Chapter 5

Northern Great Plains[1,2]

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I. INTRODUCTION

Wheat Production in the Region. United States wheat (*Triticum aestivum* L.) production has more than doubled since the early 1950's (Figure 1). In most years since then, roughly 25% of this wheat has been produced in the Northern Great Plains (91). This region encompasses eastern Montana, North Dakota, South Dakota, and northwestern Minnesota. Most hard red spring wheat and durum wheat (*Triticum durum* Desf.) grown in the United States are produced within this region (35). Since 1950, 75 to 90% of hard red spring wheat (Figure 2) and 80 to 100% of durum wheat (Figure 3) were grown in the Northern Great Plains. Durum production is second to spring wheat in the region. The region produced all of the durum wheat grown in the United States until 1975 when New Mexico and California initiated limited production. Durum wheat is a specialty wheat used mainly by the pasta industry. It is tetraploid while most other wheats are hexaploid. Most durum wheat is produced in the northeastern and north-central part of North Dakota. The combination of cool temperature during maturation and moderate rainfall throughout the season produces the vitreous kernels needed for quality durum grain. The Northern Great Plains grow less than 10% of United States winter wheat (Figure 4).

Regional wheat hectarage has remained relatively constant since 1950 although summer fallow has decreased in importance (Figure 5). Areas practicing extensive summer fallow, such as western North Dakota and Montana, have experienced slight (5%) decreases in harvested

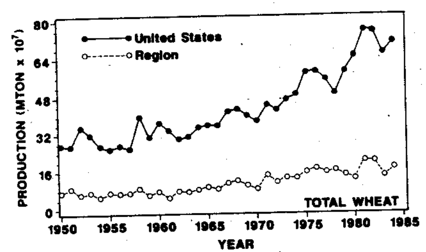

Figure 1. Total wheat production in the United States (•—•) and the Northern Great Plains (o---o) from 1950 to 1984 (134).

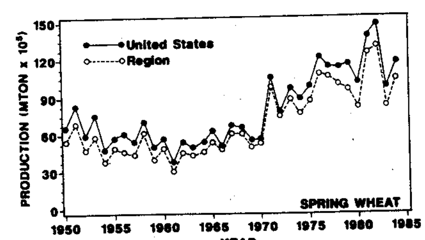

Figure 2. Hard red spring wheat production in the United States (•—•) and the Northern Great Plains (o---o) from 1950 to 1984 (134).

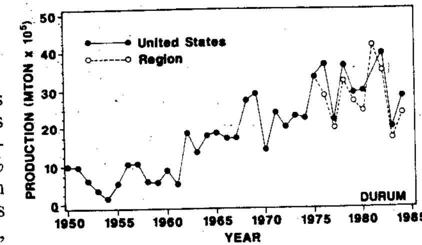

Figure 3. Durum wheat production in the United States (•—•) and the Northern Great Plains (o---o) from 1950 to 1984 (134).

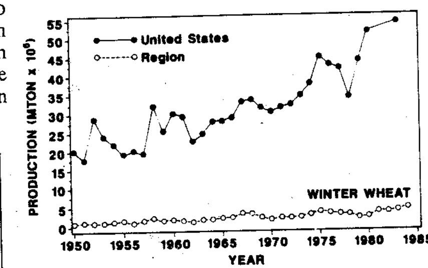

Figure 4. Winter wheat production in the United States (•—•) and the Northern Great Plains (o---o) from 1950 to 1984 (134).

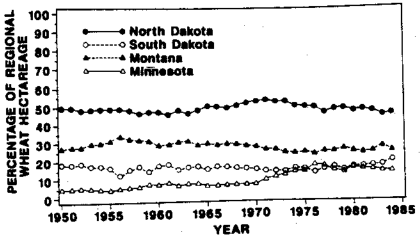

Figure 5. The percentage of regional wheat hectarage produced in North Dakota (·—·), South Dakota (o---o), Montana (+—+), and Minnesota (Δ—Δ) from 1950 to 1984 (134).

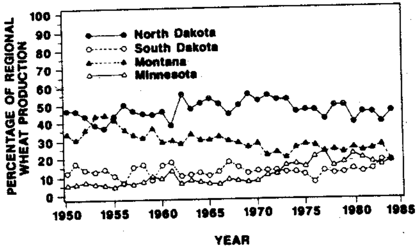

Figure 6. The percentage of regional wheat production in North Dakota (·—·), South Dakota (o---o), Montana (+—+), and Minnesota (Δ—Δ) from 1950 to 1984 (134).

wheat hectarage, while Minnesota wheat hectarage has increased especially in the last 15 yr since the early 1970's. Minnesota also practices continuous cropping, with only limited summer fallow. New higher yielding wheat varieties with greater insect and disease resistance also have been adopted (32). The classes of wheat that are grown in the region have changed. The relative contribution of durum wheat to regional wheat production has remained constant, whereas winter wheat production has increased. Fertilizer, pesticide, and herbicide use has increased. In addition, improved cultural practices have contributed to yield increases.

The absolute variability in wheat yield is greater in arid western North Dakota and eastern Montana than in the humid east (3, 4). In the western Northern Great Plains, the proportion of land devoted to continuous cropping decreases as the percentage of fallowed land increases (3, 4). Wheat yields also are less variable after fallow. However, in the western half of the Northern Great Plains where wheat-fallow has been widely adopted, flexible cropping systems may be more desirable (38). In flexible cropping, the decision to plant is based on whether enough soil moisture is present at spring planting time to support early-season crop growth.

The proportion of regional wheat produced in North and South Dakota has remained constant since 1950 at about 45 and 15% of the total, respectively (Figure 6). In contrast, the percentage of regional wheat produced in Montana has declined as that in Minnesota has increased. Keep in mind that total regional wheat production has increased dramatically since 1950 (Figures 1 to 4).

The relative contribution of different states to regional total, winter, spring, and durum wheat production is summarized in Figures 7 to 10,

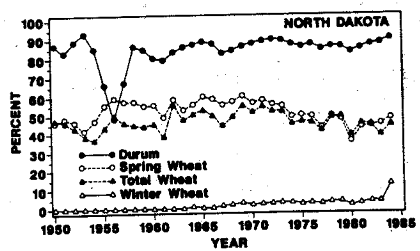

Figure 7. The percentage of regional durum wheat (·—·), spring wheat (o---o), winter wheat (+—+), and total wheat (Δ—Δ) production in North Dakota from 1950 to 1984 (134).

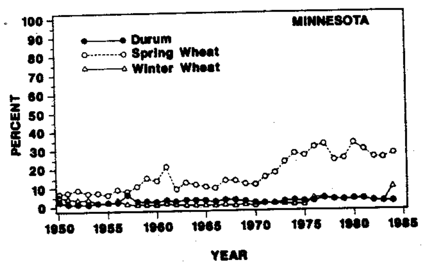

Figure 8. The percentage of regional durum wheat (·—·), spring wheat (o---o), winter wheat (+—+), and total wheat (Δ—Δ) production in Minnesota from 1950 to 1984 (134).

respectively. North Dakota grows most of the region's durum wheat (greater than 80%) (Figure 7). Durum also is produced in northeastern Montana, northeastern South Dakota, and northwestern Minnesota in the Red River Valley. North Dakota produces about 45% of the hard red spring wheat grown in the Northern Great Plains (Figure 7). Minnesota spring wheat production has increased recently so that it now

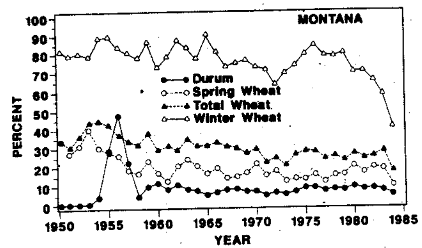

Figure 9. The percentage of regional durum wheat (·—·), spring wheat (o---o), winter wheat (+—+); and total wheat (Δ—Δ) production in Montana from 1950 to 1984 (134).

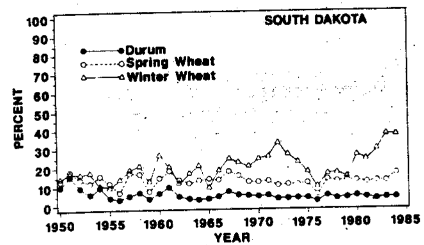

Figure 10. The percentage of regional durum wheat (·—·), spring wheat (o---o), winter wheat (+—+), and total wheat (Δ—Δ) production in South Dakota from 1950 to 1984 (134).

represents about 25% of total spring wheat grown in the region (Figure 8). At the same time, Montana's share of regional spring wheat production has declined (Figure 9). While Montana still grows most (75%) winter wheat produced in the Northern Great Plains, its relative contribution has decreased steadily since 1950 (Figure 9). Winter wheat grown in North Dakota (Figure 7) and Minnesota (Figure 8) still contributes relatively little to regional winter wheat production, despite recent dramatic increases in production. Only Montana produces more winter wheat than spring wheat in the Northern Great Plains.

Weather. *Climate.* As one pioneer put it, "Dakota is a great land for extremes, either too hot or too cold, too wet or too dry." (118). The same could be said for weather in the Northern Great Plains. The area is best characterized by seasonal extremes, as well as frequent and rapid changes in weather. Aspects of regional climate have been reviewed for North Dakota (15, 77, 82, 107, 112, 115, 137), Montana (77, 98, 132, 137), South Dakota (77, 137), and Minnesota (137).

The Northern Great Plains have a continental climate with well-defined seasons and large seasonal changes in temperature (112, 132). They have both relatively high amounts of sunshine and continuous air movement. They also have low relative humidity, and light, often irregular, precipitation. The climate in eastern North Dakota and Minnesota is cool and temperate, but somewhat subhumid. As one moves westward to eastern Montana, the climate becomes semiarid although it remains cool and temperate (107).

The climate of western Montana is milder than the rest of the Northern Great Plains because Pacific air masses moderate temperature (98). Western slopes in Montana are generally wetter than eastern slopes because of the prevailing westerly winds (77). Western Montana has wetter winters and springs than does eastern Montana. In contrast, the spring and early summer are the wettest periods for eastern Montana. Wheat production and weed control in western Montana are discussed in the chapter on the Pacific Northwest.

The geography of the region influences its continental climate. The Rocky mountains, Polar Region, and Gulf of Mexico all modify regional climate (112, 132). Eastern Montana and North Dakota form a broad channel through which either cold dry air masses from Canada or warmer air from the south pass. Frequent and rapid changes in weather are due to a lack of barriers to air masses from both the north and south. The Rocky Mountains form a barrier to airflow from the west. Air masses from the west are dry and warm. Air masses from the Gulf of Mexico are generally warm and moist and bring most of the regional precipitation received during the growing season. Most precipitation occurs during the growing season from April to September, with the bulk falling between May and July. If air masses from the south pass over mainland Mexico, then air coming into the region is drier. Generally, weather in the Northern Great Plains is unrelated to that in the Southern Plains (100).

Temperature. January tends to be the coldest month in the region. Temperatures begin to rise rapidly in April and reach a maximum in July (Figure 11). Then temperatures level off in August before decreasing in the fall. The temperature from mid-June to mid-July seldom falls below 1 to 4 C. Wheat seldom experiences subfreezing weather during seedhead formation or maturation. However, warm summer days are frequently followed by cool nights (112).

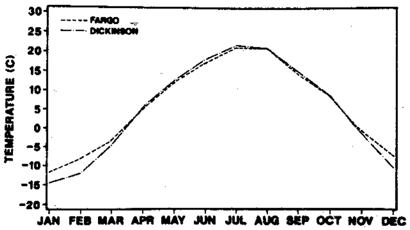

Figure 11. Average monthly temperature for various locations in North Dakota (112).

The upper limit for wheat production is 32.2 C and high temperatures within the region range between 31 and 37 C (112). Temperatures in North Dakota greater than 38 C seldom occur for five or more consecutive days.

The region is ideally suited for wheat production because of favorable temperatures and adequate moisture. Wheat requires a soil temperature of 1.1 to 2.2 C for germination (115). Spring wheat is planted as early as the soil can be worked into a seedbed after the air temperature reaches 4.4 C, usually between the first and third week of April in South and North Dakota, respectively. As spring planting is delayed after recommended dates of seeding, spring wheat yield decreases. Delayed planting may cause spikelet sterility because pollen shed occurs during the warmest and driest period of summer.

The base temperature is usually 2.8 to 4.4 C for calculating growing degree days for spring wheat in the Northern Great Plains (112). Likewise, the minimum germination temperature is taken as 4.4 C for a number of weeds, including wild oats (*Avena fatua* L. # AVEFA[4]), wild mustard (*Sinapis arvensis* L. # SINAR), and wild buckwheat (*Polygonum convolvulus* L. # POLCO). Kochia [*Kochia scoparia* (L.) Schrad. # KCHSC] germinates earlier at a base temperature of 1.7 C, whereas redroot pigweed (*Amaranthus retroflexus* L. # AMARE), green foxtail [*Setaria viridis* (L.) Beauv. # SETVI], and yellow foxtail [*S. glauca* (L.) Beauv. # SETLU] emerge after wheat planting because their minimum temperature for germination is about 10 C (112). If soil moisture is adequate, temperature requirements for weed seed germination and wheat planting often dictate the sequence of weed problems that develop in spring wheat. Kochia, wild oats, wild mustard, and wild buckwheat are problems in early planted spring wheat, whereas later planting favors green and yellow foxtail, common lambsquarters (*Chenopodium album* L. # CHEAL), and pigweed species.

Growing season length and frost-free days. The growing season length is determined by the frost-free period, the number of days between the last spring killing frost at 0 C and the first fall killing frost (120). Growing season length determines which spring-sown crops can be grown. Spring wheat requires at least 100 days to mature (118). Winter severity often limits survival of fall-sown winter wheat in the Northern Great Plains, despite introduction of adapted winter-hardy varieties. (See Section III below.)

The growing season in North Dakota is 110 to 150 days long and extends from mid-April to mid-September (112). The last killing frost of the spring in the northern portion of the Northern Great Plains occurs between May 15 and May 30, whereas the first killing frost of the fall generally occurs between September 15 and September 25 (115). In Montana the frost-free period lasts from about 110 to 125 days (111), whereas in South Dakota it lasts from 120 days in the north to 160 days in the east (142). The last spring frost in South Dakota occurs between May 5 and May 20 and the first fall frost occurs between September 15 and October 5. Detailed geographic maps of growing season length are available for the region (137), North Dakota (115), and Montana (132).

Regional weather influences several critical events in wheat production (112). These include spring tillage, spring planting, early wheat growth, postemergence herbicide application, and harvest. Temperature is a major factor limiting cropping practices. Federal crop insurance indemnities paid in North Dakota document typical hazards of the region (115). Excess moisture, drought, hail, freezing temperatures, and wind accounted for 80% of the benefits paid on cereals between 1947 and 1967 (100).

Rainfall. Rainfall is the most limiting factor for wheat production in the region. Most wheat is not irrigated; for example, only 3% of Montana hectarage is irrigated (121). Water storage is the major means of conserving moisture for wheat production. The type and timing of many farming practices were developed to maximize soil water storage.

Precipitation is irregular, light to moderate, and increases as one moves eastward in the Northern Great Plains (112). Relative humidity is generally low. Approximately 75% of the yearly rainfall occurs during the growing season (Figure 12). Winter precipitation usually is low and is carried into the region by low-pressure systems which travel from the west over the Rocky Mountains. Rainfall increases in April to peak in June (Figure 12) (112). In April a transition in air movement occurs and summer precipitation is generated from moist air masses moving up the Great Plains from the Gulf of Mexico. Precipitation decreases in July to a minimum in later summer and fall. High temperature is associated with low rainfall during this period (115, 116).

A rain-free period often occurs after snow melts in spring. Fields are generally wet from melting snow but dry rapidly. Stored moisture is usually sufficient for spring seeding and early-season growth (112). During spring tillage and seedbed preparation, rainfall is light. However, lack of rainfall in some years limits the herbicidal activity of postplant-incorporated herbicides, such as triallate [*S*-(2,3,3-trichloro-2-propenyl)bis(1-methylethyl) carbamothioate] and trifluralin [2,6-dinitro-*N*,*N*-dipropyl-4-(trifluoromethyl)benzenamine]. Evaporative losses are low in spring due to low temperatures; wet soil conditions may limit spring field operations. For this reason, primary tillage is done in fall in the eastern half of the region. As summer progresses, evaporation increases to peak shortly after the peak of maximum precipitation (22).

The distribution of rainfall is more critical for wheat production in the Northern Great Plains than the total amount that is received (110). Rainfall coming in the middle of the growing season often arrives when water stored in the soil profile is close to being depleted by wheat evapotranspiration. Half of the water that spring wheat needs for growth occurs as rainfall from May to July when wheat is most actively growing in North Dakota (13). The increase in rainfall during early summer occasionally limits postemergence herbicide application in the region. This is critical for some wild oat or grass herbicides which must be applied during a short period of time to achieve maximum selectivity or herbicidal activity. Evaporation from the soil exceeds rainfall only after June. The effect of stored water, seasonal precipitation, and temperature on spring wheat yield has been reviewed by Bauer (13).

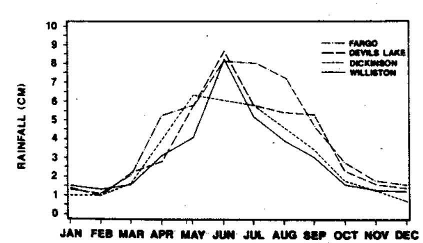

Figure 12. Average monthly precipitation for various locations in North Dakota (112).

Not only is the mean yearly rainfall near the critical minimum level for wheat production in the western portion of the Northern Great Plains, but it also is highly variable from year to year (100). Erratic rainfall patterns result in variable yields, although crop management practices may modify wheat response to drought. Drought drastically influences yield if it occurs during sensitive stages of the wheat life cycle. Drought also can influence yield losses due to other causes. For example, drought may reduce yield losses from hail but increase grasshopper damage (100). Drought also reduces the efficacy of soil-active and postemergence herbicides.

Unseasonable precipitation occasionally damages wheat before harvest. Excess rainfall from the soft dough stage until harvest or during harvest has little effect on yield but may reduce grain quality and delay combining. Rain on swathed grain may lengthen the period that wheat grain needs to dry in the swath and may cause shattering losses and lead to grain discoloration (116). Prolonged rains cause sprouting and reduce test weight.

Usually, rainfall is limited during spring wheat harvest in August. Infrequent precipitation at harvest permits a relatively rapid harvest. Direct combining of spring and durum wheat is limited in the eastern part of the region, where swathing is more prevalent. Wheat is swathed at high moisture contents (25 to 35%) and allowed to dry in the swath to 14% moisture content before combining. Swathing reduces the harvesting problems due to moist green weeds and speeds harvest operations.

The practice of fallowing and the rotational crops grown in the Northern Great Plains depend on the amount of precipitation. Black (23) has divided the Northern Great Plains into three precipitation regions (Table 1). Wheat requires at least 76 mm of stored water to a depth of 1.2 m at planting for successful yields in the region (23). Black (23) ranked the drought tolerance of crops grown in the Northern Great Plains according to their water requirements, based on

[4]Letters following this symbol are a WSSA-approved computer code from Composite List of Weeds, Weed Sci. 32 Suppl. Available from WSSA, 309 W. Clark St., Champaign, IL 61820.

Table 1. Northern Great Plains regions and cropping systems employed as related to precipitation (23).

Region	Location	Cropping systems	Precipitation (mm)
I	North central and central Montana and northwestern Wyoming	Winter wheat-fallow Barley-fallow Spring wheat-fallow Winter wheat-barley-fallow	330
II	Eastern Montana, western North Dakota, and northwestern South Dakota	Spring wheat-fallow Winter wheat-fallow Spring wheat-winter wheat-fallow Oilseed-fallow-spring wheat Oilseed-barley-winter or spring wheat	330-380
III	Eastern North Dakota and eastern South Dakota	Spring wheat-barley-fallow Spring wheat-oilseed-fallow Spring wheat-oilseed Spring wheat-oats-oilseed-barley	380

depletion of soil water to a 2-m depth (23). The crops ranked from most to least drought tolerant were: safflower (*Carthamus tinctorius* L.), winter wheat, flax (*Linum usitatissimum* L.), mustard (*Brassica* spp.), sunflower (*Helianthus annuus* L.), rapeseed (*Brassica napus* L.), spring wheat, and barley (*Hordeum vulgare* L.). At Fort Benton, MT, the order of ranking was different: safflower, sunflower, winter wheat, rapeseed, spring wheat, barley and corn (*Zea mays* L.). In the latter study, winter and spring wheat rooted to a depth of 1.8 and 1.2 m, respectively, and extracted 200 and 152 mm of water, respectively.

The efficiency of water storage in fallow and its contribution to subsequent crop yield have been reviewed (23, 70, 71). Historically, 20 to 25% of annual precipitation falls as snow in fall and winter but is not retained well (146). Most is lost as spring runoff because of poor infiltration into frozen soil. Water losses in fallow are caused by evaporation, transpiration by weed growth, snow removal by wind, and deep percolation of moisture below the rooting zone of wheat. Little moisture is added or lost from the soil profile during the second winter after fallow. Conservation and zero-tillage practices may increase snow water infiltration.

Wind. Windspeed is generally greatest in spring and least in summer (82). Winds restrict the period when herbicides may be sprayed within the region, just as spring rains do. Wind limits the timely application of postemergence wild oat and broadleaf herbicides in spring. This is important because these herbicides must be applied to particular growth stages of weeds and wheat in order to be most effective. Most wheat herbicides are applied exclusively postemergence, except triallate, trifluralin, chlorsulfuron {2-chloro-*N*-[[(4-methoxy-6-methyl-1,3,5-triazin-2-yl) amino] carbonyl] benzenesulfonamide}, and metsulfuron {2-[[[[(4-methoxy-6-methyl-1,3,5-triazin-2-yl) amino] carbonyl] amino] sulfonyl] benzoic acid}. Often, spraying is limited to the morning and evening when winds are less than 16 km/h. Special spray hoods or shrouds over the spray boom are being used more widely in the region to extend the spraying day. Drift from 2,4-D [(2,4-dichlorophenoxy)acetic acid], MCPA [(4-chloro-2-methylphenoxy)acetic acid], dicamba(3,6-dichloro-2-methoxybenzoic acid), and picloram (4-amino-3,5,6-trichloro-2-pyridinecarboxylic acid) applications to wheat has damaged fields of sunflower, soybeans (*Glycine max* L.), and sugarbeets (*Beta vulgaris* L.), as well as shelterbelt trees.

Soils. Western Montana is mountainous with elevations up to 1520 m (145). The eastern edge of the Rocky Mountains merges into the Piedmont region in central Montana (132). The eastern half of Montana varies from nearly level to gently rolling. Most Montana wheat is grown in the relatively flat eastern plains. Farther east, the elevation drops from 1100 m in southwestern North Dakota to 240 m in northeastern North Dakota (107). Elevation has been graphed in relation to annual precipitation for the entire Great Plains (117 in Figure 4).

North Dakota is divided into three major geographic regions. The Missouri Plateau is southwest of the Missouri river and dissects the state from the northwest corner to the south-central region. The drift prairie is east of the Missouri Plateau. The Lake Agassiz Basin in eastern North Dakota includes the Red River Valley. In Minnesota most of the wheat is grown in or bordering the Red River Valley.

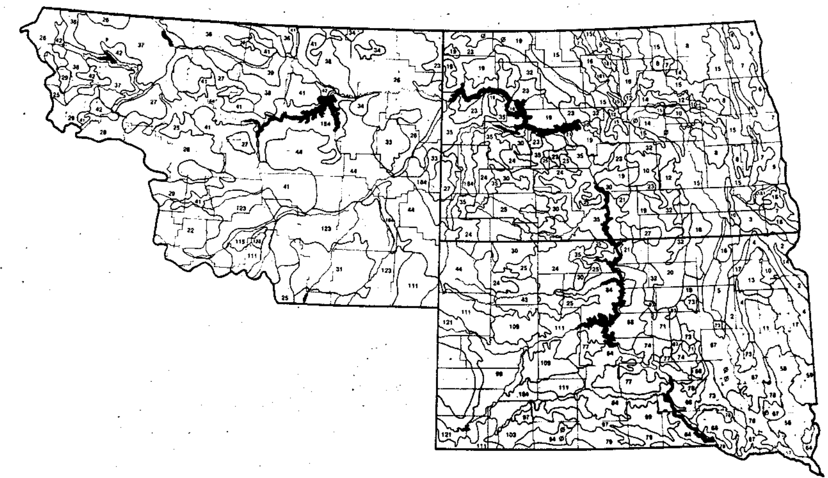

Figure 13. Soil groups and types in Montana, North Dakota, and South Dakota (1).

Regional soil types are quite diverse (Figure 13) (7, 41, 132, 140). North Dakota alone has over 250 different soil types (107, 109). Agriborolls and Haploborolls are the major soil types (31). These are cool, well-drained soils that are characteristic of continental climates. They are dark and high in base content. Soil organic matter ranges from about 1 to 6% (121, 142). Soil organic matter decreases as one travels westward in North Dakota (46) and South Dakota (140). The northern part of the region, including wheat-producing regions of Montana and North Dakota, was glaciated during the Late Pleistocene Age which influenced both topography and soil formation (7, 31, 132).

Wheat growth is optimal in soils of pH 6.5 (121). However, regional soils tend to be alkaline and range from about pH 6 to 8.2 because of alkaline substrates (32, 141). Thus, liming is unnecessary (117, 141). The alkalinity of soils in North Dakota and northern regions of Minnesota and Montana pose problems because several herbicides tend to be more persistent and phytotoxic to rotational crops in high pH soils. The triazine herbicides, dicamba, chlorsulfuron, and metsulfuron pose the greatest problems. A lime layer may form in drier western soils at a depth of only 15 cm, as opposed to a depth of 1.5 m in higher rainfall areas in the east. Trifluralin and picloram applied at registered rates in wheat generally do not persist at phytotoxic levels from one season to the next to damage rotational crops. However, atrazine [6-chloro-*N*-ethyl-*N'*-(1-methylethyl)-1,3,5-triazine-2,4-diamine] and ethofumesate [(±)-2-ethoxy-2,3-dihydro-3,3-dimethyl-5-benzofuranyl methanesulfonate] can carry over from preceding crops to damage wheat if application rate, soil pH, and seasonal rainfall are unfavorable.

Saline seeps caused by cropping practices and summer fallow are an increasing concern in Montana and the western third of North Dakota (34, 37, 72). A distribution map of saline seeps in Montana, North Dakota, and South Dakota has been published (34). Saline seeps form when excess soil water percolates below the root zone and accumulates. Generally, salt-laden water accumulates in a recharge area of permeable soil above an impermeable soil layer. When this water moves down the slope and resurfaces at a lower position, salts are deposited as it evaporates (72). The location of saline seeps depends upon soil texture and surface terrain, as well as the nature of underlying permeable layers (37). Cropping economics can determine whether this is a potential problem in particular regions. Taprooted species, such as alfalfa (*Medicago sativa* L.) or sunflower, may more effectively reduce the severity of saline seeps than shallower rooted annual species, such as wheat. Deep-rooted crops extract salts from deeper soil layers and prevent or reduce salt movement below the rooting zone by limiting

Table 2. The relative ranking of North Dakota, South Dakota, Montana, and Minnesota in United States crop production among the top 10 states in 1986 (North Dakota Agric. Stat. Serv. 1987).

Crop	North Dakota	South Dakota	Montana	Minnesota
	Ranking			
Corn for grain	–	10	–	4
Corn for silage	–	10	–	4
Winter wheat	–	8	7	–
Durum wheat	1	5	3	6
Spring wheat	1	4	3	2
All wheat	2	7	4	8
Oats	4	2	–	3
Barley	1	4	2	6
Rye	2	1	–	4
Flaxseed	1	2	–	3
Potatoes	4	–	–	9
Sugarbeets	4	–	7	1
Soybeans	–	–	–	4
Pinto beans	1	–	–	7
Dry edible beans	1	–	–	7
Sunflowers	1	2	–	3
Alfalfa hay	10	4	–	2
All hay	–	3	–	2

leaching and absorbing salts. Either mechanical or chemical fallow permits water percolation below the rooting zone, increasing saline seeps. Several common weed species, such as kochia and foxtail barley (*Hordeum jubatum* L. #HORJU), are better adapted to saline seeps than cereals (34). They may increase around a saline seep to later spread onto neighboring cropland by farm practices, wind, or water.

Most well water in the region used for herbicide spraying is alkaline and contains high levels of magnesium and calcium because of the underlying basic soil substrate (92). Such carrier water can reduce the efficacy of some herbicides, such as glyphosate [*N*-(phosphonomethyl)glycine] (108), especially at low application rates. The influence of water quality on wheat herbicide efficacy has not been researched systematically in the region.

Crops. *Crops in different regions.* Rainfall, temperature, growing season length, and, to a limited extent, topography influence which crops are grown in the Northern Great Plains (118). As one moves eastward from the Rocky Mountains, farming practices change gradually. In the far west, livestock and wheat are the major farming operations. There are fewer crops than farther east. As one moves eastward, wheat farming becomes more important. In the Red River Valley and northwestern Minnesota, more diversified continuous cropping is important. Spring wheat, alfalfa, oilseed crops, winter wheat, barley, oats (*Avena sativa* L.), and corn are the major crops grown in the Northern Great Plains (23) (Tables 1 and 2). The oilseed crops include flax, safflower, soybeans, and sunflower. Sunflower production is shifting westward. There is additional limited hectarage of specialty crops, including sorghum [*Sorghum bicolor* (L.) Moench], millet [*Setaria italica* (L.) Beauv.), sugarbeets, potatoes (*Solanum tuberosum* L.), sweetclover (*Melilotus* spp.), rye (*Secale cereale* L.), specialty mustards (*Brassica* spp.), and dry beans (*Phaseolus vulgaris* L.). Safflower is grown in the western part of the region, whereas alfalfa, potatoes, and sugarbeets tend to be grown in the east (70, 71). Sorghum is grown most widely in south-central South Dakota.

In the early part of the century, cropping was more diversified than it is now (75). Cropland in Montana has decreased and pasture has increased as farm size has increased. However, a similar shift has not occurred in the eastern third of the region. Between 1954 and 1964 the hectarage devoted to corn, sorghum, oats, rye, flax, wild hay, and spring wheat increased in Montana. Earlier, dry beans, field peas (*Pisum sativum* L.), and potatoes had been grown but have subsequently declined. Between 1954 and 1969 the hectarage of winter wheat, durum wheat, alfalfa, and grass silage increased in Montana (75). The greatest increase in winter wheat production in the region has occurred in Montana (22). Since 1965, winter wheat hectarage in Montana has exceeded that of spring wheat. Spring wheat is the major type of wheat grown in North and South Dakota, and Minnesota.

Increased winter wheat production in eastern Montana and South Dakota was due to improved tillage and seeding equipment, better management systems for handling crop residues and soil, and improved winter wheat varieties which have greater winter hardiness. If severe winters kill winter wheat, spring crops can be sown instead, providing greater flexibility in crop rotations.

Wheat production in North Dakota remained constant between 1969 and 1982 although the proportion of farmers producing wheat has declined (84). Barley and potato hectarage also has remained constant. Sunflower, soybeans, edible dry beans, and sugarbeets have increased, but the hectarage devoted to oats, rye, and flax has declined. Production changes in the principal crops of North Dakota have been summarized (57).

Between 1965 and 1979, corn and oats were the major crops harvested in South Dakota followed closely by spring wheat (90). Sunflower, winter wheat, soybeans, barley, and durum wheat have increased in hectarage somewhat, whereas flax and sorghum have declined. Only in South Dakota has rye hectarage remained unchanged. Wheat is generally grown in central and northern South Dakota, whereas corn and soybeans are grown in the east. Flax and rye are concentrated in the northeastern portion of the state.

Wheat or wheat stubble is not grazed in the Northern Great Plains. Wheat can be undersown with small-seeded legumes, such as alfalfa or sweetclover, as a way of establishing a forage legume stand. This is done to a limited extent, primarily in Minnesota. Oats for hay is used more commonly as a companion crop with small-seeded legumes than is wheat. When wheat is used, it is harvested for grain. Underseeding wheat with legumes limits which herbicides can be used safely in wheat (20).

Crop competition with weeds. Weeds reduce crop yields to a greater relative extent for some crops than others. For example, the relative competitive ability of flax with wild oats is less than with wheat or barley (102). In other field studies, spring-sown 'Prolific' rye was more competitive with wild oats than standard height 'Waldron' spring wheat (127). Although wild oats reduced the relative yield of rye and wheat to the same extent, wild oat panicles were more numerous in wheat than in rye. Dubbs (55) suggested that different crops varied in their competitiveness with wild oats in Montana. He ranked winter wheat, barley, oats, and spring wheat from most to least competitive but did not provide documentation. Bond and Umberger (32) asserted that hard red spring wheat and durum were less competitive with weeds than hard red winter wheat. While these opinions are probably qualitatively correct, they remain undocumented. Quantitative data for particular combinations of weeds and various crops would be useful to establish whether nonchemical weed control using crop selection and rotation has potential for controlling some weeds.

II. SPRING WHEAT PRODUCTION AND WEED CONTROL

Tillage Practices. The cycle of spring wheat-fallow cropping is summarized in Figure 14 (145). From spring wheat harvest in August until mid-May, the wheat stubble may be left undisturbed over the first winter (70, 71). In mid-May, secondary tillage or fallow is initiated and continued. Following the second winter, spring wheat is planted in late April. Spring wheat production practices used in Montana have been well reviewed (85).

Primary tillage. Primary tillage may be done with a chisel plow having 30- or 45-cm sweeps, a tandem or one-way disk, or a moldboard plow (24). In continuous cropping the moldboard plow may be used in the fall followed by spring seedbed preparation with a field cultivator or a combination of field cultivator and harrow. Where land is to be fallowed, the sequence is different. If straw residues are greater than 3000 kg/ha, the area may be disked, whereas if the residue levels are less than 3000 kg/ha, a sweep cultivator might be used (24). Subsequent fallow tillage operations to maintain weed control are generally conducted with a sweep cultivator equipped either with or without a rod weeder or harrow.

The chisel plow began replacing the moldboard plow since its introduction in the late 1950's and early 1960's (62). Offset and tandem disks also are partially replacing one-way disks. Their increased size, concavity, and depth penetration tend to increase residue burial so that 30 to 70% of crop straw can be buried. Both chisel plowing and disking leave loose straw on the soil surface for erosion control. Wheat can be grown successfully on land prepared by surface or subsurface tillage with disking or field cultivation if weeds are controlled adequately (63). If not controlled, foxtails, Russian thistle (*Salsola iberica* Sennen and Pau # SASKR), and wild buckwheat increased fastest on land that was spring cultivated or one-way disked 10 cm deep compared to deeper moldboard plowing (65, 66). Most tillage implements kill weeds by partially inverting the soil or severing roots.

Fall tillage operations vary across the Northern Great Plains (122, 123, 124). In northeastern Montana and western North Dakota, a high proportion (57%) of land receives no fall tillage, especially if fall weeds are sparse. Wheat yielded less following fall plowing than spring tillage in western North Dakota (63). Fall tillage is usually accomplished by chisel plowing. Fall moldboard plowing increased from only 3% in western North Dakota to 37% in the eastern part of the state (122, 123, 124). Fall tillage is advantageous where there is excess moisture, as in eastern North Dakota (63). In eastern North Dakota and the Red River Valley, 22% of the land receives no fall tillage while 20% is chisel plowed (124). In the Red River Valley and

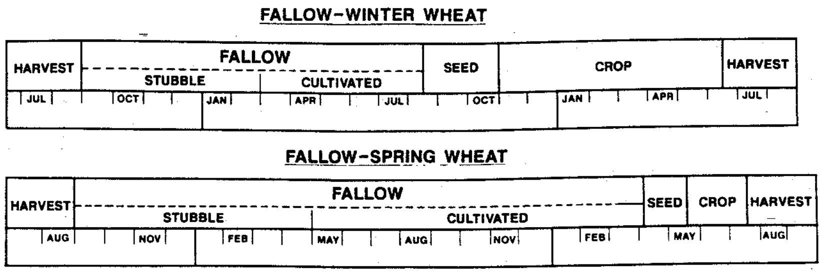

Figure 14. Time line over 2 yr for typical winter wheat- or spring wheat-fallow rotations in the Northern Great Plains (145).

northwestern Minnesota, land is plowed in fall to allow frost heaving to mellow the heavy clay soil and facilitate timely spring seedbed preparation and planting. If tillage is delayed until spring on heavier clay soils, often it is difficult or impossible to invert the wet soil and allow it to dry properly, delaying planting. Early spring tillage also compacts soil and produces a dry cloddy surface which is poor for planting and crop emergence.

Several researchers concluded that fall tillage had no advantage over spring tillage for wheat yield except in the eastern portion of the Northern Great Plains (53, 63, 117). However, it may be necessary to till in fall in order to adequately distribute labor. Spring planting is started as early after the spring thaw as possible and is usually quite rushed. Consequently, fall tillage has economic and labor advantages even though it leaves land subject to erosion (53, 63). In the arid west, spring tillage is preferred because surface straw holds snow and allows greater water infiltration during snow melt. In contrast, fall tillage has an advantage where there may be excess spring moisture, as in the Red River Valley.

In the west, shallow tillage with field cultivators, disks, or sweeps for seedbed preparation without any primary tillage yielded less than when primary tillage was used because there was less nitrate nitrogen; and weeds, predominantly green or yellow foxtail and Russian thistle, grew excessively in such systems (63). Use of one-way or tandem disking, or field cultivators for seedbed preparation may be feasible if these weeds are controlled. Uncontrolled weeds reduced wheat yields when wheat was planted into either wheat straw or corn stubble in this research (63, 66).

Many tillage practices that are now common were developed before widespread use of fertilizers and herbicides (53). Consequently, early research comparing fall versus spring tillage and the types of tillage implements may need to be reexamined.

Primary tillage and weed control. Primary tillage alters the distribution of weed seed in the soil profile (103). While moldboard plowing distributes wild oat seed evenly throughout the soil profile to the plow depth, chisel plowing leaves seed near the surface (60). On chisel-plowed land, 50 to 60% of wild oat seed was found in the top 2.5 cm of the soil profile (102). Since deeper buried wild oat seed survive longer, moldboard plowing may actually prolong a wild oat problem, compared to more shallow tillage methods. Seed buried by moldboard plowing may be subsequently unearthed over a period of time, resulting in reinfestation. The timing of tillage operations also may influence weed control and weed seed production. Plowing immediately after harvest may prolong wild oat infestations by burying highly dormant seed.

Other weeds increased more slowly following spring or fall moldboard plowing than with other tillage methods in western North Dakota (65, 66). Late-fall tillage controls winter annuals, such as field pennycress (*Thlaspi arvense* L. # THLAR) and flixweed [*Descurainia sophia* (L.) Webb. ex Prantl # DESSO]. Weeds increased most following shallow spring cultivation or disking with a one-way disk (65, 66). Foxtails, Russian thistle, and wild buckwheat increased, whereas wild mustard and field pennycress remained at the same densities following shallow tillage. As early as 1903, Waldron (139) suggested that continual disking, rather than moldboard plowing, favored the buildup of perennial weeds, such as wild rose (*Rosa* spp), Canada thistle [*Cirsium arvense* (L.) Scop. # CIRAR], and field bindweed [*Convolvulus arvensis* L. #CONAR).

Secondary tillage and weed control. The one-way, offset, or tandem disk, the sweep cultivator, Danish tines, and rod weeder are major secondary tillage implements used in the region (23, 122, 123, 124). Cultivation and disking for seedbed preparation are generally left until spring. The farmers in the western portion of North Dakota either cultivate once or twice, or cultivate and then harrow for seedbed preparation. In eastern North Dakota, a third of the farmers cultivate and then harrow once. Fewer farmers harrow twice after cultivation for seedbed preparation. Spring seedbed preparation begins in the west and progresses eastward in the Northern Great Plains (23). In western North Dakota and eastern Montana, where land is moldboard plowed in spring, it usually is followed by packing and harrowing and then seeding with a double-disk drill in one operation (65).

The effect of secondary tillage practices on weed biology and control has been inadequately researched in the region. To date, most research has dealt with wild oats, although other weed species respond to tillage quite dramatically. In Canada, fall tillage was more effective than spring tillage in stimulating wild oat germination (127). A cultivator appeared to be more effective than a double disk. However, harrowing was ineffective in stimulating germination. The cultivating and double disking were done to a depth of 7.5 cm, somewhat deeper than a harrow can be used.

Relatively little research has been conducted to determine the efficacy of harrowing for post-emergence weed control in wheat. Harrowing at the two- to three-leaf stage of wheat controls some shallowly emerging weed species, such as foxtails (103). At that wheat leaf stage, wheat is well enough developed to withstand partial burial. Harrowing damages wheat more easily once tillering begins at the four- to six-leaf stage.

Tillage method influences seed persistence of certain weed problems, such as wild oats. The time of tillage may determine whether a weed problem increases or decreases. In Minnesota, disking or plowing in October increased volunteer sunflower as a problem, whereas disking or plowing in April or May provided better long-term control (119). Unburied sunflower seed were lost more quickly than buried seed. Incorporating seed into soil in fall enforced dormancy and allowed greater seed persistence. Prevention of seed production could deplete the soil of volunteer sunflower seed within 3 yr.

Fewer weeds occur on mechanically tilled fallow than on chemically fallowed land (26). Wild oats, wild buckwheat, Russian thistle, and pigweed species were less numerous following mechanical tillage than following chemical fallow. Seed persisted on the soil surface in chemical fallow but were incorporated and germinated when the subsequent seedbed was prepared and planted. While many potential herbicides for chemical fallow have been evaluated, a commercial, economical system has not been developed for the Northern Great Plains. In no instance was chemical fallow superior to conventional mechanical fallow (26). However, herbicides examined in this mid-1960's research did not control grasses adequately.

Reduced tillage fallow, incorporating some elements of chemical and mechanical fallow, was reviewed recently (130). The following herbicides were registered for use in chemical fallow in 1988, although some can be used only before rotating to cereals: atrazine, chlorsulfuron {2-chloro-*N*-[[4-methoxy-6-methyl-1,3,5-triazin-2-yl)amino] carbonyl]benzenesulfonamide}, cyanazine {2-[[4-chloro-6-(ethylamino)-1,3,5-triazin-2-yl]amino] -2-methylpropanenitrile}, 2,4-D, dicamba, glyphosate, metribuzin [4-amino-6-(1,1-dimethylethyl)-3-)-methylthio)-1,2,4-triazin-5(4*H*))-one], metsulfuron {2[[[[(4-methoxy-6-methyl-1,3,5-triazin-2-yl)amino]carbonyl]amino]sulfonyl]benzoic acid}, paraquat (1,1′-dimethyl-4,4′-bipyridinium ion), propham (1-methylethyl phenylcarbamate), terbutryn [*N*-(1,1-dimethylethyl)-*N*′-ethyl-6-(methylthio)-1,3,5-triazine-2,4-diamine], and trifluralin. However, complete reliance on herbicides for the entire fallow period is not practical because of incomplete weed control and herbicide costs. Soil residues of persistent herbicides, such as atrazine, cyanazine, or dicamba, also may carry over to damage subsequent crops. The number of tillage operations can be reduced in fallow by proper herbicide selection and application timing. Full-season weed control in chemical fallow is inconsistent because seasonal climate and moisture levels vary from year to year (26).

Reduced tillage systems and weed control. Tillage practice, contour plowing, and strip cropping help control soil erosion (147). Residue management, tree or brush shelterbelts, and windbreaks consisting of rows of flax or tall wheatgrass [*Agropyron elongatum* (Host) Beauv.] also can control erosion (24). The history of reduced tillage and tillage implements for stubble-mulch farming have been reviewed (5).

The amount of wheat straw needed to prevent erosion often depends upon soil type and slope (83). Fall tillage determines the amount of straw persisting from harvest until spring planting (24). The amount of straw produced by a crop increases as its yield increases. Straw residues of 2400 kg/ha are fairly common for spring wheat, but about 33% of this is lost over winter. Only 800 kg/ha may be left following four operations to apply fertilizer and prepare a seedbed, or only 1/6th of that present initially.

The presence of wheat straw influences weed populations (30). When winter wheat was planted in tilled land in Montana, green foxtail was more dense than when wheat was planted into undisturbed stubble. The stubble height ranged between 15 and 38 cm. Direct seeding into stubble reduced the density and severity of green and yellow foxtail. Perhaps other weeds also may become less abundant in zero tillage.

Conventional cropping sequences are altered for zero-tillage crop production (Figure 15). Following wheat harvest in August, there may be no need to treat with herbicides for weed control in the fall, depending upon rainfall. However, if perennial weeds, such as Canada thistle, quackgrass [*Agropyron repens* (L.) Beauv. # AGRRE], foxtail barley, or smooth bromegrass (*Bromus inermis* Leyss. # BROIN), are problems, high rates of systemic postemergence herbicides, such as glyphosate or dicamba, may be applied in the fall. The area may be fertilized in either the fall or spring. Fertilizer may be either broadcast or deeply banded in fall or at planting. At seeding in May, a nonselective herbicide is applied, usually paraquat or glyphosate. Glyphosate at 0.5 to 2.2 kg ai/ha may be used to suppress or kill perennial grasses that are present at planting, although lower rates, such as 0.25 or 0.35 kg ai/ha, are used for annual weeds. Glyphosate at low rates controls fall-germinating winter annual weeds, such as field pennycress, shepherdspurse [*Capsella bursa-pastoris* (L.) Medik. # CAPBP], and flixweed, which otherwise would be large at planting, as well as early emerging summer annual weeds, such as kochia, wild mustard, and wild buckwheat. Subsequent postemergence herbicides are applied in the crop as needed. Harvest is similar to that in conventional tillage, although residue management during harvest is critical for no-till crop production. Straw and chaff spreaders on combines prevent piling of crop residues which would prevent proper crop seed placement, emergence, and weed control. Also, straw may be spread after harvest by harrowing.

Fertilization. *Nitrogen Fertilization.* Nitrogen fertilizer requirements for wheat are well established for "conventional" tillage (79). Approximately 30 kg of nitrogen is needed for each 1000 kg of grain that is produced, up to 2200 kg/ha. Beyond 2200 kg/ha, more nitrogen is needed for each kg increase in yield. Thus, fertilizer nitrogen can be used to increase yield goals (117). Spike number and grain number per unit area are the yield components that increase most with fertilization, if weed control is adequate (58).

The hectares of wheat treated with nitrogen and phosphorous in the Northern Great Plains have increased dramatically since the 1950's (32, 56, 73). For example, there was a sixfold increase in fertilized hectarage in North Dakota between 1957 and 1977 (6). Roughly 85 to 90% of the area in wheat now is fertilized with nitrogen, phosphorus, or both. Generally, potassium and micronutrients, including zinc, iron, copper, and manganese, do not limit wheat production in the region. However, much more potassium is used on wheat in Minnesota than in the other three states (73).

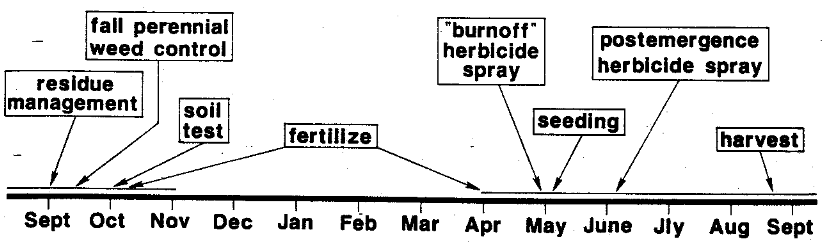

Figure 15. Time line over 1 yr for typical no-till spring wheat production practices in North Dakota.

Increased nitrogen and phosphorous use has accompanied adoption of semidwarf wheat varieties that are responsive to nitrogen. The ratio of returns from wheat to fertilizer cost and past government restrictions on hectarage have favored adoption of nitrogen fertilization. As one moves farther west in the Northern Great Plains, the fertilized area decreases as rainfall decreases (32). Even so, fertilization of the drier west also has increased since the 1960's. Prior to 1960, only irrigated wheat was fertilized in Montana (76).

Fertilizer practices. Less nitrogen is needed for wheat grown after fallow than following another crop. Mineralized nitrogen becomes available during fallow. However, soil organic matter has become so low in western North Dakota and Montana that wheat now responds to nitrogen even after summer fallow. Fertilizer nitrogen reduces the yield advantage of summer fallow, favoring a trend toward continuous cropping.

Fall broadcast nitrogen application can be made, but more nitrogen is lost than if it is applied in spring. In 1984, farmers in North Dakota, South Dakota, Montana, and Minnesota applied 27, 38, 41, and 45% of all their fertilizer in the fall, respectively (73). Fall-applied anhydrous ammonia is less likely to injure cereals than when it is spring applied (135). Farmers can drill nitrogen in spring with or near the crop seed or broadcast it. However, spring moisture loss is possible if fertilizer is incorporated or deep banded (135). Recent planter innovation has allowed nitrogen to be banded deeply between crop rows allowing for higher rates of nitrogen at planting with less chance of crop phytotoxicity. Less than 11 kg/ha nitrogen should be applied with wheat seed due to phytotoxicity (79). Banded (knife) application is the most efficient application method in no-till wheat production (47).

Most farmers (90 to 97% in 1979) in North Dakota do not broadcast fertilizer on fallowed land when growing wheat (122, 123, 124). More often, nitrogen is drilled with the seed at planting on fallow. Eleven to 21% of North Dakota farmers broadcast fertilizer on continuously cropped land (122, 123, 124). Generally, dry forms of nitrogen fertilizer have been preferred over liquid forms. Liquid forms of nitrogen and anhydrous ammonia have found greater use in eastern North Dakota and the Red River Valley than in the west. Generally, urea and anhydrous ammonia have increased and ammonium nitrate has decreased in importance importance within the Northern Great Plains (73, 79, 136). However, at high nitrogen application rates, urea is less effective in supplying nitrogen compared to some other forms of nitrogen fertilizer. Nitrogen solutions, aqua ammonia, ammonium sulfate, sodium nitrate, ordinary superphosphate, concentrated superphosphate, and ammoniated phosphates are used much less than anhydrous ammonia or urea (73). Those nitrogen forms which have increased most are lowest in cost and provide the highest percent nitrogen (136).

Fertilizer and wheat competitiveness with weeds. The rate and placement of nitrogen influences wheat competition with weeds. Adequate nitrogen allows a denser wheat canopy to develop and the wheat leaf area index can peak at 4 to 6, almost completely blocking light interception (58). Soil water also is more efficiently used by fertilized than unfertilized wheat (33). Vegetative growth and preheading water extraction from soil are greater with adequate fertility than with low fertility.

Spring wheat planted early and fertilized with nitrogen is more competitive with green foxtail than late seeded, unfertilized wheat (74). Green foxtail was denser and more competitive with spring wheat in Montana when urea was broadcast compared to ammonium nitrate (29). When nitrogen was applied earlier with early planting, there were fewer weeds compared to when it was applied at later planting dates. Presumably early applied nitrogen allowed the crop to develop a canopy early and enhanced crop competitiveness with green foxtail. In Canada, nitrogen applied to spring wheat at 22 to 66 kg/ha enhanced seed production of green foxtail (99). Nitrogen banded 10 to 15 cm below the wheat seed reduced the growth of certain weeds compared to a broadcast application (128). Growth of common lambsquarters or field bindweed increased when nitrogen was broadcast compared to deep banding. In other research, broadcast application was not critical to wild oat competition (104). Yield losses due to wild oats in fertilized wheat depended on residual soil fertility. Yield losses were greater from wild oats in fertilized wheat at Carrington than at Fargo. The latter site had higher residual soil fertility levels. If fertility limited wheat yield, wild oat competition was reduced by fertilization without a change in crop quality. When 'Chris' spring wheat was planted at rates between 50 and 150 kg/ha, increasing wild buckwheat densities from 0 to 215 plants/m^2 reduced yield more on fertilized than on unfertilized plots

(95). Wheat spike number and kernel weight were reduced most by wild buckwheat competition. Since these two yield components are most influenced by fertilizer, it was suggested that wild buckwheat was competing with wheat for nutrients.

Nitrogen applied below 15 cm may be more available to the crop than to developing weeds (83). However, most regional research dealing with the effect of nitrogen on crop competitiveness has not considered fertilizer placement, even though a large proportion of spring-applied nitrogen would be banded with the crop or applied below the zone where weed seedlings germinate. However, only broadcast fertilizer applications were used in the above research on competition between wheat and weeds. Likewise, the bulk of research has dealt with nitrogen, ignoring phosphorus.

Wheat Varieties. *Shifts in wheat varieties.* The major objective of wheat breeding programs in the Northern Great Plains has been increased yield and improved resistance to diseases and insects (11). Agronomic traits, such as lodging resistance, shattering resistance, and uniformity or evenness of maturity have been important secondary breeding goals, as well. Of course, adequate crop maturity and quality are prerequisites for commercial acceptance of high-yielding selections. Early maturing varieties may yield less than full-season wheat lines (48).

Semidwarf wheat varieties have increased in the Northern Great Plains (48). As of 1974, semidwarf lines were planted on 42% of the hectarage devoted to hard red spring wheat. Short-strawed semidwarf varieties have increased most in Minnesota and eastern North Dakota because they are better adapted to the more favorable moisture and fertility levels in the east. Standard height wheat lines have remained important in South Dakota, Montana, and western North Dakota. One advantage of semidwarf lines is their responsiveness to increased fertilizer use, chiefly nitrogen, without increased lodging. The major varieties of hard red winter, hard red spring, and durum wheat were tabulated for 1974 and 1979 for each state of the Northern Great Plains (35). Historical changes in leading wheat varieties in North Dakota (129) and Montana (121) have been summarized.

Great Plains wheat breeders have made no effort to select wheat lines that are more competitive with weeds. Once varieties have been commercialized, some attempt has been made to determine their susceptibility to currently registered herbicides. This research has contributed to registration labels restricting difenzoquat (1,2-dimethyl-3,5-diphenyl-1*H*-pyrazolium) use to only certain spring and durum wheat varieties. Durum wheat generally is considered similar to hard red spring wheat in response to herbicides. Propanil [*N*-(3,4-dichlorophenyl) propanamide] was more injurious to 'Rugby' durum than to 'Era' spring wheat regardless of stage at treatment (69). Generally, durum wheat has been more tolerant than spring wheat to triallate and more susceptible to picloram. Picloram registration for use on durum wheat was withdrawn after reports of injury with commercial usage. However, the differences between the wheats may be confounded by differences among cultivars within each wheat type.

Wheat varieties and wheat competitiveness with weeds. New semidwarf wheat varieties are believed to be less competitive with weeds than older standard height varieties (103). As mentioned earlier, there has been no attempt to select for competitive ability in developing new wheat varieties. Adequate weed control or a lack of weed competition has been assumed as a standard aspect of crop management for new wheat varieties. Whether semidwarf or standard wheat lines are competitive or not depends upon the competing weed species and environment. In a preliminary field study in Minnesota, the competitiveness of standard height Chris and semidwarf Era spring wheats was compared with a mixed weed population of foxtails, Pennsylvania smartweed (*Polygonum pensylvanicum* L. #POLPY), pigweed species, and common lambsquarters (17). While the dry weight of broadleaf weeds was unaffected by competition with these wheat varieties, grass weed biomass was greater in the semidwarf than in the standard height wheat variety, whether or not broadleaf weeds were controlled in each wheat variety with MCPA plus bromoxynil (3,5-dibromo-4-hydroxybenzonitrile) at 0.28 kg ai/ha.

In eastern North Dakota, the semidwarf spring wheat varieties Era and 'World Seeds 1809' were compared with the standard height wheat lines Waldron and Chris for their competitiveness with wild oats (126). As wild oat densities increased, wheat yields decresed to the same extent in both tall and semidwarf wheats. Also, tall and semidwarf varieties reduced the number of culms, panicles, and seed dry weight of wild oats to the same extent. Unfortunately, neither this study nor the previous one (17) was taken beyond a preliminary stage. It is very likely that there will be an interaction between wheat variety,

weed species, and date of planting in studies of the relative competitiveness of different wheat cultivars.

Planting. *Planters.* The types of planters used in the region have been reviewed (12). Double-disk press wheel and hoe drills are the major types of planters used in the Northern Great Plains (31, 143). The disk seeder or 'disker' is no longer widely used. In fact, the disker reduced 'Selkirk' spring wheat yields at six locations in North Dakota compared to conventional press drills (89). The major problem with the disker was poor contact between the seed and soil. Often seed were placed in dry, loose, or trashy soil. Consequently, emergence was delayed compared to the press drill, resulting in later heading and maturity, and reduced yield. While the disker worked well on straw residues, it provided uneven penetration on rough ground or at high operating speed. Seeds were placed in soil in a partially broadcast manner, often at the tillage depth.

The use of the hoe drill is advantageous in the west because it has no moving parts and allows deep placement of seed near moist soil. However, depth control is uneven (64). The semideep or deep-furrow hoe drills frequently are used for winter wheat (31). The deep furrow catches snow and reduces winterkill of winter wheat. It also provides greater distribution of moisture near developing winter wheat seedlings in the spring. The effect of hoe and disk planters on soil movement has been compared (143). Recently, use of cultivator- or chisel plow-type air seeders has increased on conventional and reduced tillage because of good depth control, seed placement, and soil packing (36).

Zero tillage presents unique problems for wheat planters because of dense residues, narrow cereal row spacing (18 to 29 cm), and penetration difficulties (87). Often the drill must penetrate matted straw to place both seed and fertilizer at the proper soil depth. No-till disk drills, hoe drills, and air seeders have been adapted to these problem surfaces in the Northern Great Plains (11, 12).

Weed-free seed. The importance of weed-free seed for crop production was recognized and recommended to farmers in the 1890's in North Dakota (138). Mustard species, including tansymustard (*Descurainia* spp.), wild mustard, haresear mustard [*Conringia orientalis* (L.) Dumort, #CNHOR], falseflax (*Camelina* spp.), shepherdspurse, field pennycress, and peppergrass (*Lepidium* spp.) were serious problems at that time. Many of these weeds, particularly wild mustard, still pose a serious threat in the region and are adapted to zero-tillage surfaces. The concept of using clean wheat seed, free of weed seed, is as applicable today as it was in 1892.

A 1980 to 1981 seedbox survey summarizes some of the major weed species that contaminate North Dakota wheat (Table 3) (10). Between 61 and 78% of surveyed North Dakota farmers planted their own noncertified seed (122, 123, 124). Only 5.6 to 7.7% of the farmers purchased registered or certified seed (10). Thus, there is a great potential for resowing weed problems on farmland. Forty-four and 35% of the hard red spring wheat [sample size (N) = 325] and durum samples (N = 139), respectively, were contaminated with weed seed. Thirty-one percent of the seedbox samples contained no weed seed, whereas 98% of the respondents reported an elevator had "cleaned" their seed. A 1969 South Dakota drill box survey (N = 109) indicated the primary noxious weeds were field bindweed, Canada thistle, leafy spurge [*Euphorbia esula* L. #EPHES], and quackgrass in 1.8, 0.9, 0, and 31.2% or spring wheat samples, respectively (86). Wild oats, wild mustard, and field pennycress, which are secondary noxious weeds, were found in 34.9, 27.5, and 11.0% of South Dakota wheat samples, respectively. State laws limit noxious weed seed in commercial seed (Table 4).

Planting practices. In the Northern Great Plains, wheat planting begins in the south and progresses northward. Planting progresses slowly but accelerates as the soil dries before spring rains begin. Farmers in the western half of the Northern Great Plains generally plant wheat between March 20 and April 30, while those in the eastern half plant between May 1 and June 10 (23, 112). Yields decrease with later seeding dates (106, 111). Delayed seeding also decreased wheat response to nitrogen and phosphorous when applied either as ammonium nitrate or treble superphosphate (29). Not only is the growing season shorter for later planted wheat, but heat stress at heading is more likely (36). Heat units accumulate faster for later planted wheat, which hastens maturity. Because later planted wheat develops faster than earlier planted wheat, harvest is not delayed by late planting (29).

Proper wheat seeding rate, depth, and spacing have been summarized (83, 85). Spring wheat in the Northern Great Plains is planted at 55 to 80 kg/ha, with 67 kg/ha as the average (23).

Table 3. Species and frequency of weed seed found in the 1980-1981 North Dakota drillbox survey for wheat (10).

Weed species: Common name	Weed species: Scientific name	No. samples in which found	Percent of total samples
None found		186	31
Wild oat**	*Avena fatua* L. # AVEFA	224	38
Green foxtail	*Setaria viridis* (L.) Beauv. # SETVI	187	31
Wild buckwheat	*Polygonum convolvulus* L. # POLCO	130	22
Yellow foxtail	*Setaria glauca* (L.) Beauv. # SETLU	85	14
Wild mustard	*Sinapis arvensis* L. # SINAR	47	8
Barnyardgrass	*Echinochloa crus-galli* (L.) Beauv. # ECHCG	38	6
Common lambsquarters	*Chenopodium album* L. # CHEAL	32	5
Field bindweed*	*Convolvulus arvensis* L. # CONAR	24	4
Quackgrass**	*Agropyron repens* L. # AGRRE	19	3
Pigweed spp.	*Amaranthus* spp.	17	3
Wild sunflower	*Helianthus annuus* L. # HELAN	15	3
Common mallow	*Malva neglecta* Wallr. # MALNE	12	2
Russian thistle	*Salsola iberica* Sennen and Pau # SASKR	6	1
Japanese bromegrass	*Bromus japonicus* Thumb. ex Murr. # BROJA	4	2
Field pennycress**	*Thlaspi arvense* L. # THLAR	4	2
Kochia	*Kochia scoparia* (L.) Schrad. # KCHSC	4	2
Pink cockle	*Vaccaria* sp.	3	2
Persian darnel	*Lolium persicum* Bioss. and Hohen. ex Boiss. # LOLPS	2	2
Nightflowering catch-fly	*Silene noctiflora* L. # MELNO	2	2
Downy brome	*Bromus tectorum* L. # BROTE	2	2
Western wheatgrass	*Agropyron smithii* Rydb.	2	2
Dock spp.	*Rumex* spp.	1	1
Canada thistle*	*Cirsium arvense* L. # CIRAR	1	1
Buffalobur	*Solanum rostratum* Dun. # SOLCU	1	1
Giant ragweed	*Ambrosia trifida* L. # AMBTR	1	1
Wildrose	*Rosa* spp.	1	1
Marshelder	*Iva xanthifolia* Nutt. # IVAXA	1	1
Pale knotweed	*Polygonum* spp.	1	1
Common milkweed	*Asclepias syriaca* L. # ASCSY	1	1

*Prohibited noxious weeds
**Restricted noxious weeds

Durum wheat is recommended to be planted at 70 to 90 kg/ha. Wheat in thin sparse stands due to planter skips or hail often is infested by late emerging weeds, such as green foxtail and yellow foxtail, which then can compete effectively. Post (III) recommended lower seeding rates of 50 to 67 kg/ha for dryland than for irrigated land (84 to 100 kg/ha). Low seeding rates were better when water was limiting (49, 144).

Planting in relation to weed competitiveness. Decreasing row spacing of wheat will greatly increase its competitive ability (103). For example, when row spacings of 15, 30, and 60 cm were compared for Waldron spring wheat, wild oat seed production was reduced most with the 15-cm spacing, as was shoot dry matter (103, 126). Seed production was 85 g/m^2 for wild oats grown alone and only 7 g/m^2 when wild oats competed with wheat at a 15-cm row spacing. Wild oat seed yield was reduced 83%, averaged across row spacings.

Wheat seeding rate enhanced crop competitiveness with wild oats in England (114). In North Dakota, increasing the seeding rate of Chris spring wheat from 50 to 150 kg/ha decreased the seed yield of wild buckwheat at densities of 54 to 215 plants/m^2 (95).

High wheat planting rates in Canada decreased the competitiveness of both wild oats and wild mustard based on comparisons of 60, 100, and 134 kg/ha seeding rates (68). Little research has been published recently on the influence of seeding rate on weed competition with wheat. It may be that different seeding rates could influence the efficacy of postemergence herbicides for new semidwarf wheat varieties.

Delayed seeding was recommended in the 1940's and 1950's to reduce wild oat infestations in spring wheat (103). However, delayed seeding favors the buildup of foxtails if it is practiced repeatedly and may affect crop quality in other ways. If planting is postponed in the spring, kernel number, size, and weight are decreased, as is spike number per plant. Both dry

Table 4. Weeds declared as noxious weed seed by state seed laws.

Weed: Common name	Weed: Scientific name	Minnesota	Montana	North Dakota	South Dakota
Prohibited weed seed					
Bull thistle	*Cirsium vulgare* (Savi) Tenore # CIRVU	X	–	–	–
Canada thistle	*Cirsium arvense* (L.) Scop. # CIRAR	X	X	X	X
Creeping bellflower	*Campanula rapunculoides* L. # CMPRA	–	X	–	–
Dalmatian toadflax	*Linaria genistifolia* ssp. dalmatica (L.) Maire and Petitmengin # LINDA	–	X	–	–
Field bindweed	*Convolvulus arvensis* L. # CONAR	X	X	X	X
Hairy whitetop	*Cardaria pubescens* (C.A. Mey.) Jarmolenko	–	–	X	–
Halogeton	*Halogeton glomeratus* (Stephen ex Bieb.) C.A. Mey. # HALGL	–	X	–	–
Hoary cress	*Cardaria draba* (L.) Desv. # CADDR	X	X	X	X
Horsenettle	*Solanum carolinense* L. # SOLCA	–	–	–	X
Leafy spurge	*Euphorbia esula* L. # EPHES	X	X	X	X
Marijuana	*Cannabis sativa* L. # CNISA	X	–	–	–
Medusahead	*Taeniatherum caput-medusae* (L.) Nevski # ELYCM	–	X	–	–
Musk thistle	*Carduus nutans* L. # CRUNU	X	–	–	–
Perennial sowthistle	*Sonchus arvensis* L. # SONAR	X	X	X	X
Plumeless thistle	*Carduus acanthoides* L. # CRUAC	X	–	–	–
Quackgrass	*Agropyron repens* (L.) Beauv. # AGRRE	–	X	–	X
Russian knapweed	*Centaurea repens* L. # CENRE	X	X	X	X
Yellow toadflax	*Linaria vulgaris* Mill. # LINVU	–	X	–	–
Restricted weed seed					
Annual bluegrass	*Poa annua* L. # POAAN	–	–	–	X
Black mustard	*Brassica nigra* (L.) W.J.D. Koch # BRSNI	–	–	–	X
Blue mustard	*Chorispora tenella* (Pallas) D.C. # COBTE	–	X	–	–
Buckhorn plantain	*Plantago lanceolata* L. # PLALA	X	X	–	–
Chickweed	*Stellaria* spp.	–	X	–	–
Curly dock	*Rumex crispus* L. # RUMCR	–	X	–	–
Dodder	*Cuscuta* spp.	X	X	X	X
Eastern black nighshade	*Solanum ptycanthum* Dun. # SOLPT	X	–	–	–
Field pennycress	*Thlaspi arvense* L. # THLAR	X	–	X	X
Giant foxtail	*Setaria faberi* Herrm. # SETFA	X	–	–	–
Hedge bindweed	*Calystegia sepium* (L.) R.Br. # CAGSE	–	–	X	X
Hoary alyssum	*Berteroa incana* (L.) D.C. # BEFIN	X	X	–	–
Horsenettle	*Solanum carolinense* L. # SOLCA	X	–	–	–
Indian mustard	*Brassica juncea* (L.) Czern. and Coss. # BRSJU	–	–	–	X
Oxeye daisy	*Chrysanthemum leucanthemum* L. # CHYLE	–	X	–	–
Quackgrass	*Agropyron repens* (L.) Beauv. # AGRRE	X	–	X	–
St. Johnswort	*Hypericum* spp.	–	X	–	–
Spotted knapweed	*Centaurea maculosa* Lam. # CENMA	–	X	–	–
Wild carrot	*Daucus carota* L. # DAUCA	–	–	–	X
Wild mustard	*Sinapis arvensis* L. # SINAR	X	–	X	X
Wild oat	*Avena fatua* L. # AVEFA	–	X	X	X
Wild radish	*Raphanus raphanistrum* L. # RAPRA	X	–	–	–

matter and straw also decrease, as well as leaf area index and green area duration (105). These traits may contribute to crop competitiveness with weeds. Even though delayed seeding was used widely to manage wild oats before grass control herbicides were introduced, it was relatively ineffective (74). Wild oats continue to emerge throughout early summer, even if wheat is seeded very late in the first week of June after repeated spring tillage to stimulate wild oat germination.

Early planting and proper fertilization may make wheat more competitive with foxtails. Wheat planting date also influences its competitiveness with wild sunflower (67). Sunflower was more competitive when semidwarf Era spring wheat was planted in late May compared to earlier seedings. If sunflower was not removed until the late flag leaf stage of wheat, yield was reduced relative to removal at the five-leaf stage. Earlier planting was recommended to manage wild mustard, wild oats, and field pennycress in combination with fertilizer as early as 1938 in Saskatchewan (68).

The influence of planter type and planting itself on weed control has not been researched in the region.

Harvesting. *Harvesting operations.* Most spring wheat in the Northern Great Plains is swathed or windrowed to dry it to about 14% moisture content prior to combine harvesting. There is little direct combining except for winter wheat in Montana. In North Dakota, spring wheat harvest lasts from August 5 to September 25, on average, although the most active period is from August 15 to September 5 (112).

Swathing permits a fast uniform harvest, particularly if seed maturity is variable or green weeds are present (51). If green weeds dry in the swath, they pose less of a combining problem. Swathing also allows damp grain or weeds to dry uniformly, reducing the need for artificial grain drying. However, herbicidal weed control has made it less necessary to dry weed biomass by swathing (39). If wheat is swathed at 35% moisture content or less (51), there is no loss in either seed weight or grade. Wheat yields were highest when the grain was swathed between 25 and 35% moisture content (125). Below 25% moisture content, shattering was a problem. Above 35% moisture, the seed had a greenish color. Swathing below 35% moisture content did not reduce germinability. Generally, swathed grain is cut shorter than grain that is combined directly (51). Swathed grain dries more slowly than standing grain, if it is rained upon (39); thus, weathering and sprouting damage is more likely for swathed than direct-combined grain (44).

The extent to which swathing concentrates weed seed in narrow rows in the field has not been investigated. Most combines do not have efficient straw and chaff spreaders, limiting uniform redistribution of weed seed on fields. Straw and chaff spreaders are important to no-till farmers because dense clumps of straw can interfere with later planting.

Most farmers in North Dakota (67 to 71%) own their own combines (122, 123, 124). Custom combining has moved weed seed from Texas to Canada in the Great Plains because there is little regulation of combine cleaning between farms or even between states (78).

Weed interference with harvest. Some weeds interfere with combing harvesting in addition to reducing yields (Table 5). Wild buckwheat and field bindweed are particular problems because they accumulate on the moving parts of swathers or combines, causing mechanical failure (95, 101). By adding weight to the crop stem, weeds, such as wild buckwheat, contribute to stem breakage and lodging, especially during rain storms and high winds. Dense wild oat stands also can increase lodging. Weeds can slow swathers and combines, increasing harvesting costs. Bushy weeds, such as kochia, also increase field grain losses during harvesting. If moist green weeds are harvested, the grain may need to be cleaned or artificially dried in order to minimize spoilage in storage.

Most dockage is due to weed seed (104). The weight of dockage is either subtracted from the total weight of grain prior to payment or it is reflected in the price. Special seed-cleaning equipment may be needed to remove weed seed, if the wheat is to be replanted. For example, wild buckwheat can be removed from wheat only by using triangular-holed sieves, but some wheat seed is lost.

Residue and weed management after harvest. The amount of straw left after harvest not only depends upon yield, but also whether the wheat was a semidwarf or a standard height variety (14). Generally, the yield-to-straw ratio tends to be higher for semidwarf compared to standard height wheat lines. As wheat yield increases, the ratio of straw to yield decreases. The ratio between the straw produced by a wheat crop and yield ranges from 0.7 to 4.7 in North Dakota (14). Straw on the soil surface is needed for control of wind and water erosion and to improve water infiltration. Cereal and row crop residues should be at least 15 and 75 cm tall, respectively, for catching snow (11). Generally, straw must be spread uniformly, especially if the yield is greater than 3000 kg/ha. Residues covering more than 25% of the soil surface also interfere with seeding and the activity of some herbicides (83).

Residue management after harvest is important for weed control. In studies in Montana, postharvest straw height influenced fall weed growth. When the straw was cut to 0, 15, 28 and 38 cm, the greatest decrease in fall growth and seed production of green foxtail occurred at 38 cm, the same height of cut that increased soil water storage. The area without stubble had the greatest green foxtail densities after planting

Table 5. Weed seed dispersal in relation to harvest.

Weed Species		Seed dispersal in relation to wheat harvest		
Common Name[a]	Scientific name	Before harvest	During harvest	After harvest
Wild mustard	*Sinapis arvensis* L. # SINAR	———		
Field pennycress	*Thlaspi arvensis* L. # THLAR	———		
Wild oat	*Avena fatua* L. # AVEFA	———	———	
Downy brome	*Bromus tectorum* L. # BROTE	———	———	
Canada thistle	*Cirsium arvense* L. # CIRAR	———	———	
Green foxtail*	*Setaria viridis* (L.) # SETVI		———	———
Yellow foxtail*	*Setaria glauca* (L.) Beauv. # SETLU		———	———
Barnyardgrass	*Echinochloa crus-galli* (L.) Beauv. # ECHCG		———	———
Quackgrass	*Agropyron repens* L. # AGRRE		———	———
Redroot pigweed*	*Amaranthus retroflexus* L. # AMARE		———	———
Kochia*	*Kochia scoparia* (L.) Schrad. # KCHSC		———	———
Wild buckwheat*	*Polygonum convolvulus* L. # POLCO		———	———
Common lambsquarters*	*Chenopodium album* L. # CHEAL		———	———
Field bindweed*	*Convolvulus arvensis* L. # CONAR		———	———
Russian thistle	*Salsola iberica* Sennen and Pau # SASKR		———	———
Wild sunflower	*Helianthus annuus* L. # HELAN			———
Common ragweed	*Ambrosia artemisiifolia* L. # AMBEL			———
Common milkweed	*Asclepias syriaca* L. # ASCSY			———

[a] Harvesting problem = *

winter wheat. Thus, not only fall tillage but stubble management may influence weed competition.

Several species can set seed after harvest, including foxtails and kochia (Table 5). Thus, the time between harvest and cereal stubble cultivation is important to weed seed production and future weed problems (87, 88). Fall tillage soon after harvest may prevent foxtail seed production, especially in more northern parts of the region (74). Tillage may be of limited usefulness if the seed have already matured or shattered. Fall rains in the region may cause sprouting of volunteer wheat, wild oats, wild mustard, and field pennycress. Postharvest weed control is important to conserve soil moisture after wheat harvest (38), especially in Montana (85).

Crop Rotation. *Rotations for continuous cropping.* Continuous cropping is possible only where there is adequate precipitation in the central and eastern part of the Northern Great Plains (54, 55, 56). Many regional cropping practices are determined, in part, by annual precipitation. Growing continuous wheat is not recommended because it promotes increases in weed, disease, and insect problems (117).

The types of crops preceding wheat can influence wheat yield (3, 4). Continuous wheat yielded less than wheat following corn (3, 4, 70, 71). As one moves westward, the proportion of land devoted to corn decreases while that devoted to perennial grasses and legumes for forage increases. Legumes in the rotation have the potential of increasing both corn and wheat yields, especially in areas of relatively high precipitation. However, if precipitation is low, wheat yields can be reduced following legumes. In eastern North Dakota, wheat yielded more in conventional tillage or no-till systems after flax, corn, soybean, sugarbeet, or sunflower than after barley or wheat.

Recently, a flexible cropping system was developed in which the decision to plant cereals or to fallow land is determined by available soil moisture at planting (38). Flexible cropping involves a nonsystematic adaptation of fallow and arable cropping, rather than rigid adherence to a wheat-fallow rotation. Generally, wheat and barley have yielded satisfactorily in central North Dakota and eastern Montana using flexible cropping. Crops are sown in those years when stored soil water and growing season precipitation are sufficient for adequate crop yields. Rigid adherence to a wheat-fallow or a crop-fallow sequence may not be as productive as a flexible cropping system and may lead to the buildup of grass weeds, such as downy brome (*Bromus tectorum* L. # BROTE) in winter wheat or foxtails and wild oats in spring wheat (38). Inclusion of oilseed crops, such as safflower or sunflower, in rotation has been valuable for managing many weeds of cereals because different herbicides can be used. Such a cropping system also may reduce soil erosion and formation of saline seeps (38).

The adoption of flax or tall wheatgrass barrier systems to catch snow may allow sufficient moisture to be stored to permit continuous cropping in the western half of the region (27, 28). At Sidney, MT, twin rows of tall wheatgrass spaced 90 cm apart and planted at intervals of 14.5 m were used to catch snow and increase moisture infiltration, permitting continuous cropping.

Continuous cropping and weed buildup. Crop rotations influence the buildup of weed problems. In an 8-yr study comparing various rotations at Sidney, MT, continuous spring wheat failed after 5 yr due to the buildup of grass weeds, mostly green foxtail and wild oats (27, 28). Continous winter wheat failed after 6 yr due to increases in downy brome. Thus, neither continuous spring nor winter wheat was practical without herbicides due to increases of grass weeds. However, rotations of spring and winter prevented buildup of these problem weeds without using herbicides. In Montana, inclusion of a spring-sown crop, such as barley, in a winter wheat-barley-fallow rotation controlled winter annual weeds, such as downy brome (54). In continuous barley, wild oats and green foxtail increased, as in continuous spring wheat. Dubbs (54) suggested that including an oilseed crop in a rotation also could be used to break wheat disease cycles. Appropriate use of herbicides also could reduce the buildup or severity of weed problems. In related research, Dubbs (54) observed that in a winter wheat-fallow rotation, downy brome increased significantly after 3 yr, supporting the findings of Black and Siddoway (27, 28). Delayed seeding did not reduce the severity of the problem, and root rots and *Cephalosporium* stripe developed as disease problems. In contrast, in a winter wheat-barley-fallow rotation, neither root rot diseases nor downy brome developed as problems. In contrast to the results of Black and Siddoway (27, 28), grass weeds did not develop in continuous spring wheat after 8 yr. In Montana, winter wheat can be a volunteer weed problem in barley, oats, and spring wheat. Generally, volunteer winter wheat is not a major problem in conventional-tillage systems because seedbed preparation controls it. As more winter wheat is grown in no-till cropping systems in the eastern part of the Northern Great Plains, volunteer winter wheat may become a concern.

Seeding spring wheat after safflower or sunflower that was treated with trifluralin may be valuable in managing the buildup of grass weeds, especially foxtails (27, 28, 74). Barley tended to yield more after safflower than after winter wheat because of the residual effect of trifluralin in reducing the severity of green foxtail and wild oats. There also may be some advantage in alternating winter wheat with spring-sown crops, including oilseeds or other spring cereals, such as wheat or barley, to prevent the buildup of foxtails on farmland (27, 28, 54, 74).

Crop rotation has not been researched in detail as a weed management practice, despite its obvious potential. Fundamental information on weed biology and the long-term aspect of crop rotations are needed for proper use of crop rotation in a weed control system. The recent introduction of zero or minimum tillage should force researchers to consider tillage rotation for weed management, as well as crop and herbicide rotation.

Fallow. In spring wheat, the fallow period lasts approximately 21 months and spans two winters (Figure 14) (145). Weeds are the greatest problem in fallow (62). Disks, sweep cultivators, and rod weeders are most commonly used for fallow weed control (23). If weeds are not a problem following harvest, the straw may be left over winter to catch snow (31). However, if rains cause some fall weed growth, usually volunteer cereals, the land may be tilled with either a chisel-type or small-bladed implement in fall (31). Weeds must be controlled in order to prevent loss of soil moisture and to facilitate their control during the subsequent summer fallow. If straw residues are heavy, greater than 3000 to 4000 kg/ha, disks are used which leave approximately 50 % of the residue (23). In the following season, the area may be cultivated three or four times with a field cultivator depending upon rainfall and subsequent flushes of weeds. In late summer, rod weeders might be used exclusively, usually operated at a minimum depth to keep residue on the surface. Rod weeders that are operated too shallowly may pulverize the soil surface and leave the residue loose and subject to erosion.

The portion of fallowed land increases as one moves westward in the Northern Great Plains. A minimum of 3, 5, and 7 fallow tillage operations are needed in western, central, and eastern North Dakota, respectively (81). In the east, heavier and more frequent rains favor successive flushes of weeds over a longer period throughout summer.

Fallow land is tilled to control weeds and volunteer grain, prevent weed seed production, and reduce water loss by evapotranspiration (62). Annual weeds are believed to be less troublesome in wheat after fallowing than after a crop (54), although data are lacking. In addition, fallowing by tillage leaves the soil surface in condition for increased infiltration and deeper penetration of water.

The primary reason for summer fallow has been to provide more stable production and higher yield per planted hectare than is provided by continuous cropping. Fallowed land tends to have more available soil nitrogen and fewer insect and disease problems. A fallow-crop rotation is more advantageous than continuous cropping because of increased soil water storage and available soil nitrogen (13). However, these advantages may not occur every year or on every soil.

Bauer (13) has reviewed the relative contribution of water storage in fallow to wheat yields versus continuous cropping. Increased crop yields following fallow is well documented (3, 4, 13, 31). In Montana, yields of spring and winter were 40 and 50 % higher following fallow, respectively, compared to continuous cropping (145).

Black, et al. (31) summarized the disadvantages of summer fallow as increased wind and water erosion, as well as air and water pollution. Fallowing in the Northern Great Plains results in low, inefficient soil water storage and reduces long-term soil fertility, chiefly by nitrogen mineralization from organic matter (22). Summer fallow tillage is costly and results in the loss of production in a given year (3, 4). Fallow also may decrease long-term soil productivity because of both erosion and accelerated development of saline seeps.

Technological and economic changes have influenced the proportion of fallowed land in the Northern Great Plains. Increased use of improved crop varieties, fertilizer nitrogen, and selective herbicides allows farmers to achieve yields that are comparable in continuous cropping to those in a wheat-fallow rotation. In addition, continuous cropping reduces the chance of soil problems, such as saline seeps.

Ali and Johnson (3, 4) reviewed the short-term economics of summer fallow in North Dakota. Profitability depended on crop value, production costs, fertilizer nitrogen costs, the cost of fallow tillage, and the value from increased yield stability in a wheat-fallow cropping system. High wheat prices favor continuous cropping, whereas fallowing increases if nitrogen costs are high. Only in the western third of North Dakota and eastern Montana and the western third of South Dakota was the spring wheat-fallow rotation profitable and, then, only with adequate fertilization (145).

In 1969, fallow hectarage in North Dakota was greater than wheat hectarage but fallowing has decreased steadily since then (84). This decline was attributed to more efficient methods of weed control, including new herbicides. Because nitrogen use has increased, nitrogen mineralization during fallow is not now as critical to crop production. Additional crops, such as sunflower and safflower, were added to the rotation. Soil conservation and higher cash rent also have contributed to the decline of fallow. As yields become more variable toward the western part of the Northern Great Plains, fallowing tends to be more advantageous. As yields or wheat prices increase, continuous cropping, including wheat, tends to increase. Fallowing is favored when yields and prices are low, or when nitrogen fertilizer prices are high.

Fallow is an accepted practice in the region for reducing the severity of weed problems (54, 81), but this belief is undocumented in the scientific literature. The relative efficacy of chemical or mechanical fallow on individual weed species has not been studied.

Weed Problems in Relation To Wheat Growth. *Annual grass weeds.* In the late 1970's, North Dakota, South Dakota, and Minnesota conducted scientific surveys of the distribution of problem weeds of wheat (Tables 6, 7, and 8, respectively). No surveys have been conducted in Montana at the time of writing this review. These initial studies in the late 1970's will serve as a valuable benchmark to document future changes in weeds. No grass weeds have been designated noxious weeds by state law (Table 9).

Montana weed scientists report that wild oats, green foxtail, and Persian darnel (*Lolium persicum* Boiss. and Hohen. ex Boiss # LOLPS) are major grass weeds in spring wheat (59,74). Under no-till conditions, downy brome overwinters and can be a serious problem in spring wheat if established plants are not controlled at planting.

Wild oats, green foxtail, and yellow foxtail are the major grass weed problems of spring wheat in North Dakota (50, 52), South Dakota (8), and Minnesota (16). At the turn of the century, these same weeds were of concern to North Dakota wheat producers (139).

Wild oat infestations were severe in the late 1960's and 1970's, even though triallate and barban (4-chloro-2-butynyl-3-chlorophenylcarbamate) were available for wild oat control. Wild oat infestations are now less obvious in fields prior to harvest with the advent of diclofop {(±)-2-[4-(2,4-dichlorophenoxy)phenoxy]propanoic

Table 6. Weed infestations in spring wheat fields in North Dakota in 1979 (50).

Weed species		Weed frequency	Field uniformity		Weed density		Density range		Weed index
			(%)		(plants/m²)		(plants/m²)		
Common name	Scientific name	(%)	All	Inf.	All	Inf.	Low	High	
Green foxtail	*Setaria viridis* (L.) Beauv. # SETVI	95	81.9	86.3	70.7	74.6	0.2	396.0	278.5
Wild oat	*Avena fatua* L. # AVEFA	67	29.8	44.5	5.1	7.6	0.2	289.0	64.0
Redroot pigweed	*Amaranthus retroflexus* L. # AMARE	67	23.5	35.1	4.5	6.7	0.2	197.8	56.4
Wild buckwheat	*Polygonum convolvulus* L. # POLCO	66	26.0	39.3	2.8	4.2	0.2	89.8	54.6
Yellow foxtail	*Setaria glauca* (L.) Beauv. # SETLU	27	12.9	47.5	6.5	24.1	0.2	346.4	37.1
Common lambsquarters	*Chenopodium album* L. # CHEAL	40	10.8	27.0	1.4	3.4	0.2	104.6	27.2
Wild mustard	*Sinapis arvensis* L. # SINAR	39	11.1	28.7	1.3	3.3	0.2	146.0	27.0
Russian thistle	*Salsola iberica* Sennen and Pau # SASKR	33	10.0	30.3	1.6	4.9	0.2	68.0	24.6
Kochia	*Kochia scoparia* (L.) Schrad. # KCHSC	27	5.4	20.3	0.7	2.7	0.2	62.0	16.0
Field bindweed	*Convolvulus arvensis* L. # CONAR	19	7.1	36.5	1.0	5.0	0.2	34.4	15.8
Canada thistle	*Cirsium arvense* L. # CIRAR	17	3.4	19.8	0.4	2.3	0.2	23.0	10.1
Prostrate pigweed	*Amaranthus blitoides* S. Wats. # AMABL	15	3.3	22.3	0.4	2.9	0.2	31.6	9.3
Volunteer sunflower	*Helianthus annuus* L.	15	3.3	22.2	0.4	2.6	0.2	48.2	9.2
Nightflowering catchfly	*Silene noctiflora* L. # MELNO	8	2.7	35.7	0.4	4.8	0.2	41.0	6.1
Wild rose	*Rosa* sp.	11	1.7	14.8	0.1	1.2	0.2	13.0	5.7
Field pennycress	*Thlaspi arvense* L. # THLAR	9	1.5	17.3	0.2	1.9	0.2	35.2	4.8
Perennial sowthistle	*Sonchus arvensis* L. # SONAR	8	1.6	19.9	0.2	2.0	0.2	18.2	4.7
Prostrate spurge	*Euphorbia humistrata* Engelm. ex Gray # EPHHT	8	1.3	15.7	0.1	1.3	0.2	18.8	4.4
Common cocklebur	*Xanthium strumarium* L. # XANST	7	1.6	23.8	0.2	2.7	0.2	18.0	4.1
Quackgrass	*Agropyron repens* (L.) Beauv. # AGRRE	5	1.4	31.3	0.3	5.8	0.4	29.2	3.6
Common purslane	*Portulaca oleracea* L. # POROL	4	0.7	18.9	0.2	6.1	0.2	69.6	2.5
Flixweed	*Descurainia sophia* (L.) Webb. ex Prantl # DESSO	4	0.7	14.9	<0.1	1.1	0.2	6.4	2.2
Ragweed	*Ambrosia* sp.	4	0.5	11.7	<0.1	1.1	0.2	10.8	1.9
Little mallow	*Malva parviflora* L. # MALPA	3	0.5	13.2	<0.1	1.0	0.2	6.8	1.7
Barnyardgrass	*Echinochloa crus-galli* (L.) Beauv. # ECHCG	2	0.5	19.1	<0.1	1.4	0.2	4.0	1.4
Marshelder	*Iva xanthifolia* Nutt. # IVAXA	2	0.5	23.2	0.1	2.4	0.2	15.2	1.3
Greenflower pepperweed	*Lepidium densiflorum* Schrad. # LEPDE	2	0.4	15.5	<0.1	1.2	0.2	7.8	1.3
Leafy spurge	*Euphorbia esula* L. # EPHES	1	0.3	25.9	0.1	5.5	0.4	32.2	0.9
Skeletonweed	*Lygodesmia juncea* (Pursh) D. Don # LYGJU	2	0.2	13.0	<0.1	0.7	0.2	2.2	0.8
Common milkweed	*Asclepias syriaca* L. # ASCSY	2	0.2	13.6	<0.1	1.1	0.2	3.6	0.8
Yellow woodsorrel	*Oxalis stricta* L. # OXAST	2	0.3	16.4	<0.1	1.3	0.2	7.0	0.8
Dandelion	*Taraxacum officinale* Weber in Wiggers # TAROF	1	0.3	26.0	<0.1	3.1	0.2	19.6	0.7
Wild barley	*Hordeum* sp.	1	0.1	11.4	0.1	4.3	0.2	24.8	0.7
Large crabgrass	*Digitaria sanguinalis* (L.) Scop. # DIGSA	1	0.3	37.5	<0.1	2.4	0.2	6.2	0.7
Smartweed	*Polygonum* sp.	1	0.2	11.7	<0.1	1.0	0.2	2.8	0.6
Prickly lettuce	*Lactuca serriola* L. # LACSE	1	0.1	10.5	<0.1	1.0	0.2	4.0	0.5
Fumitory	*Fumaria officinalis* L. # FUMOF	1	0.3	46.0	<0.1	4.6	0.4	9.6	0.5
Volunteer millet	*Panicum* sp.	<1	0.2	55.0	0.1	24.0	1.6	67.4	0.5
Downy brome	*Bromus tectorum* L. # BROTE	1	0.1	15.0	<0.1	2.2	0.2	6.4	0.4
Dock	*Rumex* sp.	1	0.1	10.0	<0.1	0.7	0.2	2.0	0.4
Volunteer soybean	*Glycine max* L.	<1	0.1	23.7	<0.1	1.3	0.2	3.2	0.3
Clover	*Melilotus* sp.	1	0.1	10.0	<0.1	0.8	0.2	1.8	0.3
Knotweeds	*Polygonum* sp.	1	0.1	16.0	<0.1	1.1	0.2	2.4	0.3
False chamomile	*Matricaria maritima* L. # MATMA	1	0.1	13.0	<0.1	0.7	0.2	1.4	0.3
Wild vetch	*Vicia* sp.	1	0.1	7.5	<0.1	0.4	0.2	1.0	0.3
Common mallow	*Malva neglecta* Wallr. # MALNE	<1	0.1	16.7	<0.1	1.2	0.2	3.0	0.2
Hedge bindweed	*Calystegia sepium* (L.) R.Br. # CAGSE	<1	0.1	23.3	<0.1	1.9	0.2	3.0	0.2
Sandbur	*Cenchrus* sp.	<1	0.1	16.7	<0.1	0.9	0.2	1.8	0.2
Volunteer alfalfa	*Medicago sativa* L.	<1	0.1	23.3	<0.1	1.3	0.2	3.4	0.2
Austrian fieldcress	*Rorippa austriaca* (Crantz) Bess. # RORAU	<1	0.1	37.5	<0.1	3.4	2.6	4.2	0.2
Shepherdspurse	*Capsella bursa-pastoris* (L.) Medik. # CAPBP	1	<0.1	6.0	<0.1	0.2	0.2	0.4	0.2
Volunteer corn	*Zea mays* L.	<1	0.1	25.0	<0.1	2.9	0.8	5.0	0.1
Silvery cinquefoil	*Potentilla argentea* L. # PTLAG	<1	<0.1	15.0	<0.1	1.1	0.2	2.0	0.1
Scurf pea	*Pisum* sp.	<1	<0.1	5.0	<0.1	0.6	0.4	0.8	0.1
Povertyweed	*Monolepis* sp.	<1	<0.1	20.0	<0.1	3.2	3.2	3.2	0.1
Witchgrass	*Panicum capillare* L. # PANCA	<1	<0.1	8.3	<0.1	0.6	0.2	1.2	0.1
Horsetail	*Equisetum* sp.	<1	<0.1	30.0	<0.1	2.6	2.6	2.6	0.1
Volunteer flax	*Linum usitatissimum* L.	<1	<0.1	7.5	<0.1	1.9	0.8	3.0	0.1
Waterpod	*Ellisia nyctelea* L. # ELSNY	<1	<0.1	10.0	<0.1	0.8	0.2	1.4	0.1
Western salsify	*Tragopogon dubius* Scop. # TRODM	<1	<0.1	5.0	<0.1	0.2	0.2	0.2	<0.1
Flodman thistle	*Cirsium flodmanii* (Rydb.) Arthur	<1	<0.1	5.0	<0.1	0.2	0.2	0.2	<0.1
Bromegrass	*Bromus* sp.	<1	<0.1	5.0	<0.1	0.2	0.2	0.2	<0.1
Volunteer rye	*Secale cereale* L.	<1	<0.1	5.0	<0.1	0.2	0.2	0.2	<0.1
Weed free	–	16	2.8	17.3	–	–	–	–	–

Table 7. Weed infestations in spring wheat fields in South Dakota in 1979 (N = 441) (8).

Weed species		Weed frequency	Field uniformity		Weed density		Density range		Weed index
			(%)		(plants/m²)		(plants/m²)		
Common name	Scientific name	(%)	All	Inf.	All	Inf.	Low	High	
Foxtail	*Setaria* sp.	95.69	80.81	77.32	184.12	176.19	0.80	1552.80	520.33
Wild buckwheat	*Polygonum convolvulus* L. # POLCO	53.74	37.38	20.09	11.71	6.29	0.80	93.60	52.69
Kochia	*Kochia scoparia* (L.) Schrad. # KCHSC	48.98	28.10	13.76	14.10	6.91	0.80	331.20	46.21
Russian thistle	*Salsola iberica* Sennen and Pau # SASKR	43.31	29.87	12.94	14.92	6.46	0.80	296.00	42.45
Redroot pigweed	*Amaranthus retroflexus* L. # AMARE	38.55	23.76	9.16	20.58	7.93	0.80	782.40	40.52
Field bindweed	*Convolvulus arvensis* L. # CONAR	34.24	31.32	10.73	9.70	3.32	0.80	57.60	29.89
Wild oat	*Avena fatua* L. # AVEFA	33.56	25.41	8.53	12.24	4.11	0.80	117.60	29.30
Common lambsquarters	*Chenopodium album* L. # CHEAL	35.83	23.20	8.31	9.35	3.35	0.80	120.00	28.07
Volunteer sunflower	*Helianthus annuus* L. # HELAN	17.69	15.45	2.73	3.53	0.62	0.80	27.20	10.08
Common purslane	*Portulaca oleracea* L. # POROL	5.44	27.08	1.47	33.90	1.84	0.80	309.60	7.59
Prostrate pigweed	*Amaranthus blitoides* S. Wats. # AMABL	4.99	23.18	1.16	38.95	1.94	0.80	713.60	7.35
Yellow woodsorrel	*Oxalis stricta* L. # OXAST	11.34	16.50	1.87	4.75	0.54	0.80	33.60	6.91
Wild rose	*Rosa* sp.	12.24	12.31	1.51	2.92	0.36	0.80	16.80	6.42
Unknown	—	2.72	17.92	0.49	72.40	1.97	0.80	841.60	5.99
Wild mustard	*Sinapis arvensis* L. # SINAR	7.26	18.59	1.35	3.55	0.26	0.80	13.60	4.37
Canada thistle	*Cirsium arvense* L. # CIRAR	7.26	15.63	1.13	4.52	0.33	0.80	24.00	4.32
Common ragweed	*Ambrosia artemisiifolia* L. #AMBEL	7.26	13.28	0.96	4.10	0.30	0.80	55.20	4.08
Milkweed	*Asclepias* sp.	7.71	7.65	0.59	1.65	0.13	0.80	4.80	3.46
Volunteer alfalfa	*Medicago sativa* L.	4.08	26.39	1.08	7.69	0.31	0.80	34.40	3.17
Volunteer sweetclover	*Melilotus* sp.	3.40	21.33	0.73	9.39	0.32	0.80	52.80	2.60
Proso millet	*Panicum miliaceum* L. # PANMI	1.59	28.57	0.45	11.89	0.19	0.80	44.80	1.42
White campion	*Silene alba* (Mill.) E.H.L. Krause	1.59	29.29	0.46	8.23	0.13	0.80	26.40	1.30
Witchgrass	*Panicum capillare* L. # PANCA	1.36	30.83	0.42	11.87	0.16	0.80	37.60	1.25
Hedge bindweed	*Calystegia sepium* (L.) R.Br. # CAGSE	2.04	12.22	0.25	3.29	0.07	0.80	8.00	1.09
Buffalobur	*Solanum rostratum* Dun. # SOLCU	1.81	10.00	0.18	1.80	0.03	0.80	4.00	0.86
Spotted spurge	*Euphorbia maculata* L. # EPHMA	1.59	14.29	0.23	2.40	0.04	0.80	6.40	0.84
Ladysthumb	*Polygonum persicaria* L. # POLPE	1.13	15.00	0.17	6.08	0.07	0.80	12.80	0.71
Perennial sowthistle	*Sonchus arvensis* L. # SONAR	1.13	9.00	0.10	1.60	0.02	0.80	3.20	0.52
Common mallow	*Malva neglecta* Wallr. # MALNE	1.13	7.00	0.08	1.44	0.02	0.80	2.40	0.50
Common cocklebur	*Xanthium strumarium* L. # XANST	0.91	12.50	0.11	4.00	0.04	0.80	10.40	0.50
Volunteer corn	*Zea mays* L.	1.13	7.00	0.08	1.12	0.01	0.80	2.40	0.49
Volunteer oat	*Avena sativa* L.	0.23	80.00	0.18	35.20	0.08	35.20	35.20	0.44
Field pennycress	*Thlaspi arvense* L. # THLAR	0.91	8.75	0.08	2.20	0.20	0.80	3.20	0.43
Ivyleaf morningglory	*Ipomoea hederacea* (L.) Jacq. # IPOHE	0.45	37.50	0.17	9.20	0.04	0.80	17.60	0.42
Prostrate spurge	*Euphorbia humistrata* Engelm. ex Gray # EPHHT	0.45	25.00	0.11	10.40	0.05	0.80	20.00	0.37
Prickly lettuce	*Lactuca serriola* L. # LACSE	0.45	22.50	0.10	5.20	0.02	0.80	9.60	0.31
Spikeleaf sage	*Salvia* sp.	0.23	50.00	0.11	19.20	0.04	19.20	19.20	0.29
Dandelion	*Taraxacum officinale* Weber in Wiggers # TAROP	0.68	6.67	0.05	1.07	0.01	0.80	1.60	0.29
Quackgrass	*Agropyron repens* (L.) Beauv. # AGRRE	0.45	7.50	0.03	6.00	0.03	1.60	10.40	0.25
Cutleaf nightshade	*Solanum triflorum* Nutt. # SOLTR	0.23	40.00	0.09	10.40	0.02	10.40	10.40	0.22
Volunteer flax	*Linum usitatissimum* L.	0.45	10.00	0.05	1.60	0.01	1.60	1.60	0.21
Skeletonweed	*Lygodesmia juncea* (Pursh) D.Don # LYGJU	0.45	10.00	0.05	1.60	0.01	0.80	2.40	0.21
Velvetleaf	*Abutilon theophrasti* Medik. # ABUTH	0.23	25.00	0.06	4.00	0.01	4.00	4.00	0.15
Volunteer barley	*Hordeum vulgare* L.	0.23	15.00	0.03	4.00	0.01	4.00	4.00	0.13
Perennial ryegrass	*Lolium perenne* L.	0.23	5.00	0.01	8.00	0.02	8.00	8.00	0.13
Tall thistle	*Cirsium altissimum* (L.) Spreng. # CIRAL	0.23	10.00	0.02	2.40	0.01	2.40	2.40	0.11
Black nightshade	*Solanum nigrum* L. # SOLNI	0.23	5.00	0.01	1.60	0.00	1.60	1.60	0.10
Prairie sage	*Salvia* sp.	0.23	5.00	0.01	2.40	0.01	2.40	2.40	0.10
Fringed sagebrush	*Artemisia frigida* Willd. # ARTFR	0.23	5.00	0.01	0.80	0.00	0.80	0.80	0.09
White field aster	*Aster* sp.	0.23	5.00	0.01	0.80	0.00	0.80	0.80	0.09
Volunteer rye	*Secale cereale* L.	0.23	5.00	0.01	0.80	0.00	0.80	0.80	0.09
Pricklypear	*Opuntia* sp.	0.23	5.00	0.01	0.80	0.00	0.80	0.80	0.09
Barnyardgrass	*Echinochloa crus-galli* (L.) Beauv. #ECHCG	0.23	5.00	0.01	0.80	0.00	0.80	0.80	0.09
Weed free	—	26.76	22.80	6.10	-	-	-	-	-

acid} and difenzoquat, the expanded use of triallate as a preplant fall treatment, and the use of barban at up to 0.5 kg ai/ha with liquid nitrogen fertilizer.

Green and yellow foxtail became important weeds in wheat during the 1970's. Foxtails probably increased in abundance because of a change from moldboard to chisel plowing for primary tillage. Because chisel plowing keeps foxtail seed near the soil surface, it encourages successful germination, establishment, and growth. Foxtail densities vary widely from year

Table 8. Weed infestations in spring wheat fields in Minnesota in 1979 (N=320) (16).

Weed species		Weed frequency	Field uniformity (%)		Weed density (plants/m²)		Density range (plants/m²)		Weed index
Common name	Scientific name	(%)	All	Inf.	All	Inf.	Low	High	
Green foxtail	*Setaria viridis* (L.) Beauv. # SETVI	63.0	42.1	66.4	25.3	39.4	0.2	460.2	121.6
Wild buckwheat	*Polygonum convolvulus* L. # POLCO	60.0	20.0	33.4	2.2	3.6	0.2	38.4	45.1
Wild oat	*Avena fatua* L. # AVEFA	59.0	23.7	40.0	4.5	7.6	0	73.4	54.1
Yellow foxtail	*Setaria glauca* (L.) Beauv. # SETLU	46.0	26.6	57.6	12.3	26.6	0.2	526.0	70.7
Pigweed sp.	*Amaranthus* sp.	38.0	9.7	25.7	1.4	3.6	0.2	73.0	25.5
Smartweed sp.	*Polygonum* sp.	36.0	10.5	29.3	1.5	4.2	0.2	38.2	26.2
Canada thistle	*Cirsium arvense* L. # CIRAR	36.0	8.2	22.9	0.7	2.0	0.2	9.4	21.9
Common lambsquarters	*Chenopodium album* L. # CHEAL	31.0	9.2	29.9	0.9	3.0	0.2	26.6	21.5
Wild mustard	*Sinapis arvensis* L. # SINAR	27.0	5.5	20.6	0.4	1.5	0	13.0	15.4
Perennial sowthistle	*Sonchus arvensis* L. # SONAR	19.0	3.2	16.9	0.4	1.9	0.2	19.2	10.2
Common milkweed	*Asclepias syriaca* L. # ASCSY	11.0	1.5	13.2	0.1	0.8	0.2	3.4	5.4
Common ragweed	*Ambrosia artemisiifolia* L. # AMBEL	10.0	3.1	29.8	0.4	4.0	0.2	21.2	7.5
Barnyardgrass	*Echinochloa crus-galli* (L.) Beauv. # ECHCG	10.0	2.8	27.7	0.7	7.4	0.2	81.2	7.8
Giant foxtail	*Setaria faberi* Herrm. # SETFA	10.0	3.1	32.1	1.1	11.7	0.2	166.2	9.0
Quackgrass	*Agropyron repens* (L.) Beauv. # AGRRE	8.0	2.2	28.4	0.4	4.8	0.4	18.8	5.7
Volunteer sunflower	*Helianthus annuus* L.	7.0	1.9	27.0	0.2	3.5	0.2	29.2	4.7
Kochia	*Kochia scoparia* (L.) Schrad. # KCHSC	6.0	1.2	19.3	0.1	1.5	0.2	4.2	3.5
Nightflowering catchfly	*Silene noctiflora* L. # MELNO	5.0	2.6	48.8	0.3	6.4	0.2	16.0	5.2
Marshelder	*Iva xanthifolia* Nutt. # IVAXA	5.0	1.0	19.1	0.1	1.2	0.2	5.6	2.8
Black nightshade	*Solanum nigrum* L. # SOLNI	5.0	1.5	32.7	0.2	3.9	0.2	16.0	3.5
Common cocklebur	*Xanthium strumarium* L. # XANST	4.0	1.0	23.2	0.1	1.8	0.2	4.2	2.7
Russian thistle	*Salsola iberica* Sennen and Pau # SASKR	4.0	0.7	16.5	0.1	2.4	0.2	23.8	2.3
White campion	*Silene alba* (Mill.) E.H.L. Krause # MELAL	3.0	0.8	31.3	0.1	2.5	0.2	5.2	1.8
Giant ragweed	*Ambrosia trifida* L. # AMBTR	3.0	0.4	16.9	0	1.2	0.2	4.6	1.3
Black medic	*Medicago lupulina* L. # MEDLU	2.0	0.5	22.1	0.1	2.7	0.2	13.2	1.4
Volunteer soybean	*Glycine max* L.	1.0	0.3	20.0	0	1.3	0.6	2.6	0.7
Velvetleaf	*Abutilon theophrasti* Medik. # ABUTH	1.0	0.3	25.0	0	2.7	0.8	6.0	0.8
Yellow woodsorrell	*Oxalis stricta* L. # OXAST	1.0	0.2	16.3	0	2.5	0.4	6.4	0.7
Arkansas rose	*Rosa* sp.	1.0	0.1	6.3	0	0.4	0.2	0.6	0.5
Common mallow	*Malva neglecta* Wallr. # MALNE	1.0	0.2	18.8	0	1.3	0.6	2.4	0.7
Buffalobur	*Solanum rostratum* Dun. # SOLCU	1.0	0.1	10.0	0	0.5	0.4	0.6	0.4
Hedge bindweed	*Calystegia sepium* (L.) R.Br. # CAGSE	1.0	0.4	38.3	0	4.1	0.4	11.0	0.8
Plantain sp.	*Plantago* sp.	1.0	0.1	13.3	0.1	5.9	0.6	16.4	0.6
Field pennycress	*Thlaspi arvense* L. # THLAR	1.0	0	5.0	0	0.3	0.2	0.6	0.4
Curly dock	*Rumex crispus* L. # RUMCR	1.0	0.1	8.3	0	0.5	0.2	0.6	0.4
Field horsetail	*Equisetum arvense* L. # EQUAR	1.0	0.1	8.3	0	1.5	0.2	3.6	0.4
Witchgrass	*Panicum capillare* L. # PANCA	1.0	0.4	41.7	0.1	10.7	0.2	30.0	0.9
Field bindweed	*Convolvulus arvensis* L. # CONAR	1.0	0.3	45.0	0	3.8	3.2	4.4	0.5
Cowcockle	*Vaccaria segetalis* (Neck.) Garcke ex Ashers. # VAAPY	1.0	0	5.0	0	0.4	0.4	0.4	0.2
Fall panicum	*Panicum dichotomiflorum* Michx. # PANDI	1.0	0.1	15.0	0	1.7	0.4	3.0	0.3
Ragweed	*Ambrosia* sp.	1.0	0	7.5	0	2.2	0.8	3.6	0.3
Dandelion	*Taraxacum officinale* Webber in Wiggers # TAROF	1.0	0.1	17.9	0	1.4	0.6	2.2	0.3
Mint sp.	*Mentha* sp.	0	0.1	35.0	0	1.4	1.4	1.4	0.2
Field sandbur	*Cenchrus incertus* M.A. Curtis # CCHIN	0	0	5.0	0	0.2	0.2	0.2	0.1
Wild sunflower	*Helianthus annuus* L. # HELAN	0	0	5.0	0	0.4	0.4	0.4	0.1
American germander	*Teucrium canadense* L. # TEUCA	0	0.3	85.0	0.1	18.8	18.8	18.8	0.5
Vervain sp.	*Verbena* sp.	0	0.2	75.0	0	7.4	7.4	7.4	0.4
Virginia copperleaf	*Acalypha virginica* L. # ACCVI	0	0	5.0	0	0.2	0.2	0.2	0.1
Violet sp.	*Viola* sp.	0	0.1	30.0	0	1.4	1.4	1.4	0.2
Prostate knotweed	*Polygonum aviculare* L. # POLAV	0	0	5.0	0	0.2	0.2	0.2	0.1
Crabgrass	*Digitaria* sp.	0	0	10.0	0	0.4	0.4	0.4	0.1
Wild carrot	*Daucus carota* L. # DAUCA	0	0	15.0	0	1.2	1.2	1.2	0.2
Horseweed	*Conyza canadensis* (L.) Cronq. # ERICA	0	0.1	25.0	0	7.8	7.8	7.8	0.2
Rough cinquefoil	*Potentilla norvegica* L. # PTLNO	0	0.1	35.0	0	1.8	1.8	1.8	0.2
Catnip	*Nepeta cataria* L. # NEPCA	0	0	15.0	0	1.6	1.6	1.6	0.2
Shepherdspurse	*Capsella bursa-pastoris* (L.) Medik. # CAPBP	0	0	5.0	0	0.2	0.2	0.2	0.1
Yellow nutsedge	*Cyperus esculentus* L. # CYPES	0	0.1	40.0	0	11.2	11.2	11.2	0.3
Hawksbeard sp.	*Crepis* sp.	0	0	5.0	0	0.2	0.2	0.2	0.1

to year. Foxtails have been less evident in the 1980's than in the 1970's. The use of diclofop, trifluralin, propanil, metsulfuron, and chlorsulfuron all may have contributed to the decreased incidence of foxtail in North Dakota even though less competitive semidwarf wheats now are

Table 9. Noxious weeds according to state weed control laws.

Weed		Minnesota	Montana	North Dakota	South Dakota
Common name	Scientific name				
Absinth wormwood	*Artemisia absinthium* L. # ARTAB	–	–	X	–
Bull thistle	*Cirsium vulgare* (Savi) Tenore # CIRVU	X	–	–	–
Canada thistle	*Cirsium arvense* (L.) Scop. # CIRAR	X	X	X	X
Field bindweed	*Convolvulus arvensis* L. # CONAR	X	X	X	X
Hoary cress	*Cardaria draba* (L.) Desv. # CADDR	–	X	X	X
Leafy spurge	*Euphorbia esula* L. # EPHES	X	X	X	X
Marijuana	*Cannabis sativa* L. # CNISA	X	–	X	–
Musk thistle	*Carduus nutans* L. # CRUNU	X	–	X	–
Perennial sowthistle	*Sonchus arvensis* L. # SONAR	X	–	X	X
Plumeless thistle	*Carduus acanthoides* # CRUAC	X	–	–	–
Poison ivy	*Rhus radicans* L. # TOXRA	X	–	–	–
Russian knapweed	*Centaurea repens* L. # CENRE	–	X	X	X

grown widely. Foxtails and barnyardgrass [*Echinochloa crus-galli* (L.) Beauv. #ECHCG] can be serious competitors in wet or low-lying regions of wheat fields in some years, especially in the humid eastern part of the region.

Annual broadleaf weeds. The states in the region share many of the same broadleaf weeds in spring wheat (Tables 6, 7, and 8). In Montana, kochia, Russian thistle, wild mustard, common lambsquarters, field pennycress, wild buckwheat, and haresear mustard are major broadleaf weeds (59). From North Dakota survey information, the following broadleaf weeds were ranked in decreasing order of their frequency: wild buckwheat, kochia, Russian thistle, redroot pigweed, field bindweed, common lambsquarters, wild sunflower, and common purslane (*Portulaca oleracea* L. # POROL) (50). Many of the same weed problems that are important in North Dakota are also important in South Dakota: redroot pigweed, wild buckwheat, common lambsquarters, wild mustard, Russian thistle, and kochia (8, 50). In Minnesota, wild buckwheat, pigweed species, smartweed species, common lambsquarters, and wild mustard also are serious problem weeds in spring wheat (16). The noxious weeds for Minnesota, Montana, and North and South Dakota are summarized in Table 9.

At the turn of the century, Waldron (139) summarized the major weed problems of cereals in North Dakota. While some species are no longer considered important, they are still present and have the potential for developing as problems if tillage systems are changed. For example, the winter annual weeds flixweed, shepherdspurse, and field pennycress are not now major problems in conventional spring wheat production. However, with the introduction of no-till spring wheat, these winter annuals overwinter and are so large at planting that they are incompletely controlled with available broadleaf herbicides.

The prevalence of broadleaf weed species has changed over the years and varies from year to year. Wild mustard remains an important weed in wheat although it is less frequent since the 1960's because of effective control by 2,4-D and MCPA. Wild mustard increased in frequency in the 1970's and 1980's, probably because of the inclusion of sunflower in rotation. None of the herbicides registered for use in sunflower until the mid-1980's adequately control wild mustard, so soil seed reserves have increased.

Wild buckwheat became an important weed in the early 1960's because of its tolerance to MCPA and 2,4-D. The control of wild mustard with 2,4-D apparently opened a niche for wild buckwheat. Increased use of nitrogen fertilizer also favors wild buckwheat growth.

Kochia infestations generally vary from year to year but have increased recently. Yearly variation in climate appears to be important to kochia, with most severe infestations occurring in low rainfall years. Kochia apparently can tolerate drought and may be less susceptible to herbicide treatments when stressed for moisture. Recent increases in kochia may be caused by a switch from moldboard to chisel plowing, which would leave its short-lived seed close to the soil surface.

Russian thistle is an important weed in Montana and western North and South Dakota, but it may not be as important a problem now as it was in the late 1800's when it first was introduced. Herbicides and cropping practices used today apparently have kept Russian thistle at a manageable level.

False chamomile (*Maricaria maritima* L. # MATMA) is a minor, localized weed that infests wheat in north-central and northeastern North Dakota. Becuase this winter annual has a dense root system and is large in the spring, it is difficult to control with tillage for seedbed preparation, especially in wet areas of fields. Fall-established plants are highly competitive with wheat and difficult to control with registered herbicides, except chlorsulfuron and metsulfuron. Plants that establish in spring are less competitive and are controlled by bromoxynil, clopyralid (3,6-dichloro-2-pyridinecarboxylic acid), and chlorsulfuron. Buried false chamomile seed remain viable for many years (more than 5 yr). False chamomile seed produced in road ditches and waste areas spreads into adjoining wheat fields.

Fumitory (*Fumaria officinalis* L. # FUMOF) was an important weed infesting an estimated 81000 ha in east-central North Dakota in the 1960's. Triallate used for wild oats and postemergence-applied bromoxynil controlled fumitory, and thus rendered this weed unimportant in the area.

Volunteer crops as weeds. Spring wheat is seldom a volunteer weed in rotational cereals unless contaminated seed is sown, or the fall and winter are dry. Winter wheat often volunteers in spring wheat planted after fall-sown winter wheat that failed to establish well. Moreover, winter wheat is more difficult to control in safflower than is spring wheat (21).

Other crops can be volunteer weeds in wheat. Volunteer soybean and sunflower were found in commercial wheat fields in Minnesota in 1979 (Table 8) (16). Alfalfa, corn, flax, smooth bromegrass, and rye were found in 1978 and 1979 surveys of wheat fields in North Dakota, in addition to sunflower and soybeans (Table 6). In a 1979 survey of the northern half of South Dakota, barley, sweetclover, and oats were discovered in wheat fields, as well as alfalfa, corn, flax, and rye (Table 7). It is not known whether these volunteers were seeded as contaminants in wheat or were derived from shattered seed that overwintered.

Perennial weeds. Most noxious weeds in the region are perennial species (Table 9). Canada thistle was a major problem in wheat in all four states in the Northern Great Plains (Tables 6, 7, and 8). Field bindweed was reported in Montana, North Dakota, and South Dakota. Quackgrass and perennial sowthistle (*Sonchus arvensis* L. # SONAR) were problems in Minnesota and North Dakota, whereas common milkweed (*Asclepias syriaca* L. # ASCSY) was a problem in Minnesota and South Dakota. In North Dakota, field bindweed, Canada thistle, wild rose, perennial sowthistle and quackgrass were the 10th, 11th, 15th, 17th, and 19th most frequently observed weed problems, respectively. In South Dakota, field bindweed, wild rose, Canada thistle, common milkweed, alfalfa, and sweetclover were the 6th, 13th, 16th, 18th, 19th, and 20th most serious weed problems, respectively. Alfalfa and sweetclover arise when wheat is planted on pasture or range. Canada thistle, perennial sowthistle, common milkweed, and quackgrass were the 7th, 10th, 11th, and 15th most frequent weeds in Minnesota. While perennial weeds are not responsible for the majority of weed infestations in wheat in the Northern Great Plains, they are of major concern, particularly with minimum or zero tillage. Perennial weed problems are likely to increase as reduced tillage increases. In addition to these perennial weeds, other weed problems, such as foxtail barley, smooth bromegrass, leafy spurge, common dandelion (*Taraxacum officinale* Weber in Wiggers # TAROF), and absinth wormwood (*Artemisia absinthium* L. #ARTAB), have moved onto no-till wheat fields from field borders.

Weed competition. Within the Northern Great Plains, little research has been conducted to document how serious foxtails are in terms of what densities reduce wheat yield. Wild oats have been a much more serious concern. Yields of the semidwarf Era and World Seeds 1809 spring wheat were reduced as wild oat densities were increased to the same extent as were standard height Waldron and Chris (126). Wild oats were sown at densities of 100, 500, and 1000 seeds/m^2. Absolute yield losses due to wild oats were greater at a low fertility site in North Dakota when wheat was fertilized than when it was not fertilized (18). This fertilizer effect was not observed at a second site where there was high residual fertility. When fertility was limiting to yield, wild oat competition was reduced by added nitrogen fertilizer (18).

Little recent regional information is available on the competitive ability of the following broadleaf weeds with spring wheat: Canada thistle, field bindweed, common lambsquarters, Russian thistle, or pigweed species. There is information from North Dakota on the competitive ability of wild buckwheat, kochia, wild mustard, and volunteer sunflower with spring wheat. (See below.)

The extent to which various densities (0 to 215 plants/m^2) of wild buckwheat reduced wheat yields depended upon whether the standard height Chris spring wheat was broadcast fertilized with nitrogen plus phosphorus or not (95). The percentage yield loss of fertilized wheat was much greater than unfertilized wheat, particularly at high wild buckwheat densities. Wild buckwheat reduced the spike number of wheat the most, and the seed weight least.

The effect of various densities of wild mustard on spring wheat was studied for 2 yr at Fargo and Casselton, ND (45). Grass weeds were controlled with diclofop at 1.4 kg ai/ha and Era semidwarf spring wheat was seeded at 100 kg/ha. Without herbicides for broadleaf weed control, wild mustard densities between 1 and 99 plants/m^2 reduced wheat yield between 21 and 53 %, respectively. The greatest yield losses occurred when wild mustard emerged either before or very shortly after wheat emerged. Yield losses were attributed to fewer spikes per area.

A parallel study of the effects of different densities of kochia between 0 and 70 plants/m^2 on spring wheat also was conducted as discussed above at Fargo and Casselton, ND (45). Increasing kochia densities dramatically reduced wheat yield by reducing spike number per plant and seed size. Wheat yield losses varied between 32 and 87 %, depending upon year, location, and kochia density.

Different densities of volunteer sunflower between 0 and 24 plants/m^2 also reduced wheat yield (67). As sunflower densities increased, yield of an early planting was decreased more than a planting (late May). Sunflower did not stunt wheat although it reduced tiller number as sunflower density increased. The kernel number per spike also was reduced, although the 200-kernel weight was unchanged.

Weed Management and Control. *Herbicides for annual grass control.* There are no surveys of pesticide use and application in the region other than in Minnesota and North Dakota (16, 50, 94). Most farmers in North Dakota (80 to 94%) applied herbicides themselves, treating 1 to 60% of their hectarage with grass herbicides in 1979 (122, 123, 124). A similar proportion of farmers in Minnesota applied herbicides themselves (16).

In surveys of the western, central, and eastern thirds of North Dakota, 14, 9, and 29% of farmers, respectively, applied wild oat herbicides in wheat. In Minnesota 34 % of the hectarage and 25 % of the surveyed fields of wheat were treated with wild oat herbicides. Wild oat herbicides were used on 21 % of wheat hectarage in North Dakota (94). Commonly used grass herbicides and weeds in spring wheat are tabulated (Table 10).

Triallate is the most commonly used herbicide for wild oat control in spring wheat. For example, 80 % of surveyed Montana farmers using wild oat herbicides applied triallate (133), but lesser amounts of barban, difenzoquat, and diclofop also were used. Fifty-nine percent of North Dakota farmers using wild oat herbicides in 1984 used triallate, followed by lesser amounts of diclofop (26 %), difenzoquat (9 %), and barban (6 %) (94).

Recent research has been directed at using triallate as a preplant-incorporated treatment in the fall or spring. Triallate was much more effective as a fall application than as a postplant-incorporated treatment in spring (61, 102). Fall-applied triallate permits the farm workload to be spread over a longer period, although higher application rates may be needed. Preemergence incorporated triallate has not been accepted as widely as postplant-incorporated triallate in spring in Montana, because it behaves erratically in dry environments (133).

While climate may influence the consistency of wild oat control with herbicides, the herbicide susceptibility of wild oats is inherently variable, as well (80, 102). In studies of 230 selections of wild oats from North Dakota and Minnesota, sublethal rates of diclofop at 0.4 to 0.8 kg ai/ha applied at the two-leaf stage of wild oats provided between 12 and 98 % control (97, 131). Likewise, difenzoquat applied at 0.4 to 0.8 kg/ha at the three- to four-leaf stage provided between 41 and 97 % control (97, 131). These rates were chosen for maximal differential responses. The relative response of these wild oat selections in the greenhouse and field was similar although resistant lines were controlled with a 1 kg ai/ha rate under field conditions. In the greenhouse, wild oat control with barban and triallate ranged between 10 and 95 % and between 5 and 75 %, respectively (80). Under field conditions, barban at 0.5 kg ai/ha provided between 51 and 89 % control of different selections (97). Diclofop at 1 kg ai/ha provided 94 to 100 % control of eight selections and difenzoquat at the same rate provided 66 to 93 % control. Widespread wild oat tolerance to the current herbicides is not now a problem (97, 131).

Green and yellow foxtail are the other major annual grass weed problems of spring wheat in the Northern Great Plains. Trifluralin, diclofop, and propanil effectively control foxtails. In North Dakota in 1984, trifluralin, diclofop, and propanil were applied on 12, 5, and 0.1 % of wheat

Table 10. The relative effectiveness of herbicides on problem weeds in spring wheat in North Dakota in 1987. (G = good, F = fair, P = poor, N = none).

Herbicide: Generic name	Herbicide: Tradename	Weeds: Barnyardgrass	Eastern black nightshade	Cocklebur	Field bindweed	Foxtails	Kochia	Lambsquarters	Redroot pigweed	Russian thistle	Sunflower	Wild buckwheat	Wild mustard	Wild oat
Preplant incorporated in fall:														
Trifluralin	Treflan	G	N	P	N	G	G	G	G	G	N	F	N	F
Preemergence incorporated:														
Triallate	Far-go	N	N	N	N	N-F	N	N	N	N	N	N	N	G
Trifluralin	Treflan	G	N	N	N	G	F	F	F	F	N	N	N	P-N
Triallate + Trifluralin	Buckle	G	N	N	N	G	F	F	F	F	N	N	N	G
Postemergence:														
Barban	Carbyne 2EC	N	N	N	N	N	N	N	N	N	N	P	N	F-G
Bromoxynil	ME4 Brominal, Buctril	N	–	G	P-F	N	F-G	G	F-G	G	G	G	F	N
Bromoxynil + MCPA	3 + 3 Brominal, Bronate	N	G	G	F	N	G	G	G	G	G	G	G	N
Chlorsulfuron	Glean	–	N	G	P-G	G	G	G	G	G	G	G	G	N
Clopyralid + 2,4-D	Curtail	N	F	G	G	N	F	G	G	G	G	F	G	N
Dicamba	Banvel	N	G	G	G	N	G	G	G	F-G	G	G	G	N
Dicamba + MCPA amine	—	N	G	G	G	N	G	G	G	F-G	G	G	G	N
Diclofop	Hoelon	F	N	N	N	G	N	N	N	N	N	N	N	G
Difenzoquat	Avenge	N	N	N	N	N	N	N	N	N	N	N	N	G
MCPA amine or ester	MCPA	N	G	G	F	N	F	G	P-F	N	F-G	N	G	N
Metsulfuron	Ally	N	–	–	N	N	G	F	G	G	G	G	G	N
Picloram + 2,4-D	Tordon 22K + various	N	G	G	G	N	F	G	G	G	G	G	G	N
Propanil + MCPA	Stampede CM	F	–	G	F	G	G	G	G	P	F-G	G	G	N
2,4-D	2,4-D, various	N	F	G	F	N	F	G	G	F-G	G	P	G	N

hectarage (94). While trifluralin has been applied traditionally as a postplant-incorporated herbicide, there are advantages to fall application (96). Incorporation of fall-applied granular trifluralin provided better foxtail control than surface application, but a 10- to 12-cm-deep incorporation was needed for consistent control. Trifluralin applied in combination with triallate in the fall increases the potential of wheat injury compared to either herbicide alone. Trifluralin plus triallate can be postplant incorporated in the spring using reduced rates of trifluralin to minimize the chance of wheat stand reductions. Spring-applied preplant-incorporated mixtures of these herbicides are injurious to wheat. Recent use of spring preplant-applied triallate and fall-applied trifluralin has reduced the margin of selectivity in wheat compared to the postplant incorporated application but increased the consistency of weed control. Wheat varieties differ in susceptibility to triallate and deeply seeded wheat has been injured by trifluralin, especially in cool moist soils. Trifluralin also can be applied during the fallow year to reduce the number of cultivations needed to control weeds and to provide residual foxtail control in the following wheat crop.

Triallate and trifluralin for wild oat and foxtail control, respectively, have some advantages over postemergence herbicides because wheel traffic reduces grain yield (40). The timing of spraying is critical for herbicide activity (Figure 16). Ground application of postemergence herbicides can cause soil compaction and damage wheat, resulting in wheat yield losses of 3.2 %. When the percentage of the total area is considered, this level of damage may be negligible (0.4 % for wheat). Generally, wheel traffic damages plants less during tillering and on sandy or hard soils and when soils are dry. In addition, early emerging weeds may reduce wheat yields prior to herbicide application.

Trifluralin, trifluralin plus triallate, and barban are registered for use on wheat undersown with alfalfa or sweetclover. Difenzoquat and propanil damaged alfalfa and sweetclover, whereas sweetclover tolerated difenzoquat, profluralin (*N*-(cyclopropylmethyl)-2,6-dinitro-*N*-propyl-4-(trifluoromethyl)benzenamine], propachlor [2-chloro-*N*-(1-methylethyl)-*N*-phenylacetamide], and pendimethalin [*N*-(1-ethylpropyl) -3,4-dimethyl-2,6-dinitrobenzenamine]. The latter four herbicides selectively controlled weeds in wheat undersown with these two small-seeded legumes in 2 yr of North Dakota field trials, but they are not now registered for this use (20).

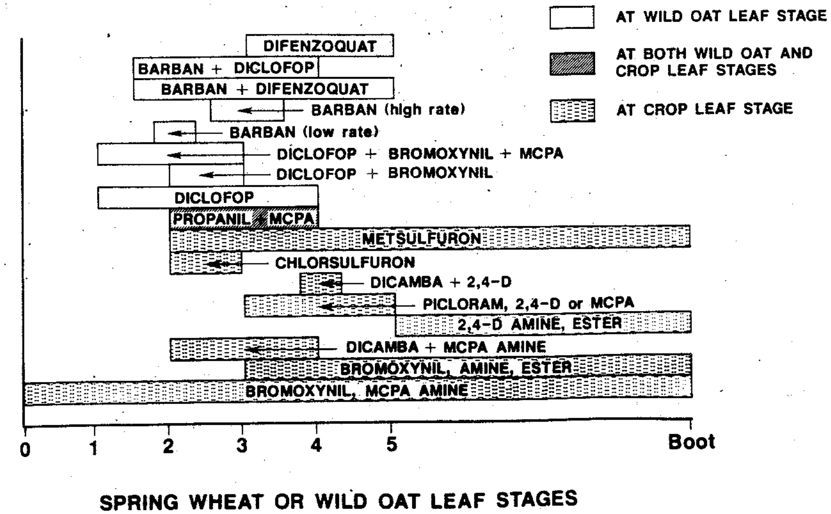

Figure 16. Postemergence herbicide timing on spring wheat.

Herbicides for annual broadleaf weed control. The only surveys of broadleaf herbicide use in wheat in the Northern Great Plains were conducted in Minnesota (16) and North Dakota (50, 94). Between 5.6 and 6.1 % of farmers did not apply herbicides in North Dakota in 1979, whereas 76 to 82 % of farmers treated greater than 95 % of their hectarage (122, 123, 124). Fewer farmers in western North Dakota treated their wheat for broadleaf weeds than in eastern North Dakota (122, 123, 124) and Minnesota (16). In 1984, 91 % of North Dakota wheat hectarage was treated with herbicides (94). Most farmers (82 and 88 %) applied postemergence broadleaf herbicides by ground sprayer (122, 123, 124).

Various formulations of AC 222, 293 [methyl-2-(4-isopropyl-4-methyl-5-oxo-2-imidazolin-2-yl)-*p*-toluate with methyl-6-(4-isopropyl-4-methyl-5-oxo-2-imidazolin-2-yl)-*m*-toluate], bromoxynil, 2,4-D, chlorsulfuran, dicamba, clopyralid (3,6-dichloro-2-pyridinecarboxylic acid), DPX-M6316 {methyl-3-[[[[(4-methoxy-6-methyl-1,3,5-triazin-2-yl) amino] carbonyl] amino] sulfonyl]-2-thiophenecarboxylate}, MCPA, and metsulfuron are registered for broadleaf control in spring wheat within the region (Table 10). 2,4-D and MCPA were used on the highest percentage of fields in 1979, 46 and 29 %, respectively (122, 123, 124) and 58 and 15 %, respectively, in 1984 (94). Dicamba, chlorsulfuron, bromoxynil, bromoxynil plus MCPA, and picloram were applied on 9.6, 2.1, 1.7, 5.8, and 0.8 % of wheat hectarage in 1984 in North Dakota (94).

In Montana in the early 1970's, between 87 and 100 % of the hectares in wheat were treated with broadleaf herbicides. 2,4-D and MCPA also were the most widely used herbicides and are effective in controlling field pennycress, wild mustard, and kochia (103, 104). However, phenoxy-tolerant species, such as wild buckwheat, frequently escape and increase on farmland (103, 104, 113).

Broadleaf weed resistance to postemergence herbicides is variable (19). When the dimethylamine salt of 2,4-D or dicamba was applied to various inbred lines of kochia that had been selfed for four generations, the response of different kochia lines to these herbicides was highly variable. Dicamba at 0.28 to 0.54 kg ai/ha injured those lines that were most and least susceptible to 2,4-D. The responses to 2,4-D and dicamba were essentially independent. Older kochia was less damaged by either 2,4-D or dicamba than were younger plants. The development of herbicide-resistant weeds in the region is not a problem at this time.

Most broadleaf herbicides used in wheat in the Northern Great Plains are applied postemergence. The timing of spraying is critical for both selectivity and herbicidal activity (Figure 16). Selectivity of 2,4-D, dicamba, and picloram also

	Barban	Bromoxynil	Chlorsulfuron	Clopyralid	2,4-D	Dicamba	Diclofop	Difenzoquat	MCPA	Metsulfuron	Picloram	Propanil	Triallate	Trifluralin
Barban							R	R						
Bromoxynil				R	R	R	R	R	R					
Chlorsulfuron				R		R	R	R		R				
Clopyralid					R	R		R						
2,4-D						R		R		R	R			
Dicamba									R	R				
Diclofop														
Difenzoquat									R					
MCPA											R	R		
Metsulfuron														
Picloram														
Propanil														
Triallate														R
Trifluralin														

Figure 17. Registered herbicide combinations (R) for spring wheat in 1986.

depends on wheat growth stage. Also, as weeds age, their susceptibility to these herbicides decreases (19). For example, the effectiveness of dicamba at 0.28 to 1.12 kg ai/ha on wild buckwheat decreased as plant age increased (113). Similar studies have been done on the best application timing for picloram at 0.06 to 0.12 kg ai/ha for wild buckwheat in spring wheat (101). Application was more effective and selective at the three-leaf stage of wheat than at tillering.

Various mixtures can broaden the spectrum of weed control, but only certain combinations are registered (Figure 17). MCPA often is combined with dicamba, bromoxynil, or picloram either as a tank mix combination or formulated mixture. MCPA is used rather than 2,4-D because wheat is more tolerant of MCPA than 2,4-D at early growth stages when these herbicides are applied. Sometimes, 2,4-D is combined with these herbicides and applied at the four- to five-leaf stage of wheat. The rate of dicamba is reduced when applied with 2,4-D to minimize potential wheat injury. Wild buckwheat and Russian thistle are controlled effectively with the reduced rate of dicamba because 2,4-D is more effective than MCPA on these weeds. Picloram plus 2,4-D is applied at one wheat leaf stage later compared to dicamba plus 2,4-D. Dicamba, picloram, and bromoxynil all control wild buckwheat and enhance wild mustard control when combined with MCPA or 2,4-D. Mixtures of dicamba and bromoxynil enhance kochia control. The use of herbicide mixtures for broadleaf weed control has been rather stable over the years. The bromoxynil and MCPA mixture was used more when sunflower hectarage was high because it controlled volunteer sunflower. However, 2,4-D is still the most widely used herbicide in wheat.

Only 2,4-DB [4-(2,4-dichlorophenoxy)butanoic acid] controlled broadleaf weeds in wheat undersown with alfalfa, but it is not registered now. Other broadleaf herbicides, such as bromoxynil, bromoxynil plus MCPA, and propanil damaged underseeded alfalfa in wheat in 2 yr of field trials in North Dakota (20). Sweetclover tolerated propanil but was damaged by 2,4-DB.

III. WINTER WHEAT PRODUCTION AND WEED CONTROL

The relative importance of winter wheat production in the Northern Great Plains was discussed in the Introduction. Until recently (42), most hard red winter wheat production was limited to north-central and eastern Montana, southwestern North Dakota, and the northwestern and southern portions of South Dakota (33). Production practices in Montana have been summarized (85). Higher average yields of winter wheat over spring wheat (10 to 50 %) have sparked interest in winter wheat production (121). With the recent successful introduction of conservation and zero-tillage systems, winter wheat production has increased in the region and moved farther north and east (42). Five different areas of North Dakota have been designated as suitable for winter wheat production (144). Cropping practices to ensure winter wheat survival of fall-sown wheat are tailored to each of these regions. Conservation tillage practices, which leave straw residues on the surface to catch snow, increase winter survival of winter wheat by providing insulation and moderating temperatures at the wheat crown (43).

Both zero-tillage crop management and winter wheat breeding have contributed to greater adoption of winter wheat. Many of the criteria for new winter wheat lines are similar to those for spring wheat (9, 11), except improved winter hardiness. Increased winter wheat production in North Dakota was made possible, in part, by the introduction of winter hardy 'Roughrider' and 'Norstar' varieties (42). The successful introduction of no-till grain drills has helped make planting in standing crop stubble possible. Otherwise, semideep or deep-furrow hoe drills are most successful on conventional seedbeds (31).

Winter wheat is planted in the Northern Great Plains from the last week in August until the last week in September. However, specific recommended planting dates vary among states. Earlier

Table 11. The relative effectiveness of herbicides on problem weeds in winter wheat in Montana in 1987. (G = good, F = fair, P = poor, N = none, T = shoots only) (85, 121).

Herbicide: Generic Name	Trade name	Barnyardgrass	Bedstraw	Blue mustard	Canada thistle	Common gromwell	Common lambsquarters	Cow cockle	Downy brome	Erect knotweed	Falseflax	Field bindweed	Fumitory	Goatsbeard	Green foxtail	Haresear mustard	Henbit	Hoary cress	Kochia	Perennial sowthistle	Persian darnel	Prickly lettuce	Prostrate knotweed	Prostrate pigweed	Redroot pigweed	Russian thistle	Shepherdspurse	Smartweed sp.	Sunflower	Tansymustard	Tumble mustard	Waterpod	Wild buckwheat	Wild mustard	Wild oat
Preemergence incorporated:																																			
Triallate	Fargo	N	N	N	N	N	N	N	F	N	N	N	N	N	N	N	N	N	N	N	P	N	N	N	N	N	N	N	N	N	N	N	N	N	G
Trifluralin	Treflan	N	N	N	N	N	N	N	F	N	N	N	N	N	G	N	N	N	N	N	F	N	N	N	N	N	N	N	N	N	N	N	N	N	P
Triallate + trifluralin		N	N	N	N	N	N	N	G	N	N	N	N	N	G	N	N	N	N	N	F	N	N	N	N	N	N	N	N	N	N	N	N	N	G
Postemergence:																																			
Barban	Carbyne	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	F
Bromoxynil	ME4 Brominal, Buctril	N	G	F	T	F	G	F	N	F	G	T	F	N	N	G	F	T	G	N	N	G	F	G	G	G	G	F	P	F	G	F	G	G	N
Bromoxynil + 2,4-D		N	G	F	T	F	G	F	N	F	G	T	G	T	N	G	F	T	G	T	N	G	F	G	G	G	G	F	P	G	G	F	G	G	N
Bromoxynil + dicamba		N	G	F	T	F	G	F	N	G	G	T	G	T	N	G	F	T	G	T	N	G	G	G	G	G	G	F	G	G	G	F	G	G	N
Bromoxynil + MCPA	3 + 3 Brominal, Bronate	N	G	F	T	F	G	F	N	F	G	T	G	T	N	G	F	T	G	T	N	G	N	G	G	G	G	F	F	G	G	F	G	G	N
Chlorsulfuron	Glean	N	F	G	FG	P	G	G	P	F	G	N	N	N	P	G	G	N	G	N	P	G	F	G	G	G	G	F	G	G	F	F	F	G	N
Dicamba + 2,4-D	Banvel + 2,4-D	N	G	F	T	F	G	G	N	F	G	T	G	T	N	G	G	T	G	T	N	G	F	G	G	G	G	F	G	G	G	F	F	G	N
Dicamba + MCPA amine	Mondak	N	G	F	T	F	G	G	N	F	G	T	G	T	N	G	G	T	G	T	N	G	F	G	G	G	G	F	G	G	G	F	F	G	N
Diclofop	Hoelon	G	N	N	N	N	N	N	G	N	N	N	N	N	G	N	N	N	N	N	G	N	N	N	N	N	N	N	N	N	N	N	N	N	G
Difenzoquat	Avenge	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	G
2,4-D amine-ester	Various	N	G	P	T	P	G	P	N	P	P	T	F	T	N	G	P	T	F	T	N	F	P	G	G	P	G	F	F	G	G	P	P	G	N
MCPA	MCPA	N	F	N	T	N	G	N	N	N	N	T	N	T	N	N	N	N	F	T	N	F	N	F	F	P	F	N	F	F	N	N	P	F	N
Metribuzin	Sencor/ Lexone	N	N	N	N	N	N	N	F	N	N	N	N	N	N	N	G	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N
Picloram + 2,4-D/MCPA		N	G	F	T	F	G	F	N	F	G	T	G	T	N	G	F	T	G	T	N	G	F	G	G	G	G	F	G	G	G	F	G	G	N
Propanil	Stampede	N	N	N	N	N	F	N	N	N	N	N	N	N	N	N	N	N	F	N	N	N	N	F	F	N	F	F	N	N	N	N	F	F	N

it was recommended to plant winter wheat between August 27 and November 7 in central Montana (111). Planting earlier than that, between July 16 and August 13, reduced winter wheat yields. The current recommendations suggest that planting should be between September 10 and 25 in central or western Montana and between September 1 and 10 in the northeastern corner of Montana. Winter wheat on fallow should be planted between September 1 and 20 and between September 10 and 30 on stubble (23). In North Dakota, the recommended planting date is between September 1 and 15 (11). This allows seedlings to be in the three- to five-leaf stage when winter begins. If fall growth of winter wheat is excessive, winter survival is poor, maturity is delayed, and yields are reduced (144). Planting on fallowed land is not recommended in North Dakota because of the potential for winterkill.

In South Dakota, Montana, and the southwestern corner of North Dakota, winter wheat is planted on fallow, with only 20 % being planted into standing stubble (23). However, standing stubble catches snow, insulates winter wheat, and reduces winterkill. In North Dakota, it is recommended that winter wheat be no-till seeded into flax, barley, or mustard stubble (11). Stubble must be at least 15 cm tall to catch snow for cereals preceding winter wheat and 75 cm tall for row crops, such as corn or sunflower. Seeding depths of 4 to 7 cm have advantages in enhancing winter hardiness of winter wheat (2, 23). Row spacings of 25 to 36 cm are used with winter wheat in western North Dakota and Montana, whereas a 15-cm row spacing is used for spring and winter wheat grown in eastern North Dakota.

Anhydrous ammonia must be applied preplant, but dry forms of nitrogen can be applied after planting before freeze-up. However, fall wheel track compaction of soil can cause winterkill. Surface-applied nitrogen in the spring is another alternative (76). Drill box application of phosphorous is recommended to make full use of nitrogen.

Winter wheat remains dormant from late fall in mid-October until mid-March or April. Shoot growth resumes in mid-March and winter wheat is harvested from late June until mid-July, often by direct combining (112). In contrast, spring wheat harvest begins in early August and is completed by late September (11). Postharvest weed control may be more critical following winter wheat than spring wheat to conserve soil moisture and prevent weed seed maturation and increases.

Winter wheat should not follow corn, sunflower, safflower or late-planted flax in rotation without an intervening fallow period (23, 25). These crops deplete soil moisture and are harvested after the optimum time for winter wheat planting. Some herbicides applied to these crops may persist to damage winter wheat seedlings.

If there is insufficient moisture for fall replanting, the land may be fallowed (Figure 11). Usually, wheat stubble is left standing from August until mid-May. From mid-May until late August, summer fallow is cultivated. Thus, the 14-month fallow for continuous winter wheat is shorter than fallow for continuous spring wheat (145).

Different grass weeds are present in winter wheat than in spring wheat in Montana. Wild oats, downy brome, jointed goatgrass (*Aegilops cylindrica* Host # AEGCY), and volunteer rye are common problems (59). Several of these weeds recur in fallow. However, control of volunteer rye, downy brome, and bulbous bluegrass (*Poa bulbosa* L. # POABU) has been most researched in fallow in Montana. Downy brome also infests northern and western South Dakota and southwestern North Dakota where winter wheat has been grown. Occasionally infestations of Persian darnel also occur in the region.

Extensive winter wheat production in Montana results in different broadleaf problem weeds than in spring wheat. These broadleaf weeds include: tansymustard, field pennycress, haresear mustard, corn gromwell (*Lithospermum arvense* L. # LITAR), smallseeded falseflax (*Camelina microcarpa* Andrz. ex DC. # CMAMI), common cocklebur (*Xanthium strumarium* L. # XANST), common knotweed (*Polygonum* spp.), blue mustard [*Chorispora tenella* (Pallas) DC. # COBTE], henbit (*Lamium amplexicaule* L. # LAMAM), bedstraw (*Galium* spp.), wild mustard, and Canada thistle (59). The major broadleaf weeds in North Dakota winter wheat are tansymustard, field pennycress, shepherdspurse, and greenflower pepperweed (*Lepidium densiflorum* Schrad. # LEPDE) (11). Commonly used herbicides for weed control in winter wheat are summarized in Table 11.

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