CHAPTER 5

Wind Erosion Control Research on Irrigated Lands of the Columbia Plateau

Most of the irrigated farmland on the Columbia Plateau lies in the Columbia Basin and its peripheral areas east and north of the Columbia River in central Washington with a small portion in north central Oregon (Figs. 1.1, 1.2). Grain, hay, tree fruit, vegetable, seed, and specialty crops are produced mostly by sprinkler irrigation, and some by furrow irrigation where the land was developed for that purpose. Most of the irrigation water has been diverted from the Columbia River and much of the land has only been farmed 50 some years. Crops are interspersed with fields or blocks ranging in size from 10 to 50 acres. Soils in the Columbia Basin are generally coarser-textured (i.e., greater amounts of sand and fine gravels) than in most dry-farmed areas, and except for the Horse Heaven Hills contain lesser amounts of PM_{10}. For this reason some soils are more subject to saltation and drifting during wind erosion, and while eroding are much more likely to cause crop damage than finer-textured soils.

Nevertheless, wind erosion on irrigated lands can produce considerable dust where conventional farming practices leave the soil bare, smooth and intermittently dry at times when there is a potential for high winds. The greatest potential for erosion of irrigated soils by wind is: 1) immediately after spring and early fall planting where extensive areas are worked by tilling and sowing that leaves the soil surface unprotected until crop cover is established and irrigation is underway; and 2) after harvest of crops that produce low amounts of above-ground biomass, and in particular when the residue withers, or decays rapidly. This is especially a problem with late-fall harvested crops after which temperatures begin to decrease and make it difficult or impossible to establish crop cover before winter.

Seedbed preparation often involves excessive tillage to take out hay crops such as alfalfa (*Medicago sativa* L.), or grass grown for seed production, or to breakdown and bury cereal residues such as corn (*Zea mays* L.). Operations with aggressive implements such as heavy double disks, moldboard plows or rotovators destroy soil structure and often leave little cover. Secondary tillage with cultivators, harrows and solid wheel packers for smoothing the soil surface loosen and/or pulverize soil, making it even more susceptible to wind erosion.

Dry beans (*Phaseolus vulgaris*), onions (*Allium cepa*), potatoes (*Solanum tuberosum*) and most vegetable crops produce relatively small amounts of residue that may decompose in several weeks. Of primary concern are root crops such as onions, carrots (*Daucus carota*), sugarbeets (*Beta vulgaris*), and late potatoes that are harvested in October or November after the weather cools. The small amounts of post-harvest residue from these crops generally decompose readily and/or are buried by the harvesting operation. Cool weather after harvest often precludes establishing a cover crop before winter, and unless alternative protection measures are available the soil is left exposed to the elements during the rest of the non-growing season.

During the past five years the CP_3 has focused most of its research for irrigated lands on residue and cover crop management for erosion control. The objective is to promote surface cover by reducing tillage and eliminating field burning of crop residues, and by encouraging grower-adoption of improved management practices for adaptable cover crops.

No-Till Sowing into Stubble of Irrigated Crops instead of Burning and Plowing

A common practice by deep-well irrigators in east central Washington for economic reasons is continuous winter wheat production with full irrigation. Grain yields range from 90 to 140 bu ac^{-1} with residue yields of 5 t ac^{-1} or more. The traditional production practice is to burn the stubble after harvest in August and then moldboard plow followed by secondary tillage before sowing the next wheat crop in September. Environmentally, field burning is problematic due to smoke emissions, and fall plowing as well because it increases the wind erosion hazard prior to crop cover establishment.

Growers say burning not only rids the field of the heavy stubble that interferes with sowing the next crop but also along with plowing helps to control downy brome, a winter annual that is difficult to control with continuous winter wheat cropping. This is especially true with minimum- and no-till systems. An alternative might be a no-till system without burning to replace the continuous winter wheat system with burning and intensive tillage. However, because of potential weed and disease problems this is only possible with cropping systems that include spring cereals and/or broadleaf crops in rotation with winter wheat.

A 6-yr irrigated research project was initiated in 2000 at the WSU Dryland Research Station at Lind, WA to determine the feasibility of no-till seeding into high levels of crop residue as an alternative to burning and plowing in a full-irrigation cropping system (Schillinger, 2002). The experimental area was sown to 'Madsen' winter wheat in fall 1999 to establish a uniform residue base. A 3-yr rotation of winter wheat–winter canola–spring barley under three stubble management methods was imposed with no-till sowing as follows: 1) into standing stubble, 2) after mechanical removal of stubble by swathing and baling and 3) after burning the stubble. Continuous annual winter wheat sown after burning and moldboard plowing was also included as the control treatment. All sowing (except for winter canola that was broadcast one year) in no-till plots utilized an ultra-low disturbance Cross-Slot drill that sows and fertilizes in one pass. A double disk drill with 6-inch row spacing is used to sow wheat in the burn/plow treatment. Water is applied by sprinkler irrigation at a rate of 15 inches per year to all crops.

In the first and third crop year (fall 2000 and 2002), the winter canola failed and so the treatment was replaced with a planting of spring canola. Sowing winter wheat into winter wheat stubble in the fall of the first year was a problem due to excessive surface residue, but not with barley into winter wheat stubble in the spring because there had been sufficient over-winter straw decomposition (Fig. 5.1). Frost damage to winter wheat during flowering, difficulties with sowing in the control plots, and other factors resulted in grain yields with considerable variation and no significant differences within any crop in 2001 as affected by stubble management methods. In 2001, grain yield averaged across residue and soil management treatments was 74 bu ac^{-1} for winter wheat, 2.93 t ac^{-1} for spring barley, and 2,447 lb ac^{-1} for spring canola (Table 5.1). Growers on the advisory committee expect per acre yields of 100 bu ac^{-1} for winter wheat, 3 t ac^{-1} for barley, and 3,000 lb ac^{-1} for canola, for the 3-year no-till rotation to be economically competitive with their continuous burn/plow winter wheat system.

The standing stubble treatment averaged 2.5 inches more water in the 6-ft profile in April (before spring irrigation) than the burned stubble treatment but only about 0.7 inch more than where the stubble had been mechanically removed. Weed mass (all species) was near negligible in winter wheat after the stubble burn treatment but significantly higher where the stubble was either mechanically removed or left standing. There were no differences among treatments for spring barley or canola. Incidence of rhizoctonia and take-all root diseases were low in all residue management treatments for winter wheat and spring barley.

Because of limited success with establishing winter canola following winter wheat, the rotation starting in fall 2001 was changed to winter wheat–spring barley–winter canola. A satisfactory stand was achieved by sowing winter canola into barley stubble immediately after harvest and then applying six inches of irrigation water. The volunteer barley that emerged was adequately controlled with a grass herbicide. There was no difficulty with sowing winter wheat into canola stubble.

As in 2001, the second and third years of the study, within-crop yields of the three crops in rotation were not significantly different for the three stubble management treatments (Table 5.1). Moreover, as in 2001, the yields of winter wheat in the 3-yr rotation were statistically equivalent with those of continuous winter wheat after burning the stubble and plowing in 2002 but significantly higher than burning and plowing in 2003. The grain yield of winter wheat in the burn/plow treatment was reduced by take-all disease caused by *Gaeumannomyces graminis* var.*tritici* which was not a factor in the other treatments.

Winter wheat yields in 2002 and 2003 were considerably higher in all of the stubble management treatments than in 2001, and higher in the burn/plow treatment in 2002 but equal in 2003. Yields trended slightly lower for spring barley in 2002 and 2003 compared with 2001 and considerably lower for canola in 2003 compared with 2001 and 2002 (Table 5.1). Assessments of several diseases in winter wheat showed the incidence to be low to moderate in all treatments except for the burn/plow treatment where take-all disease pressure was very high in 2003.

A variety of weed species were present in 2002 but the only significant difference in populations due to effects of crop and residue management was with downy brome. There was essentially no downy brome present in any plot that had been burned or in winter canola where Assure II herbicide was used. Only small populations were present in winter wheat and spring barley where the stubble was mechanically removed (Schillinger, 2002).

An annual advisory committee meeting between growers and WSU and USDA/ARS researchers is held to view the experiment, discuss results, and make procedure-related management decisions. Experimental results are also reported and discussed at the annual WSU Dryland Research Station Field Day in June to an average of 170 attendees (Fig. 5.2).

Table 5.1. Grain yields of irrigated crops under different stubble and soil management practices at Lind, WA, 2001-2003[1].

Treatment	Crop								
	Winter wheat (bu ac^{-1})			Spring barley (t ac^{-1})			Canola[2] (lb ac^{-1})		
	2001	2002	2003	2001	2002	2003	2001	2002	2003
Stubble burned	85	106	113a[4]	2.88	2.21	2.39	2,574	2,502	1,027
Stubble removed[3]	67	110	96a	3.03	2.33	2.24	2,486	2,226	1,135
Stubble standing	69	107	101a	2.88	2.26	2.08	2,282	2,188	1,326
Burn and plow	75	97	74b	—	—	—	—	—	—
LSD (0.05)	NS	NS	NS	NS	NS	NS	NS	NS	

[1]Source: Schillinger (2002); W.F. Schillinger, Washington State University, personal communication, August 2003. The crop rotations are continuous no-till winter wheat–spring barley–canola for the stubble burned, stubble removed, and stubble standing treatments, and a continuous winter wheat system for the burn and plow treatment.
[2]Spring canola in 2001 and 2003 when winter canola failed; winter canola in 2002.
[3]By swathing and baling.
[4]Within column winter wheat yields in 2003 followed by the same letter are not significantly different at P<0.05. NS = no significant differences.

Managing Cover Crops for Erosion Control and as a N Source for Crops

Cover crops not only control wind erosion and particulate emissions from irrigated farmlands but also benefit cropping systems management. For example, legumes provide biological N-fixation to improve soil fertility and reduce chemical fertilizer requirements for subsequent crops, while legumes, grasses, and cereal crops provide forage for livestock, and for biocontrol of crop pests and diseases. Compared with bare ground, properly managed cover crops increase water infiltration, reduce soil compaction, suppress weeds, and improve soil quality. With irrigation, and a diversity of crop species available for selection, researchers and growers have considerable leeway to identify site specific cover crop options that fit various cropping schedules and post-harvest windows, and that are adaptable to regional soils and microclimates.

An ongoing project of the CP_3 under the leadership of W.L. Pan and B.E. Frazier of WSU, and in collaboration with M. Stannard of the USDA Natural Resources Conservation Service, is to develop and promote the use of cover crops as an integral and profitable component of cropping systems in the irrigated areas of the Columbia Basin. Specific objectives of the research are to: 1) develop crop models to predict growth, canopy cover and N accumulation by different cover crops as a function of temperature, 2) quantify soil N dynamics and impacts on N fertilizer requirements by using different winter cover crops, 3) develop information on the status of cover crop use and factors affecting their adoption by growers, 4) develop remote sensing technology for monitoring cover crop use in the irrigated areas, and 5) promote grower use of cover crops through educational programs.

FIGURE 5.1. *Sowing spring barley with a Cross Slot no-till drill into more than 5 tons per acre of standing winter wheat stubble in the Lind irrigated cropping systems study. The study seeks alternatives to a traditional continuous winter wheat system under full irrigation that involves burning the stubble and plowing for seedbed preparation. The alternative cropping systems include spring barley and/or canola crops in rotation with winter wheat, all sown no-till in three residue management treatments: stubble burned, stubble mechanically removed, and stubble left standing. Photograph by W.F. Schillinger, WSU. See Figure 2B in Appendix B for additional detail of the drill.*

FIGURE 5.2. *The irrigated cropping systems experiment is shown and discussed each year at the WSU Dryland Research Station, Lind, WA field day to an average of 170 growers, agri-industry and agency personnel. Photograph by H.L. Schafer, WSU.*

PREDICTING THE GROWTH AND CANOPY COVER OF POTENTIAL COVER CROPS

A cover crop model was developed by empirically relating growing degree day (GDD) accumulation to biomass from replicated field plots of several different cover crops at three locations (Quincy, Othello, and Prosser) in the Columbia Basin (Kunch, 2001; Pan et al., 2001). Growing degree days (GDD) are units of temperature needed for plant growth and are accumulated starting with the sowing date by summing the average of the daily maximum and minimum air temperatures minus a base temperature. The equation is:

GDD = (maximum daily temperature + minimum daily temperature) ÷ 2 – base temperature. eq 5.1

The base temperature is determined from studies reported in the literature and represents the lower limit at which a specific plant ceases to grow. For example, mustard (*Brassica* spp.) and canola (*Brassica napus*, sometimes referred to as rapeseed) have a base temperature of 41 °F, winter wheat 36 °F, and rye (*Secale cereale* L.) and triticale 32 °F. The GDD is zero (no growth) for days when the average of the max/min temperature is equal to or below the base temperature.

For model development the field plots were sampled on a weekly or biweekly basis for percent ground cover, biomass and N accumulation and leaf stage of the growing crops. Growing degree days were calculated from weather station data at each of the three experimental locations. Historic weather records were used in association with the GDD–biomass relationships to derive planting dates required to achieve biomass production goals for eight cover crops at 11 locations (Stannard et al., 2000). The eight crops are listed in Table 5.2 and the 11 locations, all in Washington state, are Connell, Ephrata, Lind, Moses Lake, Othello, Prosser, Quincy, Richland, Ritzville, Walla Walla, and Wilson Creek.

To facilitate wider application of the GDD-cover crop relationships Pan et al. (2001) developed growth and cover equations from data for individual cover crops (i.e., canola, mustard, rye, triticale, and winter wheat) to compute biomass directly from GDD, and percent cover from biomass. For calculating biomass the relationship was sigmoidal in the form of:

$$y = a \div \{1 + \exp[-(x - x_o) \div b]\} \quad \text{eq 5.2}$$

where y is the biomass in kg ha^{-1}, x is the GDD in degrees centigrade, and a, b, and x_o are fitted parameters. For percent cover y as a function of biomass x in kg ha^{-1} the equation is:

$$y = a[1-\exp(-bx)] \quad \text{eq 5.3}$$

where a and b are fitted parameters (Pan et al., 2001). The equations are developed using metric units but the output can be converted to lb ac^{-1} by multiplying kg ha^{-1} by 0.893.

Table 5.2 is an algorithm provided by Stannard et al. (2000) for Othello, WA to aid with selection of a crop and planting date to achieve a desired level of biomass production at that particular location. To supplement this information, equation 5.3 was used to calculate the percent cover produced by winter wheat and canola for different biomass levels.

Table 5.2 shows that the planting windows in September varied from 8 to 14 days among the eight cover crops to achieve similar levels of biomass production. This variation holds true for the other 10 locations or for the same crop at different locations (Stannard et al., 2000). Calculations using equations 5.2 and 5.3 show that the accumulation of biomass and cover in the early stages of growth is exponential with GDD and declines rapidly after September. This illustrates the importance of earlier sowing to ensure adequate cover before winter.

The GDD model predicts that mustard requires approximately 235 GDD and winter wheat 455 GDD to accumulate biomass for 50% ground cover (Kunch, 2001). The author used temperature data from Quincy and Kennewick, WA in the GDD model to determine days after sowing to achieve 50% cover by mustard and winter wheat for first of the month and mid month sowing dates during August, September and October of 1998, 2000, and 2002. Kennewick being located farther south in the Columbia Basin than Quincy is generally warmest of the two locations.

The results in Table 5.3 indicate that the early growth rate of mustard is considerably greater than winter wheat for establishing ground cover at all sowing dates for all three years and at both locations. Even at a September 15 sowing date 50% cover is generally established by mustard at or within days after two weeks (an exception is 17 and 18 days at Kennewick in 2000 and 2002, respectively) whereas it is closer to three weeks with winter wheat even at the earliest sowing dates of August 1 and 15. Given time it was possible to obtain 50% cover by December 1 with both crops all years with an October 1 sowing date with the exception of winter wheat in 2000 at Quincy. However, with October 1 sowing, the model predicts it requires mustard three to four weeks and winter wheat six to seven weeks to establish 50% ground cover at these locations and years.

High winds on the Columbia Plateau can occur anytime; however, weather records indicate that their probability of occurrence is highest from mid September through late November (see Fig. 1.6 in Chapter 1). Though the probability of fall rains tends to increase in October and offset the effects of winds, dry surface soils are not uncommon going into November in the irrigated areas. Based on Table 5.3 which is a short time interval, mustard could provide effective cover where needed for most high wind events if sown by September 1 and winter wheat by August 15 at either the Quincy or Kennewick locations. However, refinements should be based on longer weather records and for specific locations as indicated in the following paragraphs.

With site-specific weather information the GDD model enables one to predict planting windows required to meet irrigated dry matter production and canopy cover for various crops at different locations. The maximum-minimum temperature database has been expanded by compiling regional weather records from the National Climatic Data Center to include 19 weather stations that have temperature records over the 29-yr period from 1965 to 1994 (Pan et al., 2001). An additional step was to integrate the GDD model with GIS long-term weather maps for predicting biomass and canopy cover from different crops as a function of planting date across the regional microclimates of the Columbia Basin, with capability to account for seasonal variations as well (Pan et al., 2001). Some results with the GDD/GIS model for five cover crops (mustard, canola, rye, triticale, and winter wheat) are as follows (Pan et al., 2001):

1. All five cover crops require 450 lb ac^{-1} of dry matter for 50% canopy cover.
2. Extreme year-to-year temperature variations can cause seasonal differences of over a ton ac^{-1} in dry matter production.

Table 5.2. Dry biomass and cover[1] produced before winter based on average growing degree days by small grain and broadleaf crops sown at different dates in September at Othello, WA[2, 3].

	Dry biomass and cover						
(lb ac^{-1})	89	178	357	714	1070	1427	1784
WW (%)	19	33	51	67	72	73	73
C (%)	23	39	56	67	69	70	70
Crop	----------------------September sowing date--------------------						
Alpowa wheat	22	18	14	10	08	07	06
Aroostock rye	30	25	21	16	14	12	11
Breaker triticale	27	22	17	2	09	08	07
Celia triticale	2	21	16	12	09	07	06
White mustard	19	16	13	10	08	07	06
Canola	16	12	09	06	04	03	02
Moro wheat	22	18	14	10	08	06	05
Stephens wheat	21	16	12	08	06	04	3

[1]Percent cover is calculated only for winter wheat (WW) representative of small grains, and canola (C) representative of some broadleafs used for cover crops.
[2]Adapted from Stannard et al. (2000) and Pan et al. (2001).
[3]For example, 89 lb ac^{-1} of biomass is produced before winter by the different crops sown on the September date indicated. This amount of biomass will provide 19% ground cover by winter wheat and 23% cover by canola.

3. Brassicas (in this case canola) provide excellent ground cover and recovery of soil N when planted by September 1 in the northern Columbia Basin and September 15 in the southern Columbia Basin.
4. Triticale provides more canopy cover per unit of dry biomass than the other crops.
5. Cover from triticale and rye exceeds 50% before winter in the southern Columbia Basin even when planting as late as October 15.

Table 5.3. Days after different sowing dates to achieve 50% ground cover by mustard and winter wheat at Quincy and Kennewick, WA during 1998, 2000, and 2002[1].

Sowing date	Crop/year					
	Mustard			Winter wheat		
	1998	2000	2002	1998	2000	2002
Quincy	Days to achieve 50% cover					
Aug 1	11	9	11	18	17	19
Aug 15	12	12	12	20	21	20
Sept 1	12	14	13	22	25	23
Sept 15	15	16	15	28	29	28
Oct 1	24	23	21	51	—[2]	51
Oct 15	—	—	—	—	—	—
Kennewick						
Aug 1	11	10	14	19	18	23
Aug 15	12	12	14	20	21	24
Sept 1	12	15	15	21	26	26
Sept 15	14	17	18	25	32	31
Oct 1	21	26	26	39	56	52
Oct 15	36	—	—	—	—	—

[1]The GDD model predicts that mustard requires 235 GDD with a base temperature of 5° C and winter wheat 455 GDD with a base temperature of 2.4° C to accumulate biomass for 50% cover (Kunch, 2001).
[2]At a cutoff date of December 1 indicating that there were not enough GDD to achieve 50% cover by that time.

FIGURE 5.3. *Yellow mustard as a cover crop can increase soil organic matter, scavenge soil nitrogen deep in the profile for release to the next crop, and greatly reduce wind erosion in irrigated farming. Even at a September 15 sowing date the crop can produce 50% cover in about two weeks. As a green manure it reduces populations of nematodes, weeds and diseases and, consequently, the need for pesticide inputs by as much as 25% for potato, onion and sugarbeet crops that follow. Photograph by W.L. Pan, WSU.*

Nitrogen recovery and recycling by cover crops to minimize soil nitrate leaching and reduce the crop's need for chemical fertilizer N

High rates of N fertilizer applied under irrigation to maximize yields of summer cash crops coupled with residue decomposition following crop harvest can lead to buildup of residual soil nitrate that may be susceptible to over-winter leaching in the absence of a growing crop. Hammond and Neilan (1992) reported increases in nitrate concentration of soil water in and below the root zone of irrigated corn in the Columbia Basin as the crop matured, as well as after harvest and into the winter. The N remaining in the root zone is then susceptible to further leaching from overwinter precipitation (Stannard and Thornton, 1994).

Research cited by Weinert et al. (2002) showed that cereal and *Brassica* winter cover crops with rooting depths of 2.5 to 5 ft have the potential to scavenge and accumulate over 130 lb soil N ac^{-1}. Moreover, if managed as a green manure and killed early enough, it can potentially supply a subsequent summer crop with as much as one-half of the recovered N, thereby substantially reducing the crop's need for chemical fertilizer N (Fig. 5.3). Such savings would help to pay for management of non-leguminous cover crops and encourage their use for wind erosion control in irrigated farming systems.

Weinert et al. (2002) conducted studies on commercial pivot-irrigated fields to 1) identify effective winter cover crops for recovering residual soil N when soil-incorporated after a sweet corn crop, and 2) determine availability of N released from the green manure cover crops for uptake by a succeeding potato crop. Research plots were established on Quincy loamy sand (mixed mesic Xeric Torripsamments) near Plymouth, WA in the southern Columbia Basin in 1993, and in the north on the same soil type near Quincy, WA in 1994. The treatments were: 1) bare fallow, 2) fall-incorporated sudangrass [*Sorghum bicolor* (L.) Moench], 3) fall-and spring-incorporated yellow mustard (*Brassica hirta*), and 4) spring-incorporated winter wheat, canola, and rye. The cover crops were sown after sweet corn harvest on August 25, 1993, and September 26, 1994. All were incorporated into the soil with a rotovator operating to a depth of 8 inches. Yellow mustard and sudangrass were incorporated after a killing frost, 60 days after sowing (Oct. 28) at Plymouth and 45 days (Nov. 11) at Quincy. Additional plots of mustard, and the winter wheat, canola and rye were allowed to grow over winter and were spring-incorporated 191 days after sowing (March 3) at Plymouth and 190 days after sowing (April 4) at Quincy. Potato seed pieces were planted by commercial methods 38 and 24 days after cover crops were soil-incorporated at Plymouth and Quincy, respectively.

Some highlights of the research results by Weinart et al. (2002) are as follows. All biomass values are expressed on a dry weight basis.

1. At Plymouth, N accumulation in the above ground biomass of fall-incorporated yellow mustard equaled that of spring incorporated rye and winter wheat for an average of about 120 lb ac^{-1}of N. The canola biomass accumulated slightly less N at 98 lb ac^{-1}. The sudangrass, also fall-incorporated, produced only 625 lb ac^{-1} of biomass with 29 lb ac^{-1}of N before frost kill, while the frost-killed mustard remaining overwinter lost 56% of the original biomass N by the time of spring incorporation. Biomass production was highest for rye and winter wheat for an average of 3,900 lb ac^{-1} followed by an average of 2,700 lb ac^{-1} for fall-incorporated mustard and spring-incorporated canola. Low temperatures at Quincy with nearly 50% fewer GDDs than at Plymouth impaired results with sudangrass and spring-incorporated mustard and limited biomass production and N accumulation of canola, rye and winter wheat to less than 50% compared with these same crops the previous year at Plymouth. Fall-incorporated mustard at Quincy produced only 540 lb ac^{-1} of biomass containing less than 10 lb ac^{-1} of N.
2. When more than 2,700 lb ac^{-1} of above-ground biomass was produced, the cover crops accumulated more than 90 lb ac^{-1} of biomass N and reduced soil N in the profile by a comparable amount.
3. Allowing cover crops to grow overwinter for spring-incorporation appears to be more effective for minimizing leaching and making N available for the following potato crop than fall-incorporation.
4. Sudangrass produced the least amount of biomass in a fall planting and recovered the least amount of N and thus, was the most ineffective cover crop of those tested.
5. Over-wintering cover crops reduced soil N by nearly 140 lb ac^{-1} to a depth of five ft compared with bare fallow.
6. Over-wintering cover crops were generally more effective in depleting soil N than frost-killed crops even when biomass N accumulation was comparable.
7. Mineral N accumulation in the upper two ft of soil was highest with overwintering cover crops and peak levels occurred within five weeks after soil incorporation or 20 to 70 days after potato planting. This indicates that these cover crops provided the potato crop with enough plant available N to serve as a significant replacement for chemical fertilizer N. Although mustard that had achieved good growth prior to frost-kill reduced N leaching compared with bare fallow, its fall-incorporation accelerated mineralization and N leaching over-winter and during the spring before the potato crop was planted.

Cover crops adapted for wind erosion control

Cover crops grown at any time will provide some degree of protection from wind erosion, even if that is not what the grower intended. However, economic benefits such as reducing the N fertilizer requirement for subsequent crops; suppressing weeds, diseases and nematodes; providing forage for livestock; and improving soil quality should encourage their use by offsetting the costs, drawbacks and potential economic risks that may be associated with producing cover crops. Where soil loss from wind erosion and blowing dust are primary concerns some crops may be environmentally more effective than others, but still contribute secondary short- and/or long-term economic benefits to the grower.

A WSU Cooperative Extension (WSU, 2003) fact sheet ranks the following species in the order of effectiveness for wind erosion control in the irrigated Columbia Basin: annual ryegrass (*Lolium multiflorum* Lam.), winter wheat, sorghum-sudan, triticale, oat, crimson clover [*Trifolium incarnatum* (Fabaceae)], hairy vetch [*Vicia villosa* (Roth)], and sweet clover (*Melilotus officinalis*). Yellow mustard is not included in this list but its erosion control benefits are well-recognized by researchers and growers because of its potential for high dry matter production (up to 5 t ac^{-1}). All of these crops produce some of the aforementioned economic benefits in addition to erosion control (Table 5.4).

Investigations are underway to evaluate options in cover crop selection and management for wind erosion control following late-harvested, low-residue crops such as potatoes and onions (Pan et al., 2001; 2002). Harvest of these crops in October and November can lead to serious wind erosion overwinter because cold weather negates establishment of growing plant cover during the non-growing season. In general, root crops not only produce low quantities of residues that decompose readily but much of the residue is soil-incorporated by the high soil-disturbance harvest operation.

Currently, cover crops are being evaluated for their tolerance to cool weather. These include spring and winter wheat cultivars, triticale, and wheat mixtures with sowing pre- versus post-harvest of potatoes at one location, and post-harvest of potatoes and onions at two other locations, all in the northern Columbia Basin. The focus is on GDDs <200 days where biomass accumulation is slow but where the percent cover increases rapidly with small increases in GDD (Pan et al., 2002). In the first experiments sowing dates in 2001 were on October 8-24. Preliminary results showed that plant emergence and leaf-stage development were superior for all cover crops when sown after potato harvest compared with sowing before harvest.

A practice adopted by a number of onion producers is to plant grain strips with or ahead of planting onions. The strips protect seedling onions from wind damage and at the same time reduce field wind erosion. This practice is low cost and may have potential for use with other high value crops as well.

Investigations are underway to determine the potential use of lignin-rich by-products from pulp production of wheat straw, for soil stabilization and wind erosion control properties (Pan et al., 2002). A portable wind tunnel will be used to evaluate the erodibility of soils after incorporation of yellow mustard as a green manure crop versus amendment with black liquor from straw pulping.

Use of Remote Sensing to Assess Soil Surface Characteristics and Cover Crop Adoption by Growers

Soil surface conditions and crop cover can vary greatly during late fall and winter in the irrigated Columbia

Basin when there is a high potential for wind erosion and N leaching on bare soils (Kunch et al., 2001). Fields may be covered with living vegetation such as winter hardy annual species (winter wheat, triticale, rye), residues of harvested crops (wheat, bean, corn, potato), or frost-killed crops (mustard, sudangrass). In other situations fields may be bare with a smooth or rough-tilled surface.

Although winter cover crops are not new, there is little information on the extent of adoption, and trends or changes in use patterns in various parts of the irrigated Columbia Basin during the non-growing season (Kunch et al., 2001). It is known that crops and soil surface conditions can be differentiated on a large scale with optical remote sensing; however, the methodology is impractical during the winter months when there is considerable cloud cover. Researchers at WSU have been experimenting with satellite radar, which is unaffected by cloud cover, as a potential technology for monitoring surface conditions of agricultural fields with regard to the susceptibility of irrigated areas to wind erosion during the fall and winter months (Pan et al., 1999).

A study was conducted in the irrigated Columbia Basin to determine: 1) the feasibility of using satellite imagery for remote sensing of winter cover crops compared with bare soil surface conditions, and 2) the physical features that influence differentiation by radar such as soil moisture, plant biomass, plant moisture level, and plant height (Kunch et al., 2001). The researchers acquired three RADARSAT-1 images for the study on each of the following dates: October 20, 1999; November 12, 1999; and March 13, 2000. Ground-truth information was obtained for the three dates on identical sites from 10 irrigated, center pivot circles near Moses Lake, WA from vegetation and soil sampling within 24 hr of the scheduled overpass by the satellite. The fields included alfalfa, flat bean stubble, standing wheat stubble, standing seed corn, sweet corn stubble, volunteer wheat, mix of wheat and mustard, mustard in full bloom, and a bare field. Measurements included soil moisture to a depth of 2 inches, plant-water content, plant biomass ac^{-1}, plant height, plant water content per unit area, and plant water content per unit volume (plant height multiplied by plant water content per unit area).

The objective was to correlate the mean radar brightness or backscatter values with different measured parameters within farm fields to identify field characteristics that are most sensitive to the radar signal. Highlights of the Kunch et al. (2001) study are as follows:

1. The radar brightness values for all three sampling dates were most sensitive to plant water per unit area and plant water per unit volume, suggesting that water on an area or volume basis is the main factor contributing to radar backscatter.
2. Six field characteristics accounted for 77% of the variation in radar backscatter in the October field data, 64% in the November data, and 74% in the March data. These were: soil water, plant dry matter, plant height, plant water content, plant water per unit area, and water per volume of plant canopy. The range of cover and surface conditions likely prevented the identification of any single characteristic as being mainly responsible for all of the variation in backscatter.
3. The brightest responses in radar backscatter were from cover types that provided the most complete cover, and contained wet biomass, e.g., standing corn stubble and mustard in October.
4. Field differentiation and grouping of the satellite imagery allowed three types of cover to be distinguished: 1) smooth surfaces that are either bare or covered with a limited amount of residue; 2) smooth surfaces covered with sparse green cover; and 3) surfaces that contain ample amounts of either residue or actively growing vegetation, or rough, bare surfaces following cultivation. Type 1 included the smooth bare surfaces, and bean crop residue and wheat stubble indicating that sparse, dry residue returned the radar signal only weakly. Type 2 included the volunteer wheat/mustard, volunteer wheat representing variable and sparse vegetation, and alfalfa (mowed in early fall) that had brightness values trending towards type 3. Type 3 included the mustard, unharvested seed corn, standing sweet corn stubble fields, and rough, bare surfaces. (Fig. 5.4) The response to the radar signal of some of the surfaces changed over the season but the groupings according to the surface characteristics generally did not.
5. Wetting the soil surface by irrigation or precipitation increases the brightness of the radar signal and, thus, knowledge of weather conditions and irrigation scheduling at the time of imaging is critical to differentiating smooth bare fields covered with low amounts of residue.

This study shows that RADARSAT-1 imagery can be successfully used in mapping to differentiate fields with sparse green cover and smooth surfaces from recently plowed, rough bare soils and fields with a heavy cover of dead residue or live vegetation. With further development and refinement, the technology should be a useful tool for determining regional trends and advances in conservation efforts to control wind erosion on irrigated lands.

Table 5.4. Added benefits of cover crops recommended for wind erosion control on irrigated croplands of the Columbia Basin, Washington[1].

Crop	Benefits in addition to wind erosion control
Annual ryegrass	N scavenger, build soil quality, suppress weeds, livestock grazing
Winter wheat	N scavenger, build soil quality, suppress weeds, livestock grazing
Sorghum-sudan	N scavenger, build soil quality, loosen subsoil, suppress weeds, diseases and nematodes
Triticale	N scavenger, build soil quality, suppress weeds, rapid biomass accumulation
Oat	N scavenger, suppress weeds
Crimson clover	Legume N source
Hairy vetch	Legume N source, build soil quality, suppress weeds
Sweet clover	Legume N source, build soil quality, loosen subsoil, suppress weeds
Mustard	Suppress diseases and nematodes

[1]Source: Washington State University (2003).

Summary Observations

Wind erosion is most severe on irrigated lands during and after planting time in the spring and early fall before crops are established, and after harvest of late fall crops where little residue cover is left on the soil surface. Traditional seedbed preparation often involves excessive tillage of poorly structured soils with aggressive tools that break down and bury crop residues and pulverize soils making them highly susceptible to wind erosion. In some situations the crop stubble is burned and the soil is then aggressively tilled before planting. Cool temperatures after late fall harvest of low residue crops such as onions, carrots, sugarbeets, and potatoes preclude establishing cover crops, leaving the soil bare and exposed during the non-growing season.

A 6-year study in progress of alternatives to irrigated production of continuous annual winter wheat sown after burning the previous crop's stubble and then plowing showed that for the first three years, within crop yields from a winter wheat–spring barley–winter canola rotation were the same for no-till sowing directly into standing stubble, after mechanical removal of stubble, or after burning the stubble. In addition, the yields of winter wheat in the no-till/stubble management rotation were the same as those for continuous winter wheat after burning the stubble and plowing for the first two years, but higher than the burn and plow treatment the third year of the study. Downy brome populations were markedly reduced by burning or mechanical removal of crop stubble.

A cover crop model based on growing degree days for irrigated crops showed the importance of sowing certain species early (e.g., *Brassica* species by early to mid September) while others could be sowed later (triticale and rye by mid October) to achieve adequate cover by winter, and that extreme year to year temperature variations can cause differences of over one ton ac^{-1} in dry matter production during the fall growing period. Some crops require less than 500 lb ac^{-1} of dry matter to produce 50% ground cover. A study of several cover crops showed that most of those sown in August in the southern Columbia Basin accumulated 100 to 125 lb of soil N ac^{-1} whereas they accumulated less than half of this when sown in September in the northern Columbia Basin.

The N accumulation by the winter crops not only reduced the potential of over-winter N leaching to a depth of 6 ft compared with bare fallow, but also provided significant amounts of available N to the following spring potato crop. The benefits of N conservation and recycling can aid growers in offsetting significant costs of producing cover crops on their farms. Crops adaptable to the Columbia Basin that are recommended as N scavengers are annual ryegrass, winter wheat, sorghum-sudan, triticale, and oat.

Although many irrigated growers use, or are encouraged to use cover crops, it is difficult to estimate the land area under cover during the winter months to protect against wind erosion. Studies show that satellite radar imagery can, on a large scale, differentiate 1) smooth bare fields including those with sparse dried residue, 2) smooth fields with sparse green cover, and 3) fields with heavy vegetation, either dead or alive, or rough, bare surfaces. Another procedure will be necessary to identify N scavenging crops since the radar imagery does not differentiate actively growing vegetation from heavy residue or rough surfaces.

Figure 5.4. *RADARSAT image of field crops and soil condition during the fall in the irrigated Columbia Basin. Satellite images provide a tool for assessing the extent that cover crops and residue management are utilized on croplands during the non-growing season. The imagery can be used to distinguish smooth, bare fields from fields with sparse, dried residue, smooth fields with sparse green vegetation, and fields with heavy vegetation, either dead or alive, or in a rough bare condition. Photograph reproduced from Kunch et al. (2001) with permission from the Canadian Journal of Remote Sensing.*

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