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Grain yield and biomass relationship for crops in the Inland Pacific Northwest United States

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Abstract: Interest in improving the performance of water and wind erosion prediction models, such as the Revised Universal Soil Loss Equation (RUSLE), the Water Erosion Prediction Project (WEPP), and the Wind Erosion Prediction System (WEPS), led to this study of the relationship between the mass of crop residue and crop yield produced on nonirrigated cropland of the Inland Pacific Northwest United States, consisting of eastern Washington, northern Idaho, and northcentral Oregon. Retaining postharvest crop residues as soil surface cover is a primary method for controlling wind and water erosion; accordingly, erosion prediction models are highly sensitive to the amount of surface residue retained as soil cover. Traditionally, crop biomass calculations and erosion prediction models used expected or modeled crop yields and a fixed residue/grain index (R/G Index) value to determine residue quantity. Literature search indicated that cereal breeding efforts that emphasize yield have reduced the amount of residue for each unit of grain produced. In order to fulfill our objective of improving the relationship between grain yield and residue production, we assembled and examined a large set of regional crop yield and residue production data collected in research plot studies, on-farm field studies, and in available literature from eastern Washington and northcentral Oregon. Results of the study indicated that the R/G Index varies with yield. We also found that residue production versus grain yield for major nonirrigated crops of wheat (*Triticum aestivum* L.) and barley (*Hordeum vulgare* L.) cereals, as well as for annual legumes and brassicas, can be fit with a linear relationship with a positive intercept and that the slope and intercept of the line are crop specific. Parameter values for specific crops are given. Using the historical fixed R/G Index can result in overestimating residue production of high-yielding winter wheat by as much as 35% and underestimating residue production for low spring wheat yields by as much as 66%. The results provide improved residue-to-grain yield relationships for use in water and wind erosion prediction models applied to the conditions of the Inland Pacific Northwest and adjacent areas. They provide a basis for estimating crop residue production in the region, and in conjunction with carbon sequestration models, a basis for determining if and where residues can be harvested for biomass in the region.

Key words: crop biomass—grain yield—residue/grain index—water erosion—wind erosion—erosion models

Development of resource management plans requires knowledge of each crop's probable residue yield; sufficient quantities of crop residue must be available to protect and sustain soil resources and to limit off-site damages to water and air quality. Erosion prediction technology, such as the Revised Universal Soil Loss Equation (RUSLE), Water Erosion Prediction Project (WEPP), or Wind Erosion Prediction System (WEPS), is used to estimate soil losses from water and wind erosion. Each of these models use either empirical or modeled relationships for the effects of elements of cropping and management practices, including crop canopy; standing, flattened, or incorporated crop residue; surface roughness; prior land use; and soil moisture. The residue production potential of a specific crop and the effect of tillage and seeding implements on residue retention are essential inputs to these or any model used to estimate water or wind erosion. Residue production as a function of crop yield is also important for determining potential for carbon sequestration and soil quality enhancement, as well as for biomass harvest opportunities.

Water and wind erosion have long been recognized as serious problems in the nonirrigated areas of the Inland Pacific Northwest (PNW) of eastern Washington, northern Idaho, and northcentral Oregon. Most of the nonirrigated soils of the PNW are derived from loess deposits, mainly glacial in origin, with additions and modifications from volcanic deposits. The loess is coarse silty in the west and southwestern lower (<300 mm [11.8 in]) precipitation areas, and fine silty in the intermediate (300 to 450 mm [11.8 to 17.7 in]) and high (>450 mm) precipitation areas (Schillinger et al. 2006) illustrated by the eastern Washington portion of the area (figure 1). Soil erosion caused by rainfall and melting snow runoff on fall-seeded small grain in the intermediate to high precipitation zones of the region has depleted soil resources and produced off-site damage though sediment deposition and impairment of water quality. Wind erosion is a more serious problem in the lower precipitation zone, damaging the soil as well as creating severe health and safety problems from fine soil dust particulate emissions. Two urban areas in eastern Washington, Spokane and the Tri-Cities (Kennewick, Pasco, and Richland) have had periodic PM-10 exceedances (meaning airborne particles less than or equal to 10 μm in aero-dynamic diameter exceeding a 24-hour average concentration of 150 μg m^{-3} as established by the US Environmental Protection Agency) caused by erosion from upwind nonirrigated cropland (Sharratt and Lauer 2006). Dust blowing across state and federal highways has resulted in numerous accidents, some involving fatalities (Larsen 2009). Retaining postharvest crop residues as soil surface cover is the primary method for controlling wind and water erosion. Application

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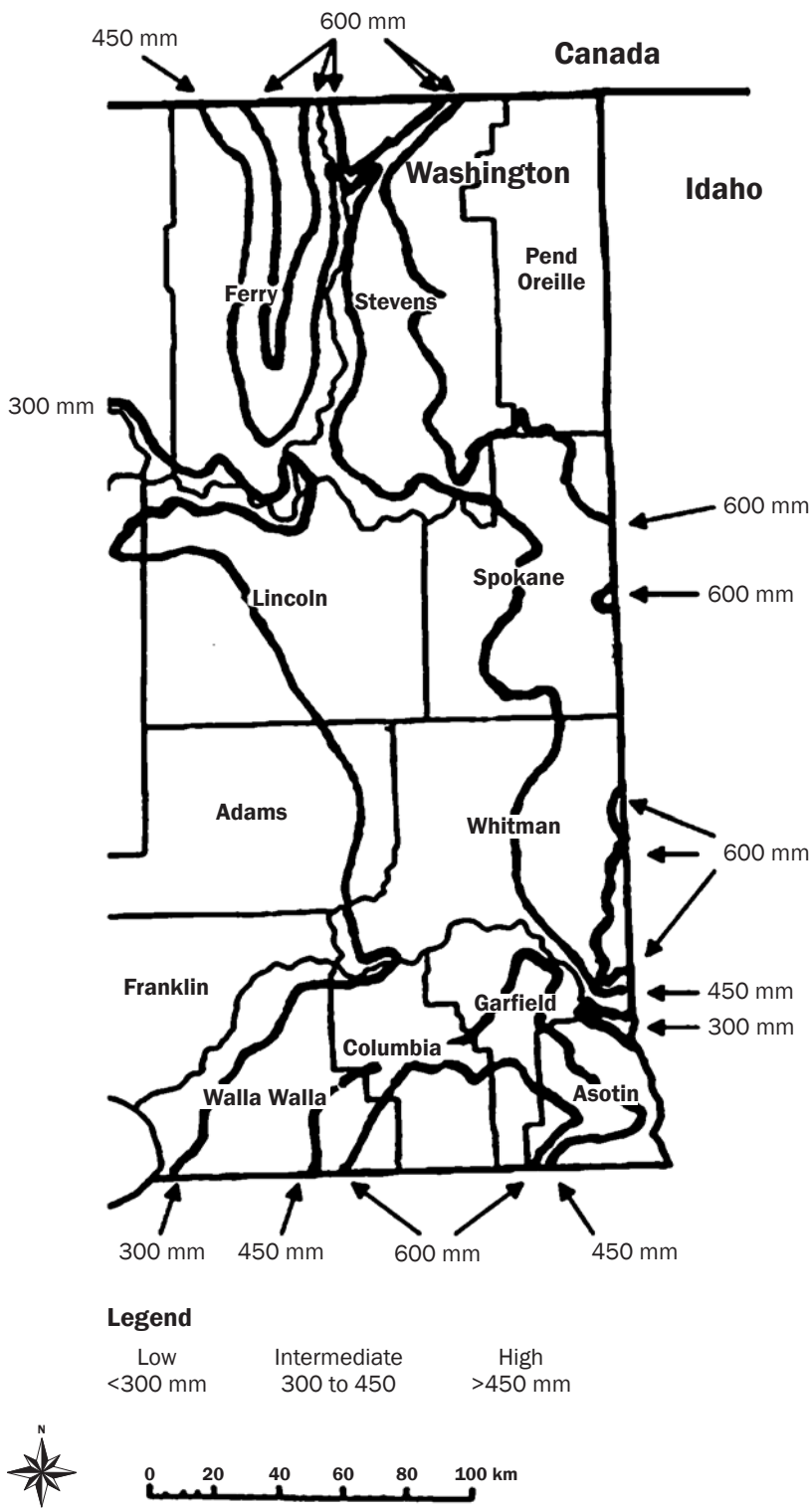
Figure 1
Eastern Washington portion of the Inland Pacific Northwest (PNW) nonirrigated cropland showing low, intermediate, and high precipitation zones.



of appropriate residue management practices is essential to maintaining soil organic matter (SOM) and water holding capacity. Both water and wind erosion processes are highly responsive to changes in amounts of residue cover (Yoder et al. 1997; Retta and Armbrust 1995). Climate, topography, soil characteristics, and type of tillage influence the amount of residue cover necessary for erosion control. No-till seeding systems retain more surface residues than tillage-based systems, but in some situations, such as seeding into sparse annual legume residue, even no-till seeding methods may not provide sufficient surface cover for adequate control of soil erosion in all years. In the high precipitation zone, excessive cereal grain residue frequently plugs tillage and seeding implements, which can cause irregular and improper seed placement and can result in reduced seed germination and poor seedling emergence.

Intensive crop production on large areas of the PNW has been carried out for only 130 years. The Nez Perce War of 1877 coincided with the start of rapid immigration and expansion of winter cereal grain production in the region (Scheurman and Clement 2003). During more than 100 years of conventional-tillage grain farming practices, organic matter levels of soils have rapidly declined. Soils have lost 50% to 60% of their original SOM since the onset of farming (Schillinger et al. 2010). Where a winter wheat (*Triticum aestivum* L.)–summer fallow rotation has been applied in the lower precipitation zone, the soil's current SOM content typically ranges from less than 1% to 1.5%. In the high precipitation annual cropping zone, current SOM content ranges upward to more than 3% (Schillinger et al. 2006). A long-term winter wheat–summer fallow rotation study at the Columbia Plateau Conservation Research Center near Pendleton, Oregon, found that SOM levels declined for all but one cropping treatment, with the decline governed by residue and nitrogen input. The one exception was a biennial application of 22.4 Mg ha^{-1} (10.0 tn ac^{-1}) of cattle manure, which increased SOM by about 10% during the 55-year study period (Rasmussen et al. 1989). Reliable information on biomass production is essential for developing and applying management systems to maintain or increase SOM.

The objective of our study was to improve the performance of water and wind erosion prediction and decision support models

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that guide conservation practice selection and residue harvest decisions by determining better relationships between residue production and crop yield for the dominant nonirrigated crops grown in the PNW. These crops are winter wheat, spring wheat (*Triticum aestivum* L.), winter barley (*Hordeum vulgare* L.), spring barley (*Hordeum vulgare* L.), peas (*Pisum sativum* L.), and lentils (*Lens culinaris* L.). Winter and spring canola (*Brassica napus* L.) and rapeseed (*Brassica napus* L.) oil crops are also produced on a small but increasing hectarage, and Austrian winter pea (*Pisum sativum var. arvense* L.) is occasionally grown for green manure. Wheat cultivars are mostly of the soft white class that differs from those produced in other farming regions of the United States. While the crops and rotations differ among precipitation zones, white winter wheat is the prevalent class of wheat grown. Winter wheat, grown in alternate years with summer fallow, is the dominant crop rotation used in the 300 mm (11.8 in) or less, low annual precipitation zone (figure 1). Average annual yields of winter wheat after summer fallow fluctuate from 1,200 to 3,500 kg ha^{-1} (1,100 to 3,100 lb ac^{-1}) (Schillinger et al. 2006), depending on the amount of moisture available for the growing crop. Average yields of spring barley or spring wheat range from 700 to 2,500 kg ha^{-1} (600 to 2,200 lb ac^{-1}) when seeded following winter wheat (Schillinger et al. 2006).

In the intermediate precipitation zone, 300 to 450 mm (11.8 to 17.7 in) annual precipitation (figure 1), a more intensive three-year rotation of winter wheat–spring grain–summer fallow cropping sequence is commonly practiced. Spring cereals are often seeded following winters of above-normal precipitation. Winter wheat yields range from 3,000 to 6,000 kg ha^{-1} (2,700 to 5,400 lb ac^{-1}). When spring barley and spring wheat are seeded following winter wheat, yields range from 2,000 to 4,000 kg ha^{-1} (1,800 to 3,600 lb ac^{-1}) (Schillinger et al. 2006).

Annual cropping is usually practiced in the higher precipitation zone receiving more than 450 mm annual precipitation (figure 1). Winter wheat is the dominant crop in this precipitation zone, with yields ranging from 6,500 to 7,000 kg ha^{-1} (5,800 to 6,200 lb ac^{-1}), but they can exceed 9,000 kg ha^{-1} (8,000 lb ac^{-1}). A two-year rotation of winter wheat, alternating with pea or lentil is commonly used for its 10% to 20% yield benefits to the succeeding wheat crop (Guy and Gareau 1998). Pea and lentil crops typically yield between 1,500 to 2,000 kg ha^{-1} (1,300 to 1,800 lb ac^{-1}) and are seeded on about 20% of this zone's hectarage. New cultivars have greatly improved yields, and growers have increased the use of spring wheat or barley. Yields of these spring-seeded crops usually are 50% to 70% of the winter wheat yield and are seeded on approximately 20% of the hectarage (Schillinger et al. 2006). Yield of all crops is strongly related to the amount of precipitation and moisture available to the growing crops. Based on the wide range of yields, a similar wide range of residue production can be expected.

Much of the plant breeding effort in the PNW has been directed toward improvement of winter wheat yields, and specifically, on development of semidwarf wheat. During the 1950s, breeding of semidwarf wheat cultivars adapted to this region was a major technological advancement; Gaines winter wheat was released in August 1961. Release of new wheat cultivars resulted in improved grain yields, shorter plant height, and improved lodging resistance as compared with the traditional standard height varieties. These results met the stated objectives of the cooperative winter wheat improvement program for the PNW during the 1950s (Vogel et al. 1956). Their report indicated that straw weights of short semidwarfs were lower than standard-height varieties and that medium-tall semidwarfs, such as Gaines, produced straw weights similar to the standard-height varieties. Ratios of straw to grain for standard height varieties ranged from 1.9 to 3.0 and for semidwarf varieties ranged from 1.5 to 1.7 (Vogel et al. 1963). Langer and Hill (1982) reported that dwarf and semidwarf wheat varieties did not necessarily produce more total dry matter, but straw production was reduced, and a higher percentage of the total biomass was in the form of grain. Over the years, the harvest index (ratio of grain to total biomass) has continuously improved. Cox et al. (1988) showed no significant change in total biomass produced by 35 hard red winter wheat cultivars introduced or released between 1874 and 1987 for use in the Great Plains. Tests of these cultivars were performed over a two-year period (1986 and 1987) at three locations in Kansas to estimate the rates of yield change resulting from the winter wheat breeding program. Genetic improvements in cultivars released during the period from 1919 to 1987 produced annual increases of 16.2 kg ha^{-1} (14.5 lb ac^{-1}) in grain yield during this period, while residue production declined by the same amount. Quoting Slafer and Andrade (1991), Donaldson et al. (2001) indicated the genetic improvements in winter wheat yield led to increased yield, but not increased total biomass, with the result that grain production increased while residue production decreased at a given yield level. Most of this was due to the use of semidwarf cultivars with increased efficiency. Schillinger et al. (2006) reported that, in the previous 35 years, all but one white wheat cultivar released in the PNW carried dwarfing genes.

Accurate residue production estimates for crops grown under typical crop rotations and tillage systems has been, and still is, of foremost importance to users of USLE and RUSLE erosion prediction models. Traditionally, residue production estimates for use with erosion prediction models were determined by multiplying grain yield by a fixed residue/grain index (R/G Index) value for each crop. Unfortunately, residue production estimates used during the 1970s and 1980s by the USDA Natural Resources Conservation Service (NRCS) (formerly Soil Conservation Service [SCS]) in the PNW were based on residue-to-grain index data from taller cereal cultivars and did not reflect the effect of the development of semidwarf cereal crops and their rapid adoption in the region. McClellan et al. (1987) reported a wide variation in R/G Index values for residue and grain yield relationships from literature sources. The R/G Index values for the dominant higher yielding cereal cultivars grown were smaller than had traditionally been reported and used in erosion models. This paper also noted a greater proportion of the residue production was made up of the smaller components of residue (awns, chaff, and leaves).

Appendix D Agriculture Handbook 703 (Renard et al. 1997) is the source of the R/G Index values in table 1, considered applicable to cropland in the United States. The authors indicated that ground cover is frequently the single most important factor affecting erosion, and therefore, the single most important crop variable at harvest and at planting is amount of residue. Because erosion is sensitive to residue cover, care should be taken to ensure that estimated cover values are reasonable. Renard et al. (1997) indicated that the fixed R/G Index values given in table

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1 should be decreased for higher yields and increased for lower yields.

Wheat breeding developments, specifically improvement of semidwarf wheat, essentially made obsolete and inaccurate the historical fixed R/G Index values that had been used for many years. The purpose of this study was to improve the performance of water and wind erosion prediction models, such as RUSLE, WEPP, and WEPS in the PNW by improving the relationship between the mass of crop residue produced and crop yield in the PNW.

Table 1
Residue/grain index (R/G Index) and yield range over which a constant index value can be used (Renard et al. 1997).

Crop	R/G Index	Yield range* (kg ha^{-1})
Corn	1.0	3,100 to 9,400
Soybeans	1.5	1,000 to 3,000
Sorghum	1.0	2,500 to 5,600
Winter wheat	1.7	1,700 to 4,000
Spring wheat	1.3	1,700 to 4,000
Spring oats	2.0	1,100 to 2,900

* If yield is less than the minimum value in the range, the R/G Index may need to be increased. If yield is greater than the maximum value in the range, the residue/yield index may need to be decreased.

Materials and Methods

Crop and residue production data have been collected from a number of plot and field studies in the PNW; several of these datasets were available for analysis. These were assembled, and criteria were established for inclusion of the data in this analysis. The following criteria were developed for use in erosion models, such as RUSLE, that estimate average annual erosion over an extended period of time through multiple cycles of a rotation and that do not provide an erosion value for a specific year with higher or lower rainfall than normal. Crop and residue data from a long period of record with inherent wide annual variation in precipitation and temperature is more desirable than that from a short period, even if a better coefficient of determination may be obtained for the shorter period because the longer record will better reflect the actual range of residue production found in the field. Because the data will be used for comparison of growers' practices under actual field conditions, yield data obtained from growers' fields is more desirable than that from small plots. If variety trial data are used, old or not yet released varieties should be deleted from the analysis. Data from fertilizer rate studies should not be included in the datasets for analysis. Datasets should be in raw form; that is, they should include the original sample weight, grain weight, row length, and any detailed field notes that might indicate exceptions to established protocol in order to determine the origin of unreasonable values in final datasets.

Table 2 lists five sources of data that were available and considered for development of residue versus yield relationships. Crops represented in each source are shown. We reasoned that data from a wide range of sources, while they might show a great deal of variation, would provide the best collection of data to represent the region. The first listed in table 2, the area/mass dataset, was collected for three years (cereals in 1990 and 1992 and legumes in 1993) in eastern Washington to establish stem coverage versus stem mass, contained 307 samples, and included eight different crops. The Columbia Plateau dataset, collected in northcentral Oregon and southeastern Washington from 1983 through 1986, included winter wheat and winter and spring barley. There were 998 winter wheat samples, but only 96 barley samples. Most of the winter wheat samples were Stephens wheat, a cultivar commonly used in northcentral Oregon but less frequently used in other areas of the PNW. The largest dataset is labeled the eastern Washington dataset and includes eight crops, 2,331 samples, and was collected over the longest time span, 1979 through 1989, although not all crops were sampled in all years. The fourth dataset, the PCFS runoff plot dataset, collected on runoff plots at the Palouse Conservation Field Station near Pullman, Washington, covered 10 years (1981 to 1990), but included only 82 samples. The Pendleton-La Crosse Lentil dataset was collected near Pendleton, Oregon, and La Crosse, Washington, in 1992 and 1993.

Table 2
Available residue and grain databases in the Inland Pacific Northwest.

Available data sources	Crops represented
Area/mass dataset	Winter and spring barley, oats, triticale, winter and spring wheat, lentils, peas
Columbia Plateau dataset	Winter wheat, barley
Eastern Washington dataset	Winter and spring wheat, winter and spring barley, oats, peas, Austrian winter peas, lentils
PCFS runoff plot dataset	Winter and spring wheat, peas, lentils
Pendleton-La Crosse lentil (Daniel Ball) dataset	Lentils

Note: PCFS = Palouse Conservation Field Station.

Table 3 lists the number of available usable samples from all data sources. A very small number of samples from some of the sources were missing data elements, and were easily identified. If the information could not be obtained, the sample was considered unusable and was excluded from the study. Data in the table are listed by crop—then by data source. The years during which the data was collected are shown next to the data source. Attempts were made to analyze the four smaller datasets separately or combine them with the eastern Washington dataset. The efforts did not yield statistically acceptable results. Based on the relatively long time period spanned by the data, the broad region from which it was collected, and the generally large number of samples represented for each crop, the eastern Washington dataset was selected as the sole data source to use for the final crop database analysis.

Data Collection Procedures. The procedures described are specific to the eastern Washington dataset. This dataset was originally collected to provide grain yield data for use in SCS soil survey reports and river basin

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Table 3
Inventory of available crops from various data sources.

Crop	Source	Number of usable samples
Wheat, winter	Eastern Washington data (1979 to 1987)	1,137
Wheat, winter	Columbia Plateau (1984 to 1986)	888
Wheat, winter	Columbia Plateau (1983 to 1984) (combine residue distribution study)	110
Wheat, winter	A/M data (1990, 1992)	84
Wheat, winter	PCFS data (1981 to 1986, 1988 to 1990)	48
Wheat, spring	Eastern Washington data (1979 to 1980, 1982 to 1987)	113
Wheat, spring	PCFS data (1982, 1984 to 1985, 1987 to 1991)	17
Wheat, spring	A/M data (1990, 1992)	7
Barley, winter	Eastern Washington data (1981 to 1983, 1985, 1987)	53
Barley, winter	A/M data (1990, 1992)	4
Barley, spring	Eastern Washington data (1979 to 1987)	743
Barley, spring	A/M data (1990, 1992)	57
Barley	Columbia Plateau (1986)	96
Barley	A/M data (1995)	59
Oats	Eastern Washington data (1981, 1987)	6
Oats	A/M data (1990, 1992)	4
Triticale	A/M data (1990, 1992)	7
Lentils	Eastern Washington data (1982 to 1987, 1989)	145
Lentils	Pendleton-La Crosse (Daniel Ball) (1992 to 1993)	48
Lentils	A/M data (1993)	46
Peas	Eastern Washington data (1979, 1982, 1985 to 1987, 1989)	118
Peas	A/M data (1993)	39
Peas	PCFS data (1981, 1984 to 1991)	17
Austrian winter peas	Eastern Washington data (1982 to 1983)	12

Notes: A/M = area/mass dataset. PCFS = Palouse Conservation Field Station.

studies. Sites selected represent cropland soils within each county. The majority of the soils are in the Order Mollisols (grassland soils that have dark-colored topsoil and high natural fertility), and the dominant parent material is loess (wind blown silt). Review of the soil data for 1985 and 1986 shows a small number of the samples were loamy sand, fine sandy loam, or loam, with the majority being classed as silt loam soil texture. These characteristics are typical of the study area.

Over the study period, many individuals participated in collecting samples. Locations were preselected using soil survey maps or historic records before going to the field for sample collection. Samples were collected from two adjacent crop rows of 1 m (3.3 ft) length. The standing grain crop stems were clipped near the soil surface, using hand clippers or a sickle. The entire sample (grain heads and biomass) was placed with heads first into a large paper bag, labeled, and wrapped securely with a string. Pea and lentil crop samples were collected in the same manner, unless the crop had lodged, making it difficult to easily distinguish separate rows. If lodged, or partially so, a quadrat of 1 m^2 (10.8 ft^2) area or a circular hoop of 0.89 m^2 (9.6 ft^2) area was placed over the plants, and all the biomass material within was clipped and collected from each site. The samples were air dried before weighing for a determination of total biomass yield, using a balance accurate to 5 g (0.01 lb).

Each crop sample was threshed in a Vogel thresher (custom-built by Bill's Welding and Machine Shop, Pullman, Washington). The residue was discarded after threshing. Each grain sample was processed in a small Clipper cleaning machine to remove weed seed and other foreign matter prior to determining grain sample weight using the same balance used to determine total biomass.

The crop fields selected for this study were managed by growers using typical (average) or normally accepted farm production practices customary to the local area. Customary rates and dates of seeding were practiced by grower participants whose fields were sampled for this project. Growers usually received fertilizer use and guidance for application rates based upon soil testing results or personal experience from fertilizer company sales representatives. Because less moisture is available in drier regions, rates of fertilization are reduced to correspond with lower crop yield potential. The highest fertilizer rates are applied to soils in the higher rainfall areas of the eastern part of the region near the Idaho-Washington state line (Granatstein et al. 1991).

Analytical Procedure. An effort was made to identify and correct any obvious errors in the data. Using filtering techniques available in Excel (Microsoft Corporation 2003), variables in the source data files, such as row spacing, row length, crop yield, and residue yield, were thoroughly scanned and compared to known or reasonable values. Any errors found were corrected if possible; if a correction could not be made, the faulty entry was deleted from the dataset used in the analysis. A linear relation between residue and crop yield was tested and then used in this analysis. This relationship was also suggested by the RUSLE2 modeling team for use with the RUSLE2 model (USDA ARS 2008), one of the primary uses of this data. The units for residue and yield are both in mass per unit area. The general form of the linear regression equation is

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$$\text{Residue yield} = S \times \text{Grain yield} + I \quad , \quad (1)$$

where residue yield is measured in kg ha^{-1}, grain yield is measured in kg ha^{-1}, S is slope of line S (kg ha^{-1}) (kg ha^{-1})$^{-1}$, and I is the intercept (kg ha^{-1}).

To arrive at a final dataset for each crop from a given data source, the data resulting from the cleanup procedure (described earlier) was used as the starting point. Using the statistical tools available in Excel, a linear regression line was fitted to each individual crop dataset using grain yield (kg ha^{-1}) as the independent variable and residue yield (kg ha^{-1}) as the dependent variable. The standard deviation of the residue values was calculated for each crop. We then followed a standard procedure of deleting all data points outside of three standard deviations.

Table 4
Linear regression analysis at a three standard deviation rejection limit of eastern Washington dataset*.

Crop	Number of samples retained	Slope (kg ha^{-1})/ (kg ha^{-1})	Intercept (kg ha^{-1})	Standard deviation (kg ha^{-1})	r^2
Winter wheat	1,135	1.1274	1,175.3	2,787	0.69
Spring wheat	112	0.8613	2,068.1	2,159	0.31
Winter barley	53	0.8310	1,747.7	2,089	0.65
Spring barley	737	0.7013	1,302.9	1,771	0.55
Lentils	144	0.4684	1,843.8	904	0.09
Peas	117	0.7181	940.9	975	0.29
Austrian winter peas	12	1.3427	1,327.2	1,236	0.63

* Residue yield (kg ha^{-1}) = slope × grain yield (kg ha^{-1}) + intercept (kg ha^{-1}).

Table 5
Traditional fixed versus yield-related residue/grain index (R/G Index).

Crop	Yield (kg ha^{-1})	AH 703 fixed R/G Index	AH 703 residue (kg ha^{-1})	Yield-related R/G Index	Yield-related residue (kg ha^{-1})
Winter wheat	1,200	1.7	2,040	2.11	2,530
	3,000	1.7	5,100	1.52	4,560
	6,000	1.7	10,200	1.32	7,940
	9,000	1.7	15,300	1.26	11,320
Spring wheat	700	1.3	910	3.81	2,670
	2,000	1.3	2,600	1.90	3,790
	4,000	1.3	5,200	1.38	5,510

Note: AH 703 = Agriculture Handbook 703 (Renard et al. 1997).

Results and Discussion

Results of the regression and confidence interval (95% confidence interval around the fitted line) analysis for the eastern Washington dataset are listed in table 4 and figures 2 through 8. Information pertaining to crop variety was not available for all samples. Crop variety was recorded for slightly less than half of the samples contained in the eastern Washington winter wheat data. Of the total number of varieties recorded, Stephens, Daws, and Hill 81 dominated at 32%, 29%, and 15%, respectively. For spring wheat, variety was recorded for 73% of the samples, with Fielder, Waverly, Dirkwin, and Urquie dominating the known varieties at 22%, 21%, 13%, and 13%, respectively. Location by county was recorded for all samples, with the winter wheat and spring barley being collected from fields in Asotin, Columbia, Garfield, Whitman, Spokane, Stevens, and Ferry Counties (figure 1) and the spring wheat from Asotin, Columbia, Whitman, Spokane, Stevens, and Ferry Counties. Winter barley samples were collected from fields in Asotin, Garfield, Spokane, and Whitman Counties. Oat (*Avena sativa* L.) samples were collected in Spokane County. Pea and lentil samples were collected from fields located in Columbia, Spokane, Stevens, and Whitman Counties. Austrian winter pea samples were collected in Asotin County.

The small number of usable samples for oats (6) prevented inclusion in the analysis. The number of usable samples for Austrian winter peas (12) was also small, but the data were fairly consistent; no data points were rejected at the three standard deviation rejection limit.

The slope of the regression line was greatest for Austrian winter peas (table 4). For wheat, the slope was greater for winter wheat and smaller for spring wheat, while the intercepts were the reverse. For barley, both the slope and intercept for winter barley were greater than for spring barley. The slope for lentils was the least, and the intercept was the highest of all crops; the coefficient of determination was quite low. The coefficient of determination was lower for peas and lentils than for the cereal crops.

Mean precipitation during 1979 through 1989 for three National Oceanic and Atmospheric Administration weather stations in Columbia, Whitman, and Spokane Counties were near the 1961 to 1990 average values of 473 mm (18.62 in), 490 mm (19.28 in), and 421 mm (16.55 in), respectively. Annual precipitation ranged from 25% to 37% above and 26% to 32% below these averages. This range and the timing of the precipitation would have had a major but unknown influence on variation in yield in this study.

Of the crops reported here, only winter wheat and spring wheat are listed in the Agriculture Handbook 703 (Renard et al. 1997). Values of the estimated mass of residue for a range of typical yields in the PNW from the Agriculture Handbook 703 and calculated using equation 1 with intercept and slope from our study are presented in table 5, along with the corresponding R/G Index values. The yield-related R/G Index from our study decreases with yield and is higher than the fixed value at lower yield levels for both crops. The R/G Index value for the lower yield level for winter wheat is much higher than the traditional value of 1.7 and is much lower for the higher yields expected in the intermediate and higher precipitation zones. For the highest nonirrigated winter wheat yields in the higher rainfall zone (9,000 kg ha^{-1} [8,030 lb ac^{-1}]) using the relationship found in our study, the estimated residue production would be 11,320 kg ha^{-1} (10,100 lb ac^{-1}), and the R/G Index would be 1.26, whereas the estimated

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Figure 2
Regression line, fitted equation, and 95% confidence interval for the eastern Washington winter wheat dataset.

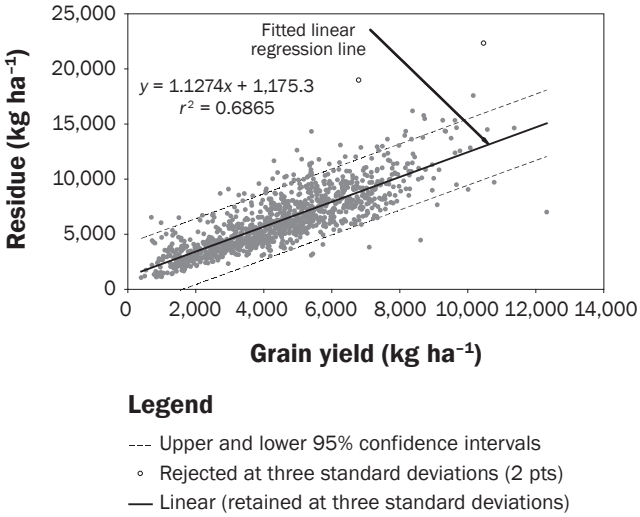


Figure 3
Regression line, fitted equation, and 95% confidence interval for the eastern Washington spring wheat dataset.

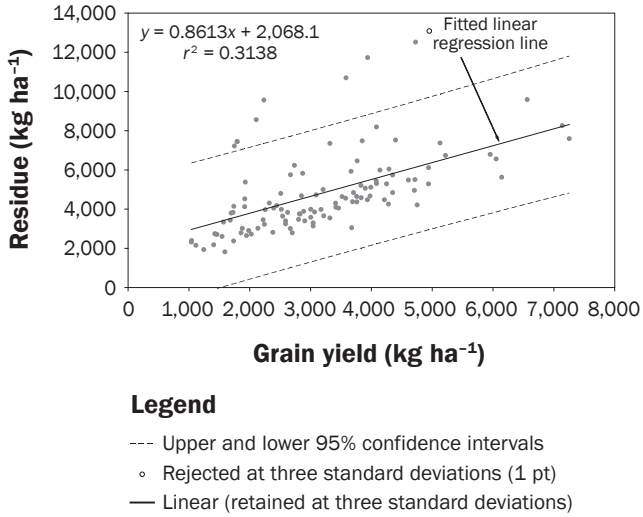


Figure 4
Regression line, fitted equation, and 95% confidence interval for the eastern Washington winter barley dataset.

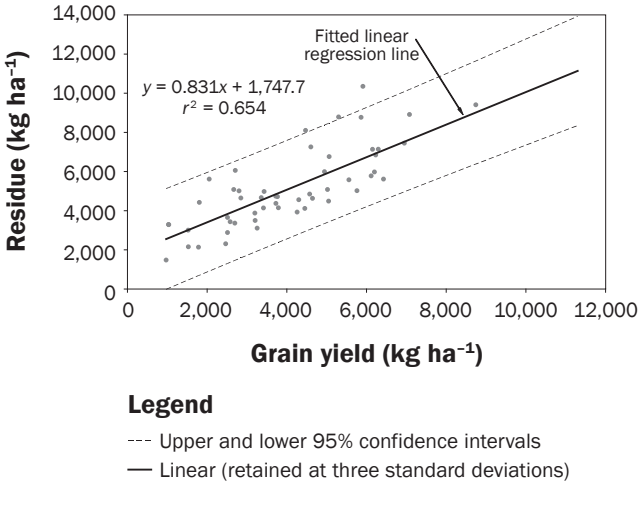
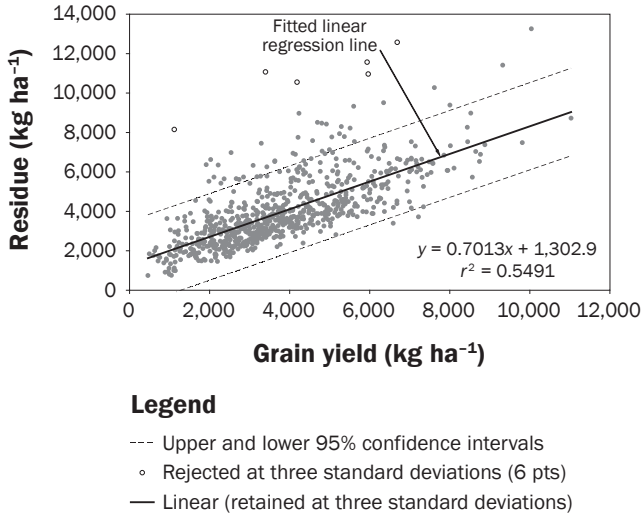


Figure 5
Regression line, fitted equation, and 95% confidence interval for the eastern Washington spring barley dataset.



residue production using the fixed ratio of 1.7 would be 15,300 kg ha^{-1} (13,650 lb ac^{-1}). The overestimation by the 1.7 fixed R/G Index value as compared to the R/G Index value estimated in our study would be 3,980 kg ha^{-1} (3,550 lb ac^{-1}) or 35%, a sizable difference if residue available for biomass harvest were under consideration. For spring wheat, the R/G Index values found in our study were higher than the fixed value of 1.3 in the Agriculture Handbook 703 for all but the highest expected yields. At the lowest expected yield level (700 kg ha^{-1} [620 lb ac^{-1}]), the value estimated in this paper would be 2,670 kg ha^{-1} (2,380 lb ac^{-1}) and that from the Agriculture Handbook 703 would be 910 kg ha^{-1} (810 lb ac^{-1}), about 66% smaller. This difference would be important in developing crop management plans to prevent excess wind or water erosion.

Summary and Conclusions

This study was initiated to enhance the performance of water and wind erosion prediction models, such as RUSLE, WEPP, and WEPS, in the PNW by improving the relationship between the mass of crop residue and crop yield produced on nonirrigated cropland of the region. Retention of post-harvest crop residues as soil surface cover is a primary method for controlling water and wind erosion; accordingly, erosion prediction models are highly sensitive to the amount of surface residue retained as soil cover. Traditionally, crop biomass calculations and erosion prediction models used expected

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Figure 6
Regression line, fitted equation, and 95% confidence interval for the eastern Washington lentils dataset.

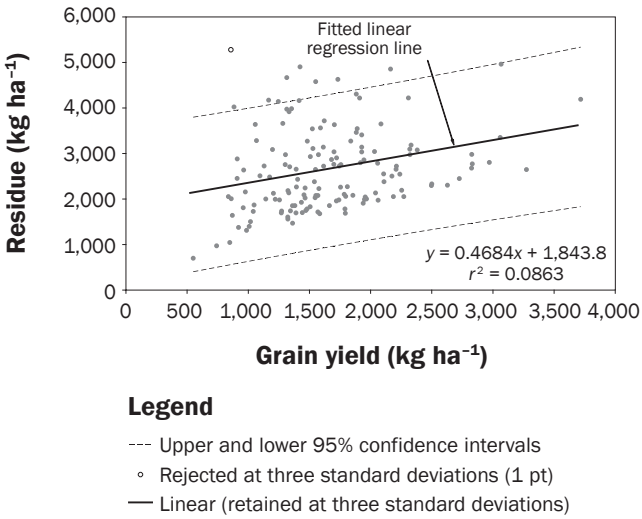


Figure 7
Regression line, fitted equation, and 95% confidence interval for the eastern Washington peas dataset.

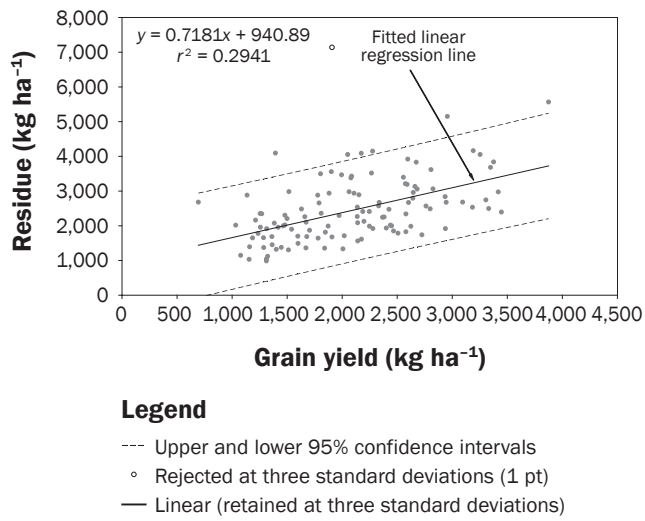
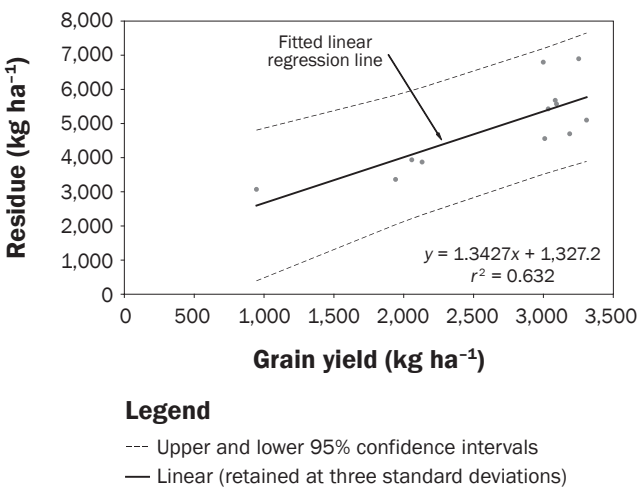


Figure 8
Regression line, fitted equation, and 95% confidence interval for the eastern Washington Austrian winter peas dataset.



or modeled crop yields and a fixed R/G Index value to determine residue quantity. A literature search indicated that cereal breeding efforts that emphasized yield have reduced the amount of residue per unit of grain produced. We assembled and examined a large set of regional crop yield and residue production data collected in plot research studies, on-farm field studies, and in available literature from eastern Washington and northcentral Oregon.

Analysis of the data indicated that residue production versus grain yield data for wheat and barley cereals as well as pea and lentil legumes can be fit with a linear relationship with a positive intercept and that the slope of the line and intercept are crop specific. The results (table 4 and figures 2 to 8) provide improved residue and grain yield relationships for use when applying water and wind erosion prediction models to the conditions of the PNW. Using older fixed R/G Index values as compared to fitted linear relationships developed from data collected in this study, cereal residue was estimated as much as 35% greater at high yields of winter wheat and as much as 66% lower at low yields of spring wheat as compared to results from this study. The residue versus yield results provide improved R/G yield relationships for use in water and wind erosion prediction models applied to the conditions of the PNW and adjacent areas. They provide a basis for estimating crop residue production in the region, and in conjunction with carbon sequestration models, a basis for determining if and where residues can be harvested for biomass. As crop breeding research responds to the challenges of an increasing global population, the relationship between residue and yield will likely change in the direction of increasing crop per unit of residue, making reduced tillage options more important in maintaining soil resources.

Disclaimer

Mention of trade names does not imply endorsement by the USDA Agricultural Research Service.

References

Cox, T.S., J.P. Shroyer, L. Ben-Hui, R.G. Sears, and T.J. Martin. 1988. Genetic improvement in agronomic traits of hard red winter wheat cultivars from 1919 to 1987. Crop Science 28:756-760.

Donaldson, E., W.F. Schillinger, and S.M. Dofing. 2001. Straw production and grain yield relationships in winter wheat. Crop Science 41:100-106.

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Journal of Soil and Water Conservation 67(1):42-50 www.swcs.org

Granatstein, D., R. Halverson, and D. Young. 1991. 1990 Palouse farm survey-fertility management results. Department of Crop and Soil Sciences Technical Report 91-2:92-97. Pullman, WA: Washington State University.

Guy, S.O., and R.M. Gareau. 1998. Crop rotation, residue durability, and nitrogen fertilizer effects on winter wheat production. Journal of Production Agriculture 11:457-461.

Langer, R.H.M., and G.D. Hill. 1982. Agricultural plants. Cambridge, UK: Cambridge University Press.

Larsen, J. 2009. The Ritzville Adams County Journal. October 8. Ritzville, WA

McClellan, R.C., T.L. Nelson, and M.A. Sporcic. 1987. Measurements of residue to grain ratio and relative amounts of straw, chaff, awns and grain yield of wheat and barley varieties common to eastern Washington. *In* Proceedings of the 10th Annual STEEP Conference, ed. L.F. Elliott. Spokane, Washington, May 20-21, 1987. STEEP-Conservation Concepts and Accomplishments 617-624. Pullman, WA: Washington State University Press.

Microsoft Corporation. 2003. Microsoft Office Excel 2003 (version 5.1)[Computer software]. Redmond, WA.

Rasmussen, P., H.P. Collins, and R.W. Smiley. 1989. Long-term management effects on soil productivity and crop yield in semi-arid regions of eastern Oregon. Oregon Agricultural Station Bulletin 675. Corvallis, OR: Oregon State University.

Renard, K.G., G.R. Foster, G.A. Weesies, D.K. McCool, and D.C. Yoder. 1997. Predicting soil erosion by water: A guide to conservation planning with the Revised Universal Soil Loss Equation (RUSLE). U.S. Department of Agriculture Handbook 703. Washington, DC: US Government Printing Office.

Retta, A., and D.V. Armbrust. 1995. Estimation of leaf and stem area in the Wind Erosion Prediction System (WEPS). Agronomy Journal 87(1):93-98.

Scheurman, R., and J. Clement. 2003. Palouse Country: A land and its people. Walla Walla, WA: Color Press.

Schillinger, W.F., R.I. Papendick, S.O. Guy, P.E. Rasmussen, and C. Van Kessel. 2006. Dryland cropping in the western United States. *In* Dryland Agriculture, eds G.A. Peterson, P.W. Unger, and W.A. Payne, Agronomy Monograph no. 23, 365-393. Madison, WI: American Society of Agronomy, Crop Science Society of America, and Soil Science Society of America.

Schillinger, W.F., R.I. Papendick, and D.K. McCool. 2010. Soil and water challenges for Pacific Northwest agriculture. *In* Soil and Water Conservation Advances in the United States, ed. T.M. Zobeck, and W.F. Schillinger, Soil Science Society of America Special Publication 60, 47-79. Madison, WI: Soil Science Society of America.

Sharratt, B.S., and D. Lauer. 2006. Particulate matter concentration and air quality affected by windblown dust in the Columbia Plateau. Journal of Environmental Quality 35:2011-2016.

Slafer, G.A., and F.H. Andrade. 1991. Changes in physiological attributes of the dry matter economy of bread wheat (*Triticum aestivum*) through genetic improvement of grain yield potential at different regions of the world. Euphytica 58:37-49.

USDA ARS (Agricultural Research Service). 2008. Revised Universal Soil Loss Equation Version 2 (RUSLE2). Draft User's Reference Guide. Washington, DC: USDA-Agricultural Research Service.

Vogel, O.A., R.E. Allan, and C.J. Peterson. 1963. Plant and performance characteristics of semidwarf winter wheats producing most efficiently in eastern Washington. Agronomy Journal 55:397-398.

Vogel, O.A., J.C. Craddock, Jr., C.E. Muir, E.H. Everson, and C.R. Rohde. 1956. Semidwarf growth habit in winter wheat improvement for the Pacific Northwest. Agronomy Journal 48(2):76-78.

Yoder, D.C., J.P. Porter, J.M. Laflen, J.R. Simanton, K.G. Renard, D.K. McCool, and G.R. Foster. 1997. Cover-management factor (C). *In* Predicting soil erosion by water: A guide to conservation planning with the Revised Universal Soil Loss Equation (RUSLE). U.S. Department of Agriculture Handbook 703, 143-182. Washington, DC: US Government Printing Office.

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