Chapter 1
Introduction

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I. CHANGES IN WHEAT PRODUCTION OVER TIME

Over the last thirty-five years, North American wheat (*Triticum* spp.) production has gradually increased so that it is now more than double what it was in 1950 (Figure 1) (40). However, the relative contribution of wheat production in the United States and Canada to total production in North America has remained relatively constant over this period (Figure 2). The contribution of Mexican wheat production to total North American production is insignificant by comparison (40).

Whereas increases in hectarage have contributed to increased wheat production elsewhere in the world, North American wheat hectarage has remained relatively constant throughout the past 35 yr (40). Bond (4) attributed increased production to increased yield rather than increases in planted hectarage, although slightly more land was used in the 1970's than in the past. United States wheat hectarage peaked shortly after World War II (4). Throughout the 1950's and 1960's, wheat hectarage was controlled by government farm policy, including hectarage allotments, and crop diversion programs. Consequently, only the most productive land was used throughout this period. But the amount of land devoted to wheat production partially depends on the availability of adapted alternate crops and their profitability relative to wheat.

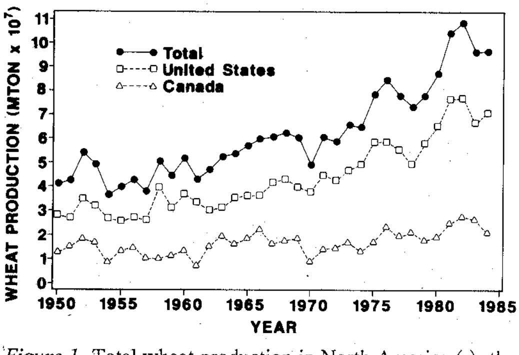

Figure 1. Total wheat production in North America (·), the United States (□), and Canada (△) from 1950 to 1984 (40).

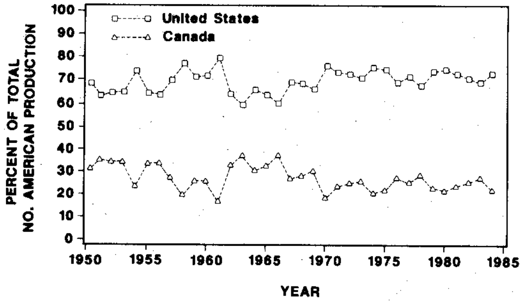

Figure 2. The relative contribution of the United States (□) and Canadian (△) wheat production to total North American wheat production from 1950 to 1985 (40).

Between 1949 and 1976, average wheat yields in North America doubled (4) from 1010 to 2020 kg/ha (15 and 30 bushels per acre), respectively. The rate of increase of wheat yields was less in the 1970's than in the 1950's and 1960's. This may have been due, in part, to the changing use of land (4). In the 1970's slightly more land was used for wheat production, leading to the use of less productive land for cropping. Government or economic conditions resulting in the use of less land means that more productive land will be employed and more emphasis will be placed on technological inputs. Regional increases in particular types of wheat (21, 22) may be greater than those cited by Bond (4).

The major types of wheat grown in the United States are hard red spring and winter wheat

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(*Triticum aestivum* L.), soft red winter wheat, white wheat, and durum wheat (*Triticum durum* Desf.) (4, 6, 32). These types of wheat and their varieties have been reviewed (6). The geographic distribution of planted hectarage of these various wheats in the United States is summarized in Figures 3 to 8 (6, 32). Spring wheat is the major wheat grown in the Prairie Provinces of Canada, with lesser amounts of winter and durum wheat.

II. CAUSES FOR CHANGING WHEAT PRODUCTION

Various authors have attributed increasing aggregate wheat yields to several causes. Undoubtedly, these various causes interact. Thompson (38), a soil scientist, attributed the bulk of change after 1945 to increased fertilizer use. However, he noted the introduction of improved varieties and a shift in land use form less productive to more productive land. Other factors, such as weeds, were not considered because of a lack of documentation. Bond (4), an agronomist, attributed increased yields to other aspects of technological change. He emphasized that the following changes in wheat management may have contributed to increased yield during the last 30 years: a) The proportion of wheat planted on summer fallow land had increased; b) wheat was grown on more productive land; c) wheat irrigation was increased in some regions; d) improved varieties incorporating disease and insect resistance were introduced; e) more fertilizer was applied; f) cultural practices were changed and improved; g) pesticide use, chiefly herbicides, was increased; and (h) mechanization was increased. Austin (1), a plant breeder, attributed increases in wheat yield to fewer factors: a) increased mechanization; b) new varieties; c) increased fertilizer use; and d) increased use of crop protection chemicals. Bond (4) felt that because of climatic variation, the relative contributions of various inputs to wheat yield in any given location or year were uncertain and unpredictable. In addition, he observed that the highest yields required multiple inputs. Because several production inputs are often used together, it is impossible to relate yield increases to individual input factors. The relative contribution of technology, nontechnological factors under farmer control, such as the timing of farming operations, and weather to wheat yield remain to be determined on an aggregate basis. However, some authors have analyzed trends in wheat yield on a regional basis in such a way as to separate the contribution of weather and technology (13, 19, 21, 34, 38).

Farming has become more dependent on the rest of the economy for inputs since World War

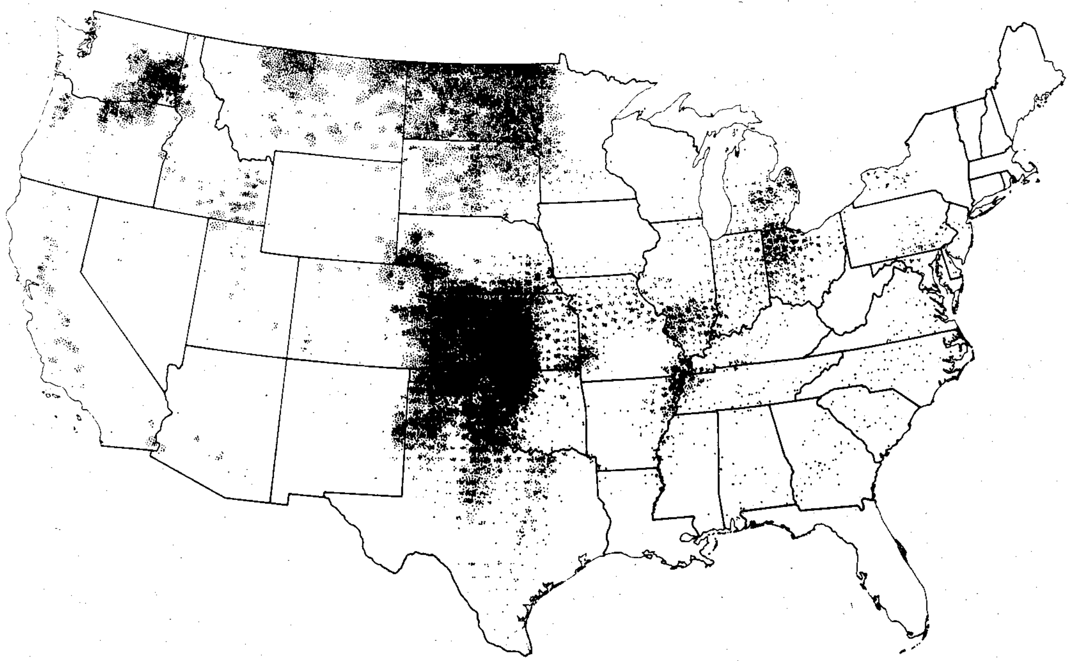

Figure 3. Distribution of total wheat hectarage seeded in the United States in 1979 (6).

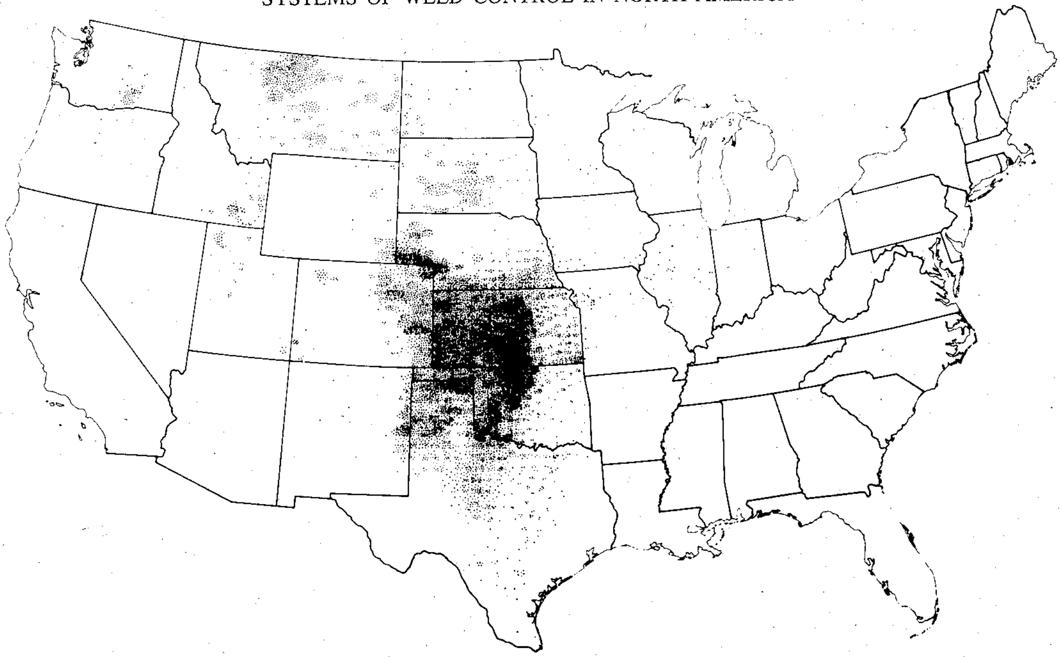

Figure 4. Distribution of hard red winter wheat in 1979 (6).

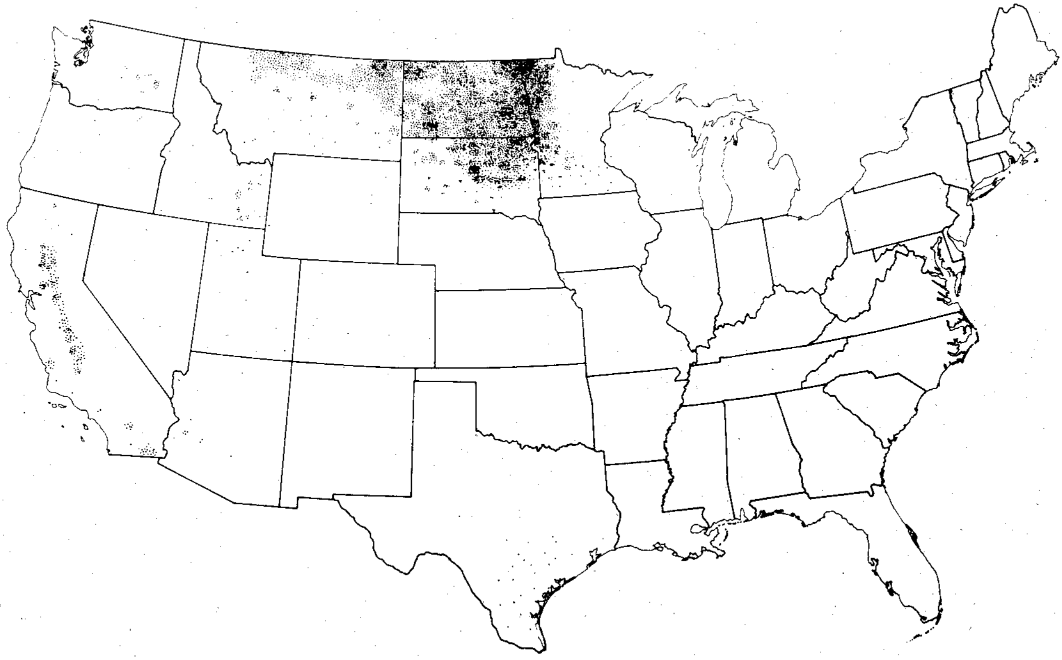

Figure 5. Distribution of hard red spring wheat in 1979 (6).

II (4). Consequently, production decisions by farmers are now determined by forces occurring outside of agriculture (4). Among other factors, government production programs have influenced production of wheat in several ways. These programs have both reduced the land needed for wheat production and increased wheat yield. Government programs have promoted substitution of technological inputs in place of land and labor as a means of increasing production. Economic and government policy have interacted to modify wheat production. Batie and Healy (3) attributed adoption of new farming practices to the following factors: a) personal

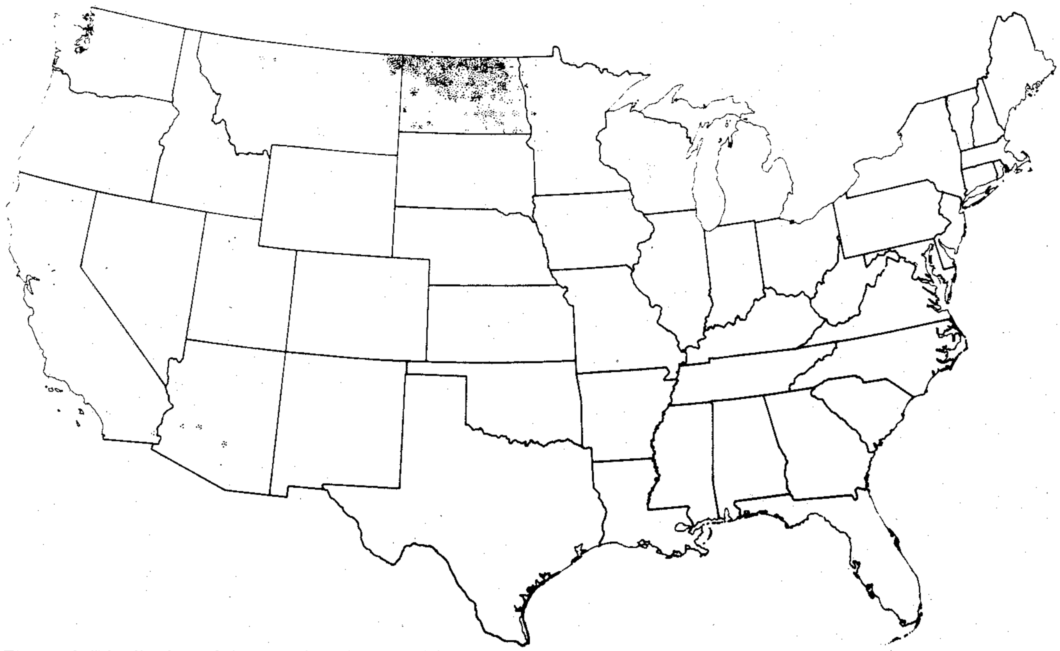

Figure 6. Distribution of durum wheat in 1979 (6).

Figure 7. Distribution of white wheat in 1979 (6).

preferences by farmers, b) land characteristics, c) tenure arrangements, d) tax policies, e) farm commodity programs, f) yield response, and g) economic benefits of new technology.

Increased yields due to technology have contributed to increased use of nonfarm inputs (4). These inputs include such things as nitrogen and phosphorous fertilizer, improved wheat varieties with insect and disease resistance, herbicides, irrigation, and energy. From 1950 to 1978, labor costs increased twice as fast as energy costs (3). Thus, there were economic incentives for substituting energy in place of hand labor. The availability of new technology and

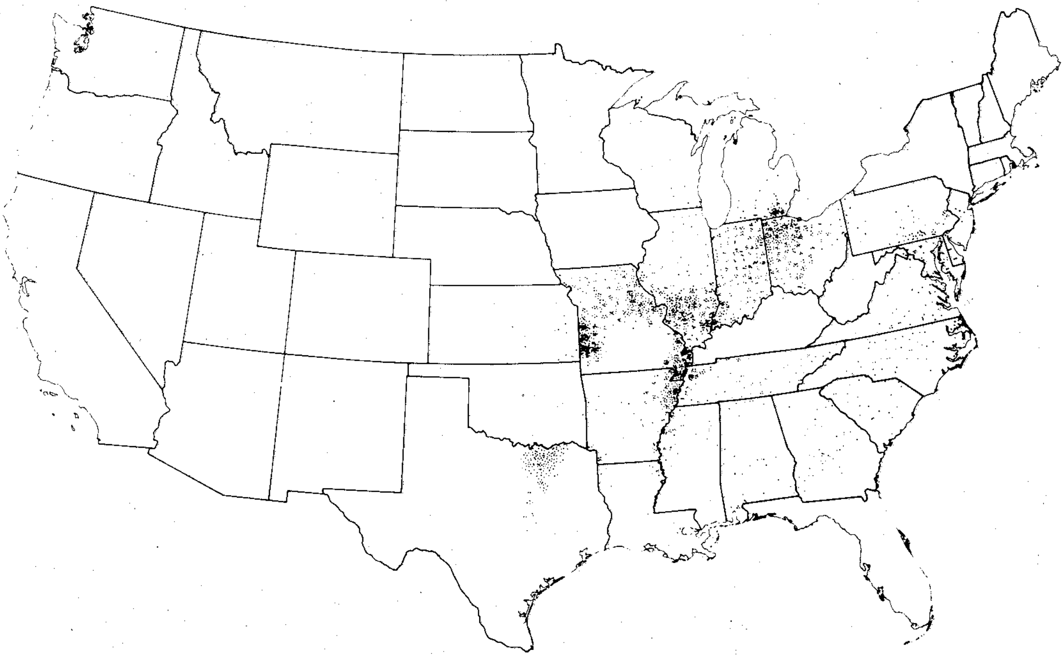

Figure 8. Distribution of soft red winter wheat in 1979 (6).

the changing ratio of costs to benefits promoted the shift to other inputs, including herbicides (29).

Most analysts seeking causes for increased wheat yields have concentrated on factors that farmers and scientists can control or manipulate, such as planting rate or the use of fertilizer (4, 32). Consequently, other natural constraints on wheat yields, such as weather or weeds, have been deemphasized or ignored. Richardson (33) has suggested that a more integrated approach must identify all major constraints and their interactions (Figure 9). Adverse soil and climate conditions probably require greater attention because of their direct effects on wheat yield and on pests, such as weeds, insects, and diseases, which constrain wheat yield.

Changes in wheat management may have contributed to increased yield stability (4). Increased mechanization also has contributed to yield stability as have better management practices. In addition, improved grain drills and seeding methods have enhanced wheat stands. Single and double disk drills have been used for a long time in more humid wheat-growing regions (4). The introduction of hoe drills, which displace dry soil and plant seed into moist underlying soil, has made wheat planting better adapted to dryland conditions. Agronomic information on more timely seeding dates also has contributed to improved stands.

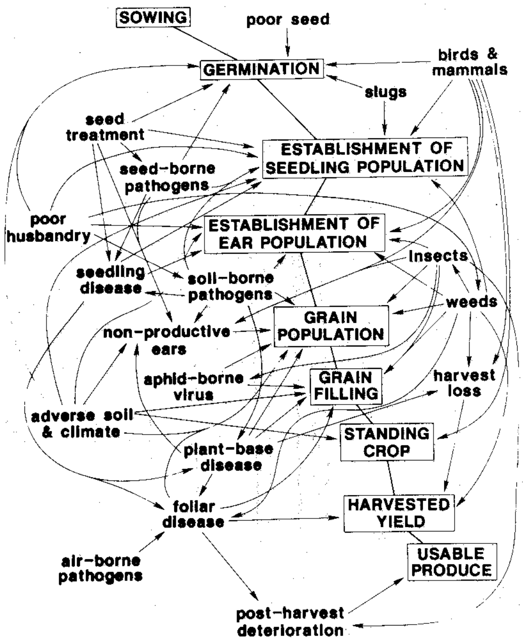

Figure 9. Interactions among several factors affecting wheat yield and yield components (33).

Weed control technology is one of several factors contributing to increased wheat yields, but only where weeds constrain wheat production. While weed control with crop management techniques and herbicides can improve realized or "actual" wheat yields, weed control does not increase the genetically determined "theoretical" yield potential of a given wheat variety in a limiting environment. Nevertheless, when weed interference stresses wheat and prevents it from achieving its full yield potential, technological innovations, such as herbicides, can contribute to improved wheat production. Obviously, weed control practices are useful only where weeds are present in high enough density to limit wheat yields.

The contribution of weed control technology to wheat production relative to other inputs will probably never be known. The same could be said for the use of insect and disease control technologies in wheat. As Ridley and Hedlin (34) pointed out, there is not enough available information to adequately evaluate the impact of herbicides on wheat production. Weed survey information is fragmentary (see Chapter 2) and weed competition data is incomplete and probably specific to the sites where the research was conducted (see Chapter 3). Bond (4) and Eichers (11) noted that herbicide use in wheat has increased over the last 30 yr. However, complete historical information on herbicide use in wheat is not available in the United States and Canada. Because of this lack of information, the impact and contribution of weed control to aggregate wheat production in the United States has been questioned or ignored (4, 13, 21, 38). A review of the impact of restricting 2,4-D [(2,4-dichlorophenoxy)acetic acid] use in Canada provides additional detailed information on the impact of herbicides on weed control in wheat, as well as identifying data gaps (25).

III. WEEDS AS A CONSTRAINT ON WHEAT PRODUCTION

Estimates of production losses due to weeds can be based on four information sources: a) statements by informed individuals, b) questionnaires, c) field research, and d) ground surveys of farms (41). Estimates of national wheat losses due to weeds in Canada and the United States have been compiled (9), but these estimates are based on statements by knowledgeable individuals, the weakest, least objective source of information.

Available information on weed distribution and severity in wheat is summarized in Chapter 2. Survey information is now limited to the Northern Great Plains and Canada, despite its potential importance in defining priorities for weed control research elsewhere in North America. Scientific surveys of changes in weed populations over time have not been conducted.

Weed problems are often geographically limited or regional in nature. The limited information on the introduction and spread of weeds in the United States and Canada has been summarized (18). Most such information is fragmentary and based on personal historical accounts. Most introduced weeds were either unintentionally introduced in soil ballast from ships or crop seed, or intentionally introduced as seed for agricultural use, as forages, or ornamentals when North America was colonized (Table 1). Many weeds have been introduced repeatedly at several locations (18).

Historical information on the spread of weeds in North America also is fragmentary. However, some attempts have been made to chart the spread of weeds using historical records, personal accounts, and herbarium samples (16, 17, 26).

Plant characteristics that make weeds adapted to wheat production practices and the wheat life cycle are summarized in Chapter 2. Most of these weeds are not specifically preadapted only to wheat; they occur in a variety of crops. However, these weeds are adapted to the wheat life cycle, current tillage practices, and currently used herbicides. Moreover, some important weeds of wheat are closely related taxonomically and are morphologically similar to wheat (14).

As pointed out by Chancellor (8), tillage practice and herbicide use are critical elements in determining which weeds will occur in wheat. Weed problems in wheat change in response to changes in farm management practices, including herbicide use (8). There are few studies documenting weed shifts over time in wheat in North America as a result of changing herbicide use. Freyman et al. (19) documented changes in spring wheat yields in various rotations at Lethbridge, Alberta, from 1912 to the late 1970's. Broadleaf weeds limited wheat yields until 1950 when 2,4-D was first used. Between 1920 and 1950, Russian thistle (*Salsola iberica* Sennen & Pau # SASKR), common lambsquarters (*Chenopodium album* L. # CHEAL), redroot pigweed (*Amaranthus retroflexus* L. # AMARE), and wild mustard (*Sinapis arvensis* L. # SINAR) were problems. 2,4-D was used to control these weeds from 1950 to 1973 after which dicamba (3,6-dichloro-2-methoxybenzoic acid), bromoxynil (3,5-dibromo-4-hydroxy benzonitrile), and bromoxynil plus MCPA [(4-chloro-2-methylphenoxy)acetic acid] were employed. Between 1956 and 1963, broadleaf

Table 1. Intentional and unintentional introduction of weeds which have become problems in wheat (18).

Intentional introduction

Weed Common name	Scientific name	Purpose of introduction
Common chickweed	*Stellaria media* (L.) Vill. #STEME	Herb
Common tansy	*Tanacetuum vulgare* L. # CHYVU	Herb
Corn cockle	*Agrostemma githago* L. # AGOGI	Ornamental
Dandelion	*Taraxacum officinale* Webber in Wiggers #TAROF	Herb
Johnsongrass	*Sorghum halepense* (L.) Pers. # SORHA	Forage
Kochia	*Kochia scoparia* (L.) Schrad. # KCHSC	Forage, ornamental
Plantain	*Plantago* spp.	Herb
Redroot pigweed	*Amaranthus retroflexus* L. # AMARE	—

Unintentional introduction

Weed Common name	Scientific name	Source
Buttercup spp.	*Ranunculus* spp.	Seed, hay, livestock
Canada thistle	*Cirsium arvense* L. # CIRAR	Seed, hay, livestock
Cocklebur	*Xanthium* spp.	Seed, hay, livestock
Common chickweed	*Stellaria media* (L.) Vill. # STEME	Ship ballast
Common groundsel	*Senecio vulgaris* L. # SENVU	Seed, hay, livestock
Crabgrass spp.	*Digitaria* spp.	Ship ballast
Dandelion	*Taraxacum officinale* Weber in Wiggers #TAROF	Ship ballast
Dodder	*Cuscuta* spp.	Seed, hay, livestock
Field bindweed	*Convolvulus arvensis* L. # CONAR	Seed
Hedge bindweed	*Calystegia sepium* (L.) R. Br. # CAGSE	Seed
Mallows	*Malva* spp.	Seed, hay, livestock
Mayweed	*Anthemis cotula* L. # ANTCO	Seed, hay, livestock
Mullein	*Verbascum* spp.	Ship ballast, seed, hay, livestock
Nightshade spp.	*Solanum* spp.	Seed, hay, livestock
Perennial sowthistle	*Sonchus arvensis* L. # SONAR	Seed, hay, livestock
Prostrate knotweed	*Polygonum aviculare* L. # POLAV	Seed, hay, livestock
Plantain spp.	*Plantago* spp.	Ship ballast, seed, hay, livestock
Quackgrass	*Agropyron repens* L. # AGRRE	Seed, hay, livestock
Russian pigweed	*Axyris amaranthoides* L. # AXYAM	Seed
Russian thistle	*Salsola iberica* Sennen & Pau	Seed
Shepherdspurse	*Capsella bursa-pastoris* (L.) Medik. # CAPBP	Seed, hay, livestock
Stinging nettle	*Urtica dioica* L. # URTDI	Seed, hay, livestock
Wild garlic	*Allium vineale* L. # ALLVI	Seed
Wild mustard	*Sinapis arvensis* L. # SINAR	Seed
Wild oat	*Avena fatua* L. # AVEFA	Seed

weed control allowed the grasses wild oats (*Avena fatua* L. #AVEFA) and green foxtail [*Setaria viridis* (L.) Beauv. # SETVI] to develop as problems. These weeds limited yields since the early 1950's despite the use of nitrogen and phosphorous fertilizer and adapted spring wheat varieties. Wheat yields increased only after the introduction of triallate [*S*-(2,3,3-trichloro-2-propenyl)bis (1-methylethyl) carbamothioate] in 1961 for wild oat control. Herbicidal weed control was more closely related than fertility to increased spring wheat yield in this Canadian study.

Timmons (39) has reviewed historical changes in weed control methods. In the 1920's and 1930's, farmers first mechanized field operations and converted from horse to tractor power. Pump-type, tractor-mounted sprayers were introduced in the 1930's. In the 1940's and 1950's, low-volume, low-pressure sprayers and nozzles were introduced for phenoxy herbicide application by ground or air. Weed control by mechanical tillage is not possible in wheat (39).

The commercial introduction of herbicides in Canada and the United States for use in wheat or wheat-fallow is summarized in Figure 10. Diallate [*S*-(2,3-dichloro-2-propenyl)bis(1-methylethyl)carbamothioate], dinoseb [2-(1-methylpropyl)-4,6-dinitrophenol], diuron [*N'*-(3,4-dichlorophenyl)-*N,N*-dimethylurea], and terbutryn [*N*-(1,1-dimethylethyl)-*N'*-ethyl-6-(methylthio)-1,3,5-triazine-2,4-diamine] have never been registered in Canada, although they have been used commercially in some parts of the United States. Diallate and dinoseb are no longer registered on wheat in the United States. Benzoylprop [*N*-benzoyl-*N*-(3,4-dichlorophenyl)-*DL*-alanine], cyanazine {2-[[4-chloro-6-

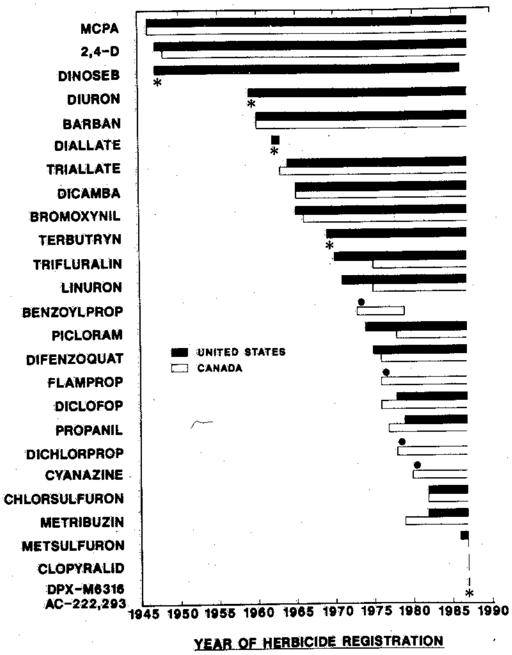

Figure 10. Chronology of initial registration and withdrawal of herbicides used commercially in wheat in the United States and Canada. Some herbicides were never registered in Canada (*) or the United States. (·).

(ethylamino)-1,3,5-triazin-2-yl]amino]-2-methylpropanenitrile}, dichlorprop [(±)-2-(2,4-dichlorophenoxy) propanoic acid], and flamprop [*N*-benzoyl-*N*-(3-chloro-4-fluorophenyl)-*DL*-alanine] have been registered on wheat in Canada but not in the United States. The history of development of wild oat herbicides in Canada has been summarized (2).

Herbicides have reduced labor, machine hours, and energy used for weed control and helped change crop production practices (35). However, it was recognized early that "Weed control is not and will not be purely chemical." (42). There is a considerable amount of information on herbicide efficacy, but few studies have evaluated the effect of management factors, such as tillage, plant population, planting date, or other crop management practices, on weed density or shifts in weed problems in wheat.

IV. WEED CONTROL IN WHEAT IN AN ECONOMIC PERSPECTIVE

The economic analysis of weed control in wheat is in its infancy. At present, weed scientists have not employed economic analysis of weed control as a routine part of their applied research programs. Only wild oat control in spring and winter wheat has received any attention by economists (10, 15, 30, 37).

Most economic analysis of weed control in wheat has been made from the farmer's perspective and is derived from Stern's concept of economic thresholds (36, 43). The application of this concept has been reviewed by entomologists and plant pathologists several times in the last 20 yr (5, 7, 12, 23, 24, 27, 28, 31, 33). Most such analyses adopt a short-term perspective, usually a single growing season, and ignore externalities (31) such as the buildup of herbicide- or tillage-tolerant or resistant weeds on farm land.

Zadock's (43) definitions of actual, attainable, and theoretical (potential) yield are valuable for any discussion of economic thresholds. Zadock defined actual yield as that achieved by the average farmer, whereas attainable yield was that which is possible with available technology. Economic yield is that which provides the highest financial return on expenditures. Economic yield is not necessarily equal to either actual or attainable yield. Zadock (43) also distinguished crop loss from economic loss. Crop loss is the difference between the attainable and actual yields, whereas economic loss is the difference between economic and actual yields.

Stern (36) defined economic threshold as the "density at which control measures should be determined to prevent an increasing pest population from reaching the economic injury level." He recognized that an economic threshold was not an absolute or constant quantity; acceptable levels of crop damage varied and depended upon interactions among the crop, weed, and environment. Moreover, economic thresholds cannot be discussed without defining the following factors: a) climate, b) time of year, c) stage of crop growth, d) crop, e) variety, f) cropping practices, and g) economic variables (36). It is also assumed that an economic threshold can be determined at a time that will allow pest control before economic damage has occurred (7). The economic threshold is highly dependent on crop price and the efficiency and cost of control measures to reduce pest populations below the economic injury level. Consequently, economic thresholds vary form place to place and year to year. Economic thresholds cannot be defined without some knowledge of weed life cycles, how weeds reduce yield, crop susceptibility to particular weeds, and the economic goals of farmers. Entomologists have questioned Stern's formulation of economic threshold on several grounds (20, 30). Recently, Pedigo and coworkers (31) pointed out several limitations to economic threshold determinations: a) Not all pests or injury can be analyzed, b) it cannot be applied to all control measures, c) multiple pests cannot be analyzed, and d) background research needs are substantial.

V. ASSUMPTIONS AND RESEARCH NEEDS

Weed scientists have made several assumptions about weed control research in wheat over the last 35 yr. Weed control technologies, chiefly herbicides, are assumed to improve yields where weeds limit or constrain wheat yield. Yet the extent to which different weeds limit wheat yield is known for only a few major, obviously competitive, weed species, chiefly in spring wheat (see Chapter 3). The crop damage due to weeds and the benefit of herbicide use often are measured under worst-situation conditions (dense infestations) rather than at the lower weed densities often found on farms. There is also little survey information on typical weed densities found on farmer's wheat fields (see Chapter 2). The net result is that losses due to weeds and the advantages of herbicide use may be overestimated or underestimated. Consequently, the contribution of weed control to wheat production in North America has been questioned or slighted by some reviewers because of these data gaps (4, 13, 21, 38). Whether it is economically worthwhile to control sparse, low-growing, or late-emerging weeds in wheat remains to be determined.

It is assumed that when herbicides or other weed control techniques improve yields that farmers benefit economically. Yet economic studies and decision rules for the use of weed control strategies have yet to be defined for management of the major weeds of wheat, as Taylor and Burt (37) have done for wild oats in spring wheat in Montana. Changing crop management practices for weed control purposes is assumed to be beneficial and economically worthwhile for farmers. The cost effectiveness of technological solutions to weed problems needs to be examined.

In economic analyses and research, weeds have been assumed to reduce yield but to have little or no effect on wheat quality, dockage, or storage quality. There is almost no information on economic losses due to the last three factors. Likewise, there is very limited information on the effect of herbicides on wheat quality or grade, in the absence of weeds.

Weed scientists and others often assume that weed control strategies have no deleterious side effects or that these secondary effects have minimal or no influence on profitable wheat production. The potential increase of tillage-tolerant, herbicide-tolerant, or herbicide-resistant weeds has been largely ignored as a result. The long-term repercussions of repeatedly using herbicides as a short-term weed control strategy remains to be evaluated.

Weed science must attempt to integrate economic weed control practices with practices that conserve soil. Technological solutions to weed control problems must be integrated into larger aspects of crop production practice and farm finance. Can increased yields always be equated with increased profitability where weeds constrain wheat yields? Are weed control measures always cost effective?

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