During the past century, corn and soybean yields in North America have increased dramatically. Corn yields have been rising each year by 1.9 bu/A in the U.S. and by 1.3 bu/A in Canada (Figure 1). Soybean yields have been mounting each year by 0.34 to 0.37 bu/A. If these trends continue, 290 bu/A corn and 75 bu/A soybeans could become averages rather than extremes by the end of the 21st century. What are the implications for future nutrient use?

Maximum yield records, set under ideal field growing conditions, exceed today’s average yields by a wide margin. Details of records set in research in the northeast U.S. are given in Table 1. In New Jersey, R.L. Flannery produced 338 bu/A corn in 1982 and 118 bu/A soybeans in 1983. In Ontario, C.K. Stevenson achieved a yield of 293 bu/A for corn and 96 bu/A for soybeans in 1985. These yields are still more than twice the current average yields.

In Ontario, the high potential yield of corn was also demonstrated in a controlled-environment growth room. With 16-hour days, nutrients supplied hydroponically, and a day/night temperature of 79ºF/68ºF, a short duration corn hybrid yielded 239 bu/A, despite lighting that provided less than half of typical outdoor irradiance. If a corn crop could maintain similar light conversion efficiency in a full-season field environment, expected yield would top 600 bu/A. One explanation for the remarkable performance of corn under these conditions is the low-stress environment: no water deficit, roots well-aerated, no cold or hot temperatures, and no excessive winds with constant air circulation.

Much of the yield gain in corn in the past century has been a result of improved genetics. Extensive research has shown that genetic yield gain in Ontario did not result from better stress tolerance, increased photosynthesis, and higher yield. Future nutrient management will need to support the critical yield determining characteristics of these crops.

Figure 1. Corn and soybean yield averages for the past century in the U.S. and Canada.
(Source: USDA-NASS and Statistics Canada).
increased yield potential, but from increased ability to tolerate stress. New hybrids suffer less yield reduction under conditions of drought stress, high plant population, weed interference, low nitrogen (N), herbicide injury, and low night temperatures. These changes in stress tolerance are likely the by-product of plant breeders selecting for yield at high plant populations and over a wide range of growing environments.

The yield benefit from enhanced stress tolerance is expressed primarily in the ability of newer hybrids to capitalize on higher plant populations. Even in an optimal growth environment, plants are under stress when grown at a population that maximizes yield. As plants are moved closer together, competition for resources results in stress that reduces their growth. However, yield per unit area continues to increase until the reduction in plant growth caused by the stress becomes larger than the yield gain by increasing the number of plants.

Crop yields can increase through either greater capture or use of resources. In the case of corn, most of the genetic gain has been in resource capture. Newer hybrids capture more light using higher plant populations and by delaying leaf senescence. They also capture more water and nutrients from the soil through increased root system activity. Smaller gains have also been made in resource use efficiency, in hybrids with more erect leaves, and more uniform distribution of light over leaf surfaces. However, new and old hybrids do not differ in the maximum photosynthetic rates of individual leaves under low-stress conditions.

Delayed leaf senescence, or “stay-green”, extends nutrient uptake longer into the fall. Continued uptake makes better use of N mineralized from the soil, and thus can increase N uptake efficiency. The impact on other nutrients has not been studied in detail, but corn

| TABLE 1. Cropping system information for record yields in Chatham, Ontario and Adelphia, New Jersey. |
|---|---|---|---|
| **Highest yield, bu/A** | **Ontario** | **New Jersey** | **Ontario** | **New Jersey** |
| Variety | Pioneer 3540 | O'S Gold SX5509 | Pioneer 9292 | Asgrow A3127 |
| Plant population, per acre | 41,820 | 37,337 | 150,000 | 261,360 |
| Row spacing, inches | 15 | 12 | 7 | 6 |
| Soil pH | 7.3 | 5.7 | 6.8 | 5.7 |
| Soil CEC, meq/100g | 16.6 | 8.5 | 16.3 | 7.5 |
| Soil organic matter, % | 4.0 | 1.3 | 4.0 | 1.4 |
| Soil texture | silt loam | sandy loam | silt loam | sandy loam |
| Soil test P, ppm<sup>1</sup> | 51 (VH) | 92 (VH) | 48 (VH) | 67 (VH) |
| Soil test K, ppm | 176 (VH) | 171 (VH) | 161 (VH) | 163 (VH) |
| Fertilizer N, lb/A | 560 | 500 | 100 | 175 |
| Fertilizer P<sub>2</sub>O<sub>5</sub>, lb/A | 150 | 350 | 150 | 225 |
| Fertilizer K<sub>2</sub>O, lb/A | 150 | 350 | 150 | 300 |
| Manure, tons/A of dry matter | 4.7 | 5.5 | residual<sup>2</sup> | residual<sup>2</sup> |
| Manure N, lb/A | 42 | 150 | – | – |
| Manure P<sub>2</sub>O<sub>5</sub>, lb/A | 80 | 100 | – | – |
| Manure K<sub>2</sub>O, lb/A | 200 | 100 | – | – |
| Secondary & Micro, lb/A: (fertilizer & manure): | | | | |
| Calcium | 261 | 672 | 44 | – |
| Magnesium | 110 | 255 | 25 | – |
| Sulfur | 141 | 179 | 64 | – |
| Zinc | 13 | 10 | 12 | 5 |
| Manganese | 33 | 25 | 4 | 25 |
| Boron | 1 | 2 | 1 | 1 |
| Copper | 6 | 5 | 6 | 5 |
| Aglime applied? | no | yes | no | yes |
| Irrigation | trickle | trickle | none | trickle |

<sup>1</sup>Ontario soil test P was Olsen, New Jersey was Mehlich-1; ppm = parts per million

<sup>2</sup>Residual manure from that applied before the previous corn crop.
continues to take up phosphorus (P) directly until maturity.

If genetic stress tolerance can increase yield, what about other means of increasing stress tolerance? Potassium (K) has long been associated with stress tolerance. Its role in turgor helps plant cells maintain the integrity of their internal machinery – chloroplasts and other structures that support photosynthesis. Plant cells that lose too much water slow down in photosynthesis because of internal distortion. Within the plant, K has an osmotic effect that helps cells retain water.

In Connecticut, G.A. Berkowitz found that leaf K concentrations above optimum for normal conditions can be beneficial for stress conditions. When wheat plants were nourished with a solution three times richer in K than normal, their leaves sustained rates of photosynthesis 67 to 114 percent higher after an 8-day water stress period. What is called “luxury consumption” under normal conditions may help plants to continue growing under stress conditions.

It is possible that new corn hybrids may require less K owing to their greater genetic stress tolerance and greater root activity. On the other hand, they may require more K to enhance expression of such tolerance. Experiments to document hybrid-specific optimal K levels are rare, and results can be inconsistent from one year to the next.

Yield increases in soybeans, in contrast to those in corn, have resulted mainly from a higher harvest index and increased rates of photosynthesis per unit leaf area. A recent study by M.J. Morrison and others documented those changes in Canadian soybeans, by comparing 14 varieties released over the past 58 years. The rate of genetic yield increase, however, is only about half the rate of actual increase in average soybean yields. Better management and movement of soybean cultivation to soils less prone to disease are other factors contributing to yield improvement.

The improved photosynthetic efficiency is interesting because in C3 species such as soybeans, it is limited by the inefficient enzyme RuBisCO – which comprises half the leaf protein and loses 20 to 50 percent of the carbon (C) it fixes to photorespiration. Scientists have discovered a more efficient RuBisCO in red algae. Both conventional plant breeding and molecular biology appear to have promising potential to improve this rate-limiting enzyme.

While soybeans have followed a separate path to yield improvement, future gains may also occur along the path of increasing stress tolerance. Drought stress affects all crop species, and maintaining photosynthesis under conditions of evaporative demand is key to drought tolerance.

The input intensity on many maximum yield plots was well above economic levels. Yet, yields close to those levels can be attained at lower cost by determining the inputs that are critical. In Ontario, yields without irrigation came within 18 bu/A of the maximum yield. Identifying the inputs critical for success is complicated by interactions. The best hybrids for a high-yield system will not necessarily be the ones best suited to the current cropping system.

The 338 bu/A corn yield in New Jersey was grown using sulfate of potash (SOP) as the sole K source. Subsequently, five years of high yield management research found that muriate of potash (MOP or KCl) produced higher yields and less stalk rot than other K sources. While SOP has advantages over muriate in some situations for specialty crops, high yield situations may require more chloride (Cl).

Intensive inputs can increase risk of nutrient loss that impairs water quality. Nitrogen and P are the two nutrients of greatest concern. Such risks must be recognized by targeting management for high yields to low-risk soils. Groundwater nitrate (NO3) contamination risks can be minimized by avoiding highly leachable soils, matching inputs as closely as possible to crop demand, and timing applications to minimize the opportunity for nitrification and subsequent leaching of NO3. The newer “stay-green” corn hybrids can help, as they continue N uptake further into the fall, preventing leaching of the N mineralized from the soil. Research in Ontario indicates that new hybrids take up as much as 60 percent of their N after silking, compared to 40 percent or less for older hybrids.

Tillage practices that prevent erosion and (continued on page 13)
shorter set times if possible. Assure ade-
quate fertility; August nitrogen (N) appli-
cation may be necessary.

- Keep irrigating to assure adequate mois-
ture for late-season boll fill (on some soils
as late as October 1).
- Defoliate with high rates of most materi-
als in mid- to late-October.
- Begin harvest in mid-November.

Mr. Rayner, his brothers, and a nephew
produced 2,439 lb lint/A (5.08 bales) in one
field in 1997 using the above strategy, netting
about $360/A based on 60-cent cotton.
Breakeven yield was 1,840 (3.83 bales).

Producing 5-plus bales/A requires coop-
erative weather. Unusually cool spring condi-
tions can retard the crop’s development, mak-
ing it impractical to manage for a second set.
At the other end of the season, cool and wet
fall weather can make defoliation difficult.
Both situations may require in-season changes in strategy, emphasizing the impor-
tance of growers staying on top of their partic-
ular production situation.

Fertilizer requirements are necessarily
high for 5-bale cotton. Each bale removes
about 31 lb N, 12 lb P₂O₅, and 14 lb K₂O from
the field. Therefore, 5 bales contain approxi-
mately 155 lb N, 60 lb P₂O₅ and 70 lb K₂O.
Actual nutrient uptake by the cotton plant is
substantially greater, but the vegetative por-
tion recycles nutrients into the soil when it is
incorporated. Inadequate fertilization with
potassium (K) over several decades of cotton
production and its rotational crops has left
many California fields depleted, requiring
buildup applications to overcome resultant K
fixation problems. University recommenda-
tions in these cases are for rates up to 400
lb/A of K₂O to correct the problem. Repeated
applications may be necessary to return diffi-
cult fields to their full yield potential.

Total seasonal requirements of nutrients
are only part of the story. Daily demand varies
with the plant’s stage of growth and must be
considered in the in-season management
strategy. Recent research in California and
other Cotton Belt states, for example, has sug-
gested that in-season foliar applications of K
can boost yield potential. This particular prac-
tice has been shown to enhance yields in
fields with good yield potential even where
soil K fertility was considered adequate.

The cotton boll is a strong sink for K. Dur-
ing its formation, most crops take up K at
the rate of 1.9 to 3.0 lb/A/day (2.3 to 3.6 lb/A
of K₂O). Inadequate absorption of K during
this peak demand period, if only for a week or
so, could significantly limit yield of potential-
ly 3-bale crops, not to mention 5-bale crops.
Where appropriate, the University of
California recommends two foliar applications
of 10 lb/A K₂O, at 7 and 14 days after first
flower. This is simply another management
tool at the grower’s disposal in planning a
high-yield strategy.

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Boosting Crop Yields... (continued from page 11)

of all plant growth resources. Managing
the crop of the future will demand
attention to supplying the critical re-
sources to support yields closer to the
potential that has been demonstrated
in maximum yield research.

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