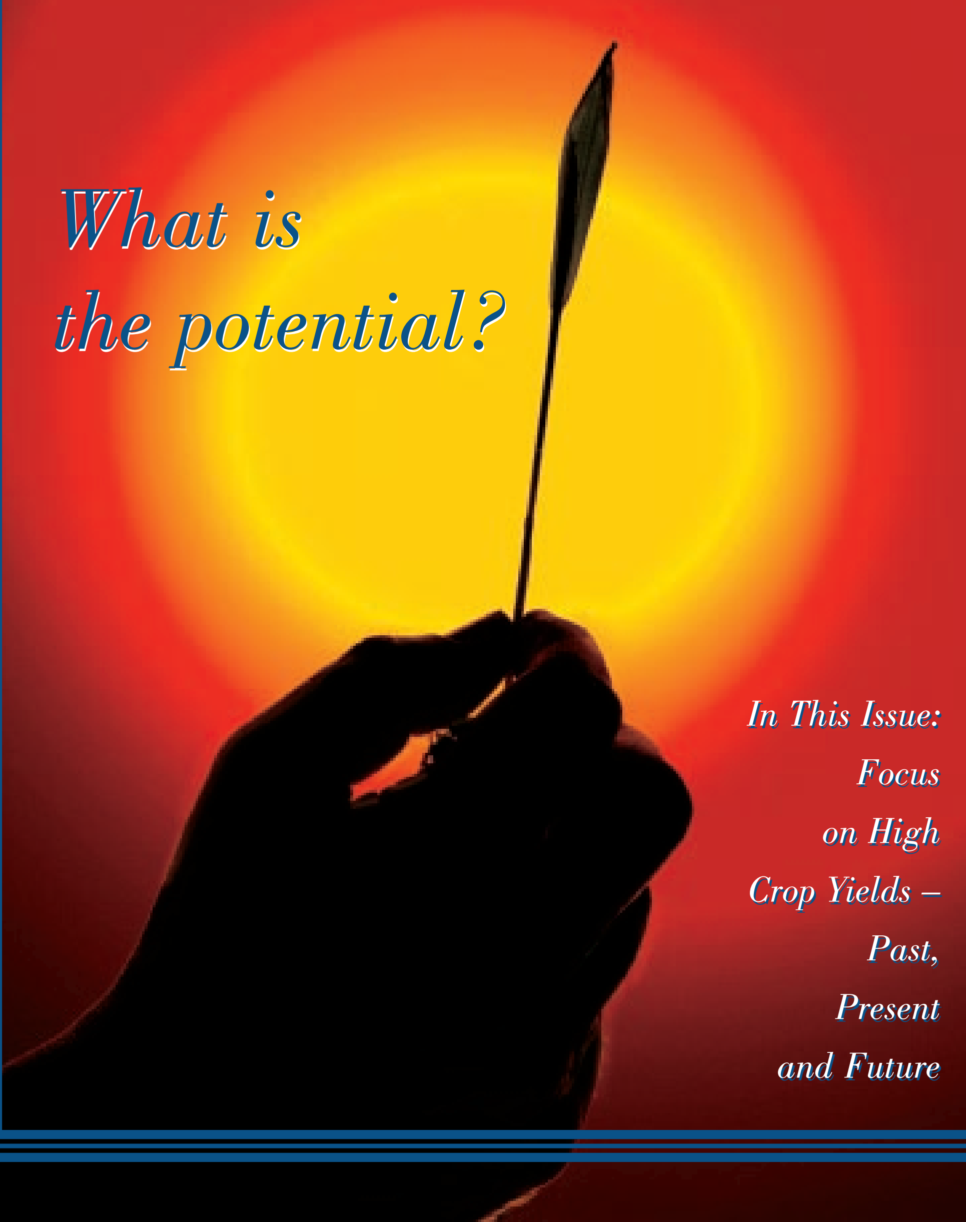
BETTER CROPS WITH PLANT FOOD

2000 Number 1



What is the potential?

In This Issue:

Focus on High Crop Yields – Past, Present and Future

BETTER CROPS WITH PLANT FOOD

Vol. LXXXIV (84) 2000, No. 1

Our Cover: A plant seedling silhouetted by the sun.
Photo Source: Debra L. Ferguson/www.southern-images.com

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Staying the Course for PPI in 2000

The strategic model of PPI has remained unchanged since the inception of the organization nearly 65 years ago. That model is to promote research relevant to the Institute's mission of advancing the worldwide use of phosphorus (P) and potassium (K) and to follow up with educational efforts to implement the results of the research. Major North American issues for PPI in 2000 involve both research and educational components of the program.

Research Issues:

- **Improvement of crop yield.** PPI has been carefully evaluating its research priorities for the next decade. We started the process fully anticipating that areas such as biotechnology, site-specific precision agriculture, nutrient management planning, or the influence of management on attributes important for specific end use of crops would receive the highest priority. Although important to the future of agriculture, we eventually realized that these were all secondary to a very fundamental research objective...the improvement of crop yield. We believe that successful accomplishment of this single objective is critical to reducing unit costs for growers and necessary for meeting future global food needs while enhancing environmental quality. At the same time, it holds excellent growth opportunity for agribusiness and rural communities.
- **Application of new technologies.** We plan to continue to address how new technologies, including biotech and the suite of site-specific technologies, can be utilized in yield improvement and risk management.
- **Crop quality and attributes for specific end use.** We hope to expand research addressing the impact of P and K management on crop attributes important for specific end use such as nutraceutical levels in functional foods.

We feel such impacts will in the near future have economic value to producers and that the information generated will have the potential to improve the consumer's image of fertilizers.

Educational Issues:

- **Improvement of crop yield.** Resources will be developed that focus on the gap existing today between attainable yields and typical yields and key practices to exploit that gap.
- **Use of the internet.** The PPI-FAR web site will be completely restructured in 2000 with a much greater focus on the needs of our clientele groups. The restructuring will improve the effectiveness of this major information dissemination tool for PPI.
- **Nutrient management planning.** Training resources for nutrient management planning prepared for InfoAg99 will be refined. We will continue to work with organizations such as The Fertilizer Institute (TFI), Canadian Fertilizer Institute (CFI), state/provincial industry associations, and other groups to influence those defining the nutrient management planning process to assure that it enhances the farmer's ability to efficiently produce high yields.
- **Water quality.** We will continue to work with technical agencies and academic groups involved with hypoxia and surface water quality and support the development and use of sound scientific data in assessing and addressing these issues.
- **Information Management.** We plan to more fully develop database tools to facilitate our ability to manage, package, and deliver information more rapidly and in a more site-specific fashion. BC

High Yields, High Profits, and High Soil Fertility

By B.C. Darst and P.E. Fixen

Consider the fact that by the year 2025 the per capita land base for world food production will be less than half what it was in 1965 (**Table 1**)...the result of more than a doubling of population, while land in crop production increases only slightly.

Imagine a highway of cereal grains circling the Earth at the equator. It is 8.3 feet thick and 66 feet wide. It represents the amount of production required to feed the world population for one year. Further, it must be completely reproduced each year and another 650 miles added... **just to feed the additional humans born that year.**

> "Use more and better machinery, plant the best seeds...cultivate effectively, and apply the kind and amount of commercial fertilizer that will produce the highest yields to reduce costs per unit..."
>
> *Southern Cultivator,* 1870

These are tough times for agriculture. Farmers are faced with low commodity prices. Fertilizer producers are shutting down or significantly curtailing production. Recovery from the economic meltdown in Asia is starting, but is slow. Western Europe and other parts of the world are backing off buying genetically enhanced crops. Why worry about growing more to feed a growing world population when farmers are being paid so poorly for what they are already producing? Farmers are in an economic squeeze, and answers don't come easy.

A recent headline in the *Southwest Farm Press* read "Good yields take the sting out of low prices." The headline emphasizes the impact low commodity prices are having on the farm economy. Input costs continue to rise while prices farmers receive sometimes resemble those of the 1970s. What can be done to ease the effects of the current economic downturn? Should farmers cut costs, turn on the cruise control, and let yields fall where they may? Such a management philosophy doesn't make sense, even in the short-term, much less when one looks to the future health of agriculture.

We all know that agriculture is a cyclic industry, controlled largely by outside forces. It is now at a low point in the cycle...things are bound to get better. While that doesn't make

TABLE 1. Arable land available for agricultural production.

Year	Arable land, A/person
1965	1.14
1980	0.84
1990	0.74
2000 (projected)	0.62
2025 (projected)	0.49

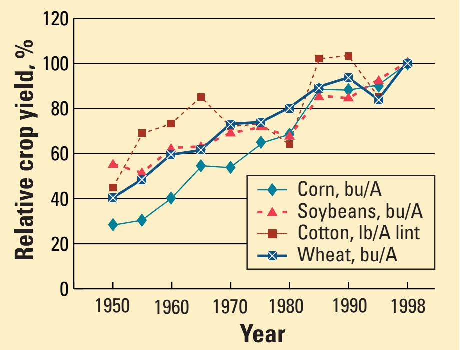

Figure 1. Relative yields of corn, soybeans, wheat, and cotton.

the situation any easier to accept, it does provide some perspective. It points critically to the need for high yield, high efficiency crop production. In 1984, the late Dr. J. Fielding Reed wrote, "The U.S. farmer will become more involved with the world food picture. Whatever farm programs evolve, the concept of maximum economic yield (MEY) is a sound principle...producing at the yield level that results in the least cost per unit of production."

High yields and low unit production costs give farmers the best chance to make a profit when prices are low. They also allow farmers to make the most profits when prices are higher. High yields mean more than higher profits in any given crop year. They are indicative of management that promotes sustainability... that is protective of the environment...and that makes most efficient use of purchased inputs such as fertilizers through sound nutrient planning.

In 1987, Dr. Reed said, "Maximum economic yield neither creates nor cures a world farm crisis. But, whatever the situation with regard to farm program, surplus, price, or exports, increasing production efficiency should be a part of the solution. Can anyone honestly disagree with that concept?" The quote at the beginning of this article, first published 130 years ago, and Dr. Reed's mid-1980s writings are still applicable today...and take us back to the basic principle that high, efficiently managed yields pay. Dr. Reed was correct: It would be difficult to honestly disagree with that concept.

The third part of the title of this article...high soil fertility...is an under-girding support of sustainable high yield crop production. The relationship among high yields, high profits, and high soil fertility is undeniable and well documented.

Yield trends for corn, cotton, soybeans, and wheat in the U.S. for the last 50 years, as shown in **Table 2**, have moved up dramatically and are reflective of increases in food and fiber production in general. **Figure 1** shows the same data plotted as relative yields for each crop, with the 1998 crop year being set at 100 percent. Many factors...mechanization, hybridization, development of the pesticide industry, improved farmer management...have contributed to these yield increases.

Efficient crop fertilization and nutrient management are also integral to the production of high yields. **Table 3** shows trends in nitrogen (N), phosphorus (P), and potassium (K) consumption in the U.S., 1950-1998. The growth in nutrient use closely parallels increases in crop yields, as would be expected. It is interesting to note, however, that even though NPK use leveled off beginning about 1980, crop yields continued to climb. One obvious conclusion to be drawn from this comparison is that farmers are making more efficient use of fertilizer nutrients. **Figure 2** verifies that conclusion. It shows that NPK use efficiency on corn has been increasing for the last 20 years. That's good news for the

TABLE 2. Corn, cotton, soybeans, and wheat yields in the U.S., 1950-1998.

Year	Yield: Corn, bu/A	Yield: Cotton lint, lb/A	Yield: Soybeans, bu/A	Yield: Wheat, bu/A
1950	38	269	22	17
1955	42	417	20	20
1960	55	446	24	26
1965	74	527	25	27
1970	72	438	27	31
1975	86	453	29	31
1980	91	404	27	34
1985	118	630	34	38
1990	118	634	34	40
1995	114	537	35	36
1998	134	618	39	43

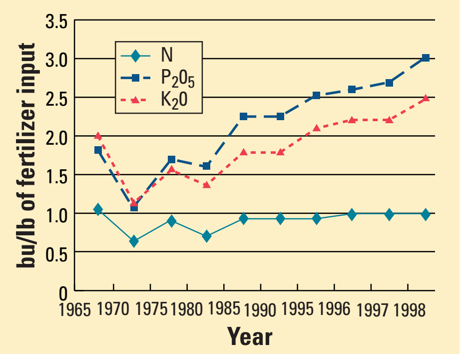

Figure 2. Corn nutrient use efficiency.

environment as well as the farmer and the consumer.

High, profitable yields also depend on proper nutrient balance. It is critical to look at total crop nutrient requirements when planning a production system and put together a nutrient management plan that meets those requirements. For example, N management doesn't depend solely on meeting the crop's N requirements. Rather, it includes considerations for other nutrients...and other management inputs...as well.

Figure 3 shows that soil K fertility has a significant impact on corn yield potential as well as N use efficiency. When soil test K was low (160 and 200 lb K/A), 320 lb N/A were required to produce the best yields. At high soil test K, 160 lb N/A resulted in best yields, which were considerably higher than those produced with 320 lb N/A, but with low soil K fertility. Similar relationships can be shown for other nutrient interactions as well. Synergism between and among essential plant nutrients can often boost yields much higher than when the nutrients are applied separately.

Data have shown that many farmers in the U.S. Corn Belt have been removing more P than they apply in the form of commercial fertilizers for several years. Indeed, recent state nutrient budgets often show negative balances for P and K...and even N. **Table 4** shows the 1982-1996 P nutrient budgets for Illinois. Data in **Table 4** indicate trends similar to those for other areas of the U.S. How long can farmers afford to mine their soils of P, K, and other nutrients and still grow high, profitable crop yields? The answer will vary, but for most it is, "not very long."

Table 5 shows the results of a long-term (10-year) study done in Maryland. It compares trends in N-only corn yields versus those where P and K were applied along with N. By the 10th year, the yield difference was 104 bu/A. Over the 10-year period, NPK corn averaged 152 bu/A compared to 73 bu/A for the N-only corn. How easy would it be for a farmer to lose 5, 10, 15, or more bushels per acre...without even knowing it...by cutting back on fertilizer use due to low commodity prices or because of some other economic challenge?

The primary goal of farmers as they evaluate changes in management systems is to increase profits. There are other goals as well.

- Environmental protection of soil and water resources;
- Compliance with state and federal regulations;
- Spending more quality time with family, including taking advantage of recreational opportunities;
- Leaving the farm in better shape...for the next generation...than the farmer found it.

The potential for profits, however, most often provides farmers the incentive to accept new technologies...to improve management. How are profits increased? Profits are the result of higher yields, improved market quality, better marketing skills, lower cost per unit of production...most likely, a combination of

TABLE 3. Nitrogen, P_2O_5, and K_2O consumption in the U.S., 1950-1998.

	Fertilizer consumption, 1,000 tons		
Year	N	P_2O_5	K_2O
1950	1,005	1,950	1,103
1955	1,960	2,284	1,875
1960	2,738	2,572	2,153
1965	4,639	3,512	2,835
1970	7,459	4,574	4,036
1975	8,601	4,507	4,453
1980	11,407	5,432	6,245
1985	11,504	4,641	5,510
1990	11,076	4,345	5,203
1995	11,720	4,417	5,123
1998	12,305	4,624	5,343

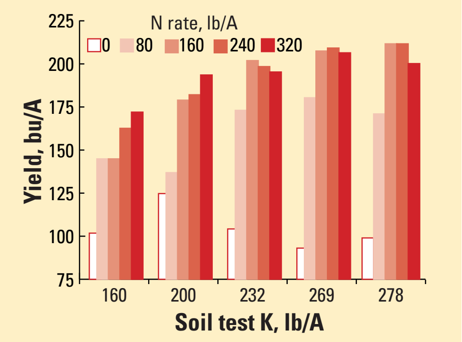

Figure 3. Adequate soil K level increases corn yield (Johnson & others, Ohio, 1992-95).

these factors.

There is a direct positive relationship between higher crop yields, if produced efficiently, and farmer profits. In a four-year Iowa Soybean Association survey, soybean growers were asked to keep track of several of their production costs, including tillage, planting, herbicides, nutrients, harvesting, land, and marketing. Growers were divided into groups, based on overall profitability. Production practices of the most profitable 20 percent were compared to those of the least profitable 20 percent.

Nearly 70 percent of increased income from the top 20 percent was attributable to higher yields (**Figure 4**). About one-fifth of increased income came from cost reductions, and less than 15 percent of the additional profits could be attributed to better marketing. We all appreciate the importance of cost control and marketing skills, but the primary driving force behind increased farmer profits is most often production of higher, more efficient crop yields.

In addition to the Iowa survey, recent studies in Kansas and Minnesota also ranked yield as a major characteristic of most profitable farmers.

While it is recognized that many factors characterize high yield farmers, one of the most critical of management inputs is the maintenance of soil fertility. The common perception is that soil fertility, specifically P and K soil test levels, seldom limit yields in North America. That perception is a myth.

PPI summarized the results of 1.8 million soil samples collected in the fall of 1996 and spring of 1997 and reported the percent of samples testing medium or below in P and K...along with pH levels of 6.0 or below. Of the 1.8 million samples included in the summary, 46 percent and 44 percent tested medium or below in P and K, respectively. The northern Great Plains had the highest frequency of medium or below P tests, in the 60 to 80 percent range, while a few states scattered around the U.S. fell in the 20 percent range. The summary also showed that significant numbers of soils have pHs too low for optimum crop production and efficient fertilizer use. (See *Better Crops with Plant Food*, 1998, No. 4, pages 16-18).

America's farmers face many challenges

TABLE 4. Illinois P budgets, 1982-1996.

	Removal		Inputs			Rem/
	Crop	Animal[1]	Fertilizer	Manure	Human	inputs,
Years	Short tons, thousands					%
82-86	517	8	466	112	16	88
87-91	498	8	385	106	16	100
92-96	574	8	381	101	16	117

[1]Meat, eggs, milk. R. Hoeft, University of Illinois

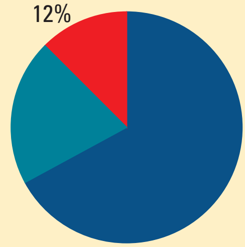

Figure 4. Characteristics of the most profitable farmers.

TABLE 5. Ten-year results of N-P_2O_5-K_2O vs. N fertilization of dryland corn.

N-P_2O_5-K_2O, lb/A/yr	Yield, bu/A for year: 1	2	3	4	5	6	7	8	9	10
160-160-160	151	149	159	153	134	159	122	190	182	125
160-0-0	146	139	116	80	104	37	13	52	23	21
Difference	5	10	43	73	30	122	109	138	159	104
Accumulated yield, bu/A										
160-160-160	151	300	459	612	746	905	1,027	1,217	1,399	1,524
160-0-0	146	285	401	481	585	622	635	687	710	731

Maryland

as they look to their future role in food production. They are truly a part of an international industry. They must be low-cost producers to remain competitive, and, at the same time, they must be profitable to stay in business. Profitable farmers will be better able to protect the environment, utilize resources, and produce abundant, safe foods. They will adapt to, adopt, and successfully use the contributions biotechnology will make.

The knowledge farmers use to make the progress necessary to feed tomorrow's world population...and feed them better than they are eating today...will come from new discoveries made from research. A part of that research will involve mineral nutrition and soil fertility. It will include studies on how to best manage soil variability and crop needs so that nutrients, both mineral and organic, can best be utilized.

Earlier, the question was asked, "What can be done to ease the effects of the current economic downturn?" Perhaps that is the wrong question. Rather, we should ask, "How can we make best use of emerging technology and combine it with proven science to continue to feed a growing world population?"

The obvious answer is to grow more yield per unit of land and do it at a higher profit by lowering unit production costs... while improving environmental protection. Building and maintaining high soil fertility...and providing balanced nutrition to the growing crop...will go a long way in making that scenario possible. BC

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High Crop Yields – Closing the Gap

This issue of *Better Crops with Plant Food* contains articles that describe circumstances surrounding record-breaking yields. These yields are summarized in **Table 1**. They clearly illustrate the remarkable attainable yields of today's genetic material and at the same time in striking fashion reveal the huge gap between attainable yields and the yields normally harvested. Narrowing that yield gap is the greatest:

- Profit opportunity available today to crop producers;
- Potential source of food for the additional 2.5 billion people expected on this planet by the middle of the next century;
- Source of environmental relief through enhanced carbon sequestration, increased nutrient use efficiency, and through freeing more land for buffer strips, wetlands, rain forests, and recreation.

TABLE 1. Record crop yields in North America reported in this issue.

Crop	Yield	Location	Year
Alfalfa	24.1 tons/A	Arizona	1982
Barley, spring	190 bu/A	Alberta	1990
Canola, spring	70 bu/A	Alberta	1999
Corn	394 bu/A	Iowa	1999
Cotton	5.4 bales/A	Arizona	1982
Soybean	118 bu/A	New Jersey	1983
Wheat, winter	205 bu/A	British Columbia	1988

So what does it take for an individual to exploit the yield gap? In one word, management...in a phrase, management and long-term dedication. The articles that follow summarize what has worked in some cases and hold insights into the necessary ingredients of a reproducible framework for high yields. However, much is yet to be learned about incorporating the power and efficiencies of today's technologies into a holistic, systems-level approach to crop, soil and water management. In other words, there are some exciting research opportunities waiting for us as we turn the corner to another century of agricultural progress. BC

NORTHEAST U.S./ EASTERN CANADA

Boosting Crop Yields in the Next Century

By T.W. Bruulsema, M. Tollenaar and J.R. Heckman

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 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

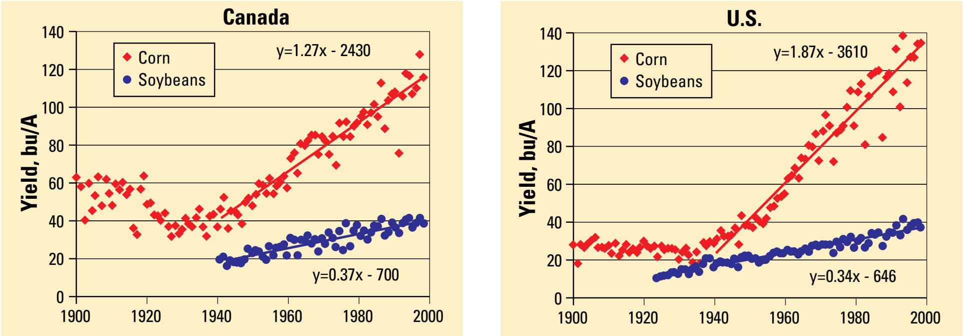


Figure 1. Corn and soybean yield averages for the past century in the U.S. and Canada. (Source: USDA-NASS and Statistics Canada).

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.

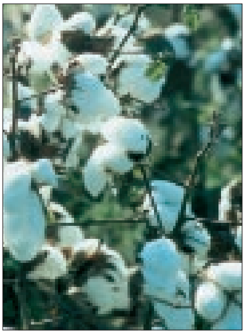
Tillage practices that prevent erosion and

(continued on page 13)

ARIZONA/CALIFORNIA

Producing 5-Bale Cotton and More

By A.E. Ludwick



How high is high? In the desert environment of Arizona, yields greater than 4 bales/A (480 lb lint/bale) are not all that uncommon with top management. A commercial yield of 5.41 bales/A was reported in central Arizona in 1982 (Pennington, Dean. 1983. "Aiming for 6-Bales/A Cotton in Arizona", *Better Crops with Plant Food*, Fall, pp. 10-11). Such a yield does not come easily. In this case a major innovation was drip irrigation.

Biotechnology advances such as varieties with the *Bacillus thuringiensis* (Bt) gene and new fertilizer strategies have created opportunities for cotton growers to aim for increasingly higher yields. A yield of 5.41 bales/A was documented in 1982. Yields over 6 bales/A could be a reality.

Water use efficiency receives a lot of attention in Arizona and California where water costs are a significant production component. Drip irrigation is widely used for high value crops such as trees, vines and vegetables. Advantages include substantially greater water use efficiency (more yield with less water), precise and frequent fertigation, and less leaching of nutrients and chemicals below the root zone. During the early 1980s, there was considerable interest among cotton growers to maximize yields. Cotton prices and production costs seemed to favor the high input, high yield approach. Growers in Arizona and California experimented with drip irrigation and production techniques to take full advantage of a long growing season.

Low cotton prices in recent years have discouraged many growers from aiming at achieving actual high yield potentials. Biotechnology, however, is a new and powerful tool that is helping to change attitudes and create new production opportunities. One new tool is Bt cotton.

Arizona growers produce their highest yields by setting two crops — a bottom crop and a top crop. Producing the late season (top) crop has been economically questionable in the past due in large part to the high cost of late-season pest control. In Bt varieties, frequent costly spraying to keep down the pink bollworm population to protect the top crop is no longer necessary. Biotechnology...Bt cotton...has solved (at least minimized) this particular problem.

Mr. Ron Rayner of the A Tumbling T Ranches near Phoenix made a presentation at the 1998 Beltwide Cotton Conference where he discussed the benefits of producing 4.5 to 5 bales of cotton per acre. His comments were summarized in an article appropriately titled, "High Inputs, High Yields", *Cotton Grower*, August 1998, pp. 10-11. He pointed out that producing high yields requires a total management plan including:

- Plant as early as possible using high seeding rates (of Bt cotton) and a fungicide.
- Push plants early with irrigation and fertilizer.
- Use low, multiple applications of Pix.
- Protect against whitefly and lygus by using integrated pest management (IPM) strategies that utilize insect growth regulators and university developed thresholds.
- Irrigate on short intervals, six to eight days during the hot weather, and use

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

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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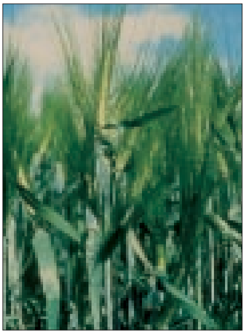
CANADIAN PRAIRIES

High Yielding Barley Production



By John Harapiak, Rigas Karamanos and Adrian Johnston

Spring barley (*Hordeum vulgare L.*) is the third most common crop grown on the Canadian Prairies, occupying approximately 9.2 million acres. The barley is grown principally for livestock feed and malt production. Next to oats, it is the highest yielding of the cereal crops grown in the region, with yields averaging from 60 to 80 bu/A.

> Spring barley responds to improved management practices, including pedigreed seed and tillage systems to conserve surface moisture. While nitrogen (N) and phosphorus (P) are key, potassium (K), sulfur (S), and other nutrients also contribute to increased yields.

The yield potential of barley is higher than that of hard red spring wheat, as barley produces more tillers and heads and has a higher rate of kernel dry matter accumulation. Achieving this increased yield potential requires that the crop's nutritional needs be met. As a result, farmers report that they manage barley with higher levels of fertility than wheat or oats. A survey of top barley producers by Alberta Agriculture found that there were a number of common management practices being used to achieve high yields. These included:

- Avoiding seeding barley on barley stubble reduces the negative effects of leaf and root diseases.
- Completing most of the tillage in the fall minimizes the tillage required for crop establishment in the spring. This is critical to managing surface soil moisture and allows for shallow seeding (less than 2 inches deep).
- Almost 50 percent of top barley producers used pedigreed seed, much higher than the 15 to 20 percent more common among the general farm population.
- Seed was treated to minimize the impact of seedling rot, blight, and covered and loose smut.
- Farmers sampled their fields to evaluate soil nutrient status at least once every four years.
- Timing of fertilizer N banding was equally divided between fall and spring, with most farmers indicating they prefer the fall application as a means of minimizing spring soil disturbance.

Westco Fertilizers Ltd. of Calgary, Alberta has worked for a number of years to evaluate the crop management strategy that would be required to achieve a 200 bu/A barley yield. Using the cool, sub-humid growing conditions of central Alberta as their trial ground, they were successful in almost achieving this yield

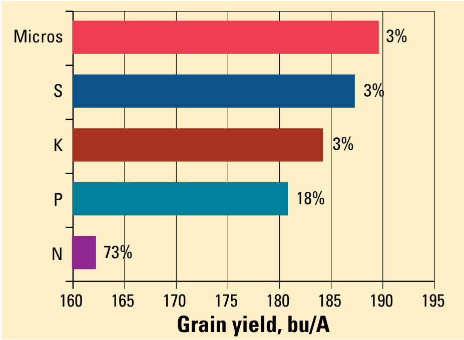


Figure 1. Westco barley yield response to macro and micronutrients. Number in percent represents the portion of total response attributable to individual nutrients. Check yield was 86 bu/A.

TABLE 1. Soil test information.

Depth, inches	Texture, hand	pH	EC mS/cm	N	P[1]	K	S	Cl
						lb/A		
0-6	Loam	7.7	0.77	66	18 (L)	208 (M)	24	24
6-12	Loam	8.4	0.53	24	2	176	22	30
12-24	Clay	8.5	1.09	20	0	352	124	20

[1]Miller and Axhley
L = low; M = marginal

goal in 1990, with a recorded yield of 190 bu/A.

Using the six-row feed barley cultivars, a series of 19 experiments was conducted between 1990 and 1998 to evaluate high yielding barley management. The trials were designed to determine the incremental effect on barley yield of adding each of the macronutrients and a blend of micronutrients. The crop was seeded at a rate of 2 bu/A (96 lb/A or about 28 seeds per square foot), with fertilizer N (urea) rates pre-seeding banded at 0, 72, 144, and 216 lb N/A. Phosphorus (triple superphosphate) was applied at a rate of 54 lb P_2O_5/A, with 50 percent in the seedrow with the seed and 50 percent with the pre-seeding N band. Potassium (KCl) was applied at the same rate (54 lb K_2O/A) and method as P. Sulfur [ammonium sulfate, $(NH_4)_2SO_4$] was pre-seeding band-applied at a rate of 21 lb/A sulfate-S (SO_4-S) with the N, and N rates were adjusted for the N in the $(NH_4)_2SO_4$. A blend of micronutrients...boron (B), 2 percent; copper (Cu), 4 percent; iron (Fe), 4 percent; manganese (Mn), 8 percent; and zinc (Zn), 18 percent...was seedrow applied at a rate of 12 lb/A of product. The foliar fungicide Tilt (propiconazole) was applied to the entire test area at flag leaf emergence for control of leaf spotting diseases.

The maximum barley yield of 190 bu/A was achieved in 1990 and is an average of the three N rates (72, 144, and 216 lb/A), in combination with the P, K, S, and micronutrient additions (**Figure 1**). The barley cultivar Virden was used. It is a late maturing variety with very good lodging resistance. The trial site had a high level of background N fertility (**Table 1**), resulting in a check yield of 86 bu/A. Considering each of the nutrients added, N was responsible for 73 percent of the yield increase over the check, P for 18 percent, while K, S and micronutrients each contributed 3 percent. These responses reflect the dominant role that N and P play in correcting the bulk of crop nutrient deficiencies on the Canadian Prairies.

Barley is also grown for silage production in many areas of the Northern Great Plains. While cultivar selection can have some effect on the final forage yield harvested, there is a strong relationship between grain yield and total crop biomass yield. Related research in Alberta evaluating barley cultivars and nutrient management for silage found that optimum N and P fertility was a cornerstone to achieving both high silage yields and high quality.

Achieving high yields of barley requires careful attention to both the agronomic and nutrient requirements of the crop. While farmers have little control over year-to-year variability in environmental conditions, they can implement management strategies that will ensure they optimize production in any given year. BC

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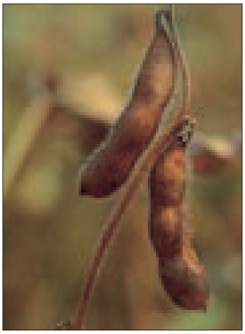
MIDWEST

The Soybean Yield Challenge: Research for Improved Production Systems



By H.F. Reetz, Jr.

Many Midwest farmers have traditionally treated soybeans as a secondary crop...usually in a rotation with corn. Fertility programs, and management systems in general, have been designed for the "main" crop, with soybeans getting what is left over from the previous year. Relatively few research projects have focused on development of a management system to provide the optimum conditions to maximize soybean yields. Yet, soybeans remove large amounts of potassium (K), so soil K depletion has become more rapid as more soybeans are grown. Nutrient management plans must account for these differences to maintain productivity.

For continued progress toward breaking soybean yield barriers, several components are needed. A concept known as "high-yield-system-in-place" (HYSIP) has helped maximize production, especially in years with favorable weather conditions.

Soybeans respond well to the best growing conditions for the other crops in the rotation, but there may be some special considerations that will help optimize soybean production as well. When management is adjusted for best soybean production, other crops in the rotation may be at less than optimum. For this reason, the corn/soybean rotation probably will not produce maximum yields of either crop, but still provides a well-balanced rotation with many advantages.

Dr. Richard Cooper, USDA-ARS Soybean Breeder at Wooster, Ohio, has devoted much of his program to looking for better soybean production systems. Through use of semi-dwarf genotypes, higher plant populations, high fertility, and supplemental irrigation, he has built a system that has produced over 100 bu/A soybean yields. Dr. Cooper's system is centered around putting a "high-yield-system-in-place"...the HYSIP concept. He emphasizes that for continued progress in maximizing yields, it is essential to pay close attention to the total production system. This doesn't guarantee high yields every year, but helps ensure that all controllable factors are managed at or near their optimum levels.

To obtain his record yields, Dr. Cooper developed a soybean maximum yield production system with the following components:

1. Well-drained soil with good surface drainage to avoid possible flooding injury from a heavy rainfall event, especially if it occurs just after an irrigation application.
2. Maintenance of high fertility levels in the soil with annual applications of 1,000 lb/A of 0-18-36 fertilizer plus 600 lb/A of 33-0-0 broadcast and incorporated prior to planting.
3. Two-year corn/soybean rotation to minimize disease and insect buildup.
4. Early planting to take advantage of the longer days and higher light intensity earlier in the growing season (last week of April or first week of May at Wooster, Ohio).
5. Use of soybean cultivars with known high yield potential and excellent lodging resistance (determinate semi-dwarf or shorter indeterminate cultivars).
6. Solid-seeding, 7-inch row spacing with a seeding rate of 300,000 seeds/A for semi-dwarf cultivars and 225,000

seeds/A for indeterminate cultivars.

7. Irrigation, with a goal of 2 inches/week (rainfall plus irrigation), beginning at the V-3 (2nd trifoliolate) or V-4 (3rd trifoliolate) growth stage, depending on natural rainfall.
8. Use of fungicides as needed to prevent or minimize foliar diseases.
9. Use of insecticides to minimize insect feeding.

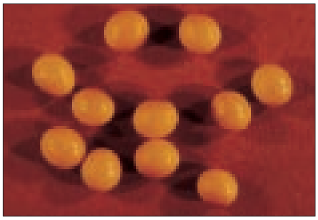
This is a research system, and some components may need adjustment for implementation on the farm. For example, nitrogen (N) fertilization is not routinely recommended for soybeans, but was used here to be sure N was not limiting.

Using this system from 1977 to 1999, Dr. Cooper produced average annual yields of 70 bu/A, with highest single cultivars averaging up to 80 bu/A. In 1982, 64 cultivars averaged 89.4 bu/A with four lines exceeding 100 bu/A. These high yields were postulated to be a result of a very early warm spring, which resulted in soybeans flowering two weeks earlier than usual. This meant they also entered the reproductive stage earlier in the season when days were longer and light intensity was higher. The length of the reproductive period was also increased. Similar early warm spring conditions occurred in 1998 and 1999. Again, yields averaged across all cultivars were over 80 bu/A, with highest individual cultivar yields of over 90 bu/A both years.

In 1999, in a sub-irrigation/drainage experiment at Wooster, nine soybean cultivars, sub-irrigated as needed, averaged 98 bu/A with three cultivars exceeding 100 bu/A. Under drainage only, these cultivars averaged 67.3 bu/A, and when constant water table was maintained by sub-irrigation, 93.6 bu/A.

While highest yields have been obtained with sub-irrigation, the HYSIP concept also works on non-irrigated fields. In a 10-year comparison at two Ohio locations, its advantages are clearly demonstrated (**Table 1**). Since the high-yield system will equal the yield of a lower yield system in dry years and produce much higher yields in favorable moisture years, having the high-yield system in place (HYSIP) every year results in higher long-term average yields.

The exceptionally high yields in 1982, 1998 and 1999, when above-normal May temperatures triggered earlier flowering, indicate early season cool temperatures can be a major barrier to higher soybean yields. Dr. Cooper has initiated a breeding program to develop earlier flowering, full season cultivars to overcome this yield barrier. In the meantime, for maximum yields, he recommends that growers plant their soybeans as early as possible and have the high yield management system in place to take advantage of those early warm spring conditions when they occur.



Future

Farmers must continue to work toward higher soybean yields to maintain a financially sound production system. Site-specific management, along with management for specific quality components, will become important to soybean production systems. BC

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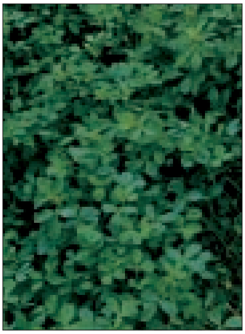
TABLE 1. Comparison of solid-seeded-semi-dwarf (SSS) management system with wide-row-indeterminate (WRI) management system at two Ohio locations over 10 years, 1988-1997.

	Management system	
System characteristics	Solid-seeded-semi-dwarf	Wide-row-indeterminate
Variety	Sprite	Williams 82
Seeding rate	300,000 seeds/A	150,000 seeds/A
Row spacing	7 inches	30 inches
Location	**Yield results**	
Northwest Ohio		
Highest yield	84.1 bu/A	66.5 bu/A
10-year average	60.9 bu/A	49.1 bu/A
West Central Ohio		
Highest yield	83.2 bu/A	68.2 bu/A
10-year average	75.0 bu/A	60.8 bu/A

ARIZONA/DELAWARE

High Yield Alfalfa: 24 tons Irrigated... 12 tons Non-Irrigated

By A.E. Ludwick



Some outstanding alfalfa yields have been harvested in research. Here's a look at how those top yields were achieved.

Irrigated Alfalfa

Researchers at the University of Arizona produced up to 24.1 tons/A of alfalfa in a trial at the Yuma Valley Agricultural Center in the 1981-82 growing season. This is a remarkable feat demonstrating the tremendous genetic potential of alfalfa. While alfalfa yields have steadily increased across North America, no one has since reported production near this level.

> Top alfalfa yields result from intensive management of a potentially high yielding cultivar grown with high soil fertility. Each ton of alfalfa removes approximately 15 lb of P_2O_5 and 60 lb of K_2O.

One factor leading to yield of more than 20 tons/A is the length of growing season. Ten cuttings were taken during the year-long experiment. Few areas have this advantage. Another way to look at this production is on a per cutting basis. The 24.1 tons/A translates to 2.4 tons/cutting, an excellent season-long average...and attainable in many growing regions.

This experiment was designed to evaluate water and nitrogen (N) use efficiency relationships using sprinkler irrigation for various agronomic and horticultural crops on the Yuma Mesa where citrus was traditionally grown using flood irrigation. Because of the coarse nature of the soil profile (Superstition sand) water rates in excess of 10 A-ft/yr have been used. Alfalfa had been replacing citrus in recent years, but requiring about 12 A-ft with flood irrigation. A summary of the alfalfa portion of the study was presented in: "Alfalfa Yield of 24 tons/A in Arizona Research", *Better Crops with Plant Food,* Winter 1983-84, p. 19.

The two cultivars of alfalfa planted were Mesa-Sirsa, a popular variety among growers at the time, and Lew, a variety that had shown greater nodulation than other alfalfa cultivars. They were seeded at a rate of 20 lb/A on March 4, 1981. Concentrated superphosphate was broadcast and incorporated prior to planting at a rate of 460 lb of P_2O_5/A. Two cuttings were made prior to the initiation of irrigation and N treatments which commenced on June 14. The first cutting for the experiment was taken on July 14. The 10th (last) cutting was taken on July 1, 1982. The N treatments were applied through the irrigation system spaced throughout the season.

TABLE 1. Yield of two alfalfa cultivars (12 percent moisture).

Water, inches/A	Nitrogen, lb/A	Total yield, tons/A Mesa-Sirsa	Total yield, tons/A Lew	Yield, lb/A-in. water Mesa-Sirsa	Yield, lb/A-in. water Lew
56	346	6.7	5.7	239	204
73	183	5.0	4.9	137	134
73	508	7.7	7.4	211	203
112	114	14.2	15.1	254	270
112	346	16.8	15.9	300	284
112	578	18.0	17.6	321	314
151	183	19.4	18.1	257	240
151	508	24.1	21.5	319	284
168	346	18.3	19.4	218	231

Soil pH 7.9. Available soil P = medium.

A reliable source of water throughout the growing season is fundamental to high yield agriculture in the arid west. Irrigation management, however, is frequently cited as the number one limiting factor in maximizing yields and was a focus of this study. The sprinkler system used was a self-moving lateral system capable of accurately applying 0.2 to 1.4 inches. Following each cutting, the forage was immediately removed from the field similar to a green-chop operation and irrigation initiated the next day. This avoided the dry period following cutting, which is typical of baling operations, and undoubtedly contributed to the high yields.

The highest yields for both cultivars were produced with a combination of 151 total inches of irrigation water plus 508 lb N/A (**Table 1**). Respective hay yields (12 percent moisture) for Mesa-Sirsa and Lew were 24.1 and 21.5 tons/A.

In this experiment, the greatest efficiency of irrigation water was associated with higher yields. Water use efficiency ranged from 134 lb hay/A-inch (4.9 tons/A total yield) to 300 lb or more hay/A-inch for several treatments producing over 15 tons/A total yield.

The fact that N was included as a variable raises a number of questions. It is not a recommended practice to apply such large rates of N to alfalfa, ignoring contributions of N fixation by rhizobia as well as environmental concerns. Supplemental N was required to achieve the highest yield for both cultivars. This is evidenced by the fact that the same irrigation treatment with less N (151 lb/A) produced a lower yield. There were insufficient comparisons to draw any conclusions as to optimum N management to achieve over 20 tons/A. It can be concluded, however, that alfalfa does have the genetic potential to produce very high yields in suitable environments with intensive management.

Non-irrigated Alfalfa

There are a number of reports of non-irrigated production of alfalfa (12 percent moisture) achieving or exceeding 10 tons/A. See **Table 2**.

TABLE 2. Some high yields of non-irrigated alfalfa.

Year	Location	Yield, tons/A
1981-82 (two year average)	Michigan State University	10.0
1982	Michigan State University	10.8
1985	University of Wisconsin	11.5
1987	University of Maryland	11.3
1987	Delaware State College	12.0

The highest reported yield from Delaware State College of 12.0 tons/A was among 34 cultivars that averaged 11.2 tons/A in 1987. Five cuttings were taken, averaging 2.4 tons/cutting for the highest yield which, interestingly, is exactly the yield per cutting reported for the previously discussed Arizona research. A full article is presented in *Better Crops with Plant Food*, Summer 1988, p. 7.

The Delaware trial was grown under high phosphorus (P) and potassium (K) fertility. The site was fertilized with 200 lb/A each of P_2O_5 and K_2O in the establishment year (1985). In subsequent years it was fertilized to replace P and K removed by 10 tons/A of alfalfa, using nutrient removal values of 15 lb of P_2O_5/ton and 60 lb of K_2O/ton. Fertilization was split equally after the first and third cuttings. Boron (B) was also applied at a rate of 2 lb B/A after both harvests. Weeds and insects were controlled as needed.

Yields were limited in 1986 due to dry weather in which only four cuttings were taken. However, the value of high K fertility in drought years was observed. Only 11.9 inches of rain fell from June to October, but the top 10 cultivars in the trial averaged 7.8 tons/A.

Previous cultivar trials in Delaware seldom yielded over 6 tons/A when averaged over all entries. The yield breakthrough came in 1987 with higher fertilizer rates, improved varieties, more intensive harvest schedules, and a complete management system. BC

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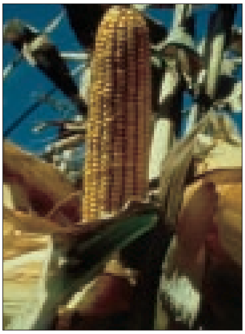
MIDWEST

Producing High Corn Yields – Herman Warsaw's Challenging Legacy

By H.F. Reetz, Jr.



Herman and Evelyn Warsaw bought their Illinois farm in 1941. It had a USDA-established corn yield of 38 bu/A. Herman knew he needed to build the yield potential if his operation was to survive. By 1960, he had reached a good average production level, but decided to try to find the limits of the fields he was farming. He started building fertility levels, increasing plant population, and looking for other limiting factors. Fifteeen years later, in 1975, he set a new world corn yield record of 338 bu/A and gave a challenge to university and industry researchers. As a new crop production systems researcher at Purdue University, I had produced my first 200 bu/A corn yield that year, yet it didn't sound very impressive compared to this Illinois farmer's achievement.

Herman Warsaw developed a corn production system that got the attention of other farmers and agribusiness when he set a new world corn yield record in 1975. His deliberate approach to removing yield-limiting factors and gathering and acting on information challenged the thinking of all those who knew him. His accomplishments left a legacy for all of us to build on.

Fortunately, PPI took some leadership in getting a group of us together to visit the Warsaw farm and then for some brainstorming on what we could do to achieve higher yields on our research plots.

Herman continued to refine his production system, constantly looking for the next limiting factor to be eliminated. From 1975 to 1989, he produced five yields over 300 bu/A, with a 15-year average of 274 bu/A. In 1985, he eclipsed his own earlier record with a new world-record yield of 370 bu/A from a measured 1-acre area in his field. I rode the combine with Herman as he harvested the crop and watched the machine creep along at 1.2 mph while the electronic monitor flashed "ROCKS" due to the heavy volume of ears coming into the machine.

The keys to Herman Warsaw's success in corn production are found in his diligence in observing the soil and the crop, gathering information, revising the plan, and carefully implementing the details. Deep tillage, working in the residue from a 200 bu/A crop and still leaving the residue from another 100 bu/A crop on the surface, helped increase soil tilth, support a healthy earthworm and micro-organism population, and incorporate applied nutrients into the root zone. High populations helped build the crop canopy early to capture all of the available sunlight, to support development of large, well-filled ears, and to produce massive amounts of crop residue that contributed to further improvement in soil tilth.

Herman's field had very high phosphorus (P) and potassium (K) levels, not just in the surface layer, but throughout the root zone. So the plants were assured of an adequate supply throughout the season, regardless of rainfall and soil moisture distribution. He used maintenance applications of P and K from commercial fertilizer and periodic heavy applications of manure. **Table 1** shows the results of incremental soil tests taken in 1978 from different areas of his fields. Note that the high yield areas are significantly higher than the fence-row samples (representing unfertilized, native prairie soil).

Soil test levels from a 10-inch sample

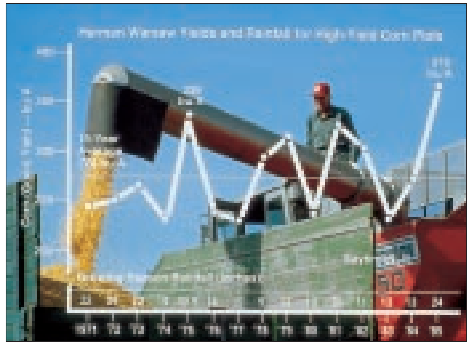
depth collected on August 6, 1985, in the field that produced 370 bu/A of #2 corn, are shown in **Table 2**.

The corn hybrid, FS 854, was planted at 37,000 seeds per acre on April 25. Harvest was on October 17, with a final stand of nearly 36,000 plants per acre. Harvest moisture was 22.2 percent.

Was it profitable? Most decisions ultimately come to dollars and cents. Analysis of Warsaw's production system costs for 370 bu/A corn is shown in **Table 3**.

Based on the 370 bu/A yield, Herman's out-of-pocket costs were $1.25 per bushel, and total costs were $1.60 per bushel. He sold the crop that year for $3.09 per bushel. High yield management paid a good return...more than $550/A. This return more than covered the costs of building the high yield system. But the real payoff came in what he learned from the plot that could be applied on the rest of his 400 acres of corn production. The intensive, high population management had too many risks (mostly of lodging) to be used on the whole farm, but he was able to produce a farm-average of 200 bu/A in 1985...considerably above the average for the area...by implementing much of what he learned from his "research" plots.

Herman Warsaw was a student of corn... and of the soil and water resources that he managed in producing it. He loved to talk about his passion for increasing corn yields and at the same time protecting those resources which he had carefully improved over the years. While his explanations didn't always match the "science", there was no question that this man knew more about growing corn than most farmers or researchers.



Herman Warsaw of Saybrook, Illinois, produced outstanding corn yields and encouraged others to question and study the factors limiting production.

Over the last three or four years Herman was farming, he annually hosted an average of about 1,000 visitors to his farm...by busloads or as individuals. They came to see first-hand what a 300 bu/A corn production system looked like. Farmers, researchers, government officials...a wide range of interests from around the world...walked the fields, looked at the implements, and listened to the expert tell his story under the old maple tree.

A videotape was produced by the University of Illinois in 1983-1985, to docu-

TABLE 1. Soil test results collected from Herman Warsaw's farm in March 1978.

		Sample depth, inches					
		0-3"	3-6"	6-9"	9-12"	12-18"	18-24"
P-1, lb/A	Normal production area	202	134	76	38	28	20
	High yield-lighter subsoil	234	192	58	20	12	8
	High yield-darker subsoil	252	204	108	42	44	36
	Fence row sample	44	26	8	6	6	4
K, lb/A	Normal production area	914	470	346	348	366	400
	High yield-lighter subsoil	740	404	270	232	300	382
	High yield-darker subsoil	1,400	556	412	332	328	320
	Fence row sample	652	452	320	338	284	262
O.M., %	Normal production area	6.6	5.4	5.5	5.4	4.1	3.6
	High yield-lighter subsoil	5.9	5.7	4.9	4.9	3.2	1.4
	High yield-darker subsoil	4.7	4.3	4.0	3.7	4.3	4.3
	Fence row sample	5.8	4.5	4.0	3.3	2.7	2.3
pH	Normal production area	5.5	5.7	5.7	5.6	5.8	5.9
	High yield-lighter subsoil	5.0	5.5	5.8	6.1	6.1	6.6
	High yield-darker subsoil	5.2	5.7	5.6	5.5	5.3	5.4
	Fence row sample	6.0	5.9	6.0	5.8	6.0	6.7

TABLE 2. Soil test levels from a field that produced 370 bu/A corn in 1985.

Phosphorus P-1	161 lb/A
Potassium	800 lb/A
Magnesium	871 lb/A
Calcium	4,850 lb/A
Cation exchange capacity	23 meq/100g
Sulfate-S	35 ppm
pH	6.0
Organic matter	5.3%
Zinc (Zn)	Good
Iron (Fe)	Good
Boron (B)	Good
Copper (Cu)	Good

TABLE 3. Production costs, $/A, that produced 370 bu/A corn in 1985.

Input category	Cost per acre
Fertilizer	$201.05
Lime	$10.42
Herbicide/insecticide	$39.10
Seed	$26.72
Field operations, harvesting, and drying	$186.50
Total out-of-pocket costs	**$463.79**
Estimated land cost	$130.00
Total production costs	**$593.79**

ment Warsaw's high yield system. This tape has been used throughout the world to teach people about the approach this master farmer used to set a new standard in corn production. Of greater importance, however, it helps keep alive the legacy left by Herman Warsaw. That is, we can substantially increase yields and profits in crop production by paying attention to details and eliminating yield-limiting factors...while at the same time being responsible stewards of our soil and water resources.

Physiology of High-Yield Corn

The late Dr. Richard Johnson (Deere and Company) projected the theoretical maximum corn yield in the Midwest to be about 490 bu/A. (*Better Crops with Plant Food,* Winter 1981-82, p. 3-7). Using a 120- to 130-day growing season, with about 90 days of full crop canopy and a daily solar energy input of roughly 20 billion calories per acre, the corn crop could produce 625 lb/A of dry matter per day [allowing for about one-third of the fixed carbon dioxide (CO_2) to be re-released in respiration]. Assuming 25 percent of the dry matter production goes to root growth and 55 percent of the remaining above-ground dry weight goes to the grain, a corn crop producing dry matter at 625 lb/A/day for 90 days would yield 490 bu/A of #2 corn.

Areas of the western U.S. with higher solar energy rates per day could have increased potential. A corn yield potential estimate of 600 bu/A has been made by scientists in Ontario based on hydroponics (see page 9 of this issue).

Dr. Richard Hageman, University of Illinois plant nutrition specialist, studied the mineral nutrition and physiology of the FS 854 corn hybrid that Herman Warsaw used for his record yields and concluded that the high K level of the soil helped maintain plant growth regulator activity needed to keep nitrogen (N) uptake and utilization functioning at full capacity about two weeks longer at the end of the growing season. With lower K levels, the N uptake system in this hybrid started to break down, and the plant began breaking down photosynthetic enzymes in the lower leaves to meet the N requirement of the developing grain. This reduced the supply of sugars available to feed the roots, further decreasing the ability to absorb water and nutrients. By keeping the lower leaves healthy and functional for about two weeks longer in the season, the potential for building higher grain yields was realized.

Renewing the High-Yield Challenge

Herman Warsaw didn't have tools such as computers or satellites, but his style was definitely site-specific. The impact of his challenge and the PPI/FAR program that helped get university and industry researchers to address it have been great. We must encourage the new generation of researchers and farmers to keep the high-yield challenge alive. Continued progress depends on their becoming infected with the Warsaw passion for eliminating that next limiting factor to produce higher yields and responsibly manage the production resources they have available. BC

Dr. Reetz is PPI Midwest Director, located at Monticello, Illinois. E-mail: hreetz@ppi-far.org. *We gratefully acknowledge the contribution of Darrell Smith,* Farm Journal, *for his assistance in recovering some of the information in this article.* *Herman Warsaw passed away in 1989.*

MIDSOUTH

Soft Red Winter Wheat – High Yields Achieved with Intensive Management

By C.S. Snyder

It wasn't too many years ago that SRWW growers were pleased with yields ranging from 40 to 50 bu/A. Today, they are disappointed if several of their fields do not yield more than 80 to 90 bu/A, or if the farm average yield dips below 60 to 70 bu/A.

Over the past decade or so, U.S. average wheat yields have continued their upward trend because of improved varieties and improved management (**Figure 1**). Future SRWW yield improvements will depend heavily on attention to management details. High yield successes have been achieved in numerous SRWW-producing states. In 1998, growers in Arkansas documented yields of 119.4 bu/A, and growers in Kentucky documented yields of 115 bu/A.

Soft red winter wheat (SRWW) yields have been increasing rapidly. Farmers now expect yields in their best fields to be as much as twice as high as those just a few years ago. In 1998, a farmer field in Arkansas produced 119.4 bu/A in that state's research verification program. Kentucky research yields consistently exceeded 100 bu/A during the 1990s, in both tilled and no-till trials. The key to continued yield increases will be attention to management details.

In Fields of Kentucky

Dr. Morris Bitzer at the University of Kentucky has worked for several years with the agricultural industry and SRWW growers in high yield contests. The top 10 yields each year in Kentucky ranged from 94 to 115 bu/A during 1993 to 1998. As a consequence of this joint effort to improve wheat management and the consistent demonstration of high yields, state average wheat yields have also increased since the early 1990s. Dr. Bitzer notes five key management considerations for high yields: 1) selection of an adapted variety with proven performance in university tests; 2) seeding rates of 30 to 35 seeds/square foot, 3) timely seeding (October 10 to 20 in Kentucky); 4) timely nitrogen (N) applications, using split applications in the spring if the yield potential is above 65 bu/A; and 5) use of pesticides as needed. The majority of the highest yields in the Kentucky contests received N-P_2O_5-K_2O fertilizers near planting in the fall. Application rates varied among years and farms, which makes it difficult to make any specific conclusions. Fall N rates ranged from 4 to 45 lb/A, P_2O_5 rates from 5 to 115 lb/A, and K_2O rates from 5 to 200 lb/A.

Arkansas Research Verification Program

Many agronomists suggest the most important management decision a grower can make to obtain high yields is the selection of an adapted variety. When the wheat drill leaves the field, as much as 60 percent of the yield may have already been determined. In the southern SRWW states, adequate soil surface drainage could be the next most important factor. Drain furrows should be established at correct intervals, with connections to outlet ditches, according to Dr. William Johnson, University of Arkansas Cooperative Extension Service. He advocates that farmers spend about half the time it takes to plant in running the drain furrows.

These principles and other research-proven practices were implemented on 11 fields in the 1997-98 University of Arkansas

Wheat Research Verification Program. Program yields ranged from 55.3 to 95.3 bu/A and averaged 73.2 bu/A at 13.5 percent moisture. Test weights averaged 59 lb/bu. The 95.3 bu/A yield was on a 53-acre field on Roxanna and Dardanelle silt loam soils (deep, well drained, with average to high native fertility) in the Arkansas River Valley in Logan county. Soil pH in the field was 6.9, and Mehlich 3 extractable phosphorus (P) and potassium (K) were 52 and 187 lb/A, respectively, in the upper 6 inches. Cation exchange capacity (by cation summation) was 9 meq/100 grams. The field was prepared by disking twice, followed by a field cultivator. The previous crop was corn. Urea was fall-applied at 30 lb N/A, the standard fall N rate when wheat follows corn in Arkansas, along with 30 lb/A P_2O_5 and 30 lb K_2O/A. The variety was NK Coker 9543 drilled on October 13, 1997 at 120 lb/A. A blend of urea and ammonium sulfate was applied to provide 113 lb N/A and 24 lb/A sulfur (S). Initial stand was 31.3 plants/square foot. Final tiller count was 5.4 tillers/plant, and the head count was 83.6 heads/square foot. The field was combined on June 5, 1998 with a test weight of 59.7 lb/bu. The excellent yield resulted in an estimated applied N use efficiency of 1.2 lb of N/bu. The field had scattered ryegrass that was below the University of Arkansas treatment threshold. No other pests were detected at treatment levels.

Based on an estimated wheat price of $2.80/bu, total income for the Arkansas field was $266.84/A. Total direct expenses were $93.28/A, and total fixed expenses were $22.75/A, which brought the total specified expenses to $116.03/A. The break-even price above total specified expenses was $1.22/bu. Net returns above total expenses were $150.81/A and changed to $84.10/A when a 25 percent crop share rental was considered. **This high-yielding field proved to be the most profitable of the 11 fields enrolled in the 1997-98 University of Arkansas Wheat Research Verification Program**. The fertilizer expense on this high-yielding field accounted for 36 percent of the total specified expenses. Just as in this Arkansas example, many wheat growers are spending more on inputs but reaping the reward in higher yields and lowered per unit costs, which translates into lower break-even prices.

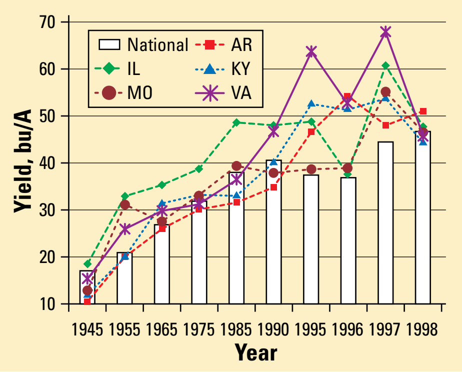


Figure 1. Selected state SRWW and national wheat yield trends. (Source: USDA-NASS.)

Several of the most successful wheat growers who participated in the research verification program cited attention to P needs as fundamental to high yield success, especially on the fields with low P which are rotated with rice. On these soils, many growers are applying P in the fall and diammonium phosphate with the first spring N.

Kentucky Research

The goal of a University of Kentucky wheat fertilization research program (at Princeton) comparing conventionally tilled and no-tillage systems is not to produce maximum yields. Instead, according to Dr. Lloyd Murdock, Extension Professor, the focus is to remove as many yield limiting barriers as possible to allow the yield potential of each variety to express itself within each system. During years with favorable weather, SRWW yields over 100 bu/A have been common in both conventionally tilled and no-tillage systems (**Table 1**).

Almost all of the wheat trials at Princeton follow corn...typical for most of the farmers in western Kentucky. In spite of good efforts, the researchers have not always been successful in removing all yield barriers. Weather frequently was unfavorable and some weeds, insects and diseases escaped control. Of course, the same is often true in many farm fields. Still, consistently high yields have been obtained in research with both conventional tillage and no-till systems. These research results illustrate the yield potential possible on many farms with skilled management.

The following methods and practices are used in the University of Kentucky tillage system and fertilization program. Although they would not always be economical for producers, according to Dr. Murdock, the principles can lead to consistent high yield production.

1. Select well-drained soils, soil test, and apply aglime and fertilizer according to research-based recommendations. Apply 20 lb/A of fall N if the previous corn crop was N-deficient.
2. Flail-mow corn stalks on no-tillage plantings; till the field to reduce surface residue cover to less than 30 percent for tilled plantings.
3. Choose a high yielding variety with a good disease resistance/tolerance package, based on university trials. Calibrate the seed drill to accurately plant 35 disease treated seeds/square foot for tilled plantings and 40 seeds/square foot for no-till plantings. Plant at 1 to 1½ inches deep during the optimum planting period (between October 10 and 20 in western Kentucky).

TABLE 1. Effects of tillage system on SRWW yields at the Princeton, Kentucky Research and Extension Center.

	Yield, bu/A	
Year	**Tilled wheat**	**No-till wheat**
1993-94	108	114
1994-95	106	107
1995-96	93	82
1996-97	91	88
1997-98	85	78
1998-99	89	87
Average	95	93

4. Apply a contact herbicide near planting for no-till plantings.
5. Make stand counts soon after emergence to determine stand adequacy. Scout weekly for pest problems. Apply herbicide in November if weed population warrants action. Scout and spray insecticide 30 to 60 days after planting to control aphids which vector Barley Yellow Dwarf Virus (if thresholds are exceeded).
6. Apply the first part of the split N rate at green-up (Feekes growth stage 3) in February. This is usually one-third of the total spring N rate. If tiller numbers are below 70/square foot, increase this first split N rate by 10 to 20 lb/A. Apply the remainder of the spring N split in March (Feekes growth stage 5 or 6) for a total spring N rate of 100 lb/A for tilled wheat and 120 lb/A for no-till wheat.
7. Apply any needed insecticide in February or March if aphid numbers exceed threshold.
8. Apply herbicide to control wild garlic and any spring weeds at Feekes growth stage 5 or 6.
9. Continue scouting for diseases and apply fungicides if necessary. Apply systemic fungicide at head emergence to protect against septoria, rust, and glume blotch.
10. Harvest as soon as practical to guard against test weight reduction that results from weathering.

Many farmers question why research plots sometimes yield more than farmer fields. Field variability can often explain yield differences. Farmers and crop advisers also need to remember that some researchers trim their plot alleys and plot ends in advance of harvest. The longer the period between plot trimming and harvest, the greater the potential for what is termed the "border effect", a yield enhancer.

Current SRWW varieties are responsive to good management, as illustrated in this Kentucky research. Excellent yields can be achieved in both tilled and no-till systems with proven crop production and protection practices. BC

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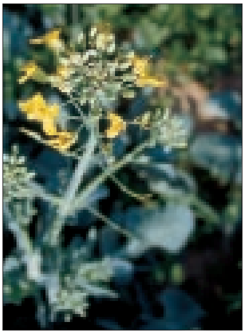
WESTERN CANADA

High Yielding Canola Production

By George Clayton, Kelly Turkington, Neil Harker, John O'Donovan, and Adrian Johnston



In the sub-humid regions of western Canada, canola is often referred to as the 'economic engine' of the farming system. This is in reference to the value of the canola crop, which often exceeds that of wheat in the region. The success of the canola crop in any given year becomes synonymous with the success of the cropping enterprise.

Canola grown on the Canadian prairies is an important economic crop and has a high demand for nutrients. Researchers are finding good results with improved seeding and other management practices.

Canola yield is positively influenced by the length of the flowering period, while reductions in yield come from pest problems, including insect damage, weed competition, and plant disease. Growing conditions in these sub-humid regions, characterized by a short frost-free period, cool night temperatures, and abundant moisture, are ideal for a prolonged flowering period for the canola crop. The 1999 growing season was cool and wet in most areas of the Canadian prairies, and as a result there were several reports of above average crop yields for cereals, oilseed and pulse crops.

Researchers working at the Agriculture and Agri-Food Canada Research Centre at Lacombe, Alberta, have been evaluating the agronomic components necessary to achieve high yielding canola. During the 1999 growing season they reported canola yields of 70 bu/A, a record for spring canola in this region where the yields generally are in the 35 bu/A range (**Table 1**). Achieving a spring canola yield approaching 70 bu/A is something that all farmers would consider a significant accomplishment. While weather conditions vary considerably from year to year, many of the management practices that support high yielding canola are also important and within the control of the grower.

In this experiment the researchers were evaluating dormant-seeding of canola, an innovative management practice developed by scientists at the Scott Experimental Farm of Agriculture and Agri-Food Canada. By seeding the canola in the fall after soil temperatures have dropped below 0°C (freezing) the seed lies dormant and does not germinate until the following spring. This seeding method has been evaluated a number of times over the past 30 years. However, its success has been limited due to the crop competition from winter annual weeds that could not be controlled in dormant-seeded canola. With the development of herbicide tolerance, the farmer is now capable of removing competitive winter annual weeds that also emerge early in the spring with the dormant-seeded canola. The results of this project show that dormant seeding increased canola yield by 17 percent over late-April and 64 percent over mid-May seeding dates. In addition, this yield increase came with

TABLE 1. Agronomic response of canola (*Brassica napus* cv. Invigor 2153) to seeding date at Lacombe, Alberta in 1999.

Plant characteristic	Seeding date: November 8	April 29	May 13
Plant emergence, plants/yd^2	81	66	75
Grain yield, bu/A	71.0	60.9	43.4
Harvest dry matter yield, tons/A	12.1	11.9	13.2
Harvest index	0.32	0.28	0.18

almost no change in harvest dry matter, resulting in an improved harvest index (**Table 1**).

Next to forage crops, canola has the greatest nutrient demand of crops grown on the Canadian prairies. With a seed protein content of 22 to 24 percent and seed oil content of 38 to 42 percent, canola requires large amounts of nitrogen (N) and sulfur (S), along with all other nutrients. The research site used for this trial had high levels of soil residual N, phosphorus (P), potassium (K), and S (**Table 2**). Nitrogen and P were side-banded at seeding, with additional N top-dressed in the spring after crop emergence. A herbicide tolerant hybrid canola cultivar was used in this study (Invigor 2153), seeded at 17 seeds/square foot (5 lb/A). Seed was pre-treated with a systemic insecticide for flea beetles and a fungicide for suppression of seedling disease. Weeds were controlled using an early single in-crop herbicide application.

Implications of Changing the Seeding Date of Canola

In addition to improved crop yield, dormant and early spring seeding has been found to bring several production advantages to the canola grower. It appears that this may be the most effective means for canola to be moved into semi-arid production regions where high temperature and moisture stress during flowering minimize the flowering period and seed formation. Early crop growth and development result in the canola avoiding the yield limiting stress, with reports of both flowering and maturity being advanced by up to two to three weeks. In addition, early season growth and development of the canola crop increase seed oil content by up to 2 percent and are effective in minimizing chlorophyll in the seed (green seed).

In sub-humid regions, where temperature and moisture stress at flowering are generally not considered a serious problem, early seeding may have a significant impact on crop yield losses due to disease, mainly white mold (*Sclerotinia* spp.). In a second seeding date study carried out in the same field as the one reported here (also using Invigor 2153), crop disease evaluation in 1999 revealed that only 9 percent of dormant seeded plants were affected by white mold, while 38 percent of the late-April and 59 percent with mid-May seeded plants were found to be diseased. Early crop development allowed the canola to flower and set seed prior to the release of disease spores, minimizing the negative effect of white mold on the crop. In 1999, the two spring seeding dates suffered moderate to severe lodging, contributing to the level of white mold observed in these treatments.

Polymer seed coatings, which effectively prevent the seed from taking up water for two to three weeks, have been developed to improve the success of dormant seeding canola. Without some form of coating, the farmer is forced to delay planting until soil temperatures drop below 0ºC (freezing). By this time the soil surface is often frozen, increasing the challenge of planting a small seeded crop shallow. In addition, the probability of ground cover with snow is high, which abruptly ends any further field operations until the following spring.

Innovative and new methods continue to be developed for the production of canola on the Northern Great Plains. The ability to include an oilseed crop in rotation with cereals in the semi-arid regions of the Canadian prairies will have a positive impact on the profitability of farming systems in this region. BC

Dr. Clayton is a cropping systems agronomist, Dr. Turkington is a plant pathologist, and Dr. Harker is a weed scientist at the Lacombe Research Centre, Lacombe, Alberta. Dr. O'Donovan is an agronomist at the Beaverlodge Research Farm, Beaverlodge, Alberta, and Dr. Johnston is PPI/PPIC Western Canada Director located in Saskatoon, Saskatchewan. E-mail: ajohnston@ppi-ppic.org.

TABLE 2. Soil nutrient concentration and fertilizer application on canola seeding date trial at Lacombe, Alberta in 1999.

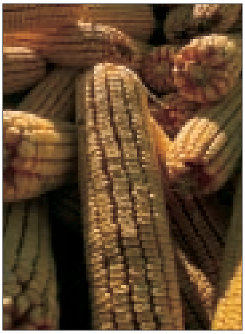
	N and S at 0 to 24 in. depth; P and K at 0 to 6 in. depth			
	NO_3-N	P	K	S
	lb/A			
Available	73 M[1]	62 O	450 M-O	83 O
Fertilizer applied:	N	P_2O_5	K_2O	SO_4-S
Side banded at seeding	61	23	0	0
Surface broadcast after emergence	45	0	0	0

[1]M - marginal soil test level; O - optimum soil test level.

COLORADO

Irrigated Corn: 300 bu/A in Colorado

By W.M. Stewart



Greater profits come from higher yields since costs are spread over more units (bushels, bales, pounds, etc.), resulting in lower cost per unit of production. Efficient and profitable production involves lowering unit cost by increasing yield to a point of maximum net return. Several factors can limit crop yield. Variables such as fertility, light, hybrid, population, row spacing, and temperature can prevent the achievement of high yields, and thus greater profit.

Research conducted in Colorado in the late 1970s and the 1980s on irrigated corn investigated some of the barriers to achieving high yields. Corn yields in excess of 300 bu/A were recorded on the western slope during the studies. This discussion focuses on some of the available details of that research.

The principle investigator in the Colorado research, Dr. Sterling Olsen, in one publication observed: "We don't know the limit to yield. High yields result from a combination of many growth factors which may limit or increase growth in a dynamic way. And we are working to find out what these factors are."

The effects of nitrogen (N) rate, plant population, and variety on corn yield were reported (**Table 1**). Interesting interactions among these three factors were observed. **Figure 1** illustrates these interactions in terms of percent yield increase. Yields were enhanced by increasing plant population with all varieties except for one at the lowest N rate. With all but one variety there was a positive interaction between N fertilizer rate and population. In other words, the higher plant populations had the potential to produce substantially higher yields with higher levels of fertility.

Another aspect of the study involved the investigation of corn response to enhanced ammonium (NH_4) supply. The hypothesis tested in these field experiments was that a combined supply of NH_4 and nitrate (NO_3) forms of N would increase N use efficiency and yield compared to either form alone. Research fields were furrow irrigated. Initial soil test phosphorus (P)...sodium bicarbonate ($NaHCO_3$) extraction...was high...14 parts per million (ppm)...and soil test potassium (K) was 110 ppm (medium). Phosphorus and K fertilizers were broadcast and incorporated preplant at the rates of 100 lb P_2O_5/A and 200 lb K_2O/A. Where N fertilizer application was split, the mid-season applications were

TABLE 1. Effect of population, variety, and N fertilizer on irrigated corn yield.

Variety	N rate, lb/A	Population, plants/A 26,596	37,985
		Yield, bu/A	
Variety A	150	192	195
	225	194	214
	320	205	229
Variety B	150	204	212
	225	226	241
	320	221	239
		Population, plants/A 38,826	**46,429**
		Yield, bu/A	
Variety C	150	216	222
	225	214	219
Variety D	150	232	226
	225	244	261

made through irrigation water. A nitrification inhibitor (nitrapyrin) was applied with the N fertilizer in some treatments to retard the conversion of NH_4 to NO_3.

Corn yields were increased with treatments that increased the proportion of available N in the NH_4 form by applying the nitrification inhibitor with NH_4 forms of N fertilizer.

Table 2 shows the effect of N application timing, nitrification inhibitor, and plant population on corn yield. The use of the nitrification inhibitor with split N applications increased yield by approximately 35 bu/A. Where no nitrapyrin was used, neither higher population nor additional N fertilizer increased yield. This suggests that delaying nitrification of NH_4-N resulted in a more favorable N balance.

Another trial involved the comparison of several N fertilizer sources in split applications (**Table 3**). Where nitrapyrin was applied with urea-ammonium nitrate (UAN) solution, corn yield was substantially higher than where none was applied with UAN or the other N sources. These data indicate that balancing N nutrition is important in maximizing N use efficiency and optimizing corn yield.

Dr. Olsen and other authors emphasized that an adequate supply of K enhances NH_4 utilization and improves yield. Potassium counteracts the possible toxic effects of NH_4 nutrition by activating enzymes that function in NH_4 assimilation. This prevents accumulation of toxic concentrations of NH_4 in plant tissue. Furthermore, the presence of adequate amounts of K are necessary for synthesis of organic acids and translocation of amino acids and carbohydrates in plants. Other scientists have observed that when corn absorbed N as NH_4 there were significant yield increases at higher K rates, while no yield increase was observed at higher K rates with NO_3-N.

This brief review clearly demonstrates the effects of a few of the variables and their interactions affecting crop yield. As fundamental barriers to the achievement of higher yields and profit are overcome, other barriers surface. For example, improved hybrids may have the potential for significantly higher yield, but that yield will not be expressed without sufficient inputs such as adequate and balanced fertility. BC

Dr. Stewart is PPI Great Plains Director, located at Lubbock, Texas. E-mail: mstewart@ppi-far.org.

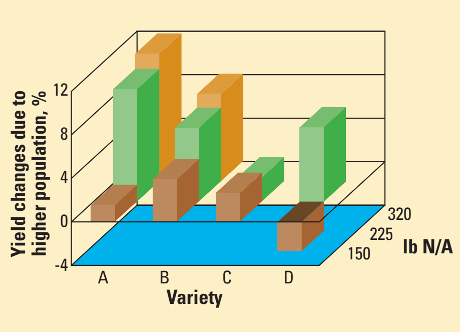


Figure 1. Influence of N fertilizer rate on yield response to higher plant population of four corn hybrids.

TABLE 2. Effects of N application timing, nitrapyrin, and plant population on irrigated corn yield.

N source	Application date[1]	Nitrapyrin	Population, plants/A	Yield, bu/A
Ammonium nitrate	5/5	no	30,165	209
Anhydrous ammonia	6/23	no	38,441	200
	7/25	no		
Ammonium nitrate	5/5	no	28,314	222
Anhydrous ammonia	6/23	yes	37,679	235
	7/25	yes		

[1]100 lb N/A/application

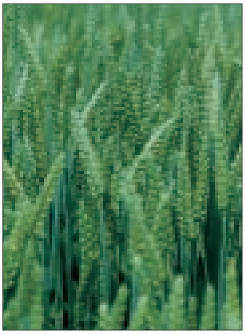
TABLE 3. Effect of N fertilizer source and nitrapyrin on irrigated corn yield.

N source	N rate, lb/A	Application date	Nitrapyrin	Yield, bu/A
UAN	100	4/19	no	
	200	7/9	no	261
UAN	100	4/19	no	
	200	7/9	yes	270
Urea	100	4/16	no	
	200	7/9	no	249
Ammonium nitrate	100	4/16	no	
	200	7/9	no	252

EASTERN U.S.

High Yield Wheat in the Eastern U.S.

By N.R. Usherwood



Record wheat grain yields in many Southeastern states are two and sometimes three times higher than state averages. Many come from research, others from farmers competing and learning how to harvest more of wheat's genetic yield potential. Such yield differences become a challenge to educators and a timely opportunity for wheat farmers. If yields can be increased, farmers stand to realize the economic benefits from lowering the unit cost of producing wheat.

High yields begin with understanding wheat plant development and needs from the time of seed germination until physiological maturity. Any stress or shortage of a vital raw material will take its toll on grain development. Equally important is the timeliness of delivery of plant input needs including plant nutrition. This article evaluates those management practices that produce top wheat yields.

Today's Record Yields: Tomorrow's Production Goals

Very high wheat yields have been documented by researchers for more than 20 years. The highest verified wheat yield in North America of 205 bu/A was obtained in British Columbia research in 1988. Split nitrogen (N) applications, fungicides, and use of a lodging resistant variety were critical production factors in this high rainfall coastal region. Details on how the record yield was produced are available in *Better Crops with Plant Food*, Fall 1989 p.7.

TABLE 1. Components of wheat grain yield, increase with yield level.

Component	50-bushel	100-bushel
Heads per square foot	42	55
Grains per head	28	35
Seed size	32 grams/ 1,000 seed	40 grams/ 1,000 seed
Seeds per pound	14,188	11,350

During this same period of time, researchers were measuring yields of nearly 120 bu/A in states such as Maryland, Virginia and Georgia. In 1997, a University of Maryland scientist produced 151 bushels of wheat per acre by applying a system of high yield management practices to a fertile Coastal Plain soil.

Research Know-How Helps Farmers to Harvest Record Yields

Success in achieving high yields in research comes with the responsibility of transferring new production technology to farmers. One approach has been the development of yield contests organized and supervised by university Extension and industry wheat specialists. The initial success of this effort has been above expectations. High yields have been measured by farmers, and state average wheat yields have been improved. Some farmers have approached and even exceeded a yield level of 100 bu/A. At the same time, the educational efforts helped other farmers to improve their wheat yields. For example, the Virginia state average wheat yield improved at a rate of about 1.5 bu/A per year.

Scientists Focus on Three Major Components of Wheat Yield

Researchers have identified three management components that are critical to the development of wheat yield.

Plant population (heads per acre).

The initial seedling population must be uniformly distributed over the field. Tillering will then fulfill this requirement for high yield by establishing the potential for number of wheat heads per unit area.

Seed number per head. The number of seeds that can develop in a wheat head is established during the early weeks of rapid spring growth.

Seed formation (test weight). Many conditions influence the rate and/or amount of photosynthates produced and deposited in the developing wheat seed. Adequate nutrition and minimal plant stress due to drought, temperature, diseases, etc. serve to establish wheat seed size or test weight.

Each farmer's high yield system will be slightly different. Each field site will need specific attention due to differences in soil characteristics, yield potential, or even the timeliness of getting a job done. Success will come from producing more and larger seed per acre. **Table 1** provides an indication of how the yield components might change as the grain yield increases from 50 to 100 bu/A.

High Yields Require a System of Best Management Practices (BMPs)

Today's record wheat yields represent only a part of the crop's full genetic potential. Selecting a realistic yield goal is a first step. Five bushels over the highest previous field yield is often attainable. The next step involves an in-depth review and possibly overhaul of each and every production practice. Some practices build yield while others serve to protect that yield from being lost to weeds, insects, diseases, or other unfavorable growth conditions.

Nutritional needs of high yield wheat can seldom be met by soil reserves alone. Soil tests can provide a good measure of aglime requirements and nutrients available in the soil reservoir. Fertilizer nutrients must be selected and applied to make up any shortage in plant needs. The nutrition package must also be woven into the production system so as to best interact with practices such as seeding rate, row width, date of planting, variety selection, or tillage practices. It will also need to be adjusted for yield goal, basic soil fertility level, plant stress, or even adjusted within season due to unpredictable climatic conditions.

High Yield Management Practices To Consider

Certain management practices are universally important for attaining high wheat grain yields. Each can be adjusted to fit site-specific needs and sometimes readjusted within the season to compensate for uncontrolled climatic or plant stress conditions. The following practices are considered to be building blocks to higher yields and are in continual need of fine tuning.

Site selection. The investment in high yield management begins with the selection of fields with soils that are fertile and capable of achieving high yields.

Tillage and seedbed preparation. Reduced tillage saves trips over the field and helps to improve soil/water relations. A firm seedbed is needed for good soil-seed contact.

Liming and adjusting soil fertility. Soil test and where possible apply needed aglime at least three months before seeding. Consider adjusting soil test levels for phosphorus (P) and potassium (K) to the high range except on soils with very low cation exchange capacity.

Variety selection and seeding. Select performance tested varieties. Plant within the

TABLE 2. Nutrient requirements for high yield wheat production (Georgia).

	Wheat yield, bu/A						Straw
	40		70		100		removal
Nutrient	Uptake	Removal	Uptake	Removal	Uptake	Removal	3 tons
Nitrogen	75	46	130	89	188	115	35
Phosphorus (P_2O_5)	27	22	47	38	68	55	14
Potassium (K_2O)	81	14	142	24	203	34	80
Magnesium	12	3	21	5	30	8	5
Sulfur	10	2	18	4	25	7	3

ideal high yield window. Consider a 4-inch row width with fewer seeds per foot of row.

Nutrition management. Each of the three grain yield components are nutrition driven. Nitrogen can do its best when balanced with K, sulfur (S), P, and other needed nutrients. Multiple applications help to deliver nutrients prior to critical growth stages. The following example might help to illustrate timing fertility to crop need for low cation exchange capacity, Coastal Plain soils that are subject to intense periods of rainfall.

- Preplant: Consider about one-third of N, all the P, and half of the K, S, and boron (B) needs. This promotes seedling growth and tiller development and helps to establish the high yield requirement for heads per acre.
- Sidedress prior to early spring growth flush (Feekes 3.0): Consider half of the remaining N and the other half of the K, S and B needs. This minimizes the risk of nutrient loss by leaching and helps to insure optimum nutrition during the second critical yield development period.
- Sidedress prior to early boot stage (Feekes 4.5): Adjustments at this time can compensate for adverse weather, crop stress, or unexpected situations detected during field scouting.

Weed, insect, and disease management. Prevention or early detection and control of stress inducing factors are essential. Each can be very site specific. Rely on area specialists for appropriate diagnosis and control.

Field scouting. In-field inspections allow in-season adjustments to unexpected problems. Global positioning, yield monitoring, stress area mapping, plant nutrient analysis, etc. are additional tools to chart the course to improved yields.

Higher Yields Increase Wheat Needs for Certain Inputs

As wheat yield increases, the demand for a balanced menu of essential nutrients will also increase. Researchers found that wheat produces most of its dry matter between the boot and milk stages of growth. They reported that a crop producing 108 bu/A accumulated 224 lb dry matter per acre per day during this 20-day period. This is also a period of high nutrient need.

Plant nutrient requirements increase as grain yields increase (**Table 2**). Nutrient removal from the field depends on the amount of grain harvested and whether straw is burned or removed from the field. Thus, nutrient removal is a factor to consider when fertilizing the following crop.

Higher Wheat Yields Can Improve Profitability

Farmers, agribusiness and consumers have all benefited from research-based high yield wheat production systems. For example, Virginia Tech and the University of Maryland scientists evaluated the economic benefits of high yield production in 1997 (**Table 3**). The cost per bushel for many wheat farmers was about $3.50. This value was lowered to $2.55 with research yields of 125 bu/A and down to $2.15 in the top research management study.

Wheat growers understand that higher yields allow for increased profit per acre. How to do it and keep doing it is the challenge. The “systems approach” for improving wheat yield continues to be a proven way for more and more farmers and for university and industry wheat specialists in the East and Southeast. BC

TABLE 3. Estimated production costs of high yield wheat systems in Maryland (1997).

Yield level, bu/A	State average 60	Top wheat farmer 85	Past intensive research 125	Top 1997 research 151
Variable costs	141	176	209	215
Fixed costs	85	100	110	110
Total costs	$226	$276	$319	$325
Cost per bushel	$3.76	$3.25	$2.55	$2.15

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IOWA

Redefining Corn Yield Potential

By T.S. Murrell and F.R. Childs

Determining the difference between a hybrid's yield potential and the actual yield attained helps us begin to quantify the level of stress under which a crop is grown and the yield that has yet to be exploited. By better understanding the yield potential of corn hybrids, agricultural science can better define management strategies that can increase crop production in ways that are agronomically, economically, and environmentally sound.

The Iowa Crop Improvement Association sponsors the Iowa Master Corn Grower Contest. It has been in existence since 1938 and allows producers to compete fairly with one another for high yields. The highest yields in the contest have consistently been much greater than the Iowa state average (**Figure 1**). The highest yields attained have been increasing over time, at an average rate of approximately 2.20 bu/A/yr. The Iowa state average yield has been increasing as well, but at a slower rate, about 1.64 bu/A/yr.

The yield gap between the contest winners and the state average provides an indication of the yield that has yet to be exploited by most farmers (**Figure 2**). This gap has been widening over time, an average of 0.56 bu/A/yr. For the last five years, Francis Childs has consistently won the non-irrigated class. In 1997 and 1998, he turned in state-confirmed yields of

The data presented here are part of an ongoing process by several researchers to characterize the site where Francis Childs grew 393.74 bu/A corn. Plans are being made to test current corn growth models to better understand the impacts climatological events had on yields in 1999. Soil fertility information is being reviewed and investigated.

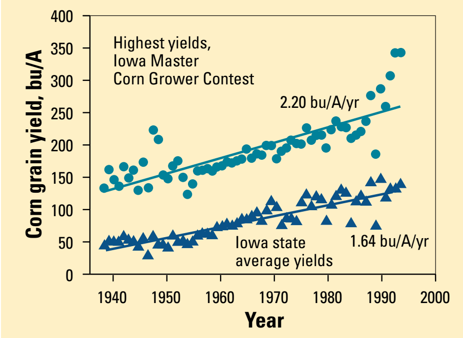

Figure 1. Highest annual corn grain yields entered in the Iowa Master Corn Grower Contest and Iowa state average corn grain yields. (Data: Iowa Crop Improvement Association and National Agricultural Statistics Service).

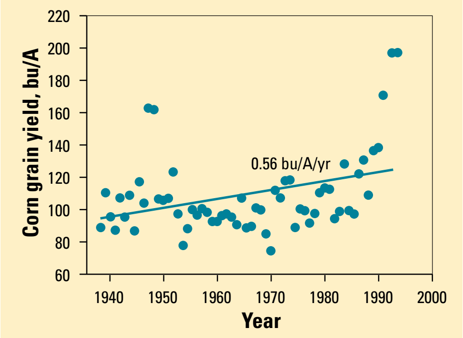

Figure 2. Annual difference between the yields attained in the Iowa Master Corn Grower Contest and Iowa state average yields. (Data: Iowa Crop Improvement Association and National Agricultural Statistics Service).

345.26 and 345.71 bu/A, respectively. In 1999, he had a state-confirmed yield of 393.74 bu/A. Mr. Childs has also won the National Corn Growers Association yield contest in the AA Non-Irrigated Class in 1997 and 1998.

The higher yields of the contest winners demonstrate that much of the corn grown in Iowa is under stress and is yielding well below what is possible. Limited yields may be related to many possible factors, such as moisture, nutrients, rooting depth, temperature, etc. What is critical to increasing yields is identifying which factors can be controlled and determining their true non-limiting levels in a given environment.

Much of the agricultural research to date has been conducted at moderate yield levels, usually below 200 bu/A. It is not known if the critical levels defined in such research are appropriate at higher production levels.

The first step in any scientific endeavor is to characterize, as fully as possible, the current state of a system one wishes to investigate. After the initial characterization, the system is then dissected into a series of controlled studies that investigate the effects of the various components as well as their interactions. The environment in which Francis Childs has been able to achieve such high yields is of particular interest to agriculture as it strives to understand corn yield potential.

Soils Information

The field yielding 393.74 bu/A in 1999 is in the Kenyon-Clyde-Floyd association (**Figure 3**). This association comprises about 51 percent of the soils in Delaware County, Iowa. Soils in this association are found in uplands. The landscape is a multilevel sequence of erosion surfaces. The Iowan-age till does not exist, but an erosion-surface complex does exist in the Iowan region. The Iowan surface formed during the time of loess deposition, about 14,000 to 20,000 years ago. Kenyon, Clyde, and Floyd soils are probably younger than 14,000 years old. A stone line, shown in **Figure 3**, marks where the Iowan surface cuts through Kansan and Nebraskan till. Kenyon soils formed from loamy sediments and in underlying glacial till on the Iowan erosion surface. Clyde and Floyd soils formed from local alluvial material coming from nearby glacial till on side slopes. The Kenyon soil is typical of soils formed under prairie grasses. The Clyde soil is typical of soils formed under prairie grasses and water tolerant plants.

The soil mapping units for the field yielding 393.74 bu/A is shown in **Figure 4**. The Kenyon soil is moderately well drained (**Table 1**) and is located on convex ridge tops and side slopes. The Clyde-Floyd complex is in the nearly level to gently sloping drainage ways. This complex is composed of both Clyde (somewhat poorly drained) and Floyd (poorly drained) soil series intermixed at a small enough scale that they could not be mapped separately. Just north of the central part of the field is a ridge, denoted by the Kenyon loam with a slope of 5 to 9 percent. Water drains from either side of this ridge into the Clyde-Floyd complex areas located near the middle

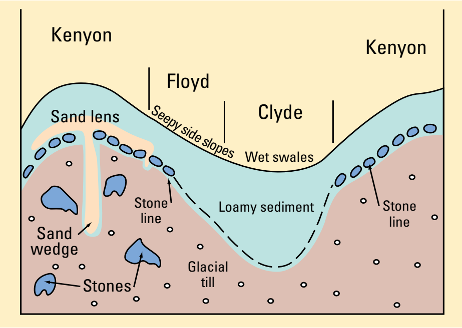

Figure 3. Parent material of the Kenyon-Clyde-Floyd association (adapted from Delaware county soil survey).

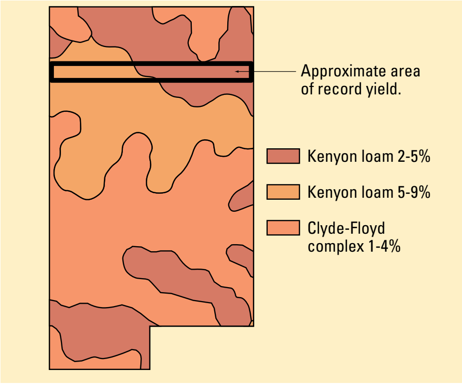

Figure 4. Soil mapping units in the field yielding 393.74 bu/A.

and both the north and south ends of the field. **Table 1** provides other characteristics of the various soils in this field. Noteworthy are the yields, defined in the soil survey, expected for each soil series when managed intensively.

Soil samples were taken to a 14 in. depth. Soil test information is still being examined and will be reported in future publications. However, soil test levels for phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg), zinc (Zn), and iron (Fe) were all well into the very high range, and soil pH was near neutral.

TABLE 1. Selected soil characteristics defined in the Delaware county soil survey, issued March 1986.

	Soil series		
Characteristic	**Kenyon 2-5%**	**Kenyon 5-9%**	**Clyde-Floyd complex**
Taxonomic class	Fine-loamy, mixed, mesic, Typic Hapludolls	Fine-loamy, mixed, mesic, Typic Hapludolls	Fine-loamy, mixed, mesic, Typic Haplaquolls (Clyde) and fine-loamy, mixed, mesic, Aquic Hapludolls (Floyd)
Drainage	Moderately well drained	Moderately well drained	Somewhat poorly drained (Clyde) and poorly drained (Floyd)
Texture	Loam	Loam	Clay loam
Permeability	Moderate	Moderate	Moderate
Runoff	Medium	Medium	Low
Expected corn yield with high management	154	149	142
Capability class	IIe (moderate limitations that require moderate conservation practices to control erosion)	IIIe (severe limitations that require special conservation practices to control erosion)	IIw (moderate limitations from water interfering with plant growth)

TABLE 2. Tillage information associated with 393.74 bu/A corn yields, 1999.

Fall tillage:	Mini-moldboard plow (Wiese Corp.), 14 in. deep
Spring tillage:	Field cultivator used to apply NH_3, 1 pass before planting
Residue cover:	About 30%, corn residue

Management Practices

The field being characterized has been in continuous corn for the past 30 years. Fall tillage (**Table 2**) is performed with a mini-moldboard plow manufactured by the Wiese Corporation. This implement was used to till the soil to a depth of 14 in., leaving about 30 percent corn residue cover. Spring tillage was performed with a field cultivator with which anhydrous ammonia (NH_3) was applied. Row cultivation is occasionally performed, although none was done in 1999 on this field.

Planting and harvest information is found in **Tables 3** and **4**. Pioneer 34G82 was planted at a population of 44,200 plants/A on April 29, 1999. Planting speed was slow to ensure even seed distribution and depth. Stand counts were taken when the corn was 4 to 5 ft. tall and revealed the population to be 44,000 plants/A (**Table 4**). The population difference is thought to have arisen from a lower than expected seeding rate, rather than from problems with emergence. Scouting of the field detected no missed seed drops from the planter. The planter plates had been retooled to ensure they were flat and could provide even distribution of seed. A trash whipper was used at planting to remove residue from an approximately 6 in. wide swath centered over the row. A seed firmer was also used to increase seed-soil contact.

Fertilizer applications were split throughout the season. Bulk applications of P (180 lb P_2O_5/A) and K (120 lb K_2O/A) were made in the fall before plowing. A small amount of nitrogen (N, 50 lb/A) was also applied in the fall to stimulate corn residue decomposition. Anhydrous ammonia was applied with a cultivator in the spring at a rate of 250 lb N/A before planting. Starter fertilizer was applied 2 in. to the side and 2 in. below the seed at a rate providing 6 lb N/A, 15 lb P_2O_5/A, and 15 lb K_2O/A. One week after planting, N was applied again with herbicide at a rate of 50 lb N/A. Nitrogen was applied a final time as a late side-dress application, dribbled between the rows at a rate of 50 to 60 lb N/A.

Climatological Information

Rainfall for the growing season was 3.63 in. above average (**Table 5**). Surplus precipitation occurred in April, May and July while below average rainfall occurred in June, August and September.

Daily and cumulative growing degree data for the 1999 year as well as long-term averages (1951-1998) are presented in **Figure 5**. Dates for silking and physiological maturity were estimated from the published growing degree data required to reach these growth stages (**Table 3**). There was a period from five days before to 12 days after the estimated silking date when growing degree days (gdd) were accumulating at a rate faster than the long-term average. There was another short period of more rapid gdd accumulation from day 237 to 247. Slower than normal accumulation began around day 256 and continued to predicted physiological maturity. At predicted physiological maturity (day 268), cumulative gdd were 2,648 and 2,586 for the 1999 season and the long term average, respectively.

Daily high and low temperatures for 1999 and the long-term average (1951-1998) are shown in **Figure 6**. Maximum temperatures were generally higher than normal for a 32-day period for days 73 to 104, ending just 15 days before planting.

TABLE 3. Hybrid and planting information associated with 393.74 bu/A corn yields, 1999.

Hybrid:	Pioneer 34G82
Genetic traits:	Contains YieldGard ® (Bt) gene
Relative maturity:	106 days
Planted population:	44,200 plants/A
Growing degree days to silking:	1,340
Growing degree days to physiologic maturity:	2,580
Row width:	30 in.
Planting depth:	1.75 - 2 in.
Planting speed:	2 - 2.5 mph
Planting attachments:	Trash whipper[1] and seed firmer[2]
Planting date:	4/29/99

[1]Removes residue in approximately a 6 in. wide band centered over the row.
[2]Press wheels that provide better seed-soil contact.

TABLE 4. Harvest information associated with 393.74 bu/A corn yields, 1999.

Harvest date:	10/20/99
Length of time crop was in the field:	174 days
Harvest population:	44,000 plants/A

TABLE 5. Rainfall data.

	Precipitation amount, inches			
Month	Farmer records, 1999	Weather station records, 1999[1]	Weather station average, 1951-1998	Farmer records, average
January		2.53	1.00	–
February		0.94	1.08	–
March		0.89	2.04	–
April	5.3	4.06	3.40	+1.90
May	7.3	8.45	3.98	+3.32
June	4.1	3.86	4.57	-0.47
July	8.3	10.12	4.22	+4.08
August	3.5	4.33	4.47	-0.97
September	1.2	1.13	3.53	-2.33
October	0.0	0.59	2.50	-2.50
Growing season total[2]	24.4		20.77	+3.63

[1]Source: Midwestern Climate Center, Oelwein, IA weather station, located approximately 30 mi wnw of Manchester, IA.
[2]Rainfall data summed over the months of May through September. No April precipitation occurred after planting on April 29, 1999.

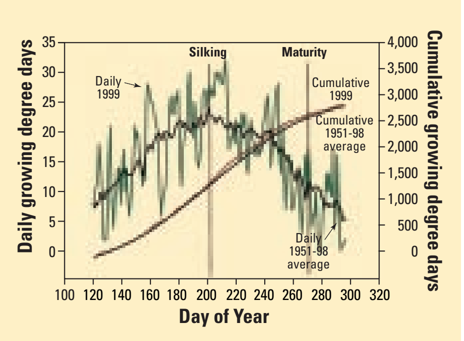

Figure 5. Daily and cumulative growing degree days (base 50ºF, ceiling 86ºF) for April 29 (day 119) - October 20 (day 293), 1999; average daily and cumulative growing degree days for the period 1951-98. Dates for silking and physiological maturity were estimated from published growing degree days **(Table 3)** needed to reach these growth stages. (Data: Midwestern Climate Center, Oelwein, IA station, located about 30 mi wnw of Manchester, IA).

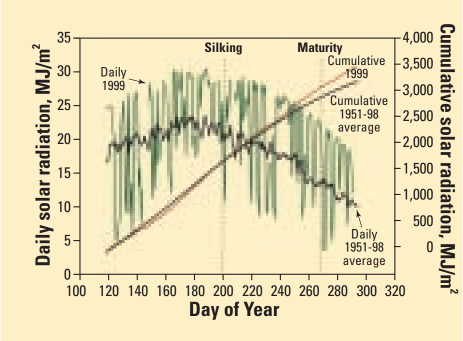

Figure 7. Daily solar radiation for April 29 (day 119) - October 20 (day 293), 1999; average daily solar radiation for the period 1951-98; 1999 missing for days 145, 147, 159, 195, 206, 207, 233, 291, and 293. Dates for silking and physiological maturity were estimated from published growing degree days **(Table 3)** needed to reach these growth stages. (Data: Midwestern Climate Center, Dubuque, IA station, located ~40 mi east of Manchester, IA).

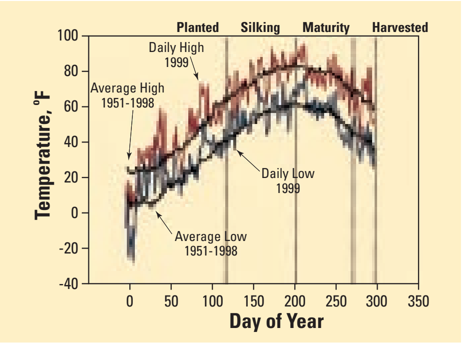

Figure 6. Daily high and low temperatures for January 1 (day 1) - October 20 (day 293), 1999; average daily high and low temperature for the period 1951-98. Dates for silking and physiological maturity were estimated from published growing degree days (Table 3) needed to reach these growth stages. (Data: Midwestern Climate Center, Oelwein, IA station, located about 30 mi wnw of Manchester, IA).

During this time, only three days, 99-100-101, had maximum temperature below normal. The maximum temperatures during this time ranged from 42 to 73ºF and 39 to 55ºF for 1999 and the long-term average, respectively. Mean maximum temperatures during this period were 56ºF (1999) and 50ºF (average). During this same period, minimum temperatures ranged from 19 to 53ºF and 22 to 35ºF, while mean minimum temperatures were 34ºF and 28ºF for 1999 and the long-term average, respectively. Minimum and maximum temperatures followed the trends discussed previously for the growing degree data.

Daily high and low solar radiation data for 1999 and the long-term average are shown in **Figure 7**. The slower accumulation of solar radiation early in the season is probably due to missing data, rather than a true effect. From approximately day 166, solar radiation accumulated faster than normal and continued this trend until harvest. Linear regression during this time period revealed average solar radiation accumulations of 20.57 MJ/m²/day for 1999 and 17.81 for the long-term average.

As we improve our understanding of the environment in which this crop was grown, we hope to better understand where research efforts should be spent to narrow the gap between yields attained and yields possible. BC

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Yield Verification

How confident can we be in the yields attained in yield contests? Verification processes used in both the Iowa Master Corn Grower Contest and the National Corn Growers Yield Contest follow.

Iowa Master Corn Grower Contest

- A grower must be sponsored (group or commercial concern).
- A representative of the sponsor must supervise the harvesting, measuring, weighing, sampling, testing for moisture, calculation of yield, and completion of contest form.
- Harvest pattern is determined by harvesting the number of rows associated with equipment size, then skipping three times the number of harvested rows before harvesting the next pass. For example, six row equipment would harvest six rows, skip 18, harvest six, skip 18 until a 1.25 acre area has been harvested.
- If the first yield in a local contest is greater than 190 bu/A, the yield must be reported immediately to the Iowa Crop Improvement Association. Yields need to be reported by the yield verifier or the sponsor. If this is not the first reported yield, then only yields greater than the one most recently reported or yields greater than the highest verified yield need to be reported.
- If a reported yield is higher than the highest reported yield or equal to or higher than the highest verified yield in a district or qualifies for the state level in one or more of the various contest's divisions, the yield will be held for verification. The Iowa Crop Improvement Association will assign a representative of the Association to verify the yield. The representative will supervise the harvest of a minimum of 1.25 acres of corn, coming from the rows skipped in the initial harvest pattern plus one set of skipped rows on one side. The Association's representative must witness all gross and tare weighings on a state-approved scale. The contestant must run the harvest machine, including the grain tank auger, to verify the machine is empty before beginning yield verification harvest.
- When yield is verified, a sample of grain will be collected by the Association's representative. A moisture test will be conducted by the Association on each corn sample. The yield resulting from yield verification and these tests will be considered the official yield.

National Corn Growers Association (NCGA) Yield Contest

- The entrant agrees to have any two of the following persons serve as his supervisor and assistant supervisor: an FFA advisor, vocational agricultural instructor, county Extension agent, county Extension agent's Assistant, senior staff person with Natural Resources Conservation Service (formerly SCS), office manager of Consolidated Farm Service Agency (formerly ASCS), a Farm Credit Services representative, Farmers Home Administration representative, bank ag loan officer, private crop consultant, state or private college agriculture staff, farm manager accredited by the American Society of Farm Managers, Iowa Master Yield Contest checker employed by Iowa Crop Improvement Association, or a retired individual from one of these occupations. The supervisors cannot have financial or direct business ties to a company that sells agribusiness supplies, i.e. totally independent.
- The entrant shall select a plot of five or

more acres of corn, of which no part has been harvested, from a field of corn 10 or more acres in size of one corn hybrid. The contest area may be any shape, but must be in one continuous block of corn.

- At least one contest supervisor must be present at the initial yield check to supervise the harvesting, measuring, weighing, (gross and tare) moisture testing, and reporting to the NCGA office.
- The supervisor(s) must have the entrant run the combine empty to make certain no corn has been left in it by mistake. All wagons or trucks must be checked to make certain they are empty.
- The four outside rows on the sides of the field and the end rows may not be a part of the contest area.
- A set of rows shall be harvested, then three times that number skipped, another set harvested and three times that number skipped and so on until the required 1.25 or more acres have been harvested. For example, six row equipment would harvest six rows, skip 18, harvest six, skip 18 until a 1.25 acre area has been harvested.
- The entrant must leave unharvested the corn remaining from the original required harvest pattern, plus one set of skipped rows on each side. The unharvested corn will be used for the recheck if the yield is 225 bu/A or more.
- One recheck is required for an initial yield check of 225 bu/A or more. Two supervisors are required to be present when rechecking the initial yield check for a yield of 225 bu/A or more. On initial yields of 250 bu/A or more, the supervisor(s) on the initial check cannot be used on the recheck. Two new supervisors must be approved by calling the NCGA office.
- All area measurements must be made with tape, chain, or measuring wheel.
- All corn must be weighed on a state-inspected scale. Supervisors must be present during the entire harvest check. All weigh wagons are prohibited.
- An experienced person must make a moisture determination of a representative sample of the corn. It is best to have the sample run through the meter three times and take an average of the three. BC

Annual Statement of Ownership

Statement of ownership, management, and circulation (required by 39 U.S.C. 3685) of *Better Crops with Plant Food*, published four times a year at 655 Engineering Drive, Suite 110, Norcross, GA 30092-2837. General business offices of the publisher are located at 655 Engineering Drive, Suite 110, Norcross, GA 30092-2837. Name and address of publisher is Potash & Phosphate Institute, 655 Engineering Drive, Suite 110, Norcross, GA 30092-2837. Name and address of editor is Donald L. Armstrong, 655 Engineering Drive, Suite 110, Norcross, GA 30092-2837. There is no managing editor. Owner is Potash & Phosphate Institute, 655 Engineering Drive, Suite 110, Norcross, GA 30092-2837. There are no known bondholders, mortgagees, or other security holders owning or holding 1 percent or more of total amount of bonds, mortgages, or other securities. Issue date for circulation data below: 1999 No. 3 (October 1999). The average number of copies of each issue during the preceding 12 months is: (a) Total number of copies printed: 17,031; (b) Paid and/or requested circulation: (1) Paid/requested outside-county mail subscriptions: 6,596; (2) Paid in-county subscriptions: 0; (3) Sales through dealers and carriers, street vendors, counter sales, and other non-USPS paid distribution: 5,827; (4) other classes mailed through the USPS: 50 (c) Total paid and/or requested circulation: 12,473; (d) Free distribution by mail: 843; (e) Free distribution outside the mail: 50; (f) Total free distribution: 893; (g) Total distribution: 13,366; (h) Copies not distributed: 3,665; (i) Total: 17,031; Percent paid and/or requested circulation: 93%. The actual number of copies of single issue published nearest to filing date is: (a) Total number of copies printed: 17,850; (b) Paid and/or requested circulation: (1) paid/requested outside-county mail subscriptions: 4,750; (2) Paid in-county subscriptions: 0; (3) Sales through dealers and carriers, street vendors, counter sales, and other non-USPS paid distribution; 6,086; (4) Other classes mailed through the USPS: 50; (c) Total paid and/or requested circulation: 10,886; (d) Free distribution by mail: 2,856; (e) Free distribution outside the mail: 350; (f) Total free distribution: 3,206; (g) Total distribution: 14,092; (h) Copies not distributed: 3,758; (i) Total: 17,850; Percent paid and/or requested circulation: 77%. I certify that all information furnished above is true and complete. I understand that anyone who furnishes false or misleading information on this statement or who omits material or information requested on the statement may be subject to criminal sanctions (including fines and imprisonment) and/or civil sanctions (including multiple damages and civil penalties).

Donald L. Armstrong, Editor

Farmers: Our Past, Our Future

All of us like to drop names. It seems that associating ourselves with someone famous helps to make us stand out...at least a little bit. A mentor of mine once said that anybody who claims not to enjoy name dropping will lie about other things, too. I'll admit I've been known to drop a name here and there. In fact, this forum gives me an opportunity to drop another one...Charlie Sisson. You haven't heard of him? Let me introduce you.

Charlie Sisson was a life-long farmer, active in church and community. He fathered three children and helped Mollie raise six more. He was a pioneer, as a young adult settling in the Indian Territory now known as Oklahoma. He cut and hued the logs, then built the house he and Mollie shared from their wedding day until his death in the fall of 1946. He was persistent, surviving two world wars, the Dust Bowl, and the Great Depression. He was also the first 'field' agronomist I ever met.

You probably still don't know who Charlie Sisson was, but you surely knew a few like him. They loved the land, worked long, hard hours, and seldom complained. In fact, I'm privileged to know those kinds of farmers today. They're pioneers like Charlie, except they're trying to grow 200 or more bushels of corn per acre instead of the 30 or so he squeezed out of the soil. Charlie and his contemporaries each grew enough to feed about 15 people. Today's farmer feeds more than 100...and will need to do even better.

This issue of *Better Crops with Plant Food* emphasizes high yields and how they can increase farmer profits, feed more people, and make more efficient use of our soil and water resources. It's about the survival of today's Charlie Sissons. We at PPI believe high, efficiently produced crop yields are essential to that survival, as well as to agriculture's ability to feed an ever-growing world population.

By the way, Charlie Sisson was my Grandpa. He died when I was six years old, but the principles he taught me still help to guide my life. To me he was famous. That's why I dropped his name on you.

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