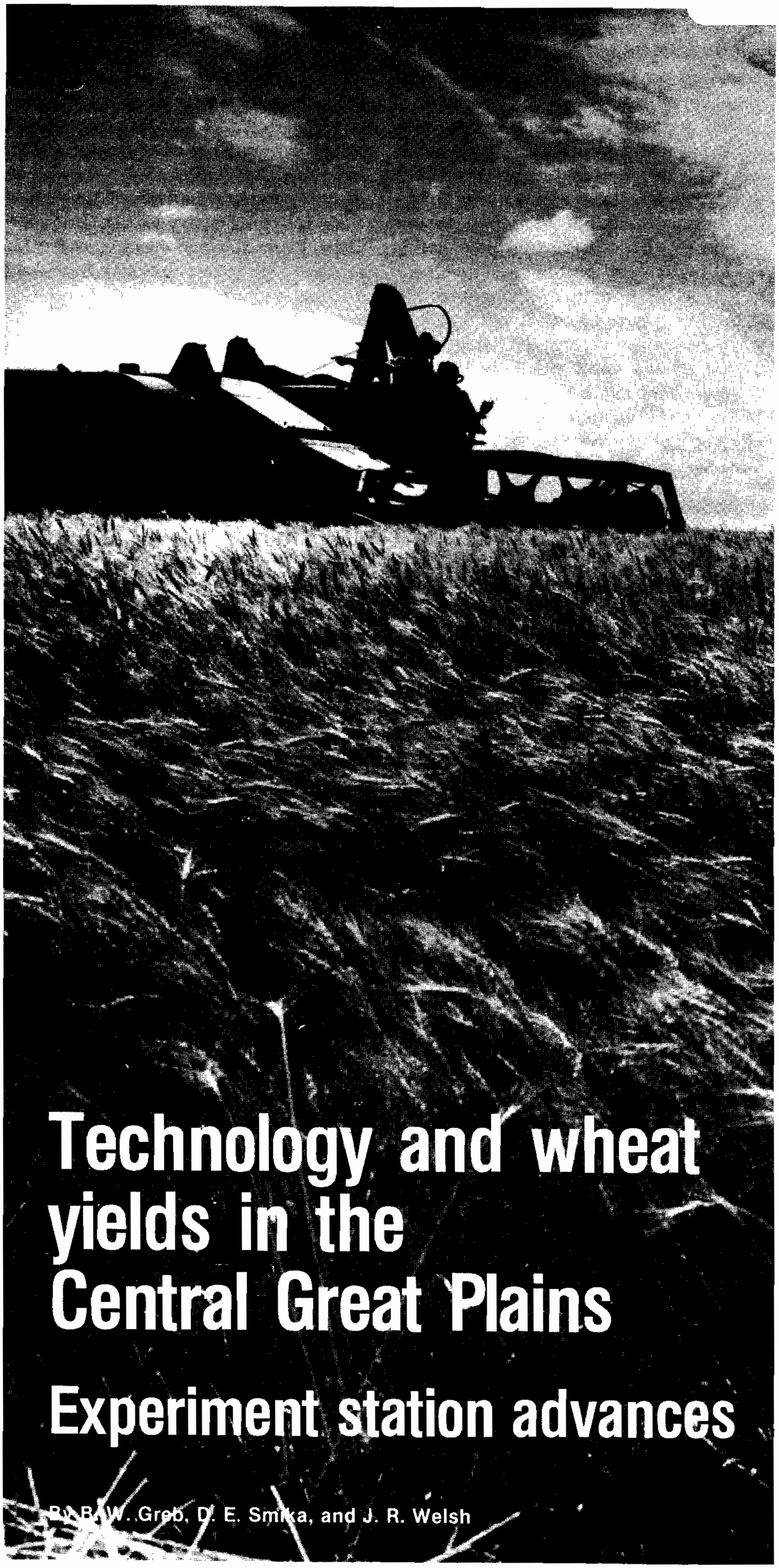

Technology and wheat yields in the Central Great Plains

Experiment station advances

By B. W. Greb, D. E. Smika, and J. R. Welsh

W. R. Grace & Co. photo

For most of this century, researchers have conducted agronomic studies to devise systems for stabilizing and increasing crop yields in the semiarid Central Great Plains, that area in Kansas and Nebraska west of the 100th meridian to the base of the Rocky Mountains in eastern Colorado and southeastern Wyoming. This climatically hazardous region regularly experiences high wind velocities, low humidity, extreme temperatures, high evaporation, and low, erratic annual precipitation, ranging from 305 to 560 millimeters (12 to 22 inches).

Before World War II, cropping experiments included long-term rotations, usually wheat (*Triticum aestivum* L.) with other adapted and some nonadapted crops. Spring wheat earlier had proved to be poorly adapted, whereas winter wheat showed considerable promise as the hardiest, best-yielding crop. Various experimental farms and universities as a result entered into long-term breeding programs to upgrade the yield potential, quality, and pest resistance of winter wheat. Continuous cropping of wheat, even during better years, produced consistently low yields—200 to 1,000 kilograms per hectare (3 to 15 bu/a)—and no yields during several of the dust bowl years in the 1930s (*1*, *12*, *15*, *16*, *18*, *27*).

Studies also involved fall-spring plowing and some tillage and fallow trials. Most tillage implements were not designed well for the prevailing crop, soil, weed, and weather conditions (*1*, *15*, *16*, *27*). Nevertheless, investigators recognized the need for stubble mulching, better wind erosion control systems, and short-term rotations, such as winter wheat-fallow and winter wheat-sorghum or millet-fallow.

During the 1940s, agricultural practices in the dryland area began to evolve rapidly into a specialized winter wheat-fallow system that now includes about 3.64 million hectares (9.0 million acres) of wheat and 3.52 million hectares (8.7 million acres) of fallow annually (*8*, *12*). Since the early 1950s, summer fallow research has expanded considerably.

It is interesting to look at the impacts of changing fallow systems and the periodic introduction of new varieties on the winter wheat yields in the region. There is a great deal of research data available, much of it from the U.S. Central Great Plains Re-

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search Station at Akron, Colorado, with a Sligo silt loam soil (Pachic Argiustoll); the North Platte, Nebraska, Experiment Station, with a Holdrege silt loam soil (Mesic Typic Argiustoll), and the Colby, Kansas, Experiment Station, with a Colby silt loam soil (Mesic Ustic Torriorthent).

Summer fallow

Winter wheat in the Central Great Plains requires that fields remain fallow because the wheat requires about 22 centimeters (8.7 inches) of water for evapotranspiration in relation to expected annual precipitation for initial grain development (*4, 12, 18*). Yields then increase rapidly—105 to 185 kilograms per hectare per centimeter of water (4 to 7 bushels/acre/inch). Adequate soil water during fallow maintains wheat through winter, a period of low water demand. The wheat then can use late spring rainfall to meet peak growth demands. The fallow period is 14 months, from harvest in early July until planting in early September the next year.

Fallow research programs have two main objectives: to increase soil water storage during fallow and to decrease the soil's vulnerability to wind erosion. Success with either objective can increase and/or stabilize wheat yields.

Research data and experience suggest that five requirements must be met to improve water conservation and erosion control in the wheat-fallow system (*2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 19, 20, 21, 22, 23, 24, 25, 26*):

- Weed control for the entire fallow period (harvest to planting) is essential.
- Stubble must be left standing overwinter.
- Straw mulches must be left on the soil surface during the warm season.
- Hard soil clods 1 to 8 centimeters (0.4 to 3.2 inches) in diameter must be left on the soil surface during the warm season.
- Soil must be managed to retain enough water in the seedbed to germinate seeds.

Meeting these requirements maximizes soil water storage and the retention of nitrate nitrogen in the soil, reduces to near zero the potential for soil erosion, and minimizes the energy required and other crop production expenses.

Weed control. Unwanted vegetation in fallow stubble includes grassy and broadleaf weeds, both cool and warm season species, and some volunteer wheat. This vegetation in undisturbed stubble produces 900 to 2,700 kilograms per hectare (800 to 2,400 pounds/acre) of dry matter and may use 0.5 centimeters (0.2 inches) water per day (*6, 26*). Dry matter production of 1,120 kilograms per hectare (1,000 pounds/acre) weeds consumes about 7.6 centimeters per hectare (3 inches) and 30 kilograms per hectare (27 pounds/acre) of available nitrogen (*6, 26*).

Until recently, weed control began during early to mid-spring, using various tillage implements. Tillage, however, results in a water loss, by evaporation, of 0.5 to 0.8 centimeters (0.2 to 0.3 inches) per operation (*4*). Experimentation with herbicides, particularly post-harvest treatment in new wheat stubble, gained momentum as broader spectrum contact and preemergence herbicides became available (*4, 6, 22, 26*). Weed control with herbicides does not disturb the soil, but to be effective herbicides must kill unwanted vegetation rapidly and completely. Stunted weeds continue to use water.

Standing stubble overwinter. Snowfall catchment by stubble is an important water source during the fallow season (*7, 23*). North of 38.5 degrees latitude snowfall exceeds 600 millimeters (24 inches) a year with a water equivalent of 72 millimeters (2.8 inches). Measurements show that 35 to 55 percent of water recharge during fallow is from snowmelt in stubble, which, together with snowfall on planted wheat the second winter, accounts for an estimated 45 percent of the region's wheat production (*7, 23*). Storage efficiency of snowmelt averaged 53 percent in undisturbed stubble at Akron over a 16-year period (*7*). Consequently, destroying fall weeds by disking is detrimental. Water saved by controlling weeds with a disk was more than offset by the water loss from snow blowoff caused by lack of stubble (*6*).

Straw mulch. Development of modern high-clearance, V-blade "sweep" implements and rodweeders with attached semichisels (tongs), in combination with greatly increased power, has made stubble mulching a widely accepted tillage practice. By absorbing raindrop impact, mulches help prevent puddling and facilitate water infiltration. Mulches also reduce evaporation by insulating the soil from the sun's energy and by decreasing wind speed at the air-soil interface (*4, 8*).

Studies at seven locations in the Central Great Plains showed an average net gain of 2.6 centimeters (1.1 inches) of soil water per season for mulched fallow compared with bare fallow (Table 1). The quantity of straw mulch available at the beginning of fallow influenced water storage during fallow (Table 2). Soil water storage increased 5 centimeters (2 inches) when the mulching rate increased from 0 to 6.6 metric tons per hectare (6,000 pounds/acre).

Application rates of straw mulch needed to cover 100 percent of the soil surface are 3.6, 2.3, 3.6, 6.8, 8.1, and 16.4 metric tons per hectare for winter wheat, spring barley (*Hordeum vulgare* L.). spring oats (*Avena sativa* L.), sudangrass (*Sorghum vulgare sudanese*), hay millet (*Setaria italica* (L) Beauv.), and grain sorghum (*Sorghum bicolor* L.), respectively (*5*). In the Central Great Plains the amount of wheat stubble available for mulching ranges from 3.4 to 4.7 metric tons per hectare (3,000 to 4,200 pounds/acre).

Straw mulches were also found to accumulate in the surface 7.6 centimeters (3 inches) of soil through at least three cycles of wheat-fallow at three Great Plains locations (*11*). Straw accumulation increased as the straw available increased, but at a decreasing percentage, which suggests a trend toward equilibrium. This trend in straw accumulation was due to the generally dry climate in the region and to tillage practices that leave the surface soil loose for rapid drying (*11*).

Although mulches increase soil water storage in fallow, they tend to reduce the accumulation of soil nitrate nitrogen at the end of fallow by 5 to 15 percent, depending upon the quantity at the beginning of fallow (*19, 24*). This nitrate reduction has not influenced yields, but it has slightly reduced the protein content of the grain (*19, 24*). Results at eight Central Great Plains locations (42 test years) showed an average gain in net yield of 170 kilograms per hectare (2.5 bushels/acre) of winter wheat for mulched fallow compared with bare fallow (*19*).

Soil clods. Only a small amount of fine, moist soil is needed around a wheat seed for germination. Surface clods resist wind erosion, help anchor mulches, slow runoff water, provide shade, and physically protect young plants. However, they do not provide a good medium for weed seed germination. Straw mulches assist in the formation of nonerodible soil aggregates by providing binding agents, such as fats, waxes, and oils (*21*).

Seedbed water. Modern deep-furrow planters can penetrate 12 to 14 centimeters (4.7 to 5.5 inches) of dry soil and place seeds in wet soil for prompt germination. This is important in case of late summer drought, which is common in the region. Nevertheless, mulches maintain soil water closer to the surface to assure good wheat stands (*20*). Poor penetrations by shallow disk drills in dry seedbeds, whether in fallow or continuous wheat, was a major factor in the dust bowl syndrome of the 1930s and 1950s. Over the last 30 years, improved management of seed-zone water for wheat, in combination with a capacity to plant deeper, has increased yields an estimated 8 percent in the Central Great Plains (*8*).

These five requirements for improving water conservation and erosion control in the winter wheat-fallow system have gradually been integrated into new fallow systems. There is now less reliance upon mechanical tillage during the spring and summer months. The fallow system now extends the full 14 months from harvest to planting, when using minimum tillage and no-till fallow systems.

Fall weed control and minimum tillage

Data previously were published on the effects of mulching rates during fallow on soil water storage at Akron (*9*, *10*). Not reported were the results of fall-spring initial tillage with V-blade sweeps. Fall tillage and fall weed control refer here to suppressing weed growth in wheat stubble, usually within 5 to 35 days after harvest.

Results showed that, compared with spring initial tillage, a single fall sweep operation within 10 days after harvest, which reduced potential fall weed growth by 40 percent, stored 1.3 centimeters (0.5 inches) more soil water and accumulated 19 kilograms per hectare (17 pounds/acre) more nitrate nitrogen in the soil by the end of fallow. These extra growth inputs, in turn, increased wheat yields an average of 200 kilograms per hectare (3 bushels/acre) over four seasons. Similar results were obtained at North Platte (*22*).

Table 1. Soil water increase at the end of fallow for bare soil versus straw mulches at seven Central Great Plains locations (*19*).

Location	*Years Tested (no.)*	*Soil Water Increase (cm)** *Bare*	*Soil Water Increase (cm)** *Mulch*
Akron, Colorado	6	14.2	17.3
Alliance, Nebraska†	8	2.9	3.1
Archer, Wyoming†	2	2.8	4.2
Colby, Kansas	4	11.5	14.1
Garden City, Kansas	6	8.6	9.0
North Platte, Nebraska	8	14.6	20.3
Oakley, Kansas	4	8.2	13.1
Total or average	38	9.0	11.6

*Soil water sampled to depths of 120 to 180 centimeters per location.
†Sampled spring to fall (4 months), other locations from harvest to planting (14 months).

Table 2. Influence of straw mulch rates on soil water storage at the end of fallow at four Great Plains locations (data interpolated from *9*, *10*, *25*).

		*Soil Water Gain (cm)**			
Location	*Years Tested (no.)*	*0 Metric Tons Straw/Hectare*	*2.2 Metric Tons Straw/Hectare*	*4.4 Metric Tons Straw/Hectare*	*6.6 Metric Tons Straw/Hectare*
Akron, Colorado	6	13.4	15.0	16.5	18.5
Bushland, Texas	3	7.1	9.9	9.9	10.7
North Platte, Nebraska	7	16.5	19.3	21.6	23.4
Sidney, Montana	4	5.3	6.9	9.4	10.2
Total or average	20	10.7	12.7	14.5	15.7

*Soil water sampled to depths of 150 to 180 centimeters per location.

Table 3. Effect of fall weed control treatments in new wheat stubble on soil water storage during fallow at two Central Great Plains locations for two time periods (*6*, *26*).

		*Soil Water Gain (cm)**		
Fall Weed Control Treatments	*Fall Weed Growth (kg/ha)*	*Fall Dormancy†*	*End of Fallow‡*	*Wheat Yield (kg/ha)*
North Platte, Nebraska (1963-1969)				
Check, spring plow	1,800	−4.4	14.6	2,690
Fall sweep, single	1,480	0.5	20.3	2,880
Fall sweep + atrazine	400	1.2	21.5	2,910
Contact herbicide + atrazine + fall sweep	350	3.4	23.7	3,040
Akron, Colorado (1969-1972)				
Check, spring disk	1,140	2.8	8.9	2,420
Fall sweep, single	650	5.3	11.2	2,690
Fall sweep, double	370	6.4	12.7	2,940
Contact herbicide + atrazine	325	6.4	12.7	2,940

*Soil water sampled to 180-centimeter depth.
†October 25 to November 10.
‡August 27 to September 10.

These results led to expanded experimentation on fall weed control using tillage and/or herbicides (*6*, *26*). Suppressing fall weed growth increased soil water storage in fallow, which increased wheat yields (Table 3).

Minimum tillage implies the application of contact and preemergence herbicides shortly after wheat harvest to kill all weeds and to inhibit any weeds or volunteer wheat from germinating until late the following spring. One sweep operation and one or two rodweedings (semi-chisel attached) usually are required until planting in early September. A variation of minimum tillage involves a single fall sweep plus a preemergence herbicide, usually atrazine.

No-till fallow

A no-till fallow system relies entirely on herbicides throughout the fallow season. Experimentation with no-till systems is currently underway at Akron; Sidney, Nebraska; and North Platte. Minimum disturbance of stubble and maximum control of weeds offers the ultimate in water storage, double that of conventional spring mechanical fallow (*4*). Wind erosion threats are nearly eliminated. No-till could conceivably be used for fallow for two consecutive seasons in regions severely affected by prolonged drought. Also, wheat yields increase with a significant reduction in energy expenditure.

Some limitations of the no-till system include the high cost of some contact herbicides, possible residual carryover of preemergence herbicides in sandy and high lime surface soils, and difficulties of planting wheat in heavy undisturbed stubble.

Progress with fallow systems

Table 4 summarizes tests with various fallow systems between 1915 and the present at Akron and North Platte. Trends show a gradual change in mechanical implements used, from soil inverting by plowing to soil cutting with disks to soil undercutting with duckfoots, sweeps, and rodweeders. This evolution in tillage systems is also being adapted by farmers in the region, but at a slower rate.

The number of operations used during fallow dropped sharply as herbicides be-

Table 4. Soil water storage efficiencies as related to fallow systems at two semiarid Central Great Plains locations (*4, 6, 8, 10, 12, 18, 19, 22, 26, 27*).

Fallow Tillage Systems	Range of Tillage Operations (no.)	Years Used or Tested		Range in Fallow Efficiencies* (%)	
		Akron, Colorado	North Platte, Nebraska	Akron, Colorado	North Platte, Nebraska
Maximum tillage (dust mulch): plow and harrow	7 to 10	1915-30	1915-30	16 to 22	18 to 23
Conventional black: shallow disk (several), rodweed or harrow	5 to 7	1931-45	1931-45	20 to 24	23 to 27
Modified conventional: disk (once), chisel, rodweed with semichisel	4 to 6	1946-56		24 to 27	
Stubble mulch: sweep (fall or spring) duckfoot, rodweed with semichisel	4 to 6	1957-62 1963-70†	1946-62 1963-70†	27 to 30 30 to 33†	27 to 35 35 to 38†
Minimum tillage: fall applied herbicides, sweep, rodweed with semichisel	2 to 3	1968-77	1962-77	33 to 38	35 to 42
No-till: herbicides only	0 to 1	1975-77	1962-77	45 to 55	45 to 55

*Fallow efficiency is defined as the percentage of precipitation retained in the soil profile, measured to 180-centimeter depth, from early July wheat harvest to early September wheat planting (14 months).

†Fall undercut of wheat stubble occurred within 10 days after wheat harvest.

gan to replace mechanical tillage. Currently, fallow efficiency with no-till averages about 50 percent, compared with about 20 percent for the original dust mulch system and 24 percent for conventional black fallow, which is still used on about a third of commercial fallow fields today.

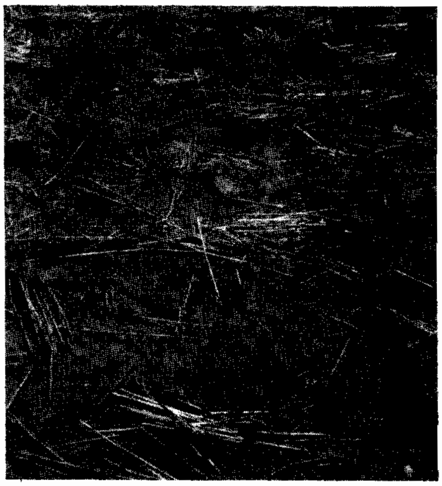
Breeding improved wheat varieties

Mennonite immigrants introduced hard red winter wheat varieties to the Great Plains in the late 1800s. The original genetic material was based on the well-adapted Turkey types, which were generally tall and winterhardy. Breeding and improvement programs were established later to improve yield potential and other wheat characteristics.

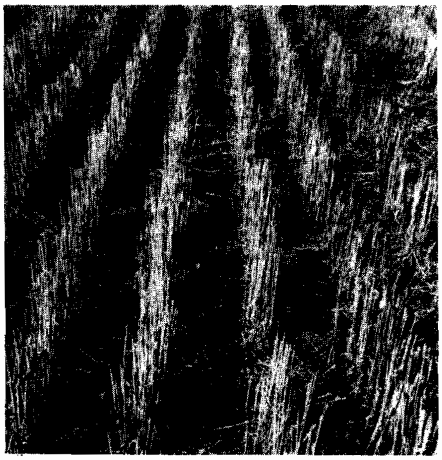
Table 5 provides some examples of the yield improvement through breeding programs in the Central Great Plains. Kharkof is a typical Turkey-type wheat with average to poor yield potential and excellent winterhardiness. Using this well-adapted type as a genetic base, breeders introduced genetic variability from many sources (*17*).

Johnson (*14*) suggested that several yield thresholds have been reached through breeding. In recent years Scout and its derivatives have increased yields over a large area of the Great Plains. Centurk provided another yield step during years and at locations where moisture was adequate.

Recent variety development has concentrated on the use of exotic germ plasm from such sources as spring wheat semidwarfs. This effort has resulted in semidwarf varieties, such as Vona, which represents an additional yield increase. Vona is now rated 30 percent better than Kharkof in terms of yield potential.



Disking early in the fallow season destroys wheat stubble, leaving the soil vulnerable to erosion and speeding up evaporation of soil water.



Undisturbed wheat stubble with chemical fallow holds more snow, reduces runoff, and suppresses evaporation at the soil surface.

These newer semidwarf varieties perform most satisfactorily under optimum environmental conditions. They may be more limited in general adaptation than Scout types. Plant heights can be reduced by the accumulation of dwarfing genes. Recently released semidwarf hard red winter varieties have generally used one dwarfing gene to reduce height by one increment. It is unlikely that plant height will be reduced more in variety development, especially in semiarid areas, because certain levels of plant residue are needed in cultural practices. Extreme shortness of straw also is detrimental to harvesting. In addition, problems associated with plant emergence and development are difficult to overcome with shorter genotypes.

While yield has been the major objective in all breeding programs, breeding has improved other specific plant characteristics, such as protein content, milling and baking properties, winterhardiness, and disease and insect resistance. Farmers can now use varieties with better characteristics, along with improved cultural practices, to convert natural resources, such as water and nutrients, efficiently and economically into consumer products with desirable properties.

Long-term wheat yields

Table 6 presents wheat yield data for the Akron, North Platte, and Colby stations. Between 1926 and 1975, average annual precipitation varied from 415 millimeters (16.3 inches) at Akron to 458 millimeters (18.0 inches) at Colby and 488 millimeters (19.2 inches) at North Platte.

Increases in winter wheat yields and water use efficiencies were remarkably similar at all locations, regardless of precipitation differences. During the 1966-1975 period, yields increased 3.1-, 2.5-, and 1.6-fold over the 1926-1935 period at Akron, Colby, and North Platte, respectively. Similarly, water use efficiencies increased 3.5-, 2.5-, and 1.7-fold over the same periods and locations.

Data in table 6 strongly refute the concept that improved weather may have been more responsible than improved technology for yield increases. Water use efficiency, an index that is independent of variations in precipitation, increased steadily each decade at the same rate as wheat yields. For all locations combined, water use efficiency increased most during the 1966-1975 period, when mean annual precipitation dropped 11 percent compared with that for the previous decade.

Progress in winter wheat technology at experiment stations in the Central Great Plains between 1926 to 1975 equaled that achieved for other crops in other regions of the United States where the climate is much less extreme. This progress cannot be credited to any single phase of technology, but improved fallow systems and better wheat varieties deserve most of the credit (*8*). Improved planting and harvesting equipment have also contributed significantly (*8*, *12*).

Table 5. Dryland yield relationships of several hard red winter wheat varieties compared with Kharkof.*

Variety	*Year Released*	*Grain Yield (% of Kharkof)*
Cheyenne	1931	113
Pawnee	1943	108
Scout	1965	127
Centurk	1973	126
Vona	1977	130

*Yield data for Kharkof is from the Southern Regional Performance Nursery at the following locations: Akron, Julesburg, Springfield, and Burlington, Colorado; Sidney and North Platte, Nebraska; and Colby and Garden City, Kansas.

Table 6. Increase in winter wheat yields grown under fallow systems and water use efficiency during five decades at three Central Great Plains locations.

Decades	*Average Precipitation (mm/yr)*	*Wheat Yield (kg/ha)*	*Water Use Efficiency* (kg/ha-cm)*
Akron, Colorado			
1926-35	432	745	9
1936-45	417	1,525	18
1946-55	447	1,665	19
1956-65	404	1,755	22
1966-75	376	2,425	32
North Platte, Nebraska			
1926-35	467	1,875	20
1936-45	483	1,955	20
1946-55	500	2,390	24
1956-65	531	2,630	25
1966-75	457	3,090	34
Colby, Kansas			
1926-35	396	1,060	13
1936-45	467	1,250	13
1946-55	472	1,815	19
1956-65	508	2,145	21
1966-75	446	2,680	30
All Locations			
1926-35	432	1,225	14
1936-45	455	1,575	17
1946-55	472	1,955	21
1956-65	480	2,180	23
1966-75	427	2,730	32

*Based on wheat yield divided by two years annual precipitation (fallow + crop year).

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