil P stratification between tillage systems have been observed, no significant differences in P uptake by wheat have been found.

In the 0 to 2 inch soil layer, soil N and K levels have been found to be greater under no-till than conventional till, gradually decreasing to similar levels as conventional till below this layer (Grant and Bailey, 1994; Lupwayi et al., 2006b). Despite stratification of K, tillage type was not found to affect K uptake by wheat (Lupwayi et al., 2006b).

Because roots grow toward higher concentrations of nutrients (Figure 6), stratification affects root growth distribution. In addition, lateral roots near the surface are more prone to drying out (Drew, 1975), thereby reducing nutrient uptake. Therefore, subsurface application of P is preferred to surface application.

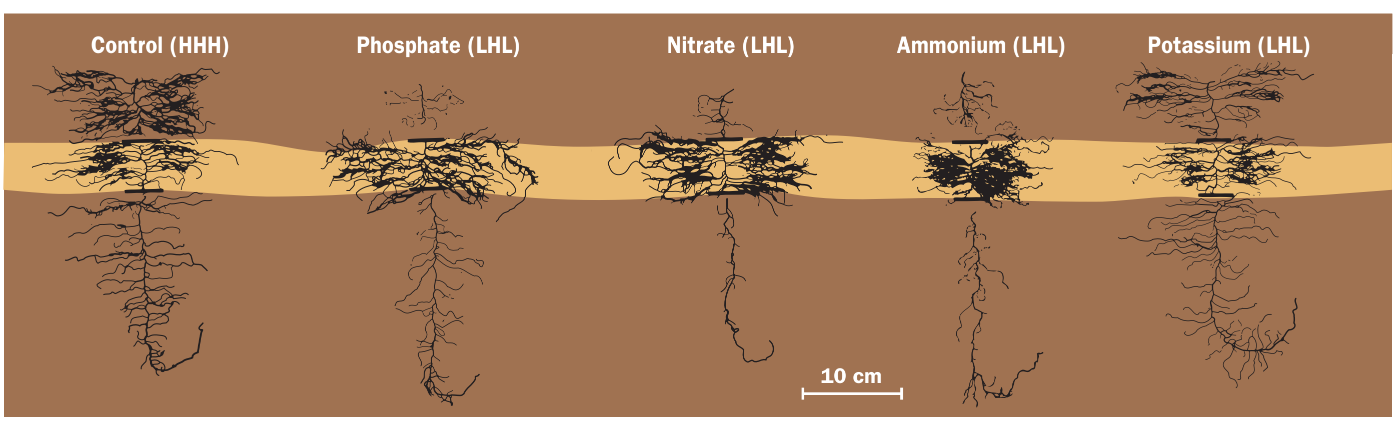

FIGURE 6. Effect of localized high (H) supplies of phosphate, nitrate, ammonium and potassium on root form. Control plants (HHH) received the complete nutrient solution to all parts of the root system. Treatment plants (LHL) received the complete nutrient solution only in the middle root zone and the top and bottom root zones were supplied with a solution low (L) in the specified nutrient. All plants were grown in a controlled environment room (Drew, 1975).

Due to horizontal stratification, more soil samples have been found to be needed in no-till and minimum till systems to accurately characterize a field. Specifically, twice as many samples per composite were found to be needed in no-till than conventional till to be 95 percent confident in the average nitrate level (0 to 2 feet) when the data were averaged for ⅔, 1⅓ and 2 inch diameter cores (Kanwar et al., 1998).

MANAGEMENT TO COUNTER STRATIFICATION

It is highly recommended to sub-surface band P and K with the seed or ideally about 2 inches below the seed to promote deeper root growth and avoid stranding these nutrients near the soil surface. In addition, application of P in a compact band may slow the conversion of fertilizer P to less soluble compounds (Grant and Bailey, 1994). A final reason to band P is that less P is needed for a similar response than broadcasting (Randall and Hoeft, 1988). All fertilizer rates should be based on soil test results. Refer to *Developing Fertilizer Recommendations for Montana Agriculture* (MT200703AG) for more information.

Although fairly high levels of P can be banded directly with the seed, only 10 to 30 lb/ac of K_2O + N are recommended with the seed for germination reasons (Jacobsen et al., 2005). Specifically, no more than 30 lb/ac of K_2O + N for barley and 25 lb/ac of K_2O+N for wheat are recommended. This is less of a concern with wider openers that minimize fertilizer-seed contact.

Because there are only slight and often non-significant differences in P and K availability between tillage systems, rates for these two nutrients likely do not need to be different among tillage systems. However, to adequately characterize P and K levels when soil sampling, at least twice as many soil samples are recommended in no-till and minimum till to accurately represent a field, especially when fertilizer has been routinely banded. These bands may persist at higher concentrations for 5 to 7 years (Stecker and Brown, 2001). For a good estimate of available P, measure Olsen P by soil sampling 6 inches below the soil surface regardless of tillage system (Jones and Chen, 2007).

Soil Erosion, Water Conservation and Temperature Differences

BACKGROUND

Successful long-term crop production requires management to conserve soil nutrients and water. A single erosion event can remove significant amounts of nutrients because of the richness of the soil surface. In a forest or native range, the soil surface is nearly always covered by a plant canopy and the soil is netted together by live roots. This protects the soil from the forces of wind and water. In contrast, soils that are tilled leave the soil surface exposed and vulnerable to soil erosion by wind and water. Topsoil loss may decrease the soil's ability to store precious soil water.

No-till systems mimic natural systems by keeping the soil surface covered with residue and by binding the soil aggregates together with plant roots. During fallow periods, decomposition of plant material continues and the soil erosion protection provided by crop residue diminishes.

In natural systems, overland flow of water rarely occurs. Water coming from precipitation generally infiltrates into the soil where it falls. In cropped systems, this is not always the case. In tilled soils, as little as ¼ inch of rainfall can cause surface runoff because of sealed soil pores which reduce water penetration. Additional precipitation tends to run along the soil surface, moving downslope. Water moving along the soil surface can remove topsoil, soil water and available nutrients for subsequent crops. Further, in dryland production regions, any substantial amounts of runoff typically result in yield loss.

Surface crop residue in no-till and minimum till systems insulates the soil surface and has greater reflective properties than exposed soil surfaces, reducing the amount of heat absorbed and keeping soil temperatures cooler. Cooler temperatures can, in turn, decrease nutrient availability.

Reducing soil erosion, increasing water conservation and understanding the effects of soil temperature on nutrient availability in no-till and minimum till systems should help reduce nutrient loss, conserve water and maximize yield.

TABLE 1. Wind erosion rates estimated with the RWEQ model (Merrill et al., 1999) and estimated nitrogen and phosphorus losses for conventional, minimum and no-till in wet and dry years.

Tillage System	Soil Loss		Nitrogen Loss[a]		P_2O_5 Loss[a]	
	tons/ac		lb/ac			
	Wet	Dry	Wet	Dry	Wet	Dry
Conventional Till	0.062	10	0.15	25	0.08	28
Minimum Till	0.068	7	0.16	17	0.08	19
No-Till	0.002	5	< 0.01	11	< 0.01	13

[a] Assumes soil contains 0.12 percent nitrogen and 0.06 percent phosphorus

SUMMARY OF STUDIES

In the Great Plains, erosion can remove significant amounts of nutrients. In a study conducted in North Dakota, substantially more soil was determined to be eroded by wind under conventional till than no-till, especially in drier soils (Table 1). In addition, a soil loss of 5 tons/ac per year, the rate considered acceptable by NRCS for soil conservation purposes, equates to an approximate loss of 11 lb of N/ac and 13 lb of P_2O_5/ac. In Montana, about 28 lb P_2O_5/ac are removed by a 45 bu/ac wheat crop, identical to the estimated amount lost by conventional tillage in a dry year, emphasizing the magnitude of these potential nutrient losses from soil erosion.

Maintaining crop residue is important for harvesting winter precipitation due largely to greater snow catch and lower evaporation rates. A wheat-fallow study in Mandan, North Dakota (Bauer and Tanaka, 1986) found that 13 to 15 inches of stubble stored 1 more inch of soil water than 2 inches of stubble, largely due to differences in snow catch (Figure 7).

Stubble height has also been found to significantly increase spring wheat grain yield due to increased growing season water use efficiency (WUE) (Cutforth and McConkey, 1997). Water use efficiency is the crop yield per unit of water. Increased yield and WUE were attributed to favorable microclimate growing conditions provided by crop stubble, lower surface soil temperatures and reduced evapotranspiration losses due to decreased wind speed on the soil surface. In addition, after 7 years, improved soil physical and chemical conditions in no-till annual cropping treatments resulted in higher infiltration rates in both dry and wet soil (Pikul and Aase, 1995). Increased water infiltration generally increases the ability of nutrients to move through the soil and, therefore, there is less chance they will be limiting. More soil water not only increases yield potential but should also increase N availability due to increased N mineralization. Within the season, higher residue levels help to moderate soil temperatures, thus reducing evaporative losses and maintaining a better micro-environment for crops. Higher moisture content near the surface of no-till systems has been found to promote higher root distribution near the surface (Moroke et al., 2005). This is advantageous in areas that receive frequent small rains, but a disadvantage in much of Montana where the majority of root water uptake during grain fill occurs from the subsurface.

According to Moroke et al. (2005), sorghum, cowpea and sunflower experienced greater grain yields, greater root length densities and correspondingly greater decreases in water content deeper in the

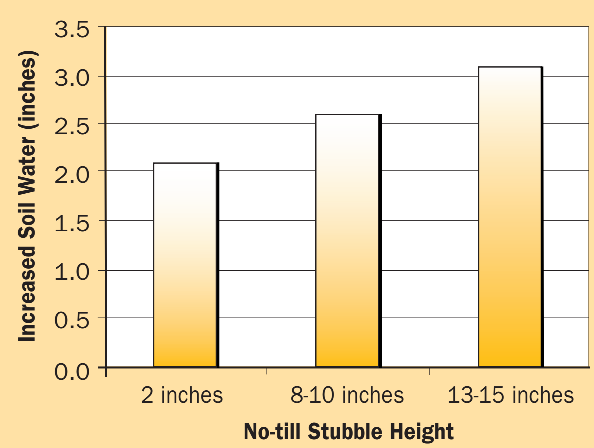

FIGURE 7. Effect of stubble height on soil water content change from fall to spring for a 4 foot depth in wheat-fallow at Mandan, North Dakota (Bauer and Tanaka, 1986).

profile in no-till compared to stubble mulch till. This suggests that water was extracted from deeper depths under no-till as a result of improved access to stored soil water deeper in the profile as well as reduced evaporation near the surface (Moroke et al., 2005).

RESIDUE MANAGEMENT

Managing crop production in no-till or minimum till systems helps conserve resources including water and nutrients. There are still management changes that can be made to better conserve these resources. For example, keep stubble height as tall as possible to maximize yield, available water and water use efficiency and to decrease soil erosion. For greater water conservation, minimize field operations to keep stubble standing as high as possible for both increased snow catch and shading. Again, when possible, place fertilizers below surface residue to minimize immobilization.

Conclusions

Overall, there are only small differences in recommended fertilizer rates, placement and timing among tillage systems. However, somewhat more care is needed in no-till and minimum till systems due to lower N mineralization rates and greater potential for nutrient stratification. In no-till and minimum till systems, N rates need to be slightly increased in the short-term (less than 5 to 15 years, depending on the field) to maximize yield and build SOM to save on N in the long-term. In general, P and K rates do not need to be adjusted based on tillage system. Ammonia volatilization of N and stratification of P and K increases the potential for nutrient loss from the soil surface, especially in surface broadcast systems, therefore, sub-surface application of these nutrients is recommended. Starter fertilizer will generally be more effective in no-till and minimum till systems.

Most problems associated with no-till and minimum till fertilizer efficiency can be overcome with good fertilizer management. When feasible, increase soil nutrient levels to high levels before converting to no-till or minimum till. Finally, a top-notch soil testing program is necessary in any no-till or minimum till system to accurately determine fertilizer rates.

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