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 very rare in dryland production in Montana over the past few decades. Minimum tillage systems leave crop residue on the field, providing 15 to 30% 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.

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 2012, approximately 64% of Montana's cropland was no-till, 16% was in minimum till, and only 18% in conventional till *(1)*. The large conversion to either no-till or minimum till has 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 due to increased soil water, reduce soil erosion and water runoff, save on fuel costs, decrease water runoff, and saves time allowing more acres to be farmed.

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. A single tillage, when done during dry summer conditions, does not undo the soil health benefits obtained through long term no-till management *(2)*. 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 N in a process called "mineralization." Vigil et al. *(3)* found that N mineralization over a 20 week growing season averaged 32 lb N/acre per 1% SOM based on 16 studies in the U.S. and Europe. For a soil with 2% SOM in the top 6 inches, which is typical in Montana, this would equate to 64 lb N/acre of available N gain over 20 weeks. However, rates in Montana are likely less because of our generally drier, cooler, shorter growing season and have been estimated at closer to 30 to 40 lb N/acre over the growing season in a soil with 2% SOM in the top 6 inches.

Mineralization rate is site-specific, but can be increased with tillage. The break-up of crop residue and soil clods increases surface area and aeration. This increases the rate of organic matter decomposition and N mineralization. The end result is reduced 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 *(4)*. Unfortunately,

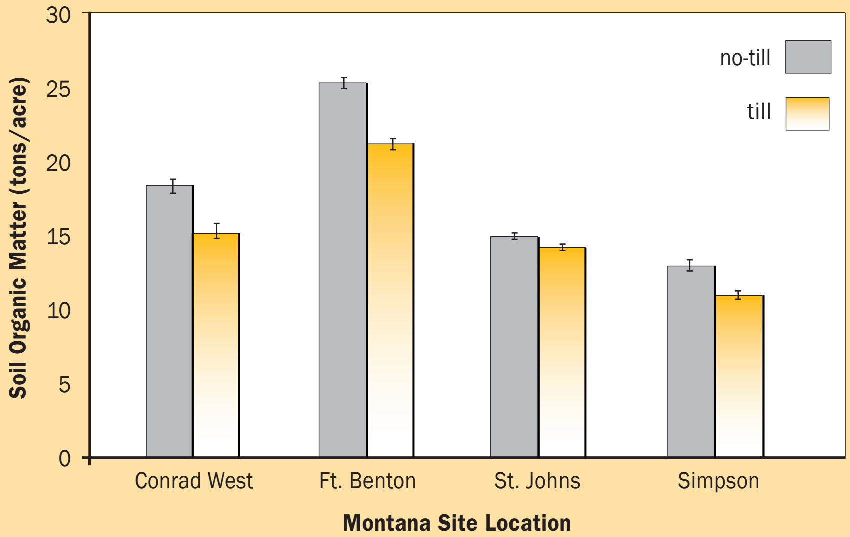

FIGURE 1. Soil organic matter in Montana in the 0 to 8 inch soil depth, 6 to 10 years after the conversion to no-till (*5;* soil organic matter does not include surface residue).

building SOM requires N. To gain 1% SOM in the upper 6 inches of soil, it takes approximately 1,000 lb N/acre 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, affects soil temperature and moisture content, which affects both N mineralization and the efficiency of N fertilizer use.

SUMMARY OF STUDIES

Mineralization of previous crop residue and existing SOM is an important N source. 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% in no-till and 19% in conventional till systems (Figure 2). The most practical approach to increase or conserve SOM and SON is by reducing tillage intensity and by maintaining more crop residue on the soil surface through conservation tillage and minimum tillage systems.

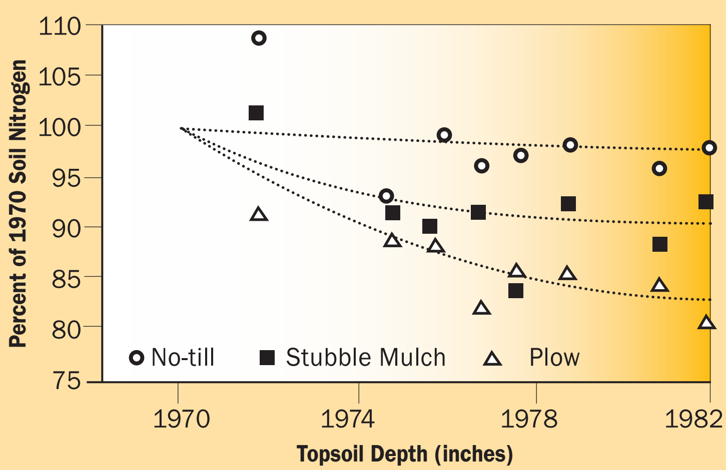

FIGURE 2. Soil nitrogen decreased approximately 19%, 8% and 3% in 12 years with conventional, stubble mulch and no tillage practices in wheat-fallow in western Nebraska *(6).*

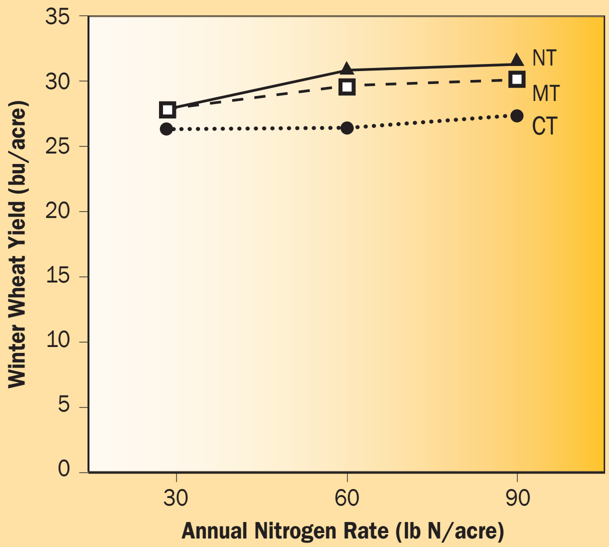

FIGURE 3. Twelve-year average grain yields near Mandan, North Dakota, under no-till (NT), minimum till (MT) and conventional till (CT) with 30, 60 or 90 lb N/acre per year applied as ammonium nitrate *(10)*. Yields were NT=MT>CT at 30 lb N/acre and NT>MT>CT at 60 and 90 lb N/acre.

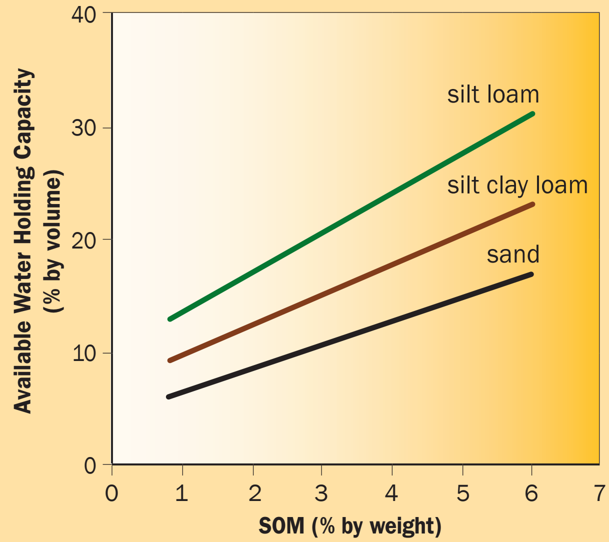

FIGURE 4. Soil available water holding capacity increases with increased soil organic matter (SOM) at different rates depending on soil texture *(11)*.

Although no-till helps increase SOM, replacing crop-fallow with annual cropping does more to increase SOM than reduced tillage *(7)*. This may not be possible in areas with limited precipitation. However, because no-till traps and stores more water, it allows for more frequent cropping.

Total soil N is generally greater under no-till than conventional till. No-till had 70 to 425 lb N/acre more than conventional tilled fields in Saskatchewan *(4)*. However, because SOM decomposition is slower in no-till than conventional-till, soil nitrate-N can be less under no-till than minimum or conventional till, especially in the spring *(4, 8)*. Therefore, no-till fields may need more fertilizer-N, at least in the short term. In a study at Moccasin, Montana, peak wheat yields were reached with 40 lb N/acre on minimum till fields, whereas no-till fields required 80 lb N/acre fertilizer to reach the same yield *(9)*.

Based on Saskatchewan trials 8 to 12 years after conversion to no-till, the apparent N deficiency of crops under no-till is higher in finer soils and with higher soil moisture *(4)*. In sandy soils, spring soil tests indicated no-till needed about 18 lb N/acre more than conventional till to produce greater or equal yields between the tillage systems. In contrast, when N rates were based on spring soil tests yields on no-till were generally lower than on conventional till in fine and medium textured soils. This implies that N recommendations based on spring soil tests overestimated the contribution of N from SOM. Less N mineralization in finer soils under no-till is due to lower soil temperatures, protection of SOM within soil aggregates and/or from less oxygen movement in fine than coarse soils.

Over a 12 year period in North Dakota, wheat yields on no-till and minimum till systems were higher than with conventional till at all fertilizer rates (Figure 3). This was especially true in drier years *(10)*. In dry years, the capture and storage of water by no-till increases the crops potential to use fertilizer N when compared to conservation tillage. If there isn't enough precipitation, the crop can't respond to fertilizer N.

Reducing tillage is more important in areas with fine to medium soils with limited precipitation. Stubble and residue catch snow and shade the soil surface, which preserves soil moisture. In contrast, the shallow soils, such as at Moccasin, generally get recharged with water every year. Minimum tillage in these clay-loam soils increased mineralization compared to no-till, which increased available soil N for increased yields when water was not limiting *(8)*. In shallow soils, the benefit of tillage to increase

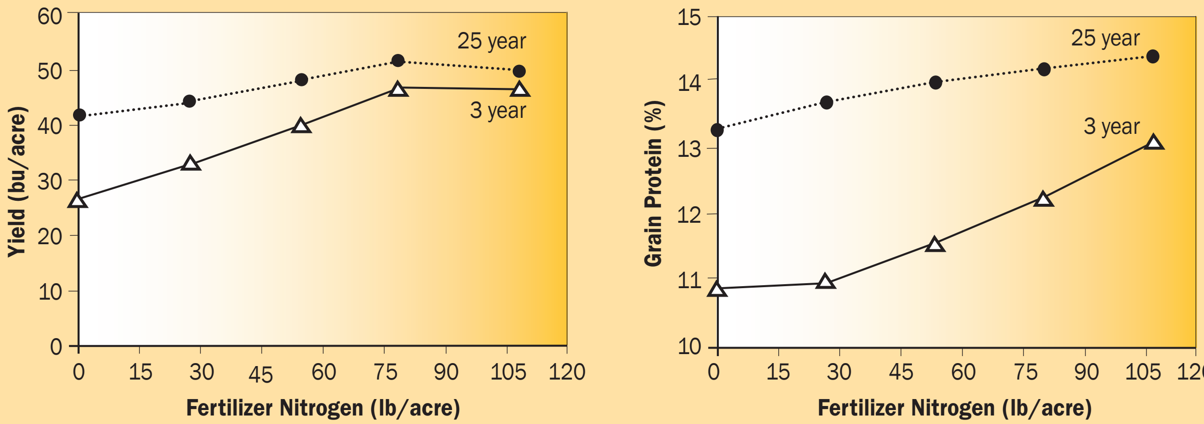

FIGURE 5. Spring wheat grain yield and protein response to fertilizer N in a long-term (25 year) vs. recently converted (3 year) no-till field in Saskatchewan *(12).*

mineralization outweighs the benefit of no-till to increase soil moisture – in the short term. However, in the long term, increasing SOM with no-till and continuous cropping would be an advantage to help store water (Figure 4).

There is no single suggestion on how much longer no-till may need more fertilizer-N than conventional till. The Saskatchewan study suggested no-till in medium and fine-textured soils may require more N for at least 15 years *(4)*. In another Saskatchewan study, much less N was needed following 25 years no-till than following only 3 years no-till to achieve the same yield and protein (Figure 5). Part of the reason for the large difference in N need may have been that the 3-year no-till was previously under conventional till for approximately 20 years. This depleted SOM prior to tillage management conversion. At the time of the study, SOM was 24% higher in the 25-year no-till than in the 3-year no-till *(12).*

Fertilizer placement also influences yield differences between tillage systems. In sub-humid north-central Alberta, 60 lb N/acre broadcast urea produced higher barley yields under conventional till compared to plots under 1 to 6 years no-till; however, when urea was banded, yield increases were similar between no-till and conventional till *(13)*. These results suggest that urea broadcast on no-till was either immobilized or lost to the atmosphere (ammonia volatilization). Ammonia volatilization is the loss of ammonia (NH_3) from the soil as a gas. This loss is more likely to occur because broadcast N is not incorporated into the soil in no-till systems and crop residue provides an environment that enhances volatilization loss. For more information on ammonia volatilization, refer to both *Factors Affecting Nitrogen Fertilizer Volatilization* and *Management to Minimize Nitrogen Fertilizer Volatilization*. See "Additional Resources" at the end of this publication for all Extension documents referenced in this bulletin.

These studies show that tillage effects on plant available N and yield varies with soil texture, degree of tillage, climate, and time since conversion from conventional till; therefore, a "one size fits all" recommendation for each tillage system is not possible. However, some general N management recommendations can be made based on the general findings that mineralization is slower and water savings are greater in no-till systems.

NITROGEN MANAGEMENT RECOMMENDATIONS

Spring soil tests provide a better indication of available N than fall tests. As SOM increases, its contribution to available N should be considered. Recent research has found combining potentially mineralizable N with soil nitrate-N greatly improved predicted grain N-yield over using soil nitrate-N alone *(14)*. Tests for potentially mineralizable N should be considered as they become available with reliable interpretations and calibrations for our region. MSU's fertilizer guidelines and on-line calculator (http://www.sarc.montana.edu/php/soiltest/) give an N "credit" if the previous crop

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 EB0161 or measured at grain elevator
[b] Montana research indicates that additional N is not needed

was a legume or if SOM is greater than 3%. MSU's small grain economic N rate calculator gives a 10 to 25 lb N/acre "credit" for each 1% SOM, depending on crop (http://landresources.montana.edu/soilfertility/small-grains-economic-calculator.html).

Plant residue can decrease plant available N through both volatilization and immobilization. Ideally urea is incorporated with at least a single ½-inch irrigation (or rain) event, or, placed about 2 inches beside and/or below the seed row to minimize volatilization losses and germination problems. Safe rates of seed placed N depend on the N source, row spacing and opener width. Some enhanced efficiency fertilizers are safer to place with seed than conventional urea and safe N rates increase as row spacing decreases or opener width increases *(15)*. Alternatively, consider injecting liquid solutions (e.g., liquid urea or urea ammonium nitrate [UAN]), adding compounds that inhibit fertilizer transformation to surface applied urea (e.g., N-(n-butyl) thiophosphoric triamide [NBPT], the active ingredient in Agrotain®), or using a nitrogen fertilizer such as calcium ammonium nitrate that has lower volatilization potential. See *Factors Affecting Nitrogen Fertilizer Volatilization* and *Management to Minimize Nitrogen Fertilizer Volatilization* for more information. Broadcasting fertilizer-N prior to seeding for partial incorporation with the grain drill did not reduce volatilization in a Montana study, likely because it did not fully incorporate the fertilizer prills *(16)*.

Because stubble decomposition in no-till tends to tie-up soil N and surface-applied N, 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 maximum of 40 lb N/acre (Calculation Box). If N is banded below the soil surface, apply slightly more N for no-till than conventional till in finer soils. On coarse soils, optimum banded N rates are similar between tillage systems. In the long-term (greater than 5 to 15 years), additional fertilizer-N will not likely be needed to maximize yield and protein in no-till systems, especially if more fertilizer-N has been added in the short-term. Including pea in rotation can off-set the higher N requirement of no-till compared to conventional till *(8)*.

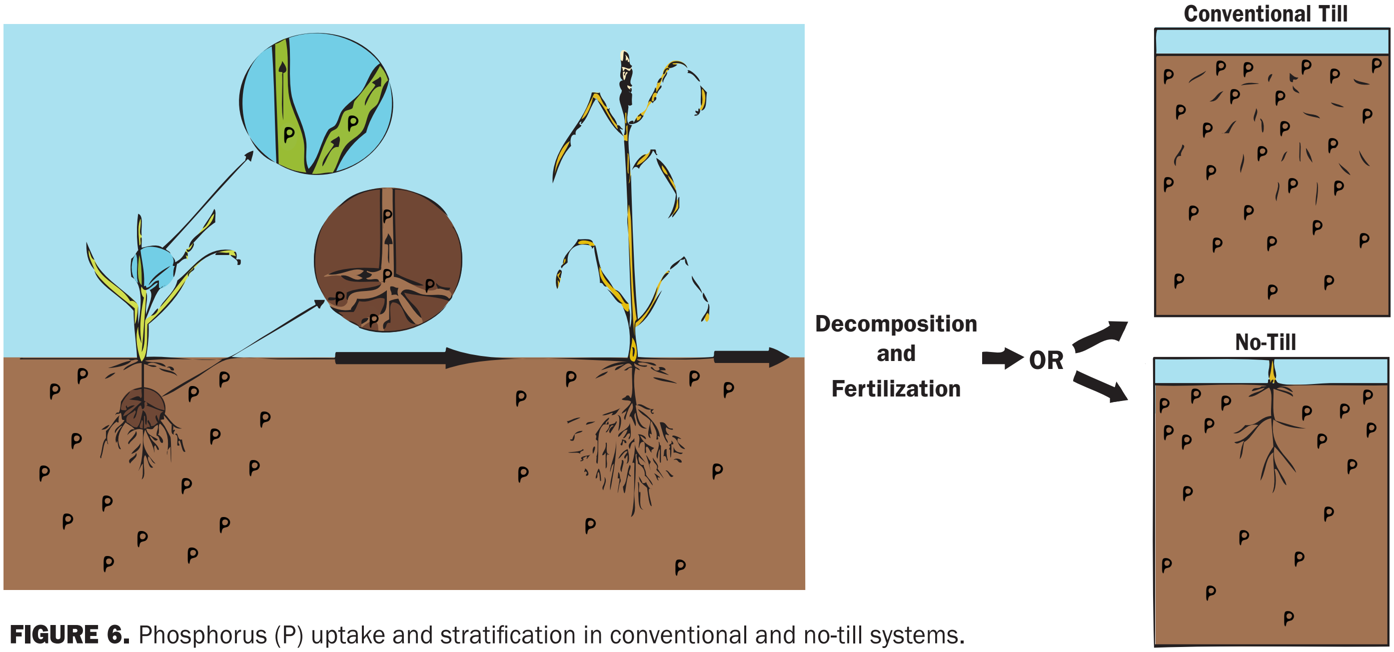

FIGURE 6. Phosphorus (P) uptake and stratification in conventional and no-till systems.

Apply starter N in recrop no-till systems due to cooler soil temperatures and generally low soil N if the previous crop was a small grain. 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 *Fertilizer Placement and Timing and Nutrient Uptake Timing by Crops: to assist with fertilizing decisions* 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 Montana Agriculture* for N fertilizer rate guidelines.

Differences in Nutrient Stratification and Uptake

BACKGROUND

Stratification refers to the accumulation of soil nutrients in certain areas more than in others. Both plant growth and fertilization can lead to stratification. 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 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 soils rich in nutrients at the surface but nutrient depleted at deeper levels. Certain nutrients, such as phosphorus (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.

SUMMARY OF STUDIES

No-till and minimum till systems often result in greater stratification of soil nutrients than conventional till systems *(17, 18, 19)*. 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 6). Yet in these studies, no significant differences in P uptake by wheat were found.

In the 0 to 2-inch soil layer, soil N and potassium (K) levels were found to be greater under no-till than conventional till, gradually decreasing to similar levels between tillage systems below this layer *(17, 18)*. Despite stratification of K, tillage type was not found to affect K uptake by wheat *(18)*.

Because roots grow toward higher concentrations of nutrients (Figure 7, page 8), stratification affects root growth distribution. Lateral roots near the surface are more prone to drying out *(20)*, thereby reducing nutrient uptake. Therefore, subsurface application of P is preferred to surface application.

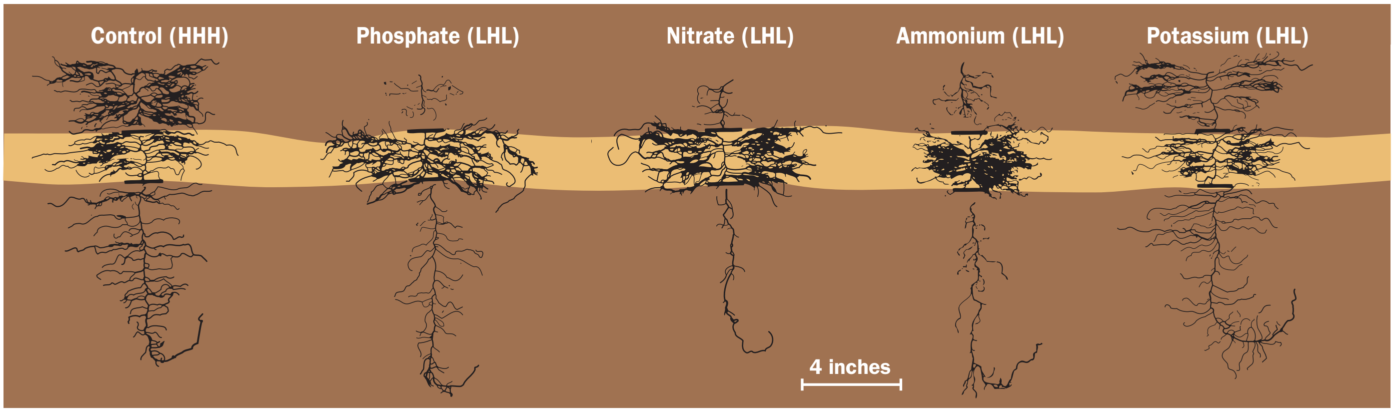

FIGURE 7. Effect of localized high (H) supplies of phosphate, nitrate, ammonium and potassium on root form. Control plants (HHH) received the complete nutrient solution to all parts of the root system. Treatment plants (LHL) received the complete nutrient solution only in the middle root zone and the 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 *(20).*

Banded fertilizer leads to horizontal stratification, especially in no-till and minimum till systems. Fertilizer bands may persist at higher concentrations for 5 to 7 years *(21)*.Therefore more soil samples are needed in no-till and minimum till systems to accurately characterize a field. Twice as many soil sub-samples per composite were necessary in no-till than conventional till to be 95% confident in the average nitrate level (0 to 2 feet) when the data were averaged for ⅔-, 1⅓- and 2-inch diameter cores *(22).*

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 *(17)*. A final reason to band P is that almost half as much P is needed when banded rather than broadcast for a similar response *(23)*. All fertilizer rates should be based on soil test results. Refer to *Developing Fertilizer Recommendations for Montana Agriculture* for more information.

Although fairly high levels of P can be banded directly with the seed, only 10 to 30 lb/acre of K_2O plus N are recommended with the seed to avoid levels that lower seed germination *(24).* Specifically, no more than 15 lb/acre of K_2O plus N for barley and 10 lb/acre of K_2O plus N for wheat are recommended. This is less of a concern with wider openers that minimize fertilizer-seed contact and in finer soil textures.

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 adjusted for tillage systems. However, when fertilizer has been routinely banded, at least twice as many soil sub-samples are recommended in no-till and minimum till than conventional tilled fields. Tracking P levels over years can help avoid basing fertilizer rates on an anomalous soil sample composited predominantly from either between or within P bands. For a good estimate of available P, measure Olsen P by soil sampling the upper 6 inches regardless of tillage system *(19).*

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 and topsoil loss may decrease the soil's ability to store soil water. In forest, range or perennial systems, 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.

No-till systems keep the soil surface covered with residue and bind soil aggregates together with plant roots. During fallow periods, decomposition

TABLE 1. Wind erosion rates estimated with the RWEQ model *(25)* 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/acre		lb/acre			
	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% nitrogen and 0.06% phosphorus

of plant material continues. This results in less crop residue to protect against soil erosion.

Standing crop residue helps trap snow and increases soil water. Also, crop residue increases water infiltration and reduces overland flow. In tilled soils, as little as ¼-inch of rainfall can seal soil pores which reduce water penetration resulting in surface runoff. Any additional precipitation tends to run along the soil surface, moving downslope. Water moving along the soil surface can remove topsoil and available nutrients for subsequent crops. In dryland production regions, any substantial amount of runoff typically results 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. This reduces the amount of heat absorbed and keeps soils cooler. This can decrease nutrient availability during cool periods, but can protect soil microbial activity and increase nutrient availability during hot periods.

Understanding the effect of no-till on potential soil erosion, water storage and soil temperature can help producers select management practices that reduce nutrient loss, conserve water and maximize yield.

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 eroded by wind under conventional till than no-till, especially in drier soils (Table 1). A soil loss of 5 tons/acre per year, the rate considered acceptable by NRCS for soil conservation purposes, equates to an approximate loss of 11 lb of N/acre and 13 lb of P_2O_5/acre. In Montana, about 28 lb P_2O_5/acre are removed by a 45 bu/acre wheat crop, identical to the estimated amount lost through erosion in a conventional tillage system, emphasizing the magnitude of these potential nutrient losses from soil erosion.

The average annual erosion on Montana cropland decreased from 11.4 tons/acre in 1987, to 6.4 tons/acre in 2007 *(26)*. This is a substantial reduction in direct loss of nutrients from the land and is likely a result of the Conservation Reserve Program and large scale conversation to no-till. The next step is to increase SOM, which increases water retention and nutrient availability.

Crop residue increases water availability because it traps snow, reduces evaporation rates, and increases SOM which increases water infiltration. A wheat-fallow study in Mandan, North Dakota *(27)* found that 13 to 15 inches of stubble stored one more inch of soil water than 2 inches of stubble, largely due to differences in snow catch (Figure 8). In a Saskatchewan study, a 13-year no-till field absorbed 84% of 3.2 inches per hour simulated rainfall, while the adjoining summer-fallow field only absorbed 47% of the rainfall *(12)*.

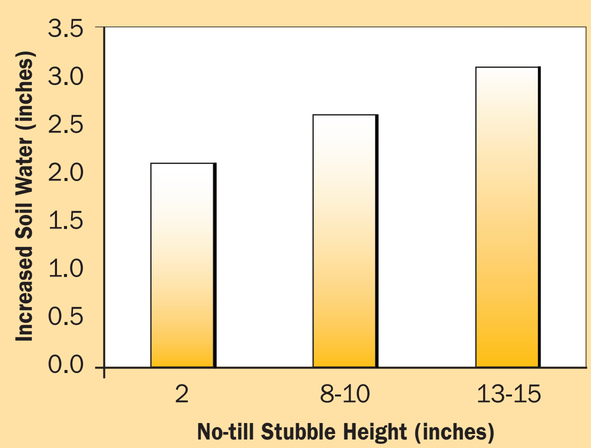

FIGURE 8. Effect of stubble height on soil water content change from fall to spring for a 4-foot depth in wheat-fallow at Mandan, North Dakota *(27)*.

Stubble height has also been found to significantly increase spring wheat grain yield due to increased growing season water use efficiency (WUE; *28)*. 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 of annual no-till cropping, improved soil physical and chemical conditions resulted in higher infiltration rates in both dry and wet soil *(29)*. 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 also increases 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.

RESIDUE MANAGEMENT

Using no-till or minimum till production systems helps conserve resources including water and nutrients. There are additional management changes that can be made to better conserve these resources. For example, keep stubble height as tall as possible and minimize field operations to keep stubble upright. These practices increase snow catch and shading which maximize available water and water use efficiency and decrease soil erosion.

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 for several 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 than conventionally tilled 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, including taking more samples, is necessary in any no-till or minimum till system to accurately determine fertilizer rates.

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Additional Resources

These bulletins, and many others, can be found by title under "Extension Publications" at http://landresources.montana.edu/soilfertility/, or by contacting MSU Extension Publications at 406-994-3273, or http://store.msuextension.org/.

Developing Fertilizer Recommendations for Montana Agriculture (MT200703AG)

Enhanced Efficiency Fertilizers (EB0188)

Factors Affecting Nitrogen Fertilizer Volatilization (EB0208)

Fertilizer Placement and Timing (MT4449-11) http://landresources.montana.edu/nm

Fertilizer Guidelines for Montana Crops (EB0161)

Management to Minimize Nitrogen Fertilizer Volatilization (EB0209)

Nutrient Uptake Timing by Crops: to assist with fertilizing decisions (EB0191)

Manitoba-North Dakota Zero Tillage Farmers Association, http://mandakzerotill.org/index.html

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