NORTHEAST U.S./ EASTERN CANADA

Boosting Crop Yields in the Next Century

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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?

> Genetic improvement has resulted in crops with better stress tolerance, increased photosynthesis, and higher yield. Future nutrient management will need to support the critical yield determining characteristics of these crops.

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 79°F/68°F, 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

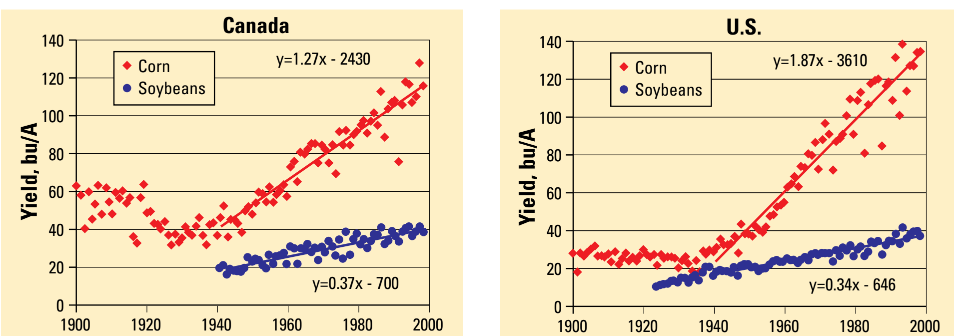

Figure 1. Corn and soybean yield averages for the past century in the U.S. and Canada. (Source: USDA-NASS and Statistics Canada).

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.

	Corn		Soybean	
	Ontario	**New Jersey**	**Ontario**	**New Jersey**
Highest yield, bu/A	**293**	**338**	**96**	**118**
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[1]	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_2O_5, lb/A	150	350	150	225
Fertilizer K_2O, lb/A	150	350	150	300
Manure, tons/A of dry matter	4.7	5.5	residual[2]	residual[2]
Manure N, lb/A	42	150	–	–
Manure P_2O_5, lb/A	80	100	–	–
Manure K_2O, 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

[1]Ontario soil test P was Olsen, New Jersey was Mehlich-1; ppm = parts per million

[2]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 (NO_3) 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 NO_3. 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

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shorter set times if possible. Assure adequate fertility; August nitrogen (N) application may be necessary.

- Keep irrigating to assure adequate moisture for late-season boll fill (on some soils as late as October 1).
- Defoliate with high rates of most materials 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 cooperative weather. Unusually cool spring conditions can retard the crop's development, making 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 importance of growers staying on top of their particular production situation.

Fertilizer requirements are necessarily high for 5-bale cotton. Each bale removes about 31 lb N, 12 lb P_2O_5, and 14 lb K_2O from the field. Therefore, 5 bales contain approximately 155 lb N, 60 lb P_2O_5 and 70 lb K_2O. Actual nutrient uptake by the cotton plant is substantially greater, but the vegetative portion 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 recommendations in these cases are for rates up to 400 lb/A of K_2O to correct the problem. Repeated applications may be necessary to return difficult 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 suggested that in-season foliar applications of K can boost yield potential. This particular practice 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. During 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 K_2O). Inadequate absorption of K during this peak demand period, if only for a week or so, could significantly limit yield of potentially 3-bale crops, not to mention 5-bale crops. Where appropriate, the University of California recommends two foliar applications of 10 lb/A K_2O, 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. BC

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conserve soil not only support high-yield management but also minimize the risk of P loss to surface waters. Buffers along waterways also help to ensure clean water. Indexes that integrate source and transport factors can help identify the particular combinations of soil texture, landform, nutrient source, and application methods that allow for use of sufficient inputs for high yield management.

The corn and soybean crops of the future will likely continue to increase in stress tolerance and in efficient use of all plant growth resources. Managing the crop of the future will demand attention to supplying the critical resources to support yields closer to the potential that has been demonstrated in maximum yield research. BC

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