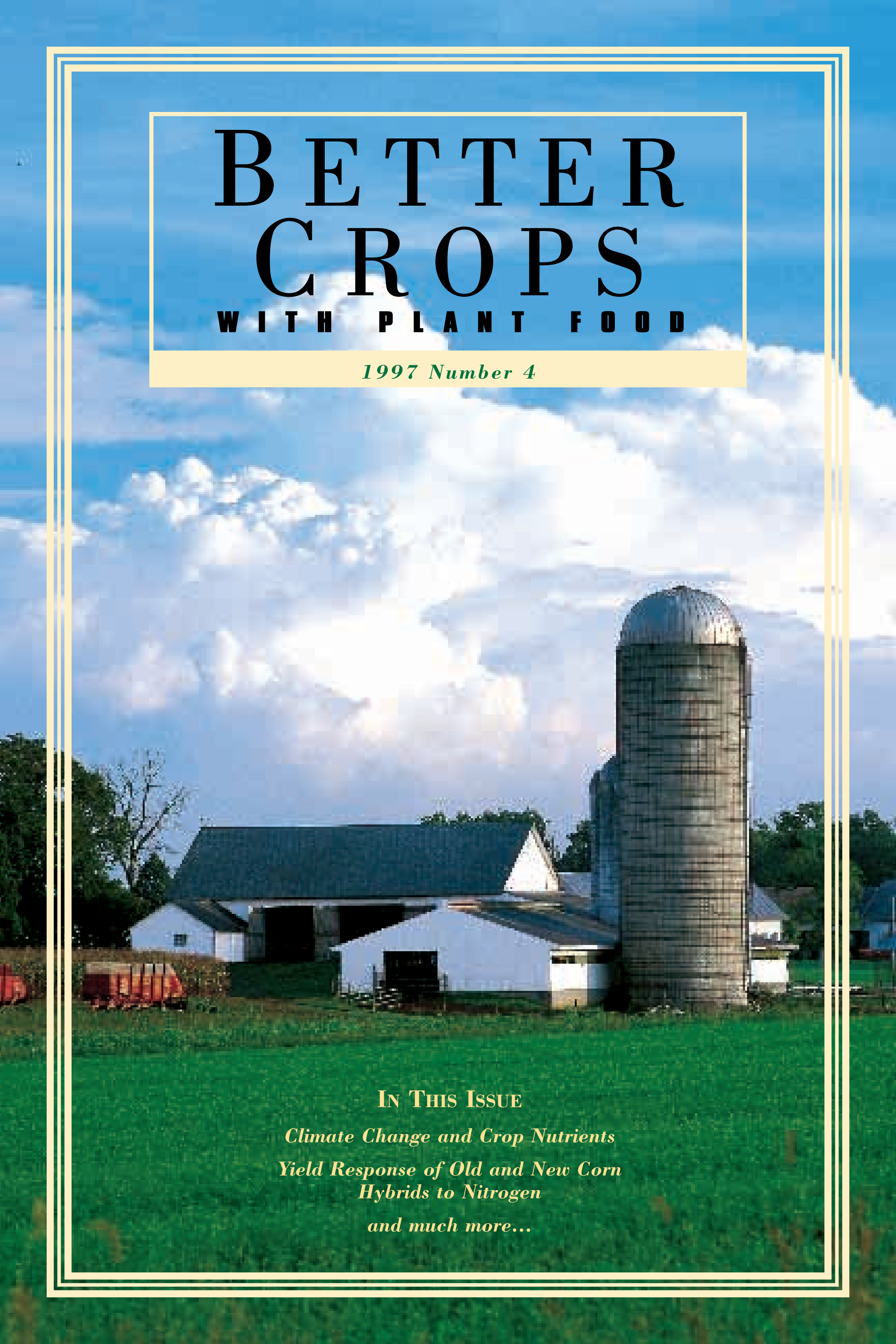
BETTER CROPS WITH PLANT FOOD

1997 Number 4



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and much more…

BETTER CROPS
WITH PLANT FOOD

Vol. LXXXI (81) 1997, No. 4

Our Cover: Thunderheads over a farmstead.
Cover Photo: Larry Lefever from Grant Heilman.

BETTER CROPS WITH PLANT FOOD
(ISSN:0006-0089) is published quarterly by the Potash & Phosphate Institute (PPI). Periodicals postage paid at Norcross, GA, and at additional mailing offices (USPS 012-713). Subscription free on request to qualified individuals; others $8.00 per year or $2.00 per issue. POSTMASTER: Send address changes to **Better Crops with Plant Food**, 655 Engineering Drive, Suite 110, Norcross, GA 30092-2837. Phone (770) 447-0335; fax (770) 448-0439.

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ONTARIO

Yield Response of Old and New Corn Hybrids to Nitrogen

By M. Tollenaar, S.P. Nissanka, I. Rajcan and T.W. Bruulsema

Corn yields in Ontario have increased at about 1.5 bu/A per year during the past four decades. Similar increases in corn yield have been documented in the U.S. and Europe. A significant portion of these increases can be attributed to genetic improvement, which has been associated with increased tolerance to stresses (high plant populations, low soil moisture, and weed competition) and delayed leaf senescence or greater leaf longevity ('stay-green'). We have conducted studies to examine the relationship among 'stay-green', stress tolerance, and soil N in an old and a new corn hybrid grown in Ontario. We gave particular attention to the effects of source and sink balance (supply and demand for assimilates produced by photosynthesis) during the grain-filling period on these factors.

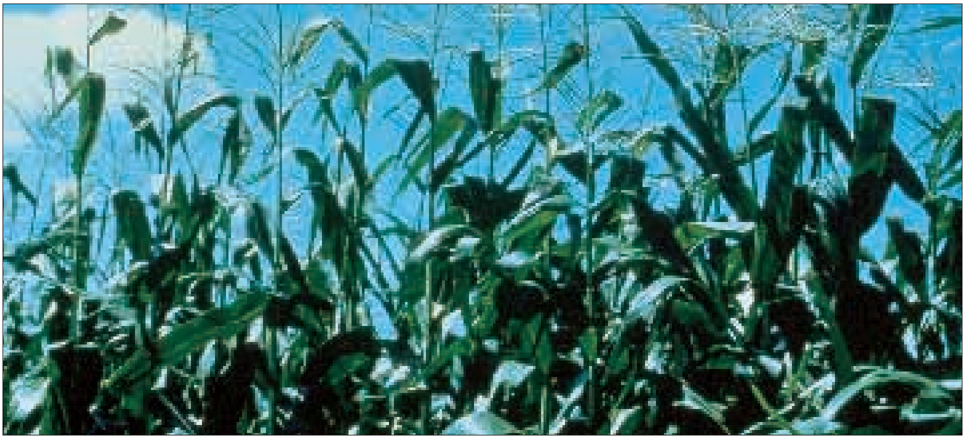
We postulated that leaves stay green longer in newer hybrids because the source-sink ratio during the grain-filling period is higher than in older hybrids. Although leaf senescence is a genetically controlled process, it can be accelerated or delayed by the source-sink ratio. Field studies were conducted with an old hybrid (Pride 5, released in 1959) and a newer hybrid (Pioneer 3902, released in 1988) grown at two N levels. The high N level was 134 lb/A of N added as ammonium nitrate (NH_4NO_3), while the low N level was no N. However, owing to high levels of organic matter and soil nitrate (NO_3), differences in grain yield due to N levels were only 10 percent.

New 'stay-green' corn hybrids take up more nitrogen (N) after silking. Expression of their increased yield potential and nutrient use efficiency advantages depends on adequate nutrient supply in the later part of the growing season.

The source-sink ratio of the hybrids during the grain-filling period was manipulated in three treatments in comparison to a control. For source reduction, 4 to 5 leaves were removed from above the ear. For sink reduction, silks

TABLE 1. Effect of source-sink ratio manipulation on change in stover weight from silking to maturity and percent leaves remaining green at 5 weeks post-silking in two corn hybrids. Means across 3 years (1993-1995) and 2 levels of N.

	Source-sink treatment			
Hybrid	Reduced source	Control	Half sink	No sink
	% change in stover weight			
Old	-36	-24	-3	20
New	-25	-7	20	30
	% of leaves remaining green			
Old	28	41	48	44
New	39	53	51	33



New 'stay-green' corn hybrids take up more nutrients later in the growing season.

were covered for either one day or completely to attain either 50 percent or 100 percent reduction in kernel numbers. The change in stover weight during the grain-filling period was used as an indicator of the source-sink ratio. Stover weight declined by about 30 percent when leaves were removed and increased by about 30 percent in the no-sink treatment (**Table 1**).

The change in stover weight was either less negative or more positive in the new hybrid, indicating that the source-sink ratio was higher than in the old hybrid. Leaf longevity in the control was greater for the new hybrid. Leaves senesce earlier when either the source-sink ratio is low due to assimilate starvation (leaves turn grey) or when the source-sink ratio is high due to assimilate overload (leaves turn red and purplish). Leaves stayed green longest in the control treatment for the new hybrid and in the 50 percent-sink treatment for the old hybrid...that is, in the treatments where the source and sink were in balance. The results confirmed our hypothesis that the higher source-sink ratio in the new hybrid kept leaves green longer.

Our second hypothesis was that N uptake after silking would be greater in the new hybrid because of the higher source-sink ratio. Nitrogen uptake is a function of N demand by the plant, N availability, and assimilate availability

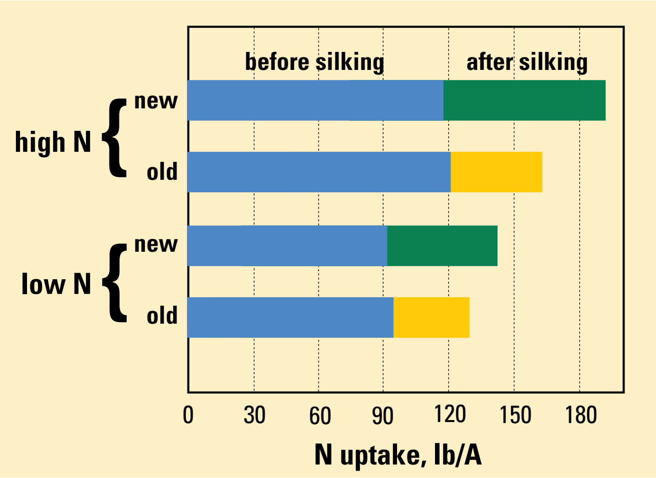


Figure 1. Corn N uptake in a new and an old hybrid in response to high and low soil N availability. Means over 3 years (1993-1995) at Elora, Ontario.

TABLE 2. Yield and kernel number per plant of an old and new corn hybrid in response to N level (3-year means, 1992-1994).

Hybrid	N level	Yield, bu/A	Reduction, %	Kernels per plant	Reduction, %
New	High	124		465	
	Low	99	20	412	11
Old	High	101		453	
	Low	80	20	307	32

within the plant because N uptake and metabolism require metabolic energy. In the control treatment of the same field studies, N uptake after silking was clearly much higher in the new hybrid, in particular when the soil N level was high (**Figure 1**).

This result is not surprising, as greater leaf activity would need to be supported by continued uptake of N, not to mention other essential nutrients including phosphorus (P) and potassium (K). The ramifications for nutrient management are important, however. The newer hybrids, bred for higher yields and stress tolerance, take up nutrients over a longer time period than do older hybrids. In the case of N, the 'stay-green' trait has positive implications for the impact of corn production on the environment, since the crop would be more effective in removing and immobilizing NO_3 mineralized from the soil in the later part of the growing season. One could say the new hybrids are in better synchrony with the natural seasonal pattern of soil N mineralization.

In separate field experiments with greater differences in N availability, yield reductions due to low N were similar for the new and the old hybrid (**Table 2**). This was unexpected as previous growth chamber experiments have indicated greater N use efficiency in new hybrids. Also, the decline in kernel number due to the low N treatment was only one-third as large in the new (11 percent) as in the old hybrid (32 percent). Total dry matter accumulation during the grain-filling period, however, was reduced more by low soil N in the new hybrid. This mitigated the effect of harvest index on grain yield. The capacity of the new hybrid to maintain kernel number under low N conditions resulted in marked decline in its source-sink ratio. We speculate that the low source-sink ratio actually reduced the yield performance of the new hybrid under low soil-N conditions.

In conclusion, the 'stay-green' trait of new corn hybrids is associated with a balanced source-sink ratio and better use of N mineralized from the soil. New hybrids are generally more stress tolerant than old hybrids, but the higher stress tolerance of new hybrids may not always result in higher yield.

The capacity to maintain kernel number under N stress reduced the source-sink ratio during the grain-filling period, which reduced the yield of the new hybrid grown under low soil N in our study. This indicates that while new hybrids are more efficient in their use of nutrients, the importance of nutrient supply for the full duration of the growing season is not diminished. BC

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MISSOURI

Using Electromagnetic Induction to Characterize Soils

By J. Glenn Davis, Newell R. Kitchen, Kenneth A. Sudduth and Scott T. Drummond

Electrical conductivity measurements have been used for years to determine salinity and moisture in soils. Probes were inserted directly into the soil to determine how well the soil conducted an applied current. This process was slow and labor-intensive and was usually reserved for scientific studies. A more recent technique for measuring conductivity is electromagnetic induction (EM), a non-invasive, non-destructive sampling method. No probes are required using EM, and measurements can be done quickly and inexpensively.

Researchers are studying use of electromagnetic induction as a convenient and low cost method for measuring variability beneath the surface, particularly for claypan soils. The information may help identify optimum nitrogen (N) rates for various field areas.

How Does EM Work?

We have used the EM-38, a commercially available instrument from Geonics Ltd., Ontario, Canada. The EM-38 is about 3 ft. long and is light-weight enough to be carried in one hand. The unit is powered by a single 9 volt battery that lasts approximately 16 to 20 hours. The principle of operation of the EM-38 is shown in the drawing in **Figure 1**.

The transmitting coil induces a magnetic field that varies in strength with depth in the soil. The relative strength of the magnetic field is illustrated by the relative diameter of the circles in **Figure 1**. The magnetic field is strongest about 15 inches below the soil surface and has an effective sensing depth of about 5 ft. A receiving coil reads primary and secondary "induced" currents in the soil. It is the relationship between these primary and secondary currents that measures soil conductivity. In **Figure 1,** the thicker circles illustrate soils that are better conductors of electrical current. Clayey soils have a higher electrical conductivity than coarser textured soils, so when a clay horizon is nearer the surface (*b* in **Figure 1**), the EM sensor reading is higher. Deeper topsoils having a clay horizon further below the soil surface (*a* in **Figure 1**) are less conductive to electrical current and have lower EM readings.

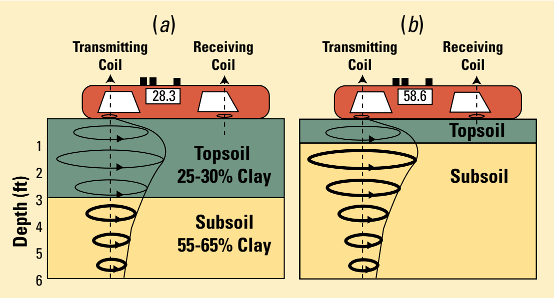

Figure 1. EM-38 principle of operation in soils.

How Are EM Measurements Used?

Electromagnetic induction technology was originally developed for the mining industry, and has been

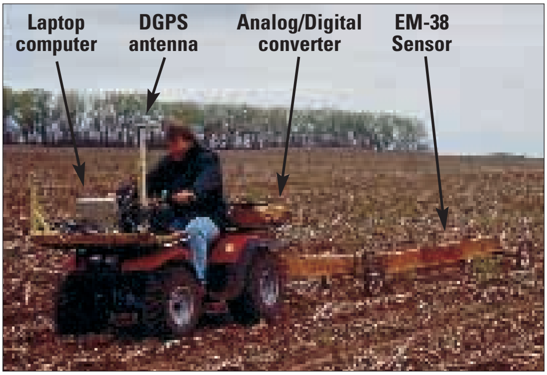

Figure 2. Mobile EM-38 sensor unit is pulled behind a four-wheel ATV, equipped with analog/digital converter, laptop computer, and DGPS antenna.

used in mineral, oil, and gas exploration, groundwater studies, and archaeology. In these applications, differences in conductivity of subsurface layers of rock or soil may indicate stratified layers or voids that could be of interest. In agriculture, the EM sensor was first used to measure soluble salts and soil moisture. Other agricultural applications now include determining soil mapping units, estimation of topsoil depth in claypan soils, depth of sand deposition after river flooding, estimation of herbicide degradation, and crop productivity. For each of the applications described above, a relationship must be established between the EM sensor reading and the soil feature of interest. Once the relationship is established, however, the readings can be gathered rapidly.

A mobile EM data collection unit is shown in **Figure 2**. The EM sensor is mounted on a wooden trailer away from metallic objects and vehicle engine interference that can affect EM readings. A differential global positioning system (DGPS) receiver is mounted on the vehicle, with an analog-to-digital converter and a computer that records EM sensor readings along with a DGPS location. Using this equipment, data from whole fields can be taken quickly, and then maps of soil conductivity can be made. Data for a 20-acre field can be collected in about one hour.

EM Research on Claypan Soils

Claypan soils are important agricultural soils in the southern Corn Belt, covering 10 million acres in seven states. They

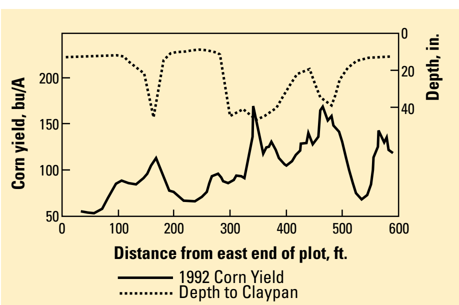

Figure 3. Corn yields and depth to claypan layer along a transect at Centralia, Missouri.

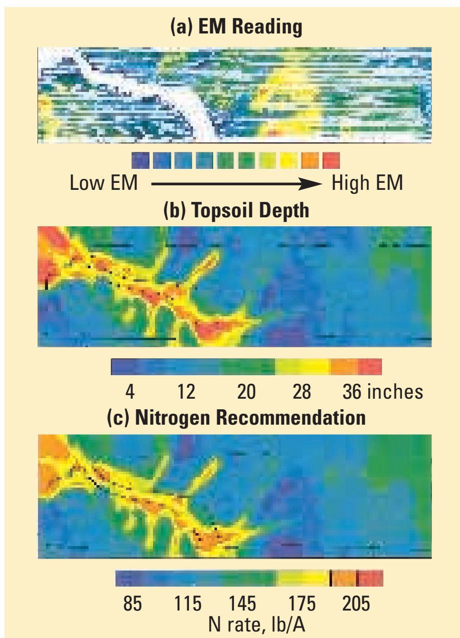

Figure 4. EM-38 soil conductivity, topsoil depth, and N recommended for corn at Centralia, Missouri.

comprise a significant portion of cropland in Missouri, and can present farmers with difficult management choices. They have an abrupt and marked increase in clay content between the upper soil layer and subsoil. The clay content increases by at least 20 percent, and this dense layer of high clay soil impedes the movement of water and air, restricting the growth of plant roots.

Topsoil depth and corn grain yield measured along a field transect is shown in **Figure 3**. The depth to the claypan layer varies from a few inches to more than 40 inches, and it is apparent that grain yield is related to the depth to the claypan layer. Within a field, the variation in depth to the claypan can be seen by spatial patterns in crop water stress. The areas having shallow topsoils (often on eroded side-slopes) are the first to have water-stressed plants. Clearly, having information on the depth of topsoil would be a valuable tool in tailoring management for crop needs.

A management example using N fertilizer for corn production is shown in **Figure 4**. The first step is to collect EM sensor data for the field using the mobile EM unit. In this case, transects for EM data were taken at a very close interval (about 15 ft.). In most cases, a transect interval of 40 to 60 ft. gives sufficient data density to map the field. For selected points in the field, topsoil depth (measured using a soil probe) and soil conductivity (by EM) were determined concurrently. From these data points, a regression equation between EM sensor reading and topsoil depth was calculated to produce a map of topsoil depth for the field. Finally, an N recommendation map was made based on topsoil depth (*c* in **Figure 4**). Nitrogen recommendations in Missouri and other Corn Belt states often use expected yield (or yield goal) as one of the parameters for estimating crop N needs. Yield goals are usually established for a whole field, and may be adjusted for previous crop, organic matter content, and/or residual nitrate. Missouri studies have shown that yield goal potential is related to topsoil depth:

Yield goal = 98 bu/A + 2.2 x topsoil depth (inches).

We used this relationship to produce a map of yield goal. From this yield goal map we made an N application map.

In **Figure 5**, the EM map is compared to an aerial photo of corn crop cover in late July. Patterns of low EM sensor readings (deeper topsoil) match patterns of darker green crop cover. Areas of shallower topsoil (high EM sensor readings) are also areas where crop cover is less dense and yellowing due to moisture stress. Using the photo of crop cover, it is easy to see differences in potential productivity within this field and how well patterns of potential productivity are correlated to soil conductivity readings using the EM-38.

Other work with the EM sensor is ongoing with alluvial and loess soils. These soils do not have the abrupt layer boundaries characteristic of claypan soils. However, soil texture can be related to EM readings, and work is continuing to relate these readings to crop response.

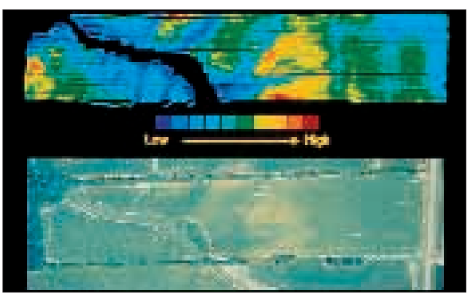

Figure 5. EM-38 sensor readings (top) and aerial corn crop cover photo (July 25, 1997) at Centralia, Missouri site.

Dr. Davis is Soil Scientist and Extension Assistant Professor, University of Missouri-Columbia; Dr. Kitchen is Soil Scientist, USDA-ARS; Dr. Sudduth is Agricultural Engineer, USDA-ARS; Mr. Drummond is Scientific Programmer/Analyst, University of Missouri-Columbia.

A Special Banding Technique Increases Effectiveness of Phosphorus Fertilizer on Alfalfa

By S.S. Malhi

Alfalfa is an important forage crop in the Canadian Prairies. It has a high demand for P and is responsive to P fertilization when soil test levels are low. Many Prairie soils do not contain enough plant-available P for optimum crop production. Surface-broadcasting is the most convenient way to apply fertilizers on established forage stands. But is it the most effective? Our previous research has shown that most of the fertilizer P recovered in soil as extractable P remains in the top 2-inch layer, even after long-term annual applications of P to alfalfa or grass. Banding fertilizers below the surface is often more efficient for cereal production in our soils, but band application in established forages has not been as effective, mainly because of disruption of root growth during the banding process.

Sub-surface banding using a narrow disc opener offers forage growers another option for phosphorus (P) placement in established alfalfa. Whether applied annually or as a large one-time application, banded P can boost alfalfa yields.

A 5-year field experiment was initiated in 1992 on existing alfalfa stands on a P-deficient Black soil at Ponoka, Alberta, to compare surface-broadcast with sub-surface band applications of P. Triple superphosphate was applied annually in mid to late April (20, 41, 62 and 82 lb/A P_2O_5) or once when the study was initiated in 1992 (102, 205, 307 and 410 lb/A P_2O_5). In the sub-surface application, the P was banded in

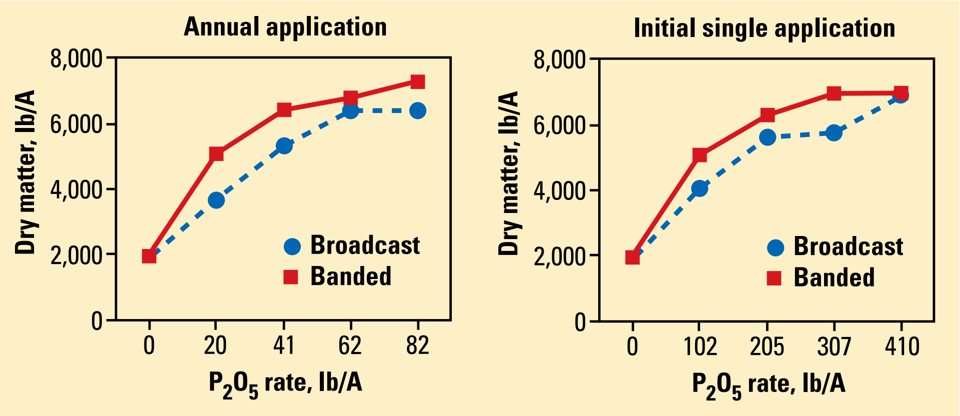

Figure 1. Alfalfa responded to P fertilization over a 5-year period when applied annually or as an initial single application at Ponoka, Alberta.

rows 6 inches apart at a 2-inch depth, using a coulter-type disc. All plots received annual blanket applications of potassium (K) and sulfur (S) fertilizers. The plots were harvested for dry matter yield in early July and mid September of each year.

Band application of P below the surface with a coulter-type disc drill may offer benefits for established alfalfa stands.

Phosphorus Response

There was an excellent response to applied P in both the annual and the single applications and for both application methods (**Figure 1**). Forage yields increased three to four-fold relative to the unfertilized check. On average, yield differences between the two application methods were greater at the lower application rates, but tended to disappear at higher application rates. Disc-banding consistently produced greater forage yield than surface-broadcasting when averaged across P rates (**Figure 2**). Over the 5-year period, band application produced an average of about 836 lb/A/yr more dry matter than the broadcast application when the P was applied annually and about 660 lb/A/yr more dry matter when the P was applied initially at the beginning of the study.

There can be several reasons for greater forage yield with subsurface banding than surface-broadcasting application. When P fertilizer is applied to the surface in established forage stands, it remains near where it is placed and may not become fully available to roots for effective use. Phosphorus fertilizer placed below the surface is immediately available to the roots and is present in the moist soil zone where roots are most active for effective uptake. In addition, subsurface banding reduces the contact between P fertilizer and the soil, which reduces the potential for conversion of the P to less available forms, leaving more P for crop uptake.

The success of subsurface banding

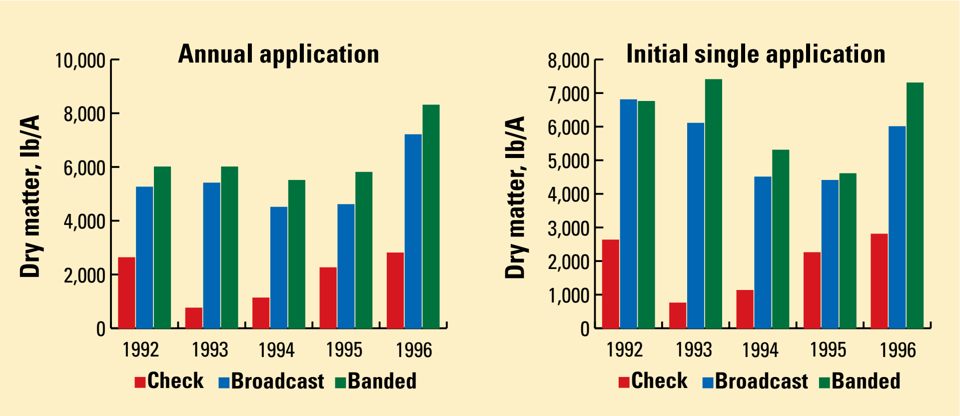

Figure 2. Banding P produced more alfalfa forage yield than broadcasting P (averaged across P rates) when applied annually or as an initial single application at Ponoka, Alberta.

also depends on the banding equipment. A "hoe drill" type implement damages forage stands, causing injury to the superficial roots and loss of moisture by opening the soil, particularly in a dry year or in a relatively dry soil-climatic zone. In the present study, the P fertilizer was banded with a special coulter-type disc drill, which apparently does not cause disturbance to soil or plant roots.

Summary

There was a marked increase in forage yield from P applications in all the five years and excellent residual effects from the single P application. Disc-banding at 6-inch spacing produced greater forage yield than surface-broadcasting, whether P was applied annually or as a single initial application.

Forage productivity can be increased by improving effectiveness of P fertilizer using disc-banding openers on established stands. And, the subsurface banding may reduce the potential for P loss due to surface runoff. However, growers need to balance the potential benefits versus the cost of the banding operation. Banding, especially with narrowly spaced openers, is more expensive than broadcast application so growers are cautioned to ensure the yield increases from the banding offset the additional cost under their soil conditions.

Dr. Malhi is a Research Scientist with Agriculture and Agri-Food Canada, Research Farm, Melfort, Saskatchewan.

Research Notes

Oregon: Residue and Fertility Effects on Yield of No-Till Wheat

Researchers found that straw residues had an adverse effect on winter wheat yield and, to a lesser extent, on spring wheat yield when cropped no-till following a cereal. Increasing nitrogen (N), phosphorus (P) and potassium (K) fertility increased grain yield substantially, but did little to alter the adverse effects of the stubble. Relative yields for none, low, moderate and high NPK fertility were 22, 59, 94 and 100 percent, respectively, for winter wheat and 36, 82, 99 and 100 percent for spring wheat.

Much of the effect appeared to be the result of standing residue because fine chopping during one year of the study increased yield in a manner similar to elimination of residue by burning in later years. Researchers concluded that results suggest that light quality, lower soil temperature, or increased soil pathogen activity is the likely source of reduced yield.

Source: Paul E. Rasmussen, Ron W. Rickman, and Betty L. Klepper. 1997. Agron.J. 89:563-567.

PLANET EARTH

Climate Change and Crop Nutrients

By T.W. Bruulsema and W.K. Griffith

Climate change could affect every one of the Earth's 6 billion inhabitants. While conclusions are far from certain, it is clear that the concentration of carbon dioxide (CO_2) has reached levels in the atmosphere not seen in the past several hundred thousand years and is continuing to increase. In addition, concentrations of several other gases are increasing. Whether the increase in these gases is responsible or not for this century's 0.5 to 1.0°F warming of the global climate is still debatable. However, future public pressure is likely to demand that such increasing trends be abated wherever possible.

Crop nutrients, particularly nitrogen (N), are intimately involved with the soil's exchange of gases involved in warming the global climate. While N fertilizer use has recently been associated with an increased role in the emission of nitrous oxide (N_2O), it also plays a positive role in the storage of carbon (C) in soils.

The gases that are mostly responsible for keeping the planet warm are CO_2 and water vapor. Without them, the global average temperature would be a chilling 5ºF instead of the balmy 60ºF we enjoy today. In addition, several other gases are active. Those of concern to agriculture are methane (CH_4) and N_2O. Recent estimates of the relative warming potential of emissions from agriculture are given in **Table 1**.

While it appears that each of the three is equally important, in fact they are individually unique. The net emission of CO_2 is dwarfed by the huge annual turnover of CO_2 involved in C assimilation by crops. At least 1,800 million tons of CO_2 are assimilated annually by North American crops. The turnover is so large that other sources of evidence indicate that the true net emission may actually be negative. That is, there is evidence that agricultural and forested land in the temperate latitudes of the northern hemisphere are actually a net sink for CO_2.

Methane emissions from soils arise mainly from lowland rice production and natural wetlands. There is little CH_4 emission associated with commercial fertilizer use. Ruminant animals and livestock manures are the main sources of CH_4 emissions in North American agriculture. Soils involved in crop production generally

TABLE 1. Some recent estimates of relative warming potential of gas emissions from North American agriculture.

Source	CO_2 equivalent, million tons U.S.	Canada	Total	Percent, %
CO_2	187	18	205	29
CH_4	211	22	233	33
N_2O	232	32	264	38
Total	630	72	702	100

TABLE 2. Estimates of nitrous oxide emissions from agricultural sources, based on new IPCC methodology.

Source	N_2O emissions, 10^3 tons			
Direct:	U.S. (1994)		Canada (1991)	
Fertilizer-N	204	27%	16	15%
Crop residues	144	19%	19	18%
Biological N fixation	77	10%	12	11%
Animal manures	67	9%	24	23%
Indirect:				
Nitrate leached	190	25%	29	28%
Atmospheric deposition	47	6%	3	3%
Sewage	20	3%	3	3%
Total	749	100%	106	100%

consume rather than emit CH_4, though the amount is small relative to the total sources.

Nitrous oxide emissions are very difficult to measure, and the relative importance of different sources is poorly understood. A 1995 U.S. Department of Energy estimate of N_2O emissions from agriculture attributed over 97 percent of the source to be fertilizer N. Recent changes in calculation methodology approved by the International Panel on Climate Control (IPCC) recognize that in addition to fertilizer N, any N source used in agricultural production such as animal manure, crop residues, legumes and municipal sewage are potential N_2O sources. This new methodology estimates that fertilizer N contributes approximately 27 percent of N_2O emissions from agriculture (**Table 2**). These figures are necessarily only crude estimates, because N_2O emissions are short-term events that occur rapidly in response to specific weather conditions. Recent research indicates that the use of nitrification inhibitors can substantially reduce direct emissions of N_2O. Research also indicates unexplained interactions between N fertilizer forms and episodic weather events.

Increased soil organic C can help mitigate increasing atmospheric concentrations of CO_2.

While N fertilizer is one of the direct contributors to N_2O emission, it also plays a positive role in the stabilization of soil C, and can help to mitigate CO_2 emissions. There are extensive reports from long-term trials indicating that wherever N enhances the yields of crops, the accumulation of C in the soil is increased. In addition, there is evidence that N itself is chemically involved in stabilizing soil C.

Data from a long-term experiment in Sweden provide the best demonstration of N stabilizing C in soil (**Figure 1**). In this experiment, the addition of N [71 lb/A as $Ca(NO_3)_2$] promoted the growth of the cereal crop. The increased root growth provided additional C to the soil, but the net storage in the long term was enhanced even more. Addition of N increased net C stored in response to additions of straw and sawdust as well. It is thought that nitrogenous compounds react with lignin in the process of humus formation, as a mechanism of C stabilization. In addition, most soil organic matter stabilizes with a C:N ratio of approximately 10:1, indicating again that if soil C storage is to increase, N is needed.

Another example of soil C increase in response to the addition of fertilizers was

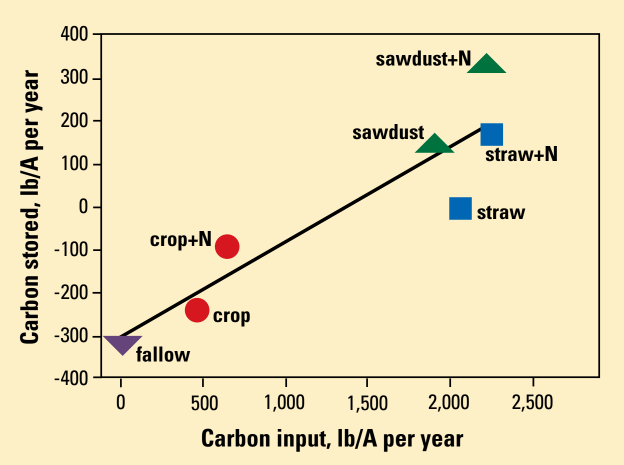

Figure 1. Annual change in soil C storage over 30 years in response to additions of N, presence of a crop, added straw and added sawdust. In all plots other than fallow, a cereal crop was grown each year and all above-ground crop residues were removed. (Adapted from Paustian et al., 1992; Soil Sci. Soc. Am. J. 56: 476-488).

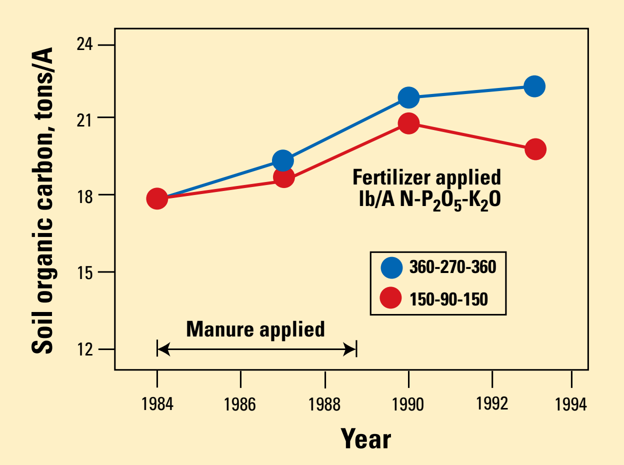

Figure 2. Soil organic C increase in response to manure and fertilizer additions in soil under continuous corn in Quebec. (Adapted from Liang et al., 1996; Soil Science 161 (2): 109-113).

observed in Quebec (**Figure 2**). In the first five years of this maximum yield study, manure was applied to all soils, while two different levels of NPK fertilizer were applied. Over the course of nine years, soil organic C levels tended to increase in all soils, but most with the high rate of fertilizer addition. The high rate of fertilizer produced about 9 percent more crop stover C than the lower rate.

The application of fertilizer nutrients to responsive crops, in combination with organic amendments, increases C storage in soils. Mitigation of increasing atmospheric concentrations of CO_2 can be added to the long list of positive benefits of increased soil organic C, including enhanced soil structure, improved tilth, and reduced erosion. BC

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Sensing Nitrogen Deficiencies in Winter Wheat and Bermudagrass

By M.L. Stone, W.R. Raun, G.V. Johnson, J.B. Solie, R.W. Whitney, H. Sembiring, J.M. LaRuffa, and E.V. Lukina

The potential replacement of wet chemical methods with non-destructive spectral analyses was first seen over 20 years ago. Near infrared (NIR) diffuse reflectance spectrophotometry was initially used to measure protein, moisture, fat and oil in agricultural products. Leaf reflectance measurements at 550 nanometers (nm) (green) and 675 nm (red) have been used to estimate the nitrogen (N) status of various growing crops.

The NIR spectral region has also been used for predicting organic carbon (C) and total N in soils. Each constituent of an organic compound has unique absorption properties in the NIR wavelengths due to stretching and bending vibrations of molecular bonds between elements. One band (780 to 810 nm) is particularly sensitive to the presence of amino acids ($R\text{-}NH_2$) which are the building blocks of proteins. The presence and/or absence of these amino acids largely determines the N content of the plant. Because of this, many researchers believe that if the plant canopy could be characterized using spectral data, the development of an indirect soil test (or measure of soil nutrient supplying capacity) could be possible.

> Non-destructive sensor based methods of analyses could replace many of the wet chemistry soil testing methods that are in place today. Recent work has targeted indirect measurements of the nutrient status in soils using spectral radiance data collected from growing crop canopies every 10 sq. ft. Because large differences are now known to exist betwen forage and/or soil samples collected less than 3 feet apart in some fields, the development of indirect sensing technologies will be necessary if this variability is to be treated.

When white light from the sun strikes the surface of soil or plants, it is reflected in wavelengths that have a characteristic frequency and energy. The visible portion of light can be separated into red, orange, yellow, green, blue and violet. The yellow-green color that we associate with N deficiencies should be characterized as having more violet light absorbed by the plant material, or alternatively, the reflected intensity of green in plants should be characterized as the amount of red light absorbed. Phosphorus deficiencies in plants should theoretically result in increased absorbance of green light since increased purple coloring of leaf margins is expected. What is actually being measured in many sensor based systems is 'spectral radiance', or the radiated energy from plant and soil surfaces.

Research prototypes of sensor based systems are now capable of detecting nutrient needs on-the-go and can simultaneously apply prescribed fertilizer rates based on those needs. Spectral radiance measurements for red (660 nm) and NIR (780 nm) wavelengths measured in winter wheat from December to February using photodiode based sensors have shown high correlation between the normalized difference vegetative index [NDVI, (NIR-red)/(NIR+red)] and wheat forage N uptake. This is important since several researchers have demonstrated that wheat forage total N uptake during the winter months can be a predictor of topdress N needs. Because N uptake can be predicted indirectly using spectral radiance measurements, sensors can reliably provide measurements equivalent to 'on-the-go' chemical analyses.

Work at Oklahoma State University has focused on using whole-plant total N in winter wheat at growth stage Feekes 5 as an indicator of fertilizer N need. The relationship between total forage N uptake at Feekes growth stage 5 and NDVI from five experiments is reported in **Figure 1**. Similar results have been found in bermudagrass forage N uptake and NDVI. Based on the indirect measures of total N uptake (NDVI), significant increases in wheat grain yield from topdress N applied between December and February have been found. Various researchers have found increased fertilizer N use efficiency in winter wheat when N was split applied or topdressed before mid January. Variable rate technology capitalizes on this timing-related efficiency gain, while also having the potential to increase N use efficiency due to finer resolution of rate applied.

Photodiode based sensors (4 white boxes) collect spectral radiance measurements in the red (660 nm) and NIR(780 nm) regions. Rear nozzles of applicator are capable of applying a prescribed N rate (0 to 100 lb N/A) to each 10 sq. ft., travelling at 10 miles per hour.

The variable N applicator developed at Oklahoma State University is illustrated in the above photo. In addition to improving site-specific N use efficiency, this technology will likely decrease the risk that over fertilization poses to the environment while maintaining or increasing yield.

Initial results suggest that fertilizer N use efficiency has increased from 50 to 70 percent using adjusted fertilizer N based on NDVI at Feekes growth stage 5. This is largely because the sensors are capable of

(continued on page 19)

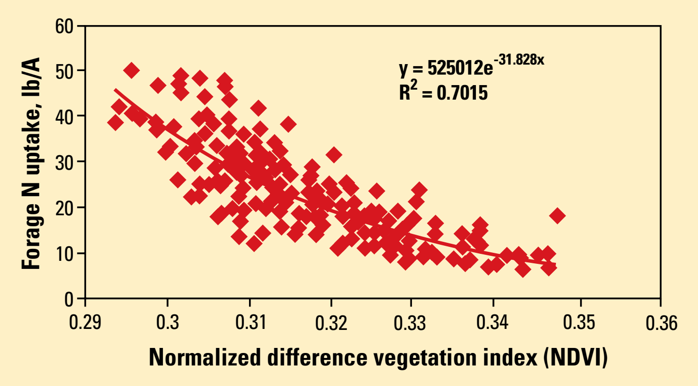

Figure 1. Relationship between NDVI and forage N uptake in winter wheat (Feekes growth stage 5) from five field experiments.

TENNESSEE

Soil and Foliar Potassium Effects on Alternaria Leaf Spot Disease in Cotton

By D.D. Howard, M.A. Newman and A.Y. Chambers

The severity of the cotton disease Alternaria leaf spot (*Alternaria macrospora* Zimm.) varies with location, year, fertility level, and other factors. In general, damage has been small, but if premature plant defoliation resulting from the disease is extensive, yields may be reduced. Researchers are continuing to evaluate new and improved disease control measures.

Research in Tennessee was established in 1991 to evaluate soil and foliar potassium (K) effects on cotton produced on low and high extractable K soils under conventional tillage (CT) and no-tillage (NT) systems. A second objective was to evaluate CT and NT systems for Alternaria leaf spot and plant defoliation.

Field investigations were conducted in 1991 and 1992 on a Memphis silt loam soil (fine-silty, mixed, thermic, Typic Hapludalf) located on the Ames Plantation at Grand Junction, Tennessee, and on a Loring silt loam soil (fine-silty, mixed, thermic, Typic Fragiudalf,) located on the Milan Experiment Station. Mehlich I extractable K for the Memphis soil was 90 and 80 lb/A (low) for the CT and NT systems, respectively. Extractable K for the Loring soil was 197 and 168 lb/A (high).

The experimental design was a split-plot arrangement of treatments in a randomized complete block. Main plot treatments were 0, 30, 60, and 120 lb broadcast K_2O/A. The K source was potassium chloride (KCl). Subplot treatments consisted of foliar applications of potassium nitrate (KNO_3) and calcium nitrate [$Ca(NO_3)_2$] and an untreated check. The KNO_3 was applied at 4.4 lb K_2O/A/application using a spray volume of 10 gal/A. The $Ca(NO_3)_2$ was applied at a rate to supply 1.4 lb/A nitrogen (N), which is equal to the N applied in the foliar KNO_3 treatments. A total of four foliar applications were applied during the year. The first application was 14 days after mid-bloom and was repeated on 14-day intervals.

The cotton cultivar Deltapine 50 was planted by mid-May on both soils in 40-inch rows. Plots were fertilized annually with 80 lb N/A using ammonium nitrate (NH_4NO_3) and 60 lb P_2O_5/A using triple superphosphate. The CT site on the Memphis soil was bedded in 1991, reshaped each fall, and the tops shaped in the spring. The NT cotton was planted on a flat seedbed.

Two separate visual evaluations were made for Alternaria leaf spot severity and for plant defoliation on September 2 on the Memphis silt loam and September 24 on the Loring silt loam. The rating scale for both evaluations ranged from 0 to 10, in which 0 indicates no symptoms and 10 is total disease coverage or total plant defoliation. Lint yields were determined by mechanically picking the two center

TABLE 1. Soil- and foliar-K effects on Alternaria leaf spot, defoliation ratings, and cotton lint yields on Memphis silt loam and Loring silt loam soils with a tillage variable.

	Memphis silt loam (low soil K)			Loring silt loam (high soil K)		
	Alternaria[1]	Defoliation[1]	Yield, lb/A	Alternaria[1]	Defoliation[1]	Yield, lb/A
K_2O, lb/A[2]			Conventional tillage			
0	7.7 A[3]	6.9 A	350 C	3.7 A	0.8 A	1,036 A
30	5.8 B	4.5 B	556 B	4.4 A	1.1 A	1,057 A
60	5.5 B	2.9 BC	621 B	3.6 A	1.2 A	894 A
120	4.7 B	1.3 C	760 A	3.7 A	1.3 A	987 A
Foliar treatment[4]						
Check	6.4 a	4.5 a	551 b	3.8 b	1.0 ab	972 a
KNO_3	5.4 b	3.1 b	612 a	3.3 c	0.9 b	1,015 a
$Ca(NO_3)_2$	6.0 a	4.2 a	552 b	4.4 a	1.4 a	994 a
K_2O, lb/A[2]			No-tillage			
0	7.5 A	5.8 A	360 C	4.8 A	4.5 A	1,294 B
30	6.1 AB	4.2 AB	531 B	4.7 A	4.3 A	1,312 B
60	5.1 BC	1.6 BC	528 B	4.6 A	4.3 A	1,391 A
120	4.5 C	0.6 C	669 A	5.7 A	4.5 A	1,313 B
Foliar treatment[4]						
Check	5.8 ab	3.1 ab	483 b	5.1 a	4.9 a	1,322 ab
KNO_3	5.5 b	2.6 b	567 a	4.5 b	3.8 b	1,365 a
$Ca(NO_3)_2$	6.2 a	3.5 a	516 b	5.2 a	4.6 ab	1,296 b

[1]Alternaria leaf spot and leaf defoliation ratings – 0 (none) to 10 (highest).
[2]Averaged across foliar treatments.
[3]Within tillage system, within soil, soil applied K, and foliar treatments, means followed by the same letter are not significantly different at the 0.05 probability level.
[4]Averaged across soil K rates.

rows of each plot twice each year. Percent lint was determined by combining samples of seed cotton from individual treatments across replications and ginning on a 20-saw gin with dual lint cleaners.

Results

Alternaria leaf spot severity and premature plant defoliation associated with the leaf disease, as well as lint yields from both tillage systems on the Memphis silt loam, were affected by broadcast and foliar K (**Table 1**). Alternaria leaf spot severity was reduced in the CT system from applying 30 lb K_2O/A. Severity was not further reduced by higher rates. For the NT system, Alternaria leaf spot severity was reduced with rates up to 120 lb K_2O/A.

Premature plant defoliation also decreased with increased broadcast K rates in both tillage systems. Defoliation was greatest in the unfertilized plots and lowest after broadcasting 120 lb K_2O/A.

Yields from both tillage systems were increased by broadcast K and corresponded well with premature defoliation data. The highest yield and the least amount of premature plant defoliation in both tillage systems occurred with the highest K rate. Plants that were 40 to 70 percent defoliated by early September produced less yield.

Applying foliar K reduced Alternaria leaf spot severity and premature plant defoliation in the CT system relative to the non-foliar and $Ca(NO_3)_2$ treatments. Different results were obtained for the NT cotton. Foliar K reduced Alternaria leaf spot and premature defoliation when compared with foliar $Ca(NO_3)_2$, but the non-foliar check was intermediate. Foliar K increased both CT and NT yields relative to the other foliar treatments.

Broadcasting K for the Loring silt loam did not affect Alternaria leaf spot or premature plant defoliation for either tillage system. Conventional tillage yields were not affected by soil applied K, but NT yields were increased by the 60 lb/A rate. Foliar-applying K reduced Alternaria leaf spot and premature plant defoliation in both tillage systems when compared with the other two foliar treatments. Conventional tillage yields were unaffected by the foliar treatments, but NT yields were greater for the foliar K relative to the $Ca(NO_3)_2$ foliar treatment.

Conclusions

Reduction of Alternaria leaf spot severity and premature leaf drop of cotton produced on soils low in extractable K can be accomplished by applying K to the soil or to the leaves. Yields were also increased by both soil- and foliar-applied K. Early identification of Alternaria leaf spot within a cotton field may indicate a low level of extractable soil K. On soils testing high in extractable K, Alternaria leaf spot severity and premature leaf drop were not factors affecting cotton yields. BC

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Sensing Nitrogen Deficiencies... *(continued from page 16)*

detecting large differences within extremely small areas (10 sq. ft.) in an entire field. Instead of applying a fixed rate to a 100 acre field, this technology allows us to apply the prescribed amount to 435,600 individual 10 sq. ft. areas within the 100-acre field at N rates that range from 0 to 100 lb/A.

It is important to note that there will be many interfering factors affecting fertilizer recommendations when using sensor based systems. While formal field experiments can remove all other factors excluding those being evaluated, the real world poses many additional problems. If a weed is present, and the sensor responds to it, one agronomic decision could be to not fertilize that area (decreased potential for weed seed). Not fertilizing this area will ultimately lead to increased field variability for that fertilizer nutrient. Alternatively, fertilizer could be applied as normal, and a point injector could be used to 'spot' treat for weeds as they are detected in the field. Added problems include the presence of clouds, time of day, plant variety, stage of growth, percent coverage, weed interference, nutrient interactions, and many others. BC

The authors are researchers and members of the precision agriculture team at Oklahoma State University, Stillwater.

M O N T A N A

On-the-Go Grain Protein Sensing Is Near

Does It Have a Future in Precision Nitrogen Management for Wheat?

By Richard Engel, Dan Long and Gregg Carlson

Technologies that apply different fertilizer rates to precisely defined areas of fields are currently available using variable rate fertilizer applicators and the global positioning system (GPS). However, an efficient and easy to interpret method for prescribing fertilizer nutrients is not in place. Methods that use intensive grid soil sampling are not practical for many operations in the semi-arid Great Plains. The cost and effort needed to obtain soil samples can be high when contrasted to potential economic benefit to the grower.

Adoption of site-specific nutrient management for dryland wheat production will require development of new methods for characterizing nitrogen (N) fertility across farm landscapes. Grain protein mapping may be one of those methods.

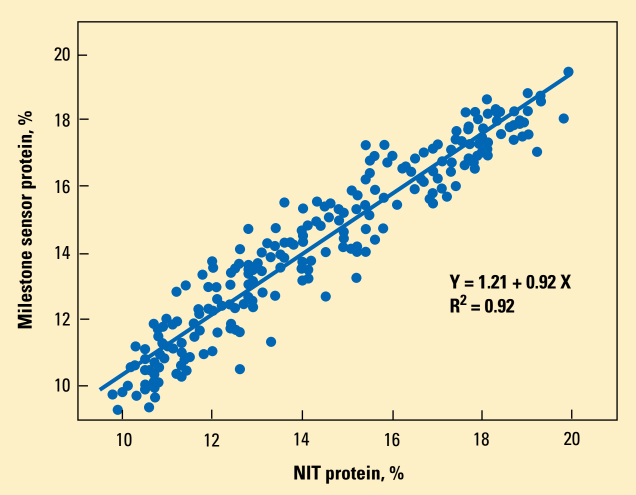

Figure 1. A bench-top test of the Milestone protein sensor on 240 spring wheat samples showed that grain protein estimates correlated well with near-infrared transmittance (NIT) analysis.

In the near future, it should be possible to develop detailed protein maps of grain fields. Milestone Technologies of Idaho is currently developing an on-the-go protein sensor for combines. The sensor uses multi-spectral optics to measure protein content in wheat to within 0.5 percent as grain travels through the auger. A recent bench-top test of this device indicated the protein measurements were consistent with laboratory analyses performed by a near-infrared transmittance (**Figure 1**). This on-the-go grain protein sensor, when integrated with GPS hardware, will enable the development of protein maps for farm fields with similar resolution to current yield maps.

On-the-go grain protein sensing may be a significant development in precision N management efforts for wheat. Grain protein concentrations in wheat are highly correlated with N fertility and available water. If a consistent relationship can be found between yield (expressed in relative terms) and grain protein, then on-the-go protein sensing could provide a method for indexing N fertility across field landscapes. This could be used to help evaluate the success of a grower's N fertility program, direct future soil sampling efforts, and prescribe future N fertilizer rates.

Grain Yield – Protein Relationships for Spring Wheat

Studies in Montana are currently in progress to determine whether a consistent relationship can be found between yield and protein in four spring wheat cultivars. The study is being conducted under an N fertility and water gradient. The water gradient is created with a solid-set irrigation sprinkler system that supplements rainfall with irrigation to achieve the desired water level. The water regimes are designed to simulate three water environments: (1) a low water regime where wheat is under water stress

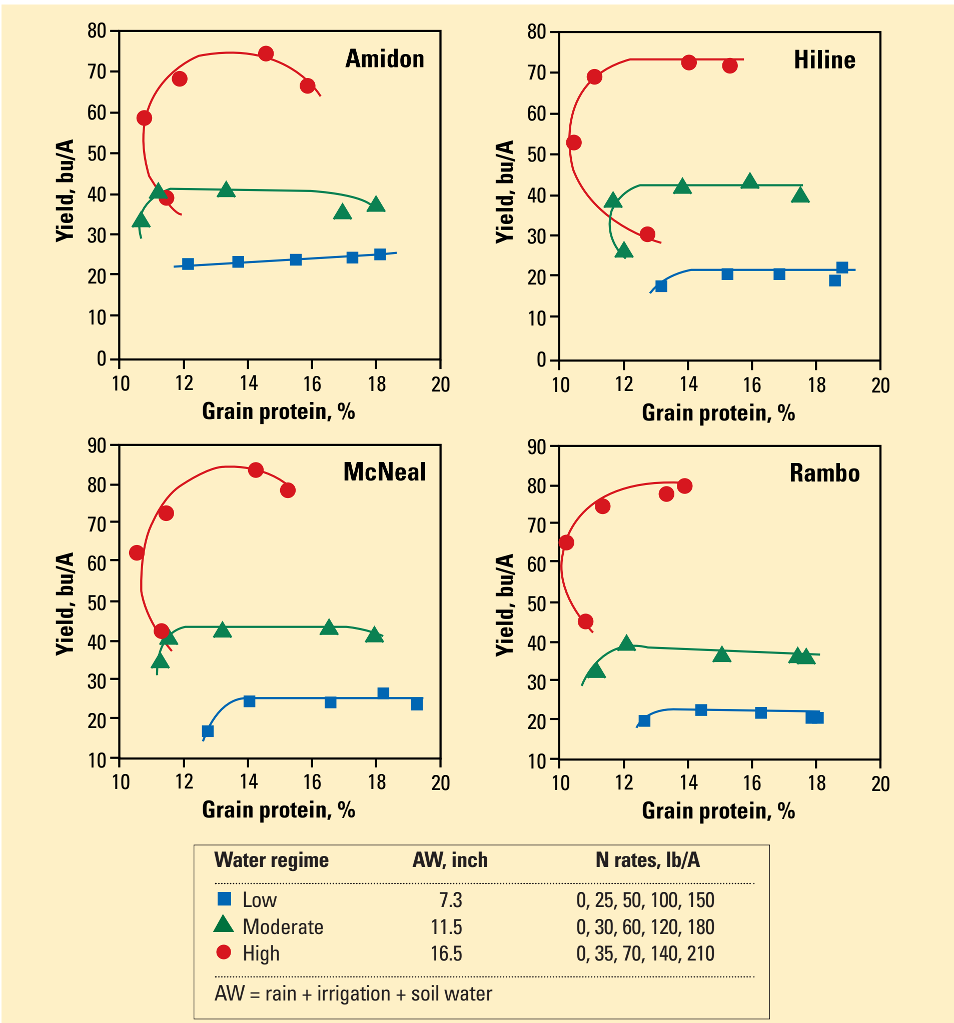

Figure 2. Yield vs. grain protein for four spring wheat cultivars grown under three water regimes. Havre, Montana. 1996.

during vegetative, reproductive, and grain-fill periods; (2) a moderate water regime where wheat is under minimal stress during vegetative and reproductive stages, then stressed during grain-fill; (3) a high water regime where wheat is grown under minimal water stress through most of the growing season.

Grain yield vs. protein curves (**Figure 2**) for the Amidon, Hiline, McNeal, and Rambo spring wheat cultivars illustrate this relationship changes with water. Under drought stress conditions the first increments of applied N produce small increases in yield and protein. Thereafter, protein increases without a corresponding increase in yield, producing a flat curve. As moisture improves, the curves become more "C-shaped." Large increases in yield are observed from applied N. However, protein first decreases then increases as N nutrition improves. This drop in protein with applied N is referred to as the "Steenbjerg effect" and occurs when crop growth is stimulated more than N uptake.

Grain Protein an Indicator of Nitrogen Nutrition

Expressing yield in relative terms, or a percent of the maximum, can normalize the relationships in **Figure 2**. Maximum yield (100 percent) is defined as the average of yields not significantly (.05 level) different than the highest yielding cultivar x water regime treatment. When relative yield is plotted against grain protein (**Figure 3**) two things become evident. First, yield levels for most of the data-points are less than the maximum at protein concentrations below 13.4 percent. Second, where protein concentrations are greater than or equal to 13.4 percent, yield is near the maximum. The implications are that grain protein concentrations provide a method for segregating wheat that is N-deficient from wheat that is N-adequate. This approach appears to be consistent across a wide range of water regimes.

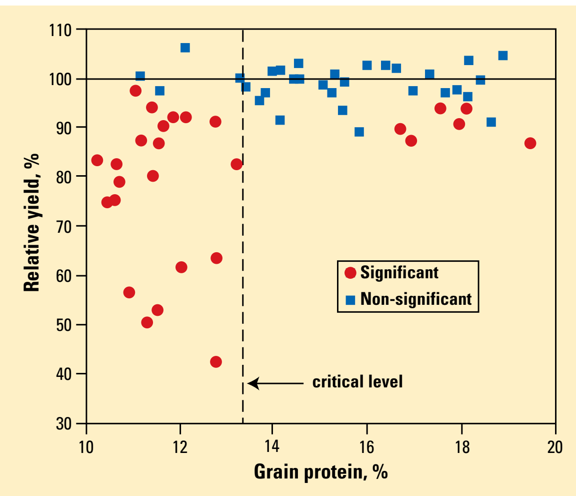

Figure 3. Relative yield vs. grain protein relationships for spring wheat grown under a wide range of N and water regimes reveal a 13.4 percent critical protein level. Protein levels below the critical level were usually significantly below the maximum yield (0.05 level) . Protein levels at or above the critical level were generally associated with maximum yield. Havre, Montana. 1996.

Application in Precision Nitrogen Management

Development of on-the-go protein sensors for combines and protein mapping will make it possible to identify areas within a field (or entire field sites) where the current N fertility program is either insufficient or adequate for maximum yield. The quantity and spatial distribution of N removed from a field could be used as a basis for future N fertility programs using variable rate application technologies. For areas of the field where N fertility is adequate based on grain protein concentrations,

This sensor uses multi-spectral optics to measure protein content in wheat during harvest. (Source: Milestone Technologies, Inc.)

future N recommendations might use a maintenance approach to nutrient management. Under this scenario N is applied at a rate equal to its removal. For example, by mathematically combining the results from protein and yield (expressed in pounds of grain per acre) maps, via the equation below, we can estimate N removal from a field site.

$$\text{N removed in wheat} = \frac{(\text{yield x \% protein})}{5.7 \times 100}$$

In areas of the field where N fertility is insufficient, a build approach to N management would be required. The quantity of N required under this scenario could be estimated by soil testing and from models that relate grain protein to available N (soil + fertilizer N). Results from our spring wheat N fertility-water gradient studies indicate that more N is required to increase protein under wet conditions than under drought. Application of these models would require an estimate of available water (soil moisture + growing season precipitation) conditions for the field site where N deficiency exists.

Looking Ahead

The ability to accurately map N fertility across field landscapes at low cost has been a barrier to adoption of site-specific N management. With on-the-go grain protein sensing, producers will be able to map in great detail areas in their fields where current N fertility programs are either insufficient or adequate for maximum production. This capability could speed adoption of site-specific nutrient management and variable-rate fertilizer application services in regions of the Great Plains where this practice is not being utilized.

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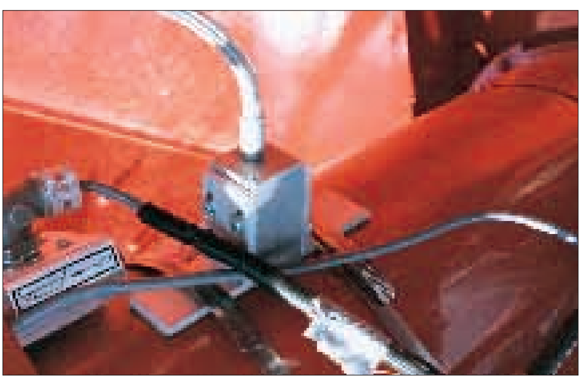

The sensor is shown here mounted on a combine during protein and moisture testing.

Intelligence

Intelligence is the mental capability that, among other things, involves the ability to reason, plan, think abstractly, comprehend complex ideas, learn quickly, and learn from experience. It is not just book learning or test-taking smarts.

The world of education is showing a great interest in "intelligence," how to measure it, what it means, what effect it has on social policy.

There is a great conflict as to the meaning and measure of intelligence. Do human beings differ? Can this be measured? Is it a matter of genetics or environment, or both? Most experts agree that it can be measured and that intelligence tests measure it well. They don't measure creativity, character or personality, but they are not intended to.

Why is all of this of any interest to those concerned with agriculture? Because the agricultural sciences are moving into a new era. And this applies to the entire field of farming.

To farm successfully today requires intelligence, training and experience. Knowledge of market outlook, crop genetic changes, pest management, electronics and computers are a part of farm life. Add to this the innovations of precision farming and machinery developments…there is little room for one who is not intelligent.

We are all affected by the debate going on as to whether intelligence matters in the first place and if so, can we measure it? Students are not admitted to colleges unless they meet certain measures of intelligence. Are farm-raised youth less likely to meet requirements?

Finally, when it comes to measuring success and happiness in life, where does intelligence stand when we line it up with creativity, character and personality?

J. Fielding Reed

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