Economic Impact of Plant Breeding Programs

Richard C. Frohberg

Increased plant productivity and improved quality are the continual goals of applied and basic plant research. The development of superior cultivars is the most visible result of this research effort. Efficient and effective utilization of genetic variation to achieve these genetically improved cultivars is the science of plant breeding. Expanding scientific knowledge and the complexities of each crop species make it necessary to form plant breeding teams to integrate different disciplines so that each breeding program is effective for a particular crop plant. Research priorities for long-term and short-term goals, breeding strategy and objectives, and selection technology need to be determined and implemented by a multidisciplinary team.

The past and expected future contributions of plant breeding to crop productivity have been categorized by Evans (1980) as follows: (i) closer adaptation to local environmental conditions and stresses, (ii) selection for resistance to pests and diseases which may either increase and/or stabilize yield performance, (iii) selection for suitability to changing agronomic practices, (iv) selection for plant genotypes with an inherent potential for progressively higher productivity, and (v) selection for quality characteristics such as protein or oil content may be required to enhance usefulness but is a constraint on yield improvement.

The relative importance of these contributions varies among crop plants. Most certainly the limitations on the ability of a breeding team to contribute are imposed by the availability of useful genetic variation and the resources to exploit that variation, and on the knowledge and skills of the team members.

A frequent perception is that improved cultivars perform well only in more optimum environments. Studies of wheat in the U.K. (Stanhill, 1976) and of several crops in the U.S. (Luttrell and Gilbert, 1976) show that the annual variation in yield does not increase as a proportion of yield. Higher yielding cultivars are neither more nor less subject to annual environmental variation. Cholick (1989) used hard red spring wheat yield data from seven to eight South Dakota locations each year (1984-1988) to demonstrate that genetic progress has been achieved for adverse environments. All improved wheat varieties yielded more than the long term check, Chris, and when averaged ranged from 25 to 44 percent improvement over the five years. The yield improvement was 12.4 bushels per acre or 33 percent in the record year of 1984 and 4.6 bushels per acre or 34 percent in the drought year of 1988.

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Plant breeding is not the only agricultural research component that has contributed to crop productivity increases. Most studies conclude that about one-half of the long term increases in regional and/or national average yields resulted from improved agronomic and technological practices (Jensen, 1978; Fehr, 1984). Cholick (1989) suggests that the increases result from an interactive system and that long term agricultural productivity is optimized only when all components are used and used properly.

The Agricultural Experiment Station of North Dakota State University has developed plant breeding research programs for those field crops of importance to North Dakota producers. These programs are initiated on an ongoing basis as additional crop plants are introduced and cultivated. The plant breeding projects for field crops are a part of the Department of Crop and Weed Sciences. The following comments on the contributions of plant breeding are from plant breeders of the various crops:

HARD RED SPRING WHEAT BREEDING

Richard C. Frohberg

The improvement effort for HRS wheat was begun by Dr. L.R. Waldron in 1910. From a very modest beginning, the program has developed into a breeding team of scientists that involves the departments of crop and weed sciences, plant pathology, cereal science and food technology, and entomology, the USDA-ARS and the research and extension centers throughout the state. The goals of this breeding program are to release high yielding, good quality cultivars that are pest and disease resistant and tolerant of drought stress for stability of production.

Since the release of Waldron in 1969, 12 HRS wheat cultivars have been developed for North Dakota producers. These cultivars have been readily accepted. For example, Stoa, released in 1984, and Butte 86, released in 1986, were each the leading North Dakota HRS wheat cultivar in 1986-88 and 1989-90, respectively. Cultivars from the program were grown on more than 70 percent of the 1988-90 North Dakota HRS acreage. Hard red spring wheat during 1985-89 was produced on an average of 6 million acres per year with an average annual production of 168.8 million bushels and an average value of $520,870,000 per year (North Dakota Agricultural Statistics Service).

Yield data from regional trials are statistically analyzed to estimate yield increases resulting from genetic improvement. These increases, called genetic gain, may be used to evaluate breeding progress. Average U.S. wheat yields of all classes increased from 25.1 bushels per acre in 1958-60 (three-year average used) to 33.1 bushels per acre in 1978-80 for a yield incresae of 32 percent. Comparisons of regional trials by Schmidt (1984) for the same period indicated a 17 percent genetic gain or about 0.2 bushels per acre per year. Feyerherm et al. (1984, 1989) concluded that there has been continued genetic improvement in U.S. wheat grain yields, based on a study of 1954-79 data and of 1979-84 data. For North Dakota, this genetic gain in yield was 0.26 bushels per acre per year (1954-79) and 0.23 bushels per acre per year for 1979-84. Hard red spring and durum wheat were considered one class for these studies.

Present and future breeding objectives will continue to emphasize the development of cultivars that combine higher yield with good breadmaking quality and sprout resistance, that have pest and disease resistance for conservation tillage management, and that have genetic diversity for resistance to new races of stem rust and leaf rust. Improved cultivars of the future will likely have a narrower adaptation to more specific environments of the state. For example, Amidon, released in 1988, has a superior 1987-90 yield performance relative to other cultivars (5 percent over Stoa) in northwestern North Dakota but is only average in the eastern part of the state.

BARLEY BREEDING

Richard Horsley, six-rowed
Jerome Franckowiak, two-rowed

The barley improvement program at NDSU was initiated in 1948 as the six-rowed barley breeding project. Since that time, the program has greatly increased and now includes both six- and two-rowed barley breeding projects and is a cooperative effort among the departments of crop and weed sciences, cereal science and food technology, and plant pathology; the USDA-ARS, and the research and extension centers throughout the state.

North Dakota is the leading state in barley acreage and production (2.9 million acres and 128.5 million bushels — five-year average) and produces 25 to 30 percent of all U.S. barley. Average yield of barley in North Dakota has increased from 21.9 bushels per acre (five-year average — 1951-1955) to 41.8 bushels per acre (five-year average — 1986 to 1990).

Six-rowed barley

The six-rowed barley breeding project's goal is to develop and release high yielding cultivars acceptable for malting and brewing. Approximately 80 percent of barley acreage in North Dakota is planted to six-rowed cultivars acceptable for malting. The six-rowed breeding project has not bred for "feed" barley cultivars per se; yet, North Dakota malting cultivars are at least equal to "feed" barley nutritionally.

Since the inception of the six-rowed barley breeding project, 10 cultivars have been developed and released by the North Dakota Agricultural Experiment Station. The most successful of these cultivars was Larker. From the mid-1960s to 1981, Larker was the preferred cultivar by the malting and brewing industry. Also, Larker was the cultivar new experimental lines from the Midwest had to at least equal before they were accepted by industry.

The six-rowed breeding project has been successful in increasing yield, test weight, kernel plumpness, straw strength, and malting and brewing quality of new barley cultivars. Improvements also have been made in reducing lodging, plant height, and resistance to the diseases spot blotch and net blotch. New challenges facing the breeding project include developing and releasing cultivars resistant to the new race of stem rust, Pgt-QCC.

Two-rowed barley

Two-rowed barley has fewer kernels per spike than six-rowed barley, but its kernels are larger and contain a higher percentage of starch. This advantage has resulted in two-rowed barley being the preferred malt type in many parts of the world. Historically, however, six-rowed barley was grown in the Great Lakes region of the U.S. as a malting barley because the introduced six-rowed varieties were more resistant to leaf spot diseases than were two-rowed ones. As malting barley production moved into the Red River Valley, six-rowed barley cultivars continued to be preferred by farmers and brewmasters. Yet, data were accumulating at the Dickinson and Williston Research Centers that showed a yield advantage for two-rowed varieties during dry growing seasons.

Development of a two-rowed barley improvement program at NDSU was encouraged strongly by superintendents of some research centers, especially Thomas J. Conlon at Dickinson. The need for two-rowed barley bred for North Dakota plus financial support by malting and brewing companies via the Malting Barley Improvement Association culminated in the employment of a two-rowed barley breeder in 1974, Melvern Anderson. The primary goal of the project was to develop superior barleys to be grown for feed in western North Dakota and/or malt in eastern North Dakota. The Minneapolis market price for two-rowed malt is often 50 to 80 cents per bushel higher than for six-rowed malt.

The initial crosses for development of two-rowed barley in North Dakota were made by Glenn Peterson in the early 1970s. He crossed two- and six-rowed cultivars and backcrossed the F_1's to two-rowed barley to combine the kernel characteristics of two-rowed barley with the disease and heat stress resistance of six-rowed barley. This approach to two-rowed improvement was continued by Anderson and later by Jerry Franckowiak, starting in 1978. The first cultivar released from the program was Bowman in 1984. It combined the tolerance to heat stress observed in Hector with stable kernel size and leaf spot resistance from six-rowed parents.

The introduction of Hector barley from Alberta to southwestern North Dakota had a major impact on the amount of two-rowed barley grown. In 1975, less than 1 percent of the barley acreage grown in North Dakota was two-rowed barley. By 1981, 2 percent was planted to two-rowed barley; by 1985, nearly 9 percent was two-rowed. In 1985, 80 percent of the two-rowed barley was Hector, but in 1987 80 percent was Bowman. Currently, about 12 percent of North Dakota's barley acreage is planted to two-rowed barley, primarily in western North Dakota where the probability of successful production of malting barley is low.

Release of the next two-rowed barley cultivar is planned for 1991. ND9866 has a yield advantage over Bowman, has larger seed, and is equal in tolerance to heat and drought stress. But, like Bowman, ND9866 will be classified as a non-malting barley. The yield potential of ND9866 in eastern North Dakota is equivalent to that of the best six-rowed malting barleys. However, the goal of a high yielding, two-rowed malting barley remains a dream of the future.

DURUM BREEDING

Elias Elias

Wheat is the most widely grown cereal crop in the world. The most important species of cultivated wheat are common wheat and durum wheat. Durum wheat occupies only about 8 percent of the total world wheat producing area. In the United States, over 75 percent of the durum wheat acreage is located in North Dakota. The annual durum wheat production in North Dakota in 1985 to 1990 averaged 73.9 million bushels having an average annual value of $243,879,000. The average annual production during this period for the entire U.S. was 92.3 million bushels. Durum wheat production in North Dakota accounts for about 79 percent of the total U.S. production.

The durum plant breeding program at NDSU has been in existence since 1929. The main objective of the breeding program is to release durum cultivars that maximize the economic return to the producer and provide high quality durum wheat for the domestic industry and international export market. With the support of the North Dakota Wheat Commission and the National Pasta Association, the program has been very successful in developing high yielding durum wheat cultivars resistant to stem rust and leaf rust and possessing excellent quality, such as intense semolina color and gluten strength. Twelve high yielding durum wheat cultivars have been developed at NDSU during the past 20 years. These cultivars are currently grown on over 95 percent of the acreage in North Dakota and surrounding states. None of these cultivars exhibited susceptible reaction to stem and leaf rust diseases during the high incidence of both diseases in 1983 and 1990.

The domestic use of durum wheat is almost entirely for pasta products. The firmness and resiliency of the cooked pasta products and the stability during cooking is known to be associated with gluten strength. Major emphasis was placed on developing high yielding strong gluten durum in the early 1970s. As a result of this effort, Edmore was released in 1976 as a strong gluten durum wheat cultivar. Edmore also possesses resistance to common root rot disease.

The cultivar Vic, also with strong gluten, was released in 1979. Vic has yield advantage over Edmore and similar quality and disease resistance. Large pure samples of Vic and Edmore were evaluated by the domestic pasta industry. The response to their superior cooking quality was very favorable.

In 1983, Lloyd was released as the first semidwarf durum cultivar with strong gluten and quality similar to that of Vic. Monroe was released in 1985 as an early maturing, high yielding, and strong gluten durum wheat cultivar. In 1988, Renville was released as a cultivar with strong gluten that exhibited a 9 percent yield advantage over other commonly grown cultivars. The present durum wheat germplasm in the project meets high quality standards. These high quality standards must be maintained to ensure market stability.

Protein content as well as protein quality has a major influence on the cooking quality of pasta. This has always been a breeding objective, but an increased awareness of this trait has occurred in recent years. It is very common to see specifications of 12 percent protein for pasta products in the market place. To consistently meet these protein specifications, durum growers need to produce 13.5 percent and higher protein in durum wheat in North Dakota.

The average protein content of the 1990 durum crop was 14.1 percent. This is in contrast to 1985 and 1986 when it was 13.1 percent and 13 percent, respectively. Extreme year to year fluctuations in protein percentage are common in this growing region, primarily due to growing environment and weather conditions. There is no discernible trend for decrease in protein over time. In spite of the negative correlation between grain yield and protein percentage, the protein level in the high yielding cultivar Renville is comparable to that of the older cultivars.

To remain economically competitive, new durum cultivars developed in the future must have high grain yield and protein content, strong gluten, pre-harvest dormancy, and disease resistance.

SUNFLOWER BREEDING

Jim Hanzel

The sunflower industry as it is known today is largely based upon genetic material produced at North Dakota State University through the cooperation of breeders and other scientists affiliated with the USDA-ARS and the university. Since production of sunflower hybrids began in the early 1970s, over 100 lines and germplasms have been developed and released to private breeding companies.

Hybrids grown today yield approximately 35 percent more than the open-pollinated varieties grown in the 1960s. The average oil content of currently grown hybrids is approximately 10 percent higher than the average of the early hybrids of the mid-1970s. It is not unusual to find hybrids that have nearly 50 percent oil content.

The major sunflower diseases — rust, downy mildew, and Verticilium wilt — have been controlled largely through the incorporation of resistance genes into commercial hybrids, and research continues toward development of tolerance to Sclerotinia. Pest resistance also has been a priority of breeders at NDSU. Research is in progress to develop germplasm with resistance or tolerance to various insects and to depredation by birds. Much progress has been made in developing confection sunflower with good agronomic performance, as well as seed quality. Breeding efforts in progress or being planned may provide valuable byproducts to the sunflower industry, such as the use of the pigment from the purple-hulled sunflower as a natural food colorant or the use of sunflower oil as an alternative for diesel fuel.

CORN BREEDING

Harold Z. Cross

North Dakota grain corn yields have increased by an average of 4.0 percent (1.59 bushels per acre) per year for the period from 1963 to 1990. We estimate that one-fourth of this yield increase is due to improved management practices such as better weed control and fertility, and three-fourths (1.23 bushels per acre) is due to genetic improvement in corn hybrids.

For the five-year period 1985 to 1989, an average 866,000 acres of corn were planted in North Dakota, and farmers received an average of $2.02 per bushel of grain sold. Assuming that the value of genetic improvements were similar for silage as for grain corn, the average value of a 1.23 bushel per acre genetic improvement on 866,000 acres would be $2.33 million annually. This figure doesn't consider the savings in drying costs and harvest losses from demonstrated genetic improvements in dry-down and stalk strength.

Our estimate of plant breeding's contribution is based on regression analyses of the average yields of commercial hybrids relative to the yield of a long-term check hybrid, NDB564, grown under identical cultural conditions across 28 years in Fargo. In 1963, NDB564 (a single cross hybrid developed at NDSU) yielded 11.7 bushels per acre more than the commercial hybrids, but by 1990 the commercial hybrids averaged 21.7 bushels per acre more than NDB564 due to a 1.23 bushels per acre per year genetic improvement in the commercial hybrids. Commercial hybrids in 1990 were faster drying and more resistant to stalk breakage than those tested in 1963. In 1963, the commercial hybrids averaged 5.7 percentage points higher moisture and had 0.2 percent more broken stalks than NDB564, but by 1990 the commercial hybrids were only 2.4 percentage points higher in moisture and had 8.5 percent fewer broken stalks than NDB564.

Because seed corn companies do not disclose pedigrees of their hybrids, North Dakota acreages planted to hybrids produced from publicly developed germplasm are unknown. However, about 60 companies annually purchase corn germplasm developed by the corn improvement project at NDSU, including 36 inbred lines and 22 breeding populations which have been released since 1963. We assessed the increase in value of NDSU developed parental lines by regressing grain yields (two-year means) of check hybrids produced from NDSU developed inbreds on year of introduction into the Fargo tests. Grain yields increased 1.36 bushels per acre per year, a rate somewhat higher than the average for the commercial hybrids. Averaged across 1989 and 1990, the two most recently developed check hybrids produced 32 bushels per acre more grain, yet had lower moisture at harvest and less stalk breakage than NDB564. At $2.02 per bushel, these hybrids would produce $65 per acre per year more profit than the older hybrid.

OAT BREEDING

Michael McMullen

Development of high yielding, early maturing, stem and crown rust resistant cultivars has been emphasized by the oat breeding project at NDSU. Oat improvement in North Dakota involved only testing of lines from other programs during the period of 1967 to 1972. Some breeding work was again initiated in 1972, and breeding efforts have been increasing since then. Recent emphasis has included resistance to new stem rust races, crown rust resistance, barley yellow dwarf virus tolerance, improved grain yield and quality, and improved straw strength. Six spring oat cultivars were released. The researchers were: H.R. Lund (1961), D.C. Ebeltoft (1961-71), J.R. Erickson (1972), G.S. Smith (1973-76), and M.S. McMullen (1976-present).

Dawn and Wyndmere, released in 1966, provided early maturing crown and stem rust resistant cultivars adapted for production in southeastern North Dakota.

Selection for protein yield among the progeny of a Hudson/Dal cross led to the 1983 release of Pierce, which provided a relatively late maturity cultivar with moderately high grain protein concentration.

The germplasm line RL 3038, provided by R.I.H. McKenzie from the Agriculture Canada Research Station, Winnipeg, was used as a source of stem rust and crown rust resistance for North Dakota breeding work. Steele was developed using this germplasm and released in 1984. At the time of its release, Steele was the only U.S. cultivar with adequate resistance to the prevalent stem rust race, NA 27. It also provided excellent resistance to the prevalent crown rust races, provided good lodging resistance, and produced high yields of high quality grain.

Valley, released in 1988, was selected with stem and crown rust resistance similar to Steele and represented an improvement in straw strength, grain yield potential, and test weight relative to Steele. Newdak was developed in North Dakota and co-released by the North Dakota and New York Agricultural Experiment Stations in 1990. Newdak produced higher grain yield and improved barley yellow dwarf virus resistance relative to Steele and Valley while maintaining similar levels of stem and crown rust resistance.

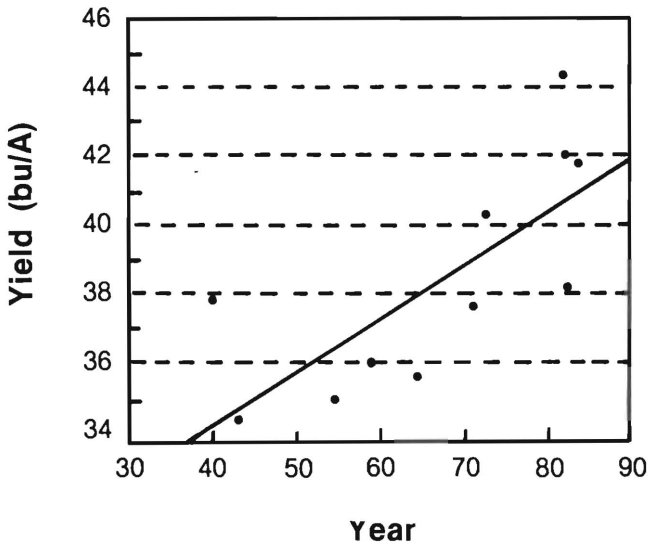
SOYBEAN BREEDING

Ted Helms

Prior to 1930, farmers in the United States who raised soybeans grew either plant introductions from the Orient or selections from these plant introductions. The first soybean cultivars developed using plant breeding methodologies were released in the 1940s. Wilcox et al. (1979) reported that newly released cultivars yielded about 25 percent more than the original plant introductions used in the 1930s.

In Minnesota, Jim Orf (personal communication) evaluated cultivars released between 1940 and 1985. He found that soybean breeding resulted in genetic gain of 0.13 bushels per acre per year in northern Minnesota. When the cultivar Capital (released in 1944) was grown in the same environments as the cultivar Ozzie (released in 1983), Ozzie yielded 7.4 bushels per acre more than Capital. The 7.4 bushels per acre difference between these two cultivars multiplied by 450,000 acres of soybean grown in North Dakota in 1990, multiplied by $6.00 per bushel price, equals approximately $20 million additional value of the soybean crop for 1990 alone. Figure 1 shows the yield of cultivars released in different time periods.

Figure 1. Genetic improvement of soybean in northern Minnesota from 1944 to 1985.



Cultivars evaluated and release date, shown in parenthesis, include: Mandarin (1940), Capital (1944), Grant (1955), Merit (1959), Traverse (1965), Swift (1972), Evans (1974), Simpson (1982), Ozzie and Dawson (1983), and Dassel (1985).

The objectives of the soybean breeding program include: 1) high yield, 2) suitable maturity, 3) improved protein and oil content of the grain, 4) disease resistance, 5) shattering resistance, 6) increased basal pod height, and 7) drought tolerance.

FLAX BREEDING

James Hammond
Jerry Miller, ARS-USDA

"For over five thousand years flax has been one of the most useful plants to man, yet its origin is lost in antiquity" (Eastman, 1976). In the United States, production of flax progressed from east to west with the settlement of the country. In the late 1800s, the center of flax production had progressed to North Dakota.

The shift in production from east to west occurred as a result of decreased yield after the initial production of flax on new land. Professor Bolley in the early 1900s identified flax wilt as the causal agent for the decreased yields with continuous flax production. As a result of Bolley's work, the center of flax production did not shift from North Dakota. The area that Bolley established (about 1890) for continuous flax (Plot 30) and used to identify the causal organism of flax wilt and resistant genotypes still is used in the North Dakota breeding program. One of the other major contributions to flax breeding (and plant breeding in general) was the research of Harold Flor, a USDA scientist located at Fargo. Flor's work with flax and flax rust has contributed not only to flax production but also to all plant breeding programs in North Dakota and throughout the world. As a result of the disease work of Bolley and Flor, numerous flax varieties have been released for production in North Dakota. The most recent releases from North Dakota have been Wishek (1979), Flor (1981), Linton (1985), Neche (1988), and Omega (1990). Miller and Hammond (1976) estimated a yield improvement of approximately 0.07 bushel per acre per year during the previous 50 years.

DRY BEAN BREEDING

Ken Grafton

Dry bean (*Phaseolus vulgaris* L.) has become an important crop in North Dakota since its introduction into this region in 1962. Acreage has increased from 22,000 in 1969 to 600,000 in 1990, and is largely of the pinto and navy classes. North Dakota growers produce 21 and 20 percent of the nation's pinto and navy beans, respectively, and the state leads the nation in both acreage and production of all dry beans. On-farm value of the edible bean crop in North Dakota and adjoining areas of Minnesota approaches $100,000,000 annually. As dry bean production continues in North Dakota, an active breeding program is needed to meet improved cultivar requirements relative to new disease and cultural problems, as well as improvements in culinary quality.

The dry bean breeding program at North Dakota State University was initiated in 1979 with the objective to develop early maturing, high yielding cultivars that are adapted to the various environmental stresses prevalent in this growing region. The primary focus of the bean breeding project was directed toward the pinto and navy bean market classes.

Three vine-type pinto bean cultivars were released jointly with the USDA-ARS in 1981, 1983, and 1984. In addition, two rust-resistant germplasm lines were released jointly with USDA-ARS in 1989.

Efforts to combine large seed size with an upright-vine growth habit in the pinto bean market class have been successful, with several promising genotypes tested for possible cultivar release in the next few years. Upright architecture in pinto beans may allow for disease avoidance and also for the possibility of direct combining, thereby offering the dry bean grower in North Dakota higher yields and greater efficiency. Early maturing navy bean breeding lines possessing the upright, short vine growth habit also have been selected and may be considered for release in the near future.

The successes of the breeding efforts in the pinto and navy bean market classes have allowed for expansion of this project to include other market classes, including kidney, black, pink, great northern, and small red bean. Adapted cultivars of these market classes will allow for further diversification and allow the North Dakota grower to meet future changes in market demands. The degree of relatedness between these minor market classes and pinto or navy also allows use of common germplasm for desirable traits; however, these efforts remain minimal with respect to the effort afforded the major market classes of pinto and navy.

In addition to improving yield potential, architectural characteristics, and adaptation of bean to the North Dakota environment, the breeding program is currently involved in research designed to improve resistance to the major diseases (white mold, rust, bean common mosaic virus, and bacterial blights); improving the nitrogen fixing capabilities of bean; and improving the culinary (cooking, canning, and nutritional) quality of bean. Improvements in these areas will allow the dry bean industry to remain an important component of the North Dakota economy.

HARD RED WINTER WHEAT BREEDING

Darrell Cox

Winter wheat production is well suited to North Dakota conditions when planting is done in conjunction with conservation tillage practices. In addition to the benefits normally associated with conservation tillage (reduced soil erosion and increased soil water storage), winter wheat survival is improved by planting into stubble that traps snow and protects the crop from freezing temperatures. Changes in tillage practices and choice of hardier varieties have contributed to an increase in winter wheat acreage in North Dakota from less than 100,000 prior to 1975 to approximately 250,000 today.

The winter wheat breeding program of the North Dakota Agricultural Experiment Station was initiated in 1969 with the objective of developing winterhardy wheats adapted to the northern latitudes. The NDAES has released Roughrider, Agassiz, and Seward since the breeding program's inception. These three varieties accounted for 85 percent of the North Dakota winter wheat acreage in 1990 and are among the most winterhardy wheats in North America.

REFERENCES

Anonymous. 1990. North Dakota Agricultural Statistics. Ag. Statistics No. 59. North Dakota Agricultural Statistics Service, Fargo, ND.

Cholick, Fred. 1989. Wheat productivity has improved, even in adverse environments. Better Crops, Winter 1989/90, p. 26-27.

Eastman, Whitney. 1976. **The History of the Linseed Oil Industry in the United States.** T.S. Denison & Company, Inc. Minneapolis, MN.

Evans, L.T. 1980. The natural history of crop yield. Amer. Sci. 68:388-397.

Fehr, W.R. 1984. Genetic contribution to yield gains of five major crop plants. Spec. Publ. 7. ASA, SSSA, Madison, WI.

Feyerherm, A.M., G.M. Paulsen, and J.L. Sebaugh. 1984. Contributions of genetic improvement to recent wheat yield increases in the USA. Agron. J. 76:985-990.

Feyerherm, A.M., K.E. Kemp, and G.M. Paulsen. 1989. Genetic contributions to increased wheat yields in the USA between 1979 and 1984. Agron. J. 81:242-245.

Jensen, N.F. 1978. Limits to growth in world food production. Science 201:317-320.

Luttrell, C.B., and R.A. Gilbert. 1976. Crop yields: random, cyclical or bunchy? Am. J. Agric. Econ. 58:521-531.

Miller, J.F., and J.J. Hammond. 1976. Analysis of yield progress in flax breeding. Proc. 46th Flax Institute of the U.S.

Schmidt, J.W. 1984. Genetic contributions to yield gains in wheat. p. 89-101. **In** W.R. Fehr (ed.) Genetic contribution to yield gains of five major crop plants. Spec. Publ. 7. ASA, SSSA, Madison, WI.

Stanhill, G. 1976. Trends and deviations in the yield of the English wheat crop during the last 750 years. Agro-Ecosystems 3:1-10.

Wilcox, J.R., W.T. Schapaugh, Jr., R.L. Benard, R.L. Cooper, W.R. Fehr, and M.H. Niehaus. 1979. Genetic improvement of soybean in the Midwest. Crop Sci. 19:803-805.

Continued from page 2

Weeds, diseases, and insects are some of the yield limiting factors of crop production in North Dakota. Crop plants do not compete well with weeds, and weed control is accomplished by both herbicides and cultural practices. Scientists using biotechnological techniques are attempting to develop crop varieties resistant to herbicides which quickly decompose, thus reducing possible negative impacts on the environment. Plant breeding has resulted in development of varieties with improved resistance to various diseases and insects, although it is a never ending struggle for the breeding team to keep up with changing biotypes of diseases and insects. Genetic resistance to pests is by far the most economical means of control and represents the best method of biological pest control.

A less tangible benefit of our plant breeding programs is the training of young scientists to work in the plant breeding field. Well over 100 masters and doctoral graduates from the crop and weed sciences department at NDSU now are working throughout the world for universities or private companies in plant breeding programs. Some of these programs produce crop varieties or hybrids which are grown here in North Dakota and provide a return on the state's investment.

North Dakota's economy is very dependent on agriculture, and over 50 percent of the state's agricultural income is directly related to sale of crop commodities. New higher yielding crop varieties provide the producer with greater income, so plant breeding is a basic form of economic development and continues to merit strong support from the citizens of the state.