general principles that make a 4R Nutrient Stewardship plan distinct from a regulatory nutrient management plan are: 1) asking the producer to state sustainability goals and performance indicators for the farm, 2) allowing producers flexibility to implement adaptive management by ensuring that the details of practices implemented for each crop and in each field are documented but kept private, and 3) publicly reporting progress in using indicators or measures of performance reflecting the economic, social and environmental pillars of sustainability. These principles are at the core of a management system consistent with international principles of accountability for sustainability performance.

Example – Managing Phosphorus Fertilizer in the Lake Erie Watershed

Phosphorus (P) is an essential nutrient for growing crops. But in the wrong place – in excess concentration in streams, rivers, and lakes – it can lead to algal blooms. In the Lake Erie watershed region in and around the state of Ohio, USA, levels of dissolved P in rivers and algal blooms in lakes have been trending upward from 1995 to 2011. Fertilizers applied to the predominant corn-soybean cropping system are not the only cause, but are one possible cause among many.

Research data show that when fertilizer P is broadcast and left on the surface, runoff resulting from rainstorms within a few days of application is enriched in dissolved P to levels far above those known to stimulate algal blooms, even though the losses amount to less than 5 to 10 percent of the fertilizer P applied. To mitigate these losses, 4R Nutrient Stewardship implemented in this region focuses on applying fertilizer at the "right time" and in the "right place." Wherever possible, fertilizer P is recommended to be placed below the soil surface, by injecting, banding, or by incorporating after broadcasting. Where incorporation is difficult, for example in no-till systems, producers are advised to pay close attention to the weather forecast, and avoid broadcasting P fertilizer when there is more than 50% chance of intense rain within the next few days.

A group of agri-business partners, government agencies and environmental organizations is working together to provide educational programs and raise awareness of how nutrient stewardship can contribute to reducing losses of dissolved P. This group includes The Nature Conservancy, the Ohio Agri-Business Association, the Ohio government departments of agriculture and natural resources, Ohio State University Extension, and several agri-retailers and crop producers. Further work is ongoing to develop better validated criteria for selecting practices, based on research monitoring actual edge-of-field losses. Further information on the program is available from The Nature Conservancy. By supporting management that is adaptive and addressed at economic and environmental goals at the same time, 4R Nutrient Stewardship assures continued progress in advancing crop yield s in this highly productive watershed.

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Reference

IPNI. 2012. 4R Plant Nutrition Manual: A Manual for Improving the Management of Plant Nutrition, Metric Version, (T.W. Bruulsema, P.E. Fixen, G.D. Sulewski, eds.), International Plant Nutrition Institute, Norcross, GA, USA.

Visual Indicators of Potassium Deficiency in Corn

T.S. Murrell

While marginal chlorosis and necrosis are the most widely recognized symptoms of K deficiency, they are not the only ones. Other plant manifestations can exist and may or may not be accompanied by marginal chlorosis or necrosis. As the number of visible symptoms increases, there is greater likelihood that the plant is experiencing a K deficiency.

The most widely recognized visual expression of K deficiency is marginal chlorosis or necrosis on older, lower leaves on the plant, such as that shown in the accompanying photo. By the time this symptom appears, however, grain yield may have already been lost (Bly et al., 2002). Although this sign is the most well known, it is not the only visual indicator of K deficiency, as this can be also evidenced by many other visual manifestations that can occur, either with or without marginal necrosis, and with severity that varies considerably within a field. As the number of visible symptoms increases, there is greater likelihood that the plant is experiencing a K deficiency. This article lists these additional evidences along with some key references. Seeing some of these indicators can be difficult, however, without a reference area in the field where K is known to be sufficient. Such an area can be created with an ample application of K that is replenished over time to keep up with the K removed by successive crop harvests.

Abbreviations and notes for this article:
GDD = growing degree days; K = potassium;
N = nitrogen.

Shorter Plants

It has been known for many years that K deficiency can result in shorter plants. Younts and Musgrave (1958) demonstrated this effect decades ago in two field studies examining different K rates, sources, and placement methods. Across all factors, they found that K fertilization significantly ($p = 0.05$) increased plant heights by 11 to 28%, 10 to 12%, 9 to 16%, and 15 to 36% when measured at 26, 31, 44, and 65 days after planting, respectively.

Reduction in Leaf Dimensions and Surface Area

A measurement quantifying relative differences in leaf area is the leaf area index, or LAI. Leaf area index is the ratio of leaf area to a given unit of land surface area (Watson, 1947). Jordan-Meille and Pellerin (2004) found that corn plants that were deficient in K had a lower LAI than healthy plants. Most of the leaves of K deficient corn plants were narrower and shorter than leaves of K sufficient plants, reducing their overall surface area (**Figure 1**). Leaf numbers 5-7 were most affected by K deficiency and showed reductions in length of approximately 25%. Similar reductions were observed for leaf width, resulting in a nearly 50% reduction in total leaf area. Leaves emerging earlier or later in the season were less affected. For example, leaf numbers 17-20 had lengths, widths, and surface areas equal to or greater than K sufficient plants. Even though these later-developed leaves had larger surface areas, increases were not great enough to compensate for the reductions coming from the older leaves, leading to an overall decrease in LAI.

Slowed Vegetative Development

Potassium deficiency can also delay corn development. At all sampling periods, Jordan-Meille and Pellerin (2004) measured a slight but significant reduction in the number of visible and fully expanded leaves in K deficient plants. The maximum difference occurred when 15 leaves were visible in K sufficient plants. At this time, K deficient plants had 0.8 visible leaves less than K sufficient ones, indicating a delay in growth of nearly one vegetative stage. In an earlier greenhouse study, Koch and Estes (1975) reported no delay in the number of fully expanded leaves up to the end of their sampling period, which was leaf 11. These results are not necessarily inconsistent with those of Jordan-Meille and Pellerin (2004), since their maximum delay in maturity was less than one leaf and they reported visible, rather than fully expanded leaves.


Marginal chlorosis and necrosis on lower, older leaves _ a visual symptom of K deficiency. The stake indicates zero K treatment.

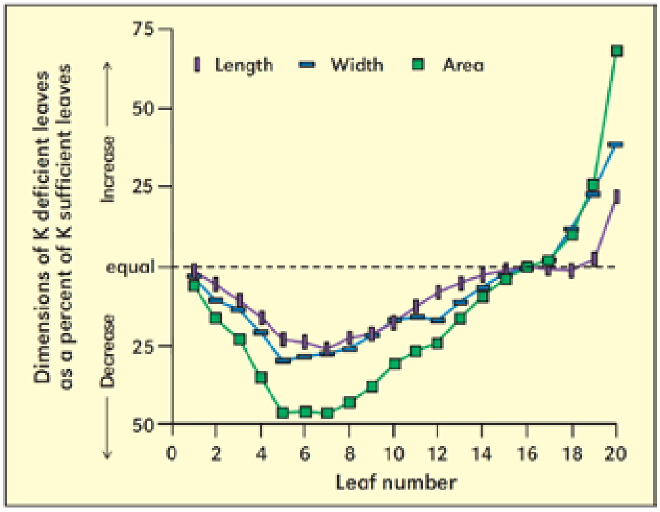

Figure 1. Leaf dimensions (length and width) and surface areas of K deficient leaves, expressed as a percentage of the leaf dimensions and surface areas of K sufficient leaves (Jordan-Meille and Pellerin, 2004).

Delayed Tasseling

Corn plants with insufficient K may take longer to reach the VT growth stage (tasseling) than plants with sufficient K. Peaslee et al. (1971) found that unfertilized, K deficient plants sown early in the season took 84 growing degree days (GDD) longer to reach VT than plants well supplied with K. Unfertilized corn planted later took 53 GDD longer to reach VT. Younts and Musgrave (1958) made a similar observation at 65 days after planting in one of their experiments, where K fertilization significantly ($p = 0.05$) increased the percent-age of plants that had reached VT by 8 to 16%. However, in their other experiment, K fertilization did not produce any significant increase in percent of plants tasseled. Conversely, one of their treatments, a 135 kg/ha (120 lb/A) rate of K_2O applied as KCl, caused a significant ($p = 0.05$), 16% decrease in percent of plants reaching VT when sampled 61 days after planting. So while a delay in tasseling is possible, it may not be a consistent result.

Delayed Silking

Like tasseling, crop development to silking (R1) may also be delayed by K deficiency. Younts and Musgrave (1958) observed that maize fertilized with K exhibited

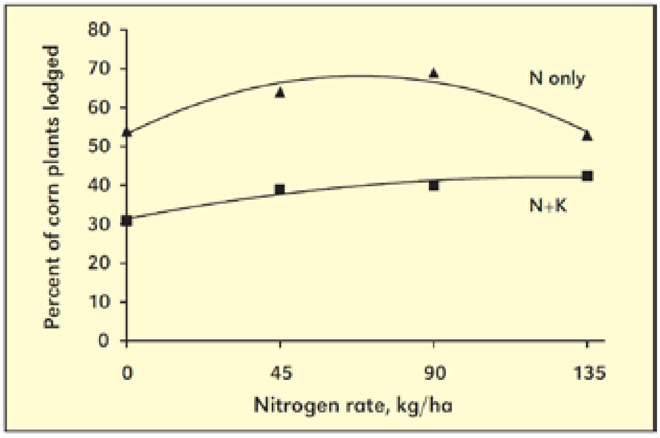

Figure 2. Percent of lodged corn as a function of N rate with and without K. Response to K was averaged over the 45 and 90 kg/ha (40 and 80 lb/A) K_2O rates (Fisher and Smith, 1960).

significant ($p = 0.05$) increases in percentages of plants that had reached R1 at 69 to 73 days after planting, depending on the experiment. These increases ranged from 8 to 34%.

Increased Lodging

Lodging in corn may result from disease, insect damage, poor plant development arising from K deficiency, or a combination of these factors.

Lodging caused by poor plant development arising from K deficiency was demonstrated by Liebhardt and Murdock (1965). In their research, they found that K deficiency led to a hastening of parenchyma cell (pith) breakdown in brace roots and caused parenchyma cell disintegration in the stalk. Poorly developed brace roots, observable in the field, led to "root lodging" which occurred earlier in the season, after R1. Parenchyma cell disintegration in the stalk led to "stalk breakage" which occurred later, during the dent stage (R5).

No disease in the stalk was observed until crop maturity (R6), when stalk parenchyma tissue had already significantly disintegrated. Boswell and Parks (1957) demonstrated that hybrids differed in their susceptibility to root lodging and stalk breakage. However, regardless of susceptibility, low soil supplies of K increased root lodging and stalk breakage by an average of 12%.

Stalk breakage was shown to be related to the ratio of N:K elemental concentrations in the stalk when K concentra-tions were low. Parenchyma cell breakdown was observed when N was 3 to 4 more times concentrated in the stalk than K (Liebhardt and Murdock, 1965).

Fisher and Smith (1960) isolated the effects of N and K on lodging and found that lodging incidence increased when N was applied without K on a low K testing soil (**Figure 2**), consistent with the results of Liebhardt and Murdock (1965). Lodging can also be caused by fungal diseases and K deficiency has been shown to increase the severity of them. In a recent review, Prabhu et al. (2007) catalogued three stalk rot pathogens (Fusarium moniliforme, Gibberella zeae, and Diplodia zeae) to which corn had greater susceptibility when deficient in K.

Summary

While marginal leaf chlorosis and necrosis are the most well known visual signs of K deficiency, there are other indicators of K shortage exhibited by corn. Although not complete, several delays or changes in plant development have been listed here to assist farmers and crop advisers as they make observations in the field. Detecting these delays and changes can be difficult without a reference area that is known to have an adequate supply of K. It is therefore suggested that such an area be established and maintained over time to provide a basis for comparison.

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References

Boswell, F.C. and W.L. Parks. 1957. Soil Sci. Soc. Am. J. 21:301.
Bly et al., 2002. Better Crops 86(3):12-15.
Fisher, F.L. and O.E. Smith. 1960. Agron. J. 52:201.
Jordan-Meille, L. and S. Pellerin. 2004. Plant Soil 265:75-92.
Koch, D.W. and G.O. Estes. 1975. Crop Sci. 15:697-699.
Liebhardt, W.C. and J.T. Murdock. 1965. Agron. J. 57:325.
Peaslee et al. 1971. Agron. J. 63:561.
Prabhu et al. 2007. p. 57-78. In Datnoff et al. (ed.) Mineral nutrition and plant disease. The American Phytopathological Society, St. Paul, Minnesota.
Watson, D.J. 1947. Ann. Bot. 11:41-76.
Younts, S.E. and R.B. Musgrave. 1958. Agron. J. 50:423-426.