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Chapter 18

CEREAL SYSTEMS OF THE NORTH AMERICAN CENTRAL GREAT PLAINS

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INTRODUCTION

For the purpose of this chapter the Central Great Plains will be defined as the area east of the Rocky Mountains in Colorado and Wyoming and the western 80% of Kansas and Nebraska (Fig. 18.1). The eastern edge will coincide with soil type rather than rainfall patterns. This area encompasses approximately 42 million ha of land, of which about 28 million are planted annually to cereal grains with 99% of the total being winter wheat (*Triticum aestivum*) (Fig. 18.2A). The total irrigated area does not exceed 0.6 million ha in any year, with less than one-quarter of this planted to cereal grains, mostly wheat. From east to west the elevation increases almost 1.9 m per km, ranging from 300 m above sea-level along the eastern boundary to 1800 m at the base of the Rocky Mountains. The elevation gradient imposes major temperature and precipitation changes on the prevailing climate throughout the area, which in turn influences the type of dryland farming system that is used in particular areas within the Central Great Plains. The topography is generally level and is drained by major eastward-flowing rivers, such as the North Platte, South Platte, Platte, Republican, Big Sandy, Smokey Hill, and Arkansas rivers. Numerous smaller catchments join the major streams, to form many series of island-like plateaus of nearly level land between drainage basins. Most of the dryland farming is conducted on these upland plateaus.

When farmers began settling the area, the crop and soil management systems they used were those brought from their earlier farming attempts. Some of these were in eastern states, others were from foreign countries, in both cases from humid climates. When these practices were used in the semi-arid Central Great Plains, these farmers had satisfactory results only when precipitation was above normal. However, in years with precipitation normal or below normal, production failed. When crop failures occurred in successive years the settlers generally moved elsewhere. In the latter part of the 19th century, there was positive evidence that the semi-arid Central Great Plains of the United States was going to be permanently settled. Stable economic crop production from these areas was needed, but was not actually achieved until the 1940s.

In 1862, the Morrill Bill was passed in the U.S. Congress which established agricultural colleges and experiment stations throughout the United States. Research from these institutions helped the early dryland farmer, but much was to be learned from the many years of research continuing to the present. As experiment station results became available there was a need to exchange ideas between those involved in the actual dryland cropping, and those involved with informing the farmer as to what was available and how it should be used. To meet this early need the first Dryland Farming Congress was held in 1907. This organization was important in promoting early dryland farming practices, and often awarded prizes for outstanding production to stimulate interest. From research, promotional activities, and farmer adoption, cropping practices evolved that provided the necessary economic stability for dryland production in the Great Plains.

The practices that succeeded and provided the economic stability to the area were those that made the most efficient use of the limited water received. The winter wheat–fallow rotation was a

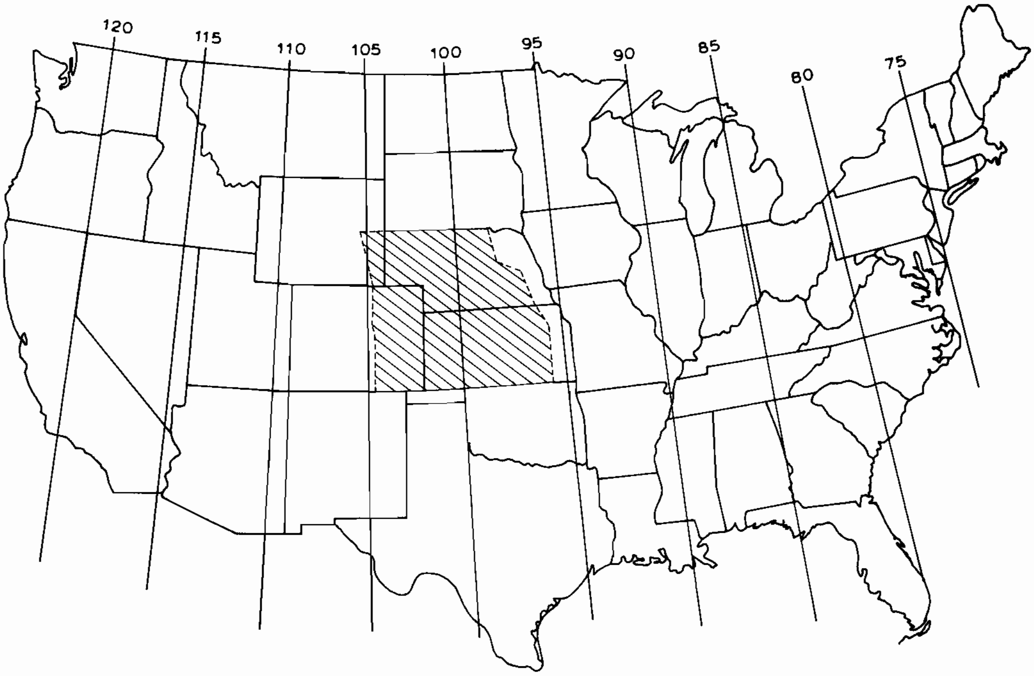

Fig. 18.1. Central Great Plains with respect to the 48 continental States of the United States.

major factor contributing to stable economic production in the area (Smika and Wicks, 1968).

CLIMATE

The climate becomes progressively drier and cooler from east to west. The area between longitudes 96 and 98°W is generally classified as continental subhumid. Between longitude 98°W and the Rocky Mountains (longitude 105°W) the climate is primarily semi-arid (USDA, 1941). The Thornthwaite precipitation–evaporation (P–E) index across the area shows approximately 75% of the Central Great Plains is semi-arid, 20% is subhumid, and 5% is arid (Thornthwaite, 1931). The average annual precipitation for the Central Great Plains ranges from less than 300 mm in parts of eastern Colorado to over 800 mm near the eastern boundary in Kansas (Fig. 18.2B). Precipitation over the Central Great Plains is highly erratic, and in some years may be nearly double or less than half of the long-term averages. Seasonal distribution of precipitation for Akron, Colorado (Fig. 18.3) is representative for the area; it shows a definite spring–summer precipitation period during the growing season in which 70 to 80% of the precipitation occurs. Humidity is generally low and wind velocities are high with varying dominant directions (Fig. 18.4A). Average annual temperatures gradually increase from north-north-west to south-south-east and range from 7°C at Cheyenne, Wyoming to 13°C at Liberal, Kansas (Fig. 18.4B). Temperature extremes can range from −34 to 46°C in much of the area. However, temperatures exceeding 38°C are rare in south-eastern Wyoming. Seasonal temperatures for Akron, Colorado (Fig. 18.3) are typical for the area and show the warm spring–summer–fall growing period.

Average annual snowfall increases in a north to north-west direction as the average annual temperature decreases. The average annual water from snowfall gradually increases from less than 50 mm (10% of the total precipitation received) across the southern half of Kansas to over 90 mm (25% of the total precipitation) in extreme north-western Nebraska and south-eastern Wyoming. Snowfall is an efficient source of water for storage in the soil. The highest average winter wheat grain production of 3700 kg ha^{-1} in the western part of the

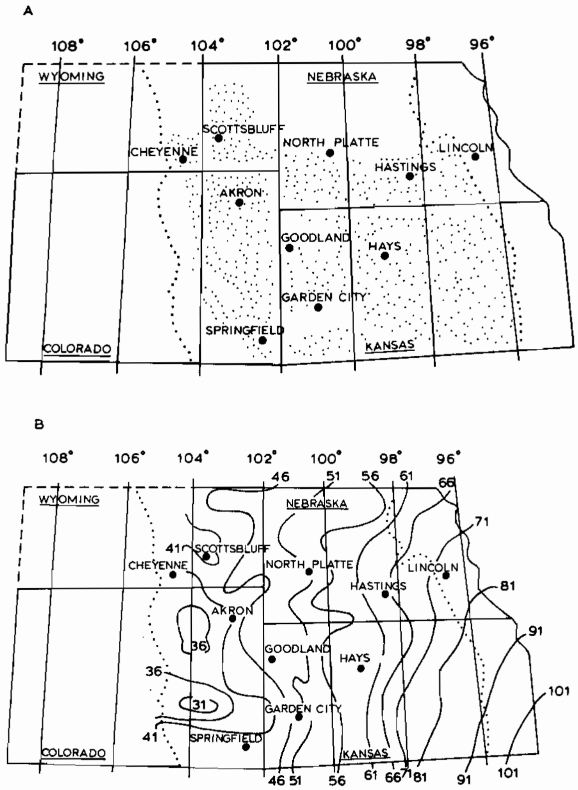

Fig. 18.2.A. Portion of the Central Great Plains where major production of winter wheat occurs is depicted by dotted area. B. Average annual precipitation (mm) in the Central Great Plains.

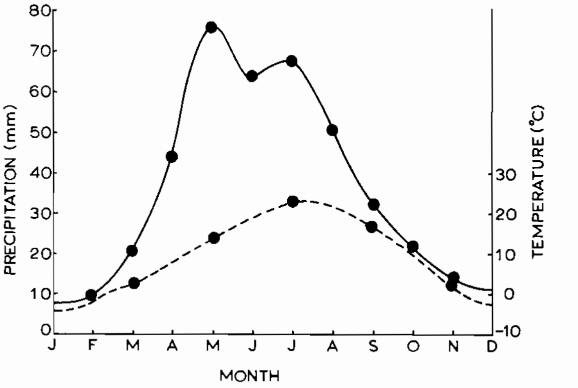

Fig. 18.3. Average monthly precipitation (mm) and temperature at Akron, Colorado.

Central Great Plains is in the area which has the highest average snowfall.

Average annual evaporation (from a "pan" or free water surface) is less at higher elevations along the western edge of the Central Great Plains than at lower elevations as one moves eastward. It increases from north to south because of the higher temperatures and decreasing elevation toward the east and south. Evaporation ranges from less than 165 mm per year in south-eastern Wyoming and north-western Nebraska to over 229 mm in south-western Kansas. The frost-free period and growing season increase gradually going from the north-west to the south-east (Fig. 18.4C). Conversely, the length of daylight hours during the growing season increases going from the south-east to north-west (Fig. 18.4D).

SOILS

The Central Great Plains includes 3 land resource areas (Austin, 1965), 9 major soils and 15 soil groups (Aandahl, 1982) (Figure 18.5A). The two largest land resource areas encompass most of the area west of longitude 100°W — that is, most of the area where fallow is used. Of the nine major soils, the Haplustolls, Argiustolls, Paleustolls, and Paleustalfs account for approximately 75% of the land area and nearly 97% of the cultivated area. Under the former soil classification system, these soils would range in a west to east direction from light brown to greater than brown, greater than dark brown, greater than chestnut, to near chernozem.

The sandy soils are residual in origin, and loam, silt loam, and clay loam are loess deposits. With few exceptions, both the sandy and medium-textured soils are deep and do not contain inhibiting rock layers except at considerable depth. Nearly all of the soils in the Central Great Plains are calcareous, with the "D" horizon lime layer varying in depth as a result of texture and amount of effective precipitation. Thus, shallow "A" horizon soil profiles are found in drier zones or on steep-sloping topography in wetter areas. Moderately deep soils, the Argiustolls (the Keith and Holdrege soil series), are generally found in nearly level land. Scott and Goshen are examples of soils found in swales in lower precipitation areas where water is more plentiful or on level land in higher precipitation areas.

Cultivated sandy soils (Ustipsamments) average less than 1% organic matter and are low in total

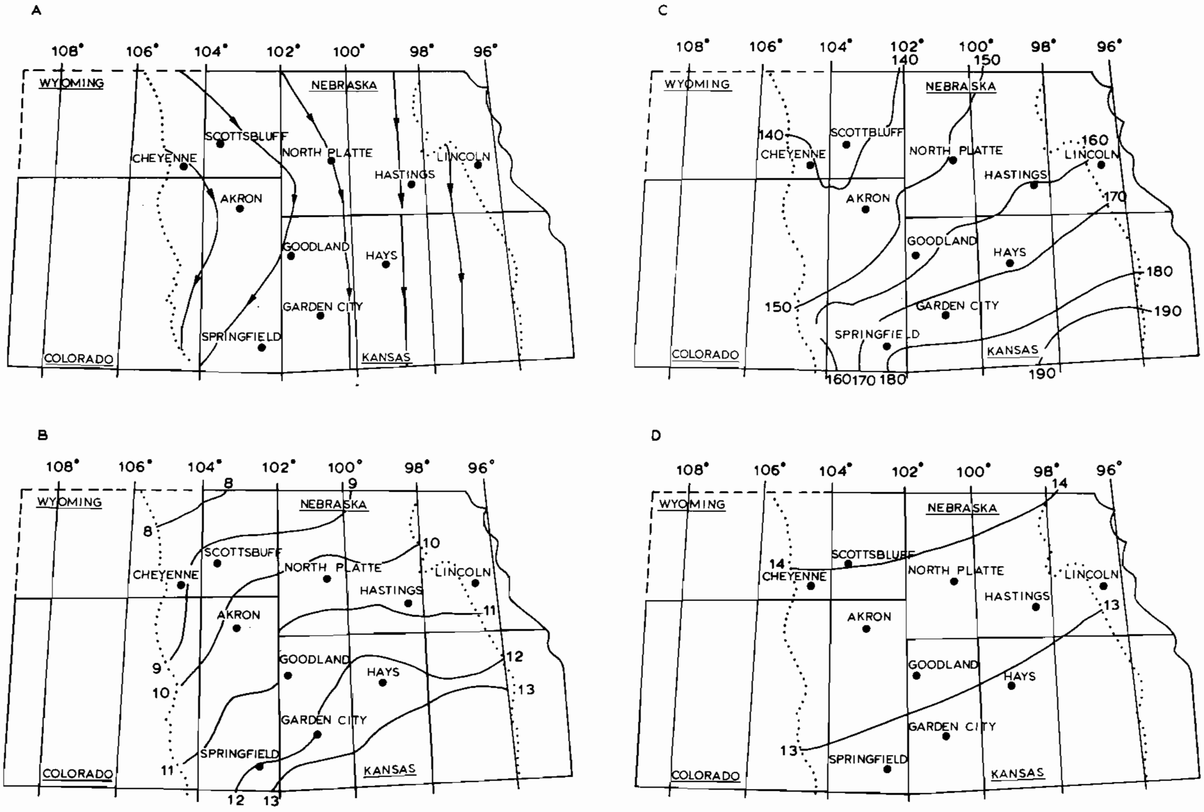

Fig. 18.4.A. Predominant annual wind direction in the Central Great Plains. B. Average annual temperature (°C) in the Central Great Plains. C. Average number of frost-free days in the Central Great Plains. D. Average growing-season daylight hours in the Central Great Plains.

nitrogen (<0.05% N) and available phosphorus (8 kg ha^{-1}), with pH ranging from 5.6 to 7.3. The non-eroded dark brown Argiustolls (Holdrege soil series) or medium texture are fertile, average 1.0 to 3.2% organic matter, 0.10 to 0.15% total nitrogen, 18 to 25 kg ha^{-1} of available phosphorus in the surface 15 cm of soil, and have pH values ranging from 5.6 to 7.2. The Paleustalfs (Ascalon, Baca, and Wiley soil series) generally average 0.7 to 1.1% organic matter, 0.08 to 0.10% total nitrogen, less than 14 kg ha^{-1} of available phosphorus in the surface 15 cm of soil and have pH of 7.2 to 7.9. The brown and light brown Argiustolls (Keith and Weld soil series) usually average 1.4 to 1.8% organic matter, about 0.08% total nitrogen, and from 7 to 14 kg ha^{-1} available phosphorus in the surface 15 cm of soil, and have pH ranging from 6.1 to 7.8. However, considering the shallow "A" horizon of the Argiustolls, any removal of topsoil by erosion leaves soil in the tillage layer with pH values ranging from 7.4 to >8.0 and deficient in nitrogen and phosphorus. These nutrient deficiencies, however, can be readily corrected by adding fertilizer according to soil tests.

The medium-textured soils of the Central Great Plains have water intake rates of 25 mm per hour for the first hour of rainfall and 5 to 10 mm per hour thereafter. These soils have a water-holding capacity of 22 to 25% in the "A" and "B" horizons and 18 to 22% in the "C" horizon. Typical medium-textured soils, the Argiustolls (Rago, Keith, or Holdrege series), can hold 300 to 330 mm available water in a 1.8 m profile.

WATER CONSERVATION

Drought is normal in all semi-arid regions of the Central Great Plains. Since crop production throughout the Central Great Plains is limited

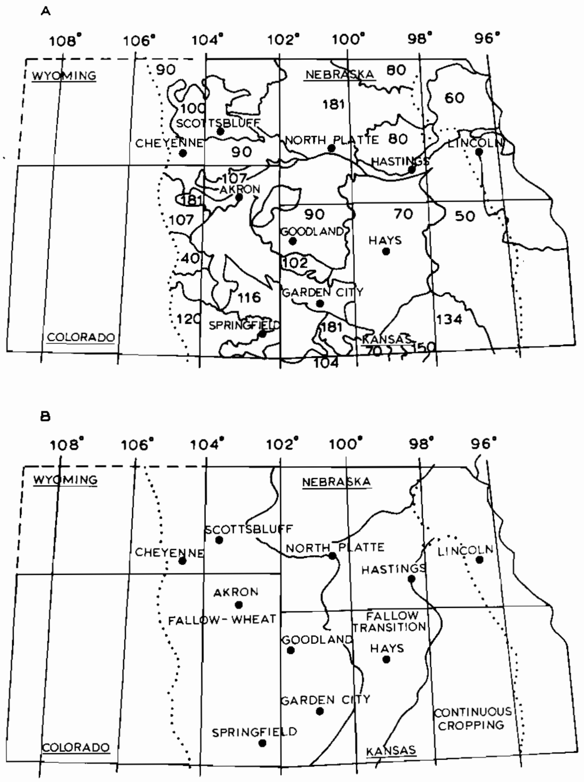

Fig. 18.5.A. Distribution of soils in the Central Great Plains. Adapted from Aandahl (1982). 40 — Haploborolls–Eutroboralfs–Argiborolls; 50 — Argiustolls; 60 — Haplistolls–Ustipsamments; coarse–silty; 70 — Argiustolls-Haplustolls–Calciustolls; 90 — Argiustolls–Haplustolls; 100 — Haplustolls-Paleorthids; 102 — Haplustolls–Torriorthents; 104 — Paleustalfs–Haplustalfs–Ustipsamments; 107 — Paleustolls–Haplargids–Torriorthents; 116 — Haplargids–Torriorthents; 120 — Torriorthents; loamy; 134 — Argiustolls–Argiaquolls; 151 — Ustochrepts–Argiustolls–Haplustalfs; 181 — Psamments. B. Distribution of cultivated land in the Central Great Plains.

largely by the availability of water, conservation of rainfall is of utmost importance for the success of any cropping system (Greb, 1979). Fallow, which is the practice of leaving the soil free of any plant growth for a period of time to store water in the soil for subsequent crop growth, is the most widely used system for circumventing the effects of drought. Brengle (1982) summarized the principles and methods of summer fallow in the semi-arid regions of the world. A 14- to 16-month fallow or cropping every other year has improved and stabilized crop production throughout the Central Great Plains since 1920 (Zook and Weakly, 1944). Water-storage efficiency, (the proportion of precipitation stored during the normal 14-month fallow period) has increased from less than 20% to approximately 50%, as a result of the development of new fallow techniques utilizing better equipment, residue management, weed control practices, and the integration of herbicides into the program (Greb, 1974; Greb et al., 1979). Water storage has improved because of weed control after the wheat harvest and the maintenance of crop residues in an upright position over winter to trap and hold the snow precipitation (Smika and Whitfield, 1966).

Before World War II, weed control during the fallow period was achieved by primary tillage with moldboard plows, one-way disks, and tandem disks. Modern stubble-mulch technology was introduced following World War II, when large blade and sweep plows, chisel plows, and rod-weeders with semi-chisels became available, and tractor horsepower increased to pull these implements effectively. These tillage tools maintained more residue on the soil surface and, in the heavier textured soils, produced large clods which were resistant to wind erosion.

The importance of weed control during fallow cannot be overemphasized (Black and Power, 1965; Smika and Wicks, 1968). Briggs and Shantz (1913) and Shantz and Piemeisel (1927) listed 10 common broad-leaf weeds having an average water requirement of 0.28 cm kg^{-1} dry matter produced, nearly identical to that for winter wheat (Table 18.1). Therefore, 1 kg ha^{-1} of weed tissue grown during fallow may reduce later wheat growth by 1 kg ha^{-1}. One centimeter of soil water will produce 3.6 kg ha^{-1} of weed tissue or 3.6 kg ha^{-1} of wheat tissue. If a 1 : 1 ratio of straw to grain is assumed, nearly 2 kg ha^{-1} of grain may be lost for each centimeter of water used by weeds.

In the Central Great Plains, uncontrolled weed growth between harvest and the first freeze in the fall can result in over 1100 kg ha^{-1} of dry matter production. This amount of weed growth can use over 76 mm of available water and 34 kg ha^{-1} of nitrogen (Greb, 1974). Water-use by volunteer wheat over winter can also exceed 76 mm. Therefore, practices for the control of weed growth and volunteer wheat are imperative for the success of subsequent crop production whether it be in a winter wheat–fallow or winter wheat–spring-sown crop–fallow rotation.

TABLE 18.1

Relative water requirement of 10 common broad-leaf weeds and winter wheat (Briggs and Shantz (1913) and Shantz and Piemeisel (1927))

Common name	Scientific name	Water use ($cm\ kg^{-1}$)
Redroot pigweed	*Amaranthus retroflexus*	0.16
Common purslane	*Portulaca oleracea*	0.16
Russian thistle	*Salsola kali*	0.18
Buffalobur	*Solanum rostratum*	0.22
Cocklebur	*Xanthium pensylvanicum*	0.24
Prickly lettuce	*Lactuca serriola*	0.30
Common lambsquarters	*Chenopodium album*	0.33
Kochia	*Kochia scoparia*	0.38
Common ragweed	*Ambrosia artemisiifolia*	0.41
Common sunflower	*Helianthus annuus*	0.43
Average		0.28
Winter wheat	*Triticum aestivum*	0.29

CURRENT CROPPING SYSTEMS

As precipitation, elevation and average temperatures change across the Central Great Plains, the principal cropping systems also change (Fig. 18.5B). The cropping systems include: continuous cropping, fall-seeded crop–spring-seeded crop–fallow, and fall-seeded crop–fallow (Hinze and Smika, 1983). Some continuous cropping exists throughout the entire Central Great Plains. However, historically the largest area of continuous cropping to winter wheat, winter barley (*Hordeum vulgare*), spring-seeded barley (*H. distichum*), oats (*Avena sativa*), corn (*Zea mays*), sorghum (*Sorghum bicolor*), soybeans (*Glycine max*), or long-term general-season cropping of hay, alfalfa (*Medicago sativa*) or sweetclover (*Melilotus* sp.), is in the area between longitudes 96° and 98°W.

Between longitudes 98° and 100°W a 3-year rotation is the primary cropping practice. There is considerable continuous cropping to the same crops as are grown east of longitude 98°W. There is also some alternate winter wheat–fallow in this area. The primary crops grown in the 3-year rotation are winter wheat, followed by either grain sorghum, corn, soybeans, and to some extent forage sorghum, sunflowers (*Helianthus annuus*), oats, or spring barley. Occasionally winter barley is grown in place of winter wheat. Sorghum became a profitable crop in a winter wheat–spring crop–fallow rotation in the 1960s in areas with 380 to 690 mm of rainfall (Fig. 18.2B) (Ramig and Smika, 1964). Phillips (1964) appliedatrazine [6-chloro-*N*-ethyl-*N*′-(1-methylethyl)-1,3,5-triazine-2,4-diamine] following blade plowing to control weeds during the 10-month fallow period prior to planting sorghum. Beginning in 1971, the practice was refined and is now known as "ecofallow" (Wicks, 1976) where the cropping sequence is winter wheat–either grain sorghum, corn, or proso millet (*Panicum miliaceum*)–fallow (Wicks, 1976; Hoefer et al, 1981; Nelson and Fenster, 1983). This practice relies primarily on the use of herbicides for weed control with minimal mechanical tillage during the entire crop rotation. Although much of this area is distinctly semi-arid, temperature and rainfall variations are of sufficient magnitude that the growth of two crops between a fallow period is feasible. Corn and sorghum are more popular crops than proso millet. Corn is grown in Nebraska and north-east Colorado, sorghum is grown in Kansas and south-east Colorado. Millet is grown throughout the region, but is planted on smaller areas. Soybeans have gradually moved westward during the past decade into irrigated areas in western Kansas and Nebraska. Farmers are planting winter wheat following the soybean harvest in higher-rainfall areas and irrigated wheat fields. Also, after-harvest herbicides can be applied in lieu of tillage to control weeds with soybeans planted the following spring (Burnside et al., 1980).

Winter wheat–fallow and winter wheat–sorghum or corn–fallow became important crop rotations west of longitude 100°W after World War II. West of longitude 102°W, 89% of the wheat-growers in Nebraska are in the wheat–fallow rotation while 2% grow continuous wheat, 6% use a winter wheat–corn–fallow rotation, and 1% use a wheat–millet–fallow rotation (Wicks et al., 1984). Average yields of winter wheat during a 27-year period were over three times greater when grown in a wheat–fallow rotation than with continuous winter wheat (Smika, 1970).

Continuous cropping with winter wheat without a 14-month fallow period is not reliable in the area west of longitude 100°W. Recently completed research at Akron, Colorado, has shown that when 10 cm of available water is present in the surface

60 cm of soil at the time of seeding, continuous winter wheat can be successfully grown. However, when the available soil water is between 5 and 10 cm, the chance of cropping success is only 50%. If less than 5 cm of available soil water are available at the time the crop is seeded, the chance of a complete failure is 95%. The probability of having 10 cm of available water at seeding time is approximately 3%, or 1 year in 33. The probability of having between 5 and 10 cm of available water is 15%. Continuous wheat with tillage is unlikely to become common practice in the areas west of the 100th meridian. Farmers have had reasonable success with continuous no-till wheat east of longitude 100°W. Timely weed control with herbicides is needed in order to save stored soil water.

Continuous cropping to spring-seeded crops has a much higher probability of success, and frequently a well-adapted crop such as millet can be successfully grown on the same site for several years in a continuous cropping system west of longitude 100°W. Corn and grain sorghum can also be grown continuously, but their success rate is not as high as for proso millet, because proso millet uses water more efficiently than sorghum and corn (Shantz and Piemeisel, 1927). The winter wheat–sorghum–fallow rotation can be extended by planting a second or possibly a third no-till sorghum crop following the sorghum crop that was planted into non-disturbed wheat stubble. The wheat straw persists for about 2 years. Weeds are controlled with timely applications of herbicides. Continuous cropping of practically all of the adapted crops is feasible under irrigation.

Hard red winter wheat is the predominant wheat grown in the Central Great Plains States. The four most common cultivars for the states are shown in Table 18.2. Cultivars change, and the proportions of total plantings change rapidly for various reasons. Yield is the major criterion for continued success of a cultivar.

Some hard red spring wheat is planted, especially if the winter wheat varieties seeded in the fall are lost; the most common reasons for loss are drought, wind erosion, and actual freezing death of the plants. Most of the wheat is used for milling and baking. The price of barley, corn, and sorghum feed grains dictates how much winter wheat is used

TABLE 18.2

Four common winter wheat cultivars (per cent of total sown) for four states in 1977, 1980, 1983, and 1986

	1977		1980		1983		1986	
Colorado	Scout	40.8	Scout	38.5	Baca	21.9	Baca	18.8
	Centurk	17.0	Baca	20.9	Scout	20.9	Hawk	15.8
	Baca	15.9	Centurk	12.1	Vona	17.7	Vona	14.5
	Wichita	6.6	Vona	6.0	Centurk	6.7	Scout	11.7
	Total	80.3		77.5		67.2		60.8
Kansas	Scout	21.7	Newton	17.5	Newton	41.1	Newton	21.1
	Eagle	19.9	Eagle	15.7	Larned	22.1	Arkan	18.6
	Sage	14.7	Scout	12.5	Eagle	10.2	Mustang	11.2
	Centurk	11.9	Larned	11.1	Scout	6.1	Hawk	13.5
	Total	68.2		56.8		79.5		64.4
Nebraska	Centurk	35.4	Centurk	41.1	Centurk	40.0	Centurk	37.3
	Scout	24.1	Scout	23.4	Scout	9.7	Scout	11.1
	Warrior	5.5	Buckskin	8.1	Wings	6.6	Brule	6.8
	Buckskin	4.2	Warrior	3.5	Rocky	6.4	Rocky	6.3
	Total	69.2		76.1		62.7		61.5
Wyoming	Cheyenne	22.5	Cheyenne	24.8	Cheyenne	27.4	Cheyenne	28.2
	Centurk	18.6	Centurk	17.9	Buckskin	17.4	Buckskin	11.2
	Lancer	13.9	Lancer	10.8	Scout	19.3	Scout	23.4
	Scout	22.0	Scout	26.4	Trapper	7.3	Trapper	4.8
	Total	77.0		79.9		71.4		67.6

for livestock feed. Government farm programs also have some impact on wheat plantings; these in turn influence planting of the other crops previously mentioned.

Winter wheat is grown primarily to be harvested for grain throughout the entire area. However, in southern parts of the Central Great Plains, winter wheat is frequently grazed, largely by cattle or limited numbers of sheep, during the late fall–over winter–early spring period prior to reaching the jointing stage of growth. Winter wheat provides highly nutritional pasture during this time of the year. For the purpose of grazing, a cultivar should be used that tends to tiller profusely during the fall. Research has shown that the fall tillers are most important as far as grain yield is concerned (Shanahan, 1982); therefore, winter wheat should be seeded at the proper date so that fall tillering can occur for maximum grain yield production rather than for excessive vegetative growth.

Weed control and tillage

After the advent of suitable herbicides in the 1960s, the role of tillage in weed control declined considerably in the Central Great Plains. The initial changes occurred in corn production. The use of herbicides to minimize the use of tillage in dryland winter wheat began in the 1970s. No-tillage wheat production has been successful experimentally for 10 crops in a wheat–fallow rotation (Fenster and Peterson, 1979; Wicks and Smika, 1973) and 18 years in a wheat–sorghum–fallow rotation (Wicks et al., 1987). The primary requirements for success in such a program are dependable weed control with herbicides, and seeding equipment that can be used to plant in a no-till system. Some herbicides used in these systems are still fairly expensive and, due to certain plant and environmental conditions, do not always provide acceptable weed control. To be successful, total weed control is needed, especially in fallow, since scattered weeds may deplete soil water considerably.

Planting corn or sorghum directly into undisturbed wheat stubble has been much more successful than planting winter wheat under the same conditions. Non-uniform straw and chaff distribution behind large combine headers (6–9 m wide) has caused planting problems and can reduce weed control, requiring additional herbicide or tillage operations. The moldboard plow, tandem, offset or one-way disk, chisel plow, blade plow, and sweep plow are primary tillage tools in the wheat-producing areas of the Central Great Plains. These implements bury or incorporate various amounts of plant residue per operation. The moldboard plow buries or incorporates 98% or more of the straw, the disk buries or incorporates 30 to 75% depending upon tillage depth and type of disk, the chisel plow 12 to 15%, while the blade plow buries or incorporates 10 to 12% of the straw per operation, and the sweep plow 15 to 20%. Grass weeds with fibrous roots, such as Downy brome (*Bromus tectorum*) and volunteer wheat, are difficult to control with tillage implements which do not invert the soil when soils are cool and wet. Rainfall is likely during the time tillage needs to be performed for weed control. The moldboard plow is somewhat more effective for weed control because it buries weeds rather than depending on desiccation of the soil for weed control. Moldboard plowing is used to aid in the control of downy brome, using the theory that the seeds are buried so that they will not emerge (Wicks et al., 1971). However, it does not always bury all the seed, and therefore does not provide a cure for problem weeds. Also, a second plowing should not be considered until sufficient time has lapsed for the seeds to lose their viability. Some weed species maintain their viability for up to 14 years (Zorner et al., 1984). Plowing also exposes soil to the potential for wind erosion.

The one-way disk was popular before sweep plows and chisel plows were developed. There is an excellent discussion by Fenster (1960) on the use of these implements in the wheat–fallow rotation. Large tandem and offset disks have been used in areas where the wind erosion potential is low. Tandem and offset disks are used to cut corn and sorghum stalks and to kill downy brome during the first tillage operation in the spring. Recently developed tandem and offset disks are heavily constructed, and their large concave blades effectively bury residue.

Chisel plowing has increased during the past decade. The newer machines are well built and permit crop residues to pass through the machine easier than the older chisel plows.

The blade plow is the most popular tillage tool in the wheat–fallow areas of the Central Great

Plains. Use of the blade plow leaves the stubble erect, and results in higher soil water storage by reducing evaporation, through reduced wind movement and cooler soil temperatures (Smika, 1983). This practice became known as stubble mulch farming (Duley and Russel, 1948). The large 1.5- to 1.8-m V-blades attached in flexible units of three or more are ideally suited for stubble mulching of large level wheat fields in eastern Colorado, western Kansas, and western Nebraska. The blade plow destroys little residue and leaves much of the stubble standing to trap snow. Weeds are killed easily when the soil is dry; but if soil is wet, weeds can re-establish and survive. Blade plows are used less in the higher-rainfall areas, because weeds might not be desiccated rapidly enough to be completely killed. Downy brome has increased rapidly on land tilled with this implement. Timeliness of tillage is essential for good weed control.

Sweep plows with multiple units of 0.5- to 0.8-m-wide sweeps are used as primary tillage tools, but not extensively, because of difficulties in getting the sweeps to penetrate the soil after harvest and the disturbance done to the standing wheat residue. The sweep plow is popular as a secondary tillage implement, because the increased soil disturbance enhances soil drying to promote desiccation of weeds.

Secondary tillage during the fallow period in the winter wheat–fallow and wheat–corn or sorghum–fallow rotation areas involve the use of small sweep plows, chisels, and rodweeders with semichisels. The objectives of these tillage tools are to control weeds and leave the surface suitable for planting. The rodweeder is the preferred implement to use the last one or two operations before seeding. The soil surface should have sufficient clods, residue, and surface roughness to resist wind erosion. In the Great Plains at least 30% of the soil surface should be covered with crop residue after planting to minimize the erosion hazard.

Tillage practices in areas with continuous winter wheat involve destroying much of the stubble by burning or burial with a disk or plow. Generally, less water is lost with burning because tillage is reduced or eliminated. However, burning destroys organic matter and leaves the land subject to erosion. Extensive tillage dries the surface soil, and in low rainfall years wheat cannot be sown deeply enough to reach soil water necessary for uniform germination and seedling establishment. The use of secondary tillage tools is similar to that in other wheat rotations.

Winter wheat with irrigation is becoming common as a substitute for corn under irrigation because wheat requires less water, thereby reducing pumping costs. Continuous wheat in some areas is subject to decreasing yields as succesive crops are grown. Diseases such as *Pythium* spp. may be the cause of this yield decline (Cook, 1984). Cephalosporium stripe (*Cephalosporium gramineum*) has been identified in the Central Great Plains and is a threat to continuous and alternate winter wheat–fallow rotations (Watkins and Boosalis, 1982).

Rotating soybeans (*Glycine max*) or field beans (*Phaseolus vulgaris*) with winter wheat is popular. The soil may be disked after the bean harvest, but the operation is not imperative. Planting wheat directly into the bean stubble is often effective, especially on soils susceptible to wind erosion. The soybean stubble will trap some snow; this will furnish water, protect the seedlings from winter kill, and greatly reduce erosion hazards. Soybeans must be harvested as soon as ripe, and wheat must be planted immediately because the optimum date for planting winter wheat has normally passed. Winter wheat will emerge in a week when fall soil temperatures are optimum, but emergence may be delayed 3 weeks or more if planting is late, especially after soil temperatures decrease to 10°C. When planting is delayed, wheat is less vigorous the following spring, and there is more potential for weed and disease problems.

Fertilization

Fertilization with both nitrogen and phosphorus is necessary in wheat production systems on soils that have been cultivated for periods longer than 10 years (Sander et al., 1973). The major forms of nitrogen used are anhydrous ammonia, urea ammonium nitrate, urea and ammonium nitrate. When fertilizing for winter wheat during the fallow period, anhydrous ammonia may be applied beneath the sweep plow or rodweeder between May and within 3 weeks of planting. Nitrogen can also be applied as a top-dressing during the spring tillering stage of winter wheat, generally during March and April. Herbicides such as chlorsulfuron [2-chloro-*N*-[[4-methoxy-6-methyl-1,3,5-

triazin-2-yl) amino] carbonyl] benzenesulfonamide] can be applied with liquid nitrogen. Timing of fertilizer application is extremely important in no-till systems because there are frequently as few as three opportunities for application during the crop rotation. These are: prior to the planting of a crop, during crop planting, or in the growing crop. Urea ammonium nitrate solution is often applied with the herbicide prior to planting corn or sorghum into nondisturbed wheat stubble (Hergert, 1985). Fertilization prior to planting corn or sorghum is generally better, because of the probability of receiving rainfall to move the nitrogen into the soil profile. Anhydrous ammonia is currently the least expensive form of nitrogen. For non-irrigated corn production, where 84 kg ha^{-1} of nitrogen is sufficient (Hergert, 1985), nitrogen solutions as a carrier for herbicides may be as cost-efficient as using anhydrous ammonia with the added cost of application.

Proper placement of nitrogen and phosphorus in relation to the seed is important to minimize injury during germination and initial seedling growth, and yet provide sufficient nutrients for optimum yields. Currently the phosphorus requirement, and up to 22 kg ha^{-1} of the nitrogen needs, can be applied with the seed at seeding time. Additional nitrogen, the primary nutrient needed by wheat in these soils, must be applied at some other time or placed away from the seed at planting. Potassium is rarely needed in most fields planted to winter wheat. Soil tests should be used to determine the nutrients required for the crop within the rotation that is to be planted.

Planting

Planting winter wheat in the Central Great Plains begins about 15 August in south-eastern Wyoming, about 1 September in north-western Nebraska (Fenster et al., 1972) and progresses to 20 October in south-eastern Kansas (Wilkins, 1978). Planting too early or late can place wheat under stress, allowing weeds to invade and leaving the plants susceptible to diseases such as root-rot (*Helminthosporium sativum*) and crown-rot (*Fusarium roseum* sp. *cerealis*) and to infestations of insects such as aphids.

Wheat seed should be planted into firm, moist soil in order to obtain uniform stands. Proper selection of drills is important (Fenster and Wicks, 1977). Most grain drills have difficulty planting into fields where straw and chaff were not spread uniformly during harvesting or where corn and sorghum residues were not chopped with a disk. Straw should not be pushed down into the seed furrow to come in contact with the seed during the planting operation. The seed should be covered with about 3 cm of moist soil: deeper seeding may reduce wheat yield (Robertson, 1984). Some semi-dwarf varieties of wheat will not emerge from depths greater than 5 cm. Row spacings should be as narrow as possible, and yet allow adequate trash clearance and provide uniform placement of the seed into moist soil. Seed size also influences wheat yields. Large seed (41.5 g per 1000 seed) produced 3660 kg ha^{-1} while small seed (21.4 g per 1000 seed) produced 3230 kg ha^{-1} (Robertson, 1984).

Harvesting

Harvesting winter wheat begins in south-eastern Kansas during the last half of June and moves north and west so that the wheat harvest is completed by early August in north-western Nebraska. Winter wheat is almost always harvested directly with the combine. Occasionally large weeds like lambsquarters (*Chenopodium* spp.), *kochia scoparia*, and common sunflower (*Helianthus annuus*) may necessitate swathing. Timely and efficient harvesting of any crop is important to the success of the crop rotation. Losses associated with combine harvesting were largely due to weed preventing grain from falling through the straw walkers, chaffers and sieves, and amounted to 13% in a weed-infested crop, as against 4% for a clean crop (McCuen and Silver, 1943).

Properly adjusted equipment minimizes grain loss during the harvesting operation. Grain loss can contribute to a subsequent volunteer problem. If lost grain was not concentrated behind the combine, control of volunteer wheat would be easier (Hoffman and Lavy, 1978).

In recent years, combine harvesters have become larger and farmers in the Great Plains now have headers with harvesting widths greater than 6 m. These large headers present problems with chaff and straw distribution which interfere with future weed control strategies involving herbicides and tillage, and can interfere with planting operations using grain drills or row crop planters. In areas where small grain is swathed, double windrows are frequently used, again causing problems in the spreading of straw and chaff. Equipment manufacturers must develop spreaders for combines that will distribute the straw, small seed, and chaff uniformly over the width of the header for conventional and no-till crop production. Although straw can be spread by tillage, it is more efficient to spread while harvesting.

In the Central Great Plains, average precipitation occurs rarely and all environmental factors vary from year to year. The keys to successful dryland cropping systems under these conditions are good resource management and the ability to react, respond, and adjust management decisions to the extent possible to balance the resources with the environment. Current cropping systems allow the manager opportunities to adjust to environmental changes, by contrast to cropping systems of the past which were less flexible. Future cropping systems may be different from those practised today, as those today are different from those practised yesterday. The trend of today's best cropping systems is less tillage and more crops between fallows. With improved efficiency of precipitation use through reduced and no-till practices, and new biotechnological advances, cropping systems of the future should continue the trends shown in cropping systems of today.

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