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Symposium

Long-term weed management studies in the Pacific Northwest

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The winter wheat production system of the Pacific Northwest is characterized by severe wind and water erosion and winter annual grass weeds requiring high herbicide input. Since 1985, numerous multi- and interdisciplinary, long-term, large-scale, integrated cropping systems studies have been or are currently being conducted. The primary focus of these studies was on weed biology, ecology, and management, whereas secondary evaluations were on alternative cropping systems, conservation tillage, and fertilizer or herbicide inputs. The 6-yr integrated pest management project, conducted in the high-rainfall zone (> 400 mm), showed for the first time that when weeds were adequately managed, conservation production systems were more profitable than conventional systems. In the intermediate rainfall zone (350 to 400 mm), a recently concluded 6-yr, three-state study integrated single-component research results into a multifaceted approach to managing jointed goatgrass. This project has been used as a model study for other western states and the National Jointed Goatgrass Research Initiative. At present (9 yr thus far), a study is being conducted in the low-rainfall zone (< 350 mm) to examine the feasibility of no-till spring cropping systems in lieu of the highly erosive, weed infested, wheat–fallow system. Because of these projects, the Washington Wheat Commission recognized the importance of long-term, interdisciplinary, cropping systems research and has therefore established an Endowed Chair at Washington State University for direct seed cropping systems research. Federal, national, and regional agencies have used information from these projects for farm plans and pesticide usage.

Nomenclature: Jointed goatgrass, *Aegilops cylindrica* HOST AECY; wheat, *Triticum aestivum* L.

Key words: Conservation tillage, diversified cropping, interdisciplinary research, soil erosion, winter annual grasses.

The agriculture of the Pacific Northwest (PNW) is recognized as the highest dryland wheat production (per hectare) area of the world. With approximately 70% of the precipitation occurring from November through March, the region is ideally suited for winter wheat production. The area is also a haven for winter annual grass weeds (Young et al. 1996) and is recognized as one of the most erosive agricultural areas in the United States (Batie 1983) for both wind and water.

Single-component research was initiated more than 25 yr ago to try and solve the economic and environmental problems of crop production in the PNW (Young et al. 1994c). Two major obstacles preventing successful adaptation and adoption of conservation tillage systems were the high level of required inputs and the lack of effective weed management strategies. In 1985, a field-size, long-term, IPM research project was initiated in the PNW for conservation crop production (Young et al. 1994c). This was the first inter- and multidisciplinary, long-term research project that focused on weed management and conservation tillage systems in the PNW. Since then, numerous long-term research projects have been or are being conducted in the PNW by USDA–Agriculture Research Service weed scientists, always with the same goal of developing economically feasible and environmentally sound crop management systems that prevent erosion and provide control of weeds and other pests (Young et al. 1992, 1999).

The objective of this manuscript is to provide awareness of several long-term, integrated weed management (IWM) studies conducted in the three-state area (Washington, Oregon, Idaho) of the PNW. Four studies will be described, including the research goals, location, design, and a summary highlighting some of the results. The long-term studies include a 9-yr IPM project (6-yr Phase I and a 3-yr Phase II), a 6-yr no-till weed management–fertility level project, a 6-yr, three-state IWM project for jointed goatgrass, and a current multiyear, no-till, spring cropping systems study. The backbone of each of these projects was the integrated approach to systems research on a large tract of land in contrast to traditional short-term, small-scale component research.

Long-Term Weed Management Studies

All the long-term studies discussed are multi- and interdisciplinary, often having numerous scientists from many disciplines cooperating together. Because of the environmental concerns in PNW agriculture, these studies have a similar theme composed of (1) increasing our knowledge of weed biology, ecology, and management in cropping systems; (2) developing, as opposed to testing, alternative cropping systems that do not rely on winter wheat; (3) using conservation tillage to reduce wind and water erosion; and (4) reducing fertilizer and herbicide inputs. In the past, weed science, like so many other disciplines in the PNW, conducted the majority of its research in conventional tillage, winter wheat production systems. In contrast to many of the long-term projects discussed at the symposium, our projects were fortunate to be established by weed scientists to solve specific weed problems inherent to common farming practices.

Integrated Pest Management Project

The first long-term, field-scale, integrated and multidisciplinary research project in the PNW was established in 1985, with initial funding provided by the National IPM/PT (Pilot Test) projects in Beltsville, MD. The IPM project was established near Pullman, WA, in the annual cropping area (> 400 mm annual precipitation) of the Palouse Region of the PNW. At the time of the project's initiation, federal crop subsidies, regional climate, and winter wheat farming heritage dictated that winter wheat would be produced as often as possible without regard to pest problems and erosion. Specific objectives of this long-term project were to (1) evaluate the effect of crop production practices on pest incidence and their impact on crop yield and quality, and (2) develop crop production systems that effectively prevent erosion, control pests, and are profitable (Young et al. 1994c, 1994d).

The experimental design was a randomized complete block with a split-plot feature containing four replications. This design allowed evaluation of 12 cropping systems, which included all possible combinations of two crop rotations, two tillage systems, and three weed management levels. Main plots on the 32-ha experimental site were combinations of rotations by tillage regimes with every crop grown every year. Each main plot was divided into three weed management levels representing subplots (Boerboom et al. 1993; Veseth et al. 1992). Two 3-yr rotations, with winter wheat as the primary crop of each rotation, were compared. The cropping sequence of winter wheat–winter wheat–spring wheat comprised the continuous wheat rotation, whereas winter wheat–spring barley (*Hordeum vulgare* L.)–spring dry pea (*Pisum sativum* L.) comprised the diverse 3-yr rotation. The conventional tillage system consisted of moldboard plowing after cereal grains and disking after dry pea. The conservation tillage system was a hybrid system combining minimum tillage and no-till planting. No-till system was used to plant winter wheat after either spring wheat or spring pea in each rotation. Herbicide types and rates for the three weed management levels—minimum, moderate, and maximum—were determined by scouting plots in the spring. Weed species were identified and populations counted. A complete description of all field operations has been previously published (Boerboom et al. 1993).

After two complete crop rotation cycles (6 yr), Phase I of the IPM project was completed. The project successfully developed a cropping system that integrated nonchemical cultural practices (crop rotations and limited tillage) with herbicides to control winter annual grasses and soil-borne pathogens. This study was the first to show that, when weeds were effectively controlled, a conservation tillage, diversified cropping system was more profitable (Young et al. 1994a) and less risky (Young et al. 1994a, 1994d) than continuous wheat rotations or conventional tillage production systems (or both). In the spring dry pea production system, the moderate level of weed management was more profitable than the maximum level in both tillage systems (increased yield compared with herbicide costs) (Young et al. 1994b). This disagrees with some of the criticisms that in conservation tillage, herbicide usage and cost will be higher compared with conventional tillage (Swanton and Weise 1991).

One of the most important and unique concepts derived from the first 6 yr of the IPM study was the actual development (as opposed to evaluation) of a hybrid tillage system, which allowed growers to efficiently plant crops while providing sufficient residue for conservation compliance and increasing soil moisture (Young et al. 1994b, 1994d). In the PNW, high-yielding winter wheat varieties can produce 14,500 kg ha^{-1} of residue (Young et al. 1990), which has often been burned to improve the efficiency of no-till planting (Cook et al. 1987).

In contrast to our hybrid tillage system, area growers (F. L. Young, personal observations) and scientists (Hammel 1995) have either used or evaluated two or three distinct tillage methods on their farms or research projects. As in the PNW, other North American researchers have also concentrated on evaluating (as opposed to developing) two or three separate tillage systems consisting of conventional, minimum, and no till (zero-till) in wheat production systems (Blackshaw et al. 2001; Halvorson et al. 1999; Légère and Samson 1999; Schreiber et al. 1987). An extensive review of the literature has found one other study that used a combination tillage system. In a winter wheat–grain sorghum [*Sorghum bicolor* (L.) Moench] rotation in the southern Great Plains, two continuous no-till systems (standing or shredded residues) were compared with a no-till sorghum–tilled wheat system. Contrary to our results, tillage did not affect either wheat or sorghum yield in their study.

After 6 yr, downy brome (*Bromus tectorum* L.) and several diseases became major pests in the continuous wheat rotation with conservation tillage (Young et al. 1994d). These cropping systems were therefore discontinued for the next 3 yr (1991–1994) of the IPM study (Phase II) (Young et al. 1996). The 3-yr rotation, with conservation and conventional tillage from Phase I, was maintained. The reduction of pesticides, mainly herbicides, was the major focus of Phase II. In the PNW, growers have adopted farming practices, mainly winter wheat production, that conform to the life cycle of several problem weeds such as wild oat (*Avena fatua* L.) and winter annual grass and broadleaf species. Because of these weeds, PNW growers apply at least one herbicide to 84% of their winter wheat acreage (USDA 1992). In contrast, only 15 and 34% of the nation's and corn belt region's winter wheat acreage is treated, respectively. With regard to weed management levels, a flexible system was introduced, dividing the three old levels of weed management (subplots) in half to receive a recommended and minimum level of weed management (Young et al. 1996). The amount of herbicide applied in the recommend level was based on scouting plots for weed species and populations that had carried over from Phase I. The adjacent, minimum level plot received one-half the rate of herbicide applied to the paired recommended plot.

Data from Phase I and II cropping systems studies suggest that a successful, long-term weed management approach should specifically target major weed species (in our case, wild oat) to reduce their impact in cropping systems. This approach dramatically reduced herbicide costs and inputs compared with a more broad-spectrum approach to controlling weeds (Young et al. 1996). At the conclusion of Phase I, grass weed population, of which wild oat was the main species, was > 200 plants m^{-2} in the minimum weed management level. During this same time period grass weed population (mainly wild oat) for the maximum weed management level was < 5 plants m^{-2}. At the conclusion of Phase II, the wild oat population in the previous maximum weed management level from Phase I was less than 5% ($< 10\ m^{-2}$) of the total weed population in 1994 (Young et al. 1996). This was even after wild oat herbicides in the Phase II recommended level were applied only in spring pea of the 3-yr rotation.

Extensive research on bioeconomic modeling has been conducted on data collected from Phase I of the IPM study. Data from Phase I were used to develop a first-generation model (Kwon et al. 1995) that estimated the optimal postemergence (POST) herbicides and rates in a cropping system. It was the first model developed to manage several weed species in winter wheat in various crop rotations and tillage systems. Weeds selected for PALWEED:WHEAT included more than 50 species identified during the preharvest weed density count performed during the 6 yr experiment (Kwon et al. 1995). For PALWEED:WHEAT, weeds were classified into summer and winter annual grasses and summer and winter annual broadleaves.

Very rarely have bioeconomic models been tested in the field and revised (Lybecker et al. 1991). However, small changes in variable definition or in functional specification (or both) of weed survival and crop yield equations can result in large differences in profit-maximizing herbicide recommendations (Kwon et al. 1998). In light of the fact that our first generation model was too insensitive in prescribing POST broadleaved herbicides in winter wheat (Kwon et al. 1995), we systematically field tested and subsequently revised the model (Kwon et al. 1998). In 1993 and 1994, the treatment recommended by PALWEED:WHEAT was compared with five other treatments at six field locations for profitability and weed control (Kwon et al. 1998). After field testing, herbicide recommendations were substantially modified in response to changes in model functional specifications in the second-generation model. The major change in PALWEED:WHEAT II compared with PALWEED: WHEAT was the increased recommendation of POST broadleaf herbicides in response to real-life high populations of broadleaf weeds present in growers' fields (Kwon et al. 1998). These modeling endeavors confirm the importance of field testing and revising bioeconomic weed management decision models. Our models are also unique because they expand beyond the typical economic weed management studies that focused on a single weed species in a single crop.

Fertility by Herbicide Levels Study

One of the disadvantages of long-term cropping systems–weed management studies is the large land use requirement (Wei et al. 2001). The IPM study entailed 144 plots and encompassed 32 ha (Young et al. 1994c). Initially, scientists wanted to include one additional treatment of continuous no-till and two additional treatments of fertility rates. This inclusion would have tripled the number of subplots, which would have been physically and economically impossible to manage. As an alternate solution, a smaller scale "satellite" study was conducted for 6 yr simultaneously with the IPM project. The objective of the study was to determine the effect of reducing nitrogen (N) and herbicide use in a no-till, continuous wheat system on crop grain yield, weed density, and weed biomass.

The cropping system examined was a no-till spring wheat–winter wheat–winter wheat system. The 3-yr rotation cycle was conducted twice with a single crop grown each year. The three levels of N and two levels of weed management were randomly assigned the first year and then remained consistent in each plot throughout the experiment. The N levels (main plots) included a recommended level (based on soil samples), moderate level (75% recommended), and a minimum level (50% recommended). Weed management levels were designated as minimum and maximum and were similar in the types and rates of herbicides used in the respective weed management levels in the concurrent 6-yr IPM study. Preliminary yield data indicated that winter wheat yield at the low fertility and weed management level was 32% lower than wheat yield in the maximum input level (Young et al. 1992). Complete analysis of the economics and weed population dynamics will be forthcoming.

Integrated Management of Jointed Goatgrass

A long-term field study involving weed scientists from the states of Washington, Oregon, and Idaho as well as an agricultural economist, a statistician, and cooperative extension personnel was recently completed in 2002. The study was designed to integrate best management practices generated from numerous single-component jointed goatgrass experiments previously conducted in the PNW. Field sites were located in each state in intermediate rainfall zones (350 to 400 mm) typically characterized by a winter wheat–summer fallow production system. Specific objectives of this multistate research project were to (1) develop an IWM system for jointed goatgrass control in winter wheat; (2) evaluate the effects of stubble burning, length of crop rotation, and integrated practices for planting winter wheat on the longevity of jointed goatgrass seed in the soil, and (3) identify profitable and economically stable crop production systems for fields infested with jointed goatgrass.

Treatments included a one-time stubble burn, crop rotation (length of time out of winter wheat), and integrated practices for planting winter wheat. At each location, the experimental design was a randomized complete block with a split, split-plot feature. Main plots were burn vs. no burn, subplots were crop rotations, and sub-subplots were planting practices. Crop rotations compared at all three sites included fallow–winter wheat–fallow–winter wheat and fallow–spring wheat–fallow–winter wheat. The integrated planting practices included fertilizing at planting and planting competitive, large-seeded cultivars at increased seeding rates. These practices were compared with the grower's standard practices of fertilizing in the summer fallow and planting their favorite wheat variety at the location's recommended seeding rate using commercially bagged seed. Jointed goatgrass seed in the soil was collected in all plots in the fall of each year. Samples were cleaned, dried, separated, and tested with tetrazolium for seed viability.

The project was funded by the National Jointed Goatgrass Research Program, and yearly progress reports from this study are accessible at the jointed goatgrass website (www.jointedgoatgrass.org). The first formal presentation of data occurred at the 13th Australian Weed Conference, September 2002 (Young et al. 2002). At the conference, results from the Oregon location were presented. The experiment at this site was unique because both the grower (conventional) and the researchers (integrated) planted the same winter wheat variety, 'Stephens'. Because of this coincidence, we had the opportunity to determine the direct impact of integrated winter wheat planting practices on crop production and weed management without the confounding issue of different wheat varieties for each type of planting. During the course of the 5-yr study, whenever winter wheat was planted within a rotation, the integrated planted winter wheat outperformed the conventionally planted winter wheat. Crop yield was more than 20% greater in the integrated wheat compared with the conventional wheat in four of six winter wheat planting comparisons (Young et al. 2002). Dockage due to jointed goatgrass contamination in the harvested grain generally was 50% less in the integrated wheat compared with the respective conventional wheat treatment. Data from this location indicate the importance of integrating several management strategies to suppress jointed goatgrass competitiveness in wheat production systems. However, results may vary at other locations depending on winter wheat varieties selected and initial weed populations.

No-till Spring Cropping Systems

Another study being conducted in the PNW, which focused on long-term weed management systems is located near Ralston, WA, in the wheat–fallow region (< 350 mm annual precipitation). This low-rainfall, semiarid region comprises over 60% of the wheat production area of the PNW. The century-old practice of winter wheat–tillage fallow is characterized by severe infestations of winter annual grass weeds (Thorne and Young 1998) and severe wind erosion. The overall goal of the project is to acquire knowledge to assist growers to make the transition from winter wheat–fallow to annual no-till spring cereals that will leave more hectares covered with residue over longer periods of time while economically managing pests (Young et al. 2000). The multi- and interdisciplinary research involves 14 scientists from nine disciplines and four agencies. Each discipline has its own set of specific objectives. The weed science objectives include (1) management of winter annual grass weeds in cereal cropping systems, (2) evaluation of weed species shifts during the transition from the traditional wheat–fallow system to continuous no-till spring cropping systems, and (3) economical management of problem weeds in no-till spring cereals. The four cropping systems initially evaluated include (1) reduced tillage winter wheat–summer fallow, (2) no-till spring wheat–chemical fallow, (3) no-till continuous hard red spring wheat, and (4) no-till hard red spring wheat–spring barley. The experimental design of the main core study was a randomized complete block with four replications with every crop in each rotation grown each year.

The project consisted of two elements, a main core study and additional satellite studies. The main core project evaluated no-till spring cropping systems on large plots with field-size equipment, through at least two cycles of each crop rotation. Satellite studies (generally 2 to 3 yr) were single-component experiments conducted throughout the region to evaluate new agronomic practices. Successful practices identified in these short-term satellite studies would then be incorporated into the main core study. An example of this was a satellite study which evaluated the planting of facultative wheat (in our case, spring wheat cultivars) in late fall to suppress weed growth in the spring. Facultative wheats, although no precise definition exists, usually have a strong sensitivity to photoperiod and partial sensitivity to vernalization (Stelmakh 1998). Compared with winter wheat, facultative wheats have less cold tolerance, a distinct but shorter vernalization requirement, and earlier spring growth and flowering (Braun and Sãulescu 2002). Facultative wheats are generally produced where winters are mild and late fall precipitation occurs. Our facultative wheat study was based on the fact that Russian thistle (*Salsola iberica* Sennen & Pau) is the major weed problem for spring cereals in the winter wheat–fallow region of the PNW, and early-planted spring wheat can greatly reduce Russian thistle competition (Young 1986, 1988). Russian thistle biomass and subsequent weed interference on spring wheat yield was greatly reduced when spring wheat was planted in early March compared with mid March (Young 1988).

The facultative wheat satellite study was initiated at Lind, WA, in 1996 and repeated in 1997 to determine if spring wheat would germinate, grow, and produce grain if planted in late fall or early winter in the PNW. For each experiment, wheat was seeded on four dates: November 5, 1996; February 18, 1997; March 4, 1997; and March 21, 1997 for planting dates 1, 2, 3, and 4, respectively, for the 1997 experiment. Planting dates for the 1998 experiment were November 4, 1997; December 17, 1997; February 6, 1998; and March 9, 1998. These dates were chosen for very specific reasons. The first date (early November) was approximately 1 wk before inclement weather (freezing temperatures and snow) arrives and "shuts down" all fieldwork. The last date (mid to late March) was optimal spring wheat planting time for the region and prevailing environmental conditions. The second and third dates were "windows of opportunity" when environmental conditions allowed wheat to be seeded. Spring wheat cultivars 'Alpowa', 'Wakanz', and 'Edwall' were chosen on the basis of their facultative tendencies (K. Kidwell, personal communication) such as early spring growth and maturity (Braun and Sãulescu 2002). In addition to facultative tendencies, Alpowa has a high yield potential, Wakanz has resistance to Hessian fly [*Mayetiola destructor* (Say)], and Edwall was the standard spring wheat cultivar in the < 255-cm rainfall zone (Thorne and Young 1998). Each year 'Eltan' winter wheat was planted on each date as a control. The seeding rates for the spring wheat cultivars were 65 to 67 kg ha^{-1}, and the seeding rate for the winter wheat was 62 kg ha^{-1}.

The interaction among date, variety, and year was significant for wheat yield. In general, the spring wheat cultivars

TABLE 1. Effect of planting date on spring wheat cultivars' yield, stand establishment, or spikes produced at Lind, WA, 1996–1998.

Seeding date[a]	Yield[b]		Wheat stand[c]	Wheat spikes[c]
	1997	1998	1997	1998
	kg ha^{-1}		plants m row^{-1}	no. m row^{-1}
Alpowa				
1	2,875 a	2,360 b*	10 ab	23 b
2	2,115 b	2,055 b	7 b	23 b
3	2,715 a	3,005 a	8 b	28 a
4	3,065 a	3,210 a	12 a	30 a
Wakanz				
1	2,730 bc	3,165 ab	6 b	23 b
2	2,390 c	2,735 ab	8 b	27 ab
3	3,025 ab	3,325 a	9 ab	30 a
4	3,335 a	2,630 b*	14 a	29 a
Edwall				
1	2,290 ab	2,730 a	9 b	22 b
2	2,035 b	2,640 a*	7 b	20 b
3	2,710 a	2,815 a	8 b	23 ab
4	2,885 a	3,075 a	13 a	27 a
Eltan				
1	2,070	3,090	5 b	22 a
2	1,810	1,195	6 b	18 b
3	2,015	—	7 b	19 b
4	—	—	14 a	12 c

[a] Seeding dates for the 1997 crop harvest were November 5, 1996; February 18, 1997; March 4, 1997; and March 21, 1997 for dates 1, 2, 3, and 4, respectively. Seeding dates for the 1998 crop harvest were November 4, 1997; December 17, 1997; February 6, 1998; and March 9, 1998 for dates 1, 2, 3, and 4, respectively.

[b] Means within a variety and year column followed by the same letter are not significantly different according to a protected LSD test at the 5% level.

[c] Means within a variety followed by the same letter are not significantly different according to a protected LSD test at the 5% level.

* Denotes significantly different yields across years within a variety and planting date at the 5% level.

produced the best yields when planted in the spring (March 4 or 21, 1997 and February 6 or March 9, 1998) (Table 1). However in four of the six planting dates by variety comparisons, the yield of the spring wheat planted in November was similar to the yield of spring wheat planted at the normal spring seeding date. Plant population (1997) and wheat spikes produced (1998) were generally less for November-planted wheat compared with the normal March-planted wheat (Table 1). Growers could increase seeding rate to offset the lower plant population without incurring very much additional expense because seed cost still remains a low input cost. Seeding date had no influence on test weight, but test weight was higher for Alpowa > Wakanz > Edwall (data not shown). Early spring growth, an advantage of facultative spring wheat (Braun and Săulescu 2002), was reflected in plant height recorded in 1997 (Thorne and Young 1998). Both Alpowa and Wakanz were approximately 50% taller in May when planted in November compared with March plantings. This early height advantage should reduce weed competition, especially when Russian thistle, the major agronomic weed species in this production system, germinates, emerges, and becomes established from April to mid-May (Young 1986). Additional advantages to planting facultative spring wheat in the fall or winter is to distribute spring planting and summer harvest operations and to use late fall, winter precipitation predominate to the region (Cochran et al. 1970).

In 2000, large (9 by 152 m) single-strip demonstration plots were established at Ralston, WA, to compare the yield of winter wheat planted in August in traditional summer fallow with no-till facultative Alpowa planted in November and no-till Alpowa planted in March in chemical fallow. Yield of the winter wheat and fall-planted facultative Alpowa spring wheat was similar but greater than the spring-planted Alpowa. Because of the success of the satellite and demonstration plots, the concept of using facultative wheat from late-fall planting has been incorporated into the main core study at Ralston beginning with the 2002–2003 crop growing season. Preliminary results were promising for the facultative wheat both from the yield and weed suppression standpoints (F. L. Young, unpublished data). If this system proves successful in the large-scale, long-term project, growers could use this concept in lieu of delaying winter wheat planting beyond optimum time when fall weather conditions are extremely dry. Our system does not include the additional cost of polymer coating of seed, which delays germination of late-fall–planted crops until early spring (Zarnstorff 2000). The basis for using fall-planted facultative spring wheat was to allow germination and emergence to be controlled naturally and take advantage of early spring growth. As an example, all the spring wheat cultivars planted in November 1997 had emerged by January 28, 1998 and were in the two- to three-leaf stage by February 24 (data not shown).

Phase I (2.5 rotation cycles) of the main core study was completed in 2000, and results for residue management (Thorne et al. 2003), entomology (Clement et al. 2003), and weed science (Young and Thorne 2004) have recently been published. This study showed for the first time that Hessian fly was a pest problem in no-till spring wheat in the low-rainfall zone of the PNW but that the use of host plant resistant cultivars would alleviate the problem (Clement et al. 2003). Agronomic practices showed that reduced tillage winter wheat–fallow and no-till spring cereals reduced erosion susceptibility 55 and 90%, respectively (Thorne et al. 2003). As with Phase I of the IPM project, this study also showed that intense management of the target weed species dramatically reduced the impact of downy brome in a 2-yr wheat–fallow rotation (Young and Thorne 2004). Successful management strategies for downy brome included postharvest disking to very shallowly incorporate weed seed into the soil to increase germination before the fallow year and delaying winter wheat planting beyond the optimum time to kill recently emerged downy brome. The concept of no-till spring crops for Phase I of our study is similar to other conservation crop production systems conducted in the semiarid wheat–fallow regions of Canada (Derksen et al. 1994) and the northern Great Plains (Halvorson et al. 1999). However, there is one major difference among these studies. In the other regions mentioned, spring–summer rainfall is predominant and would favor the production of spring crops. This is not true in the PNW where only about 25% of our moisture is received from March through August. If we receive $<$ 300 mm total annually, that means very little is received during critical times for spring crops. It has been said (R. J. Cook, personal communication) that the greatest challenge to production scientists is to develop a no-till spring cropping system for the arid and semiarid region of the PNW. For future research, investigators have modified main plots and satellite studies and extended the duration of the study to comply with the requests of interested growers, agribusiness personnel, and scientists (Forté-Gardner et al. 2003). New treatments include (1) no-till winter wheat or winter canola (*Brassica napus* L.)–fallow; (2) no-till soft white spring wheat (flex crop) or chemical fallow–facultative spring wheat; (3) no-till spring oats (*Avena sativa* L.) (for forage or grain)–spring triticale (*Triticale hexaploide* Lart.); and (4) no-till hard white spring wheat–one-pass till spring barley or no-till spring barley.

Influence and Impact of PNW Long-term Projects

One of the major dilemmas, both past and present, with long-term field research studies is the definition of "long-term". A brief discussion along with the pros and cons of long-term research has been presented earlier (Young et al. 1994c). Unfortunately, the term is ambiguous and is all-too-often delineated by the funding agency and how long the researchers can procure a series of short grants. It has been agreed that long term, according to funding agencies is generally 2 to 3 yr (Légère 2002; Young et al. 1994c). It is the author's opinion that the duration and design of these studies depend on the researchers' objectives. If the objective is to measure the transitions from one system to another and allow all treatments to manifest themselves and have the new system begin to stabilize, at least two complete cycles of the longest crop rotation in the system would be required. The studies must, of course, be extended if the economics (profitability and risk) and soil quality changes of the new system are to be determined. My experience has been that interest by granting agencies is initially very high but wanes considerably after the transition period (two crop rotation cycles). Unfortunately, the next cycle is where the research return on budgeted dollars is the greatest (Thill et al. 1991).

In the high-rainfall zone, the IPM Project was the impetus for the research initiated in 1995 at the Palouse Conservation Research Farm near Pullman, WA (R. Papendick, personal communication). At that time, the nonresearch areas of the farm were divided into several 3.2-ha fields, which were converted from conventional tillage to no-till systems (Steering Committee of the Pacific Northwest Direct-Seed Cropping System Coalition 2001). Local, regional, and national impact of the IPM project was dramatic and has been previously discussed (Young et al. 1996) and includes (1) methods and data used as basis and source for other IWM studies (Wille 1997); (2) use of agronomic and economic data to develop regional farm plans by federal agencies; and (3) use of data by National Association of Wheat Growers to contribute to the then current Presidential Administration's and Environmental Protection Agency's strategy for IPM farm policies and pesticide usage and reduction (Young et al. 1996). Locally, the production and economic information was used by bank loan officials to evaluate cropping systems' risk and profitability (Young et al. 1996). In addition, the Natural Resources Conservation Service estimated that half of the farmers used some aspect of the IPM project on their farm (Stelljes-Barry 1995).

The Ralston Project was the first study in the region to determine the feasibility of continuous no-till spring cereals as an alternative to tilled winter wheat–fallow (Papendick 2004). In 2002, a survey was conducted (Forté-Gardner 2003) to determine if and how the innovative research approach and design of the long-term, integrated spring cropping systems project affected interested growers regionally. Approximately 62% of individuals surveyed completed a mail questionnaire, which inquired about their attitudes toward the project and behaviors with regard to featured technology. Growers interested in no-till and alternative cropping systems overwhelmingly viewed this project as a valuable learning and adaptive production management tool. As a result of this research, 61 and 51% of the growers used and adopted technologies directly from the project, respectively. Furthermore, the regional success of the IPM project and interest in the integrated spring cropping systems project aided in establishing a Direct Seed Cropping Systems Endowed Chair at Washington State University in 1997 through the Washington Wheat Commission.

Our projects have helped generate a change in the attitudes of growers and scientists in accepting the value of cropping systems research. This has led to a change in the direction of cereal research in the inland PNW. Several new, long-term, cropping systems studies have been initiated since the IPM and Ralston Projects (Steering Committee 2001). These new projects, however, were not initiated or designed to solve any of the weed management problems that plague PNW agriculture. For the most part, the new cropping systems designers have chosen particular agronomic systems and hoped herbicides were available to control the weeds sufficiently. So, although the concept of cropping systems design has taken hold, weed management is too often a secondary focus.

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