Farming Soils, Not Fields: Varying Fertilizer and Cultivars Within Fields to Increase Profitability and Enhance Environmental Quality
by PATRICK M CARR

A thesis submitted in partial fulfillment of the requirements for the degree of Doctor of Philosophy in Crop and Soil Science
Montana State University

Abstract:
Fertilizer and other inputs are traditionally applied uniformly within a field. However, most fields contain two or more soils with different crop yield potentials. This study was conducted to 1) measure crop yield differences between contrasting soils within fields, and 2) compare the economics of Farming Soils, Not Fields, where contrasting soils in a field receive different versus uniform rates and formulations of fertilizer. Relative amounts of straw production and straw:grain ratios on contrasting soils were also compared, as was grain yield, test weight, and protein of spring wheat and spring barley cultivars.

Grain yield, test weight, and returns over variable costs varied greatly among soil units within fields in crop yield variability studies ($P < .05$). Other soil fertility studies indicated that returns were $4 to $23 per hectare greater for the soil treatment than for the field treatment in 5 of 6 fields, but overall, the returns were not significantly different. However, a recommended fertilizer treatment was not always the optimum treatment. In three fields, additional returns of $54 to $79 per hectare resulted when optimum soil treatments were applied rather than the field treatment. The data reveal the importance of appropriate crop yield goals, accurate soil tests, and reliable fertilizer recommendations when developing a strategy for generating greater returns by Farming Soils, Not Fields, than applying a uniform rate and formulation of fertilizer in a field.

Soils produced varying amounts of straw within many fields in crop residue studies, and straw:grain ratios also differed among soils. Soils influenced straw production of different spring wheat and spring barley cultivars, as well as grain yield, test weight, and protein.

A draft procedure for varying inputs within fields is presented. This procedure could be applied commercially, after some modification.

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APPROVAL

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ABSTRACT

Fertilizer and other inputs are traditionally applied uniformly within a field. However, most fields contain two or more soils with different crop yield potentials. This study was conducted to 1) measure crop yield differences between contrasting soils within fields, and 2) compare the economics of Farming Soils, Not Fields, where contrasting soils in a field receive different versus uniform rates and formulations of fertilizer. Relative amounts of straw production and straw:grain ratios on contrasting soils were also compared, as was grain yield, test weight, and protein of spring wheat and spring barley cultivars.

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INTRODUCTION

Margins of profit have declined for many farming operations over the past decade. The decline is partially due to general reductions in commodity prices that have occurred since the early 1980's (Runge, 1986). Reductions in profits have also occurred because of increased costs of fertilizer, herbicide, and other inputs (Hargrove et al., 1988). Reduced prices and increased costs have forced many farmers out of business.

Growers in the U.S. have lost market share since the mid 1970's, largely because foreign growers can produce crops at lower cost and, thus, sell these agricultural commodities at lower prices than U.S. growers. For example, wheat was produced in Argentina at half the cost incurred in growing wheat in the U.S. during 1986 (Table 1). Fewer inputs were used by producers in other major wheat-exporting countries as well.

Large production capabilities ensure that the U.S. will continue to dominate world grain markets, but competitors will make inroads into markets traditionally controlled by the U.S. (Anonymous, 1986). For example, the U.S. forfeited 17% of its market share in the world wheat market between 1981 and 1985. This trend could

Table 1. Production costs of selected wheat exporting countries in 1986.[1]

	Argentina	South Africa	U.S.	Australia
	mg ha^{-1}			
Yield	1.81	1.48	2.22	1.54
	mg ha^{-1}			
TVC[2]	17.12	31.55	27.53	17.12
TFC	16.37	23.07	36.91	31.26
TC	33.49	54.62	64.44	48.38

[1]Ortmann et al. (1987)

[2]TVC, total variable costs; TFC, total fixed costs; TC, total costs.

continue, unless the U.S. is willing to accept lower returns from wheat exports.

American agriculturalists are productive, but inputs must be used more efficiently for U.S. farmers to be competitive in world markets (Jolliff and Snapp, 1988). Current cropping systems need to be modified, and new systems adopted, if the U.S. farm industry is to retain or gain a significant share of the market. Current yield levels should be maintained but at lower input costs.

New cropping systems need to be more profitable and environmentally sensitive than current systems to enhance the sustainability of U.S. agriculture. A sustainable system provides basic food or fiber needs, is profitable for the grower, and enhances environmental quality (Anonymous, 1989). Components of any sustainable cropping system include crop rotation, cultivar selection, fertility, pest management, and tillage strategies (Francis et al., 1987).

Farming Soils, Not Fields is a strategy for managing soils differently within a given field according to each soil's potential. This strategy might reduce costs, increase profit margins, and improve the quality of soil and water resources. The economic and environmental consequences of Farming Soils, Not Fields, suggest that this cropping system will become an integral part of sustainable cropping systems in the future.

The Concept: Farming Soils, Not Fields

Large differences in yield occur within many fields. This yield variation often corresponds to differences in the capabilities of contrasting soils to supply water and nutrients to plants. Farming Soils, Not Fields is a system in which inputs are tailored to individual soils within a field. For example, different fertilizer rates and formulations are applied to each soil in a field, and cultivars are seeded according to soil type. Varying inputs by soil type might allow optimum management of each soil in a field, in contrast to applying inputs uniformly across different soils.

Efficient use of inputs occurs when inputs are varied in a field rather than applied uniformly. For example, optimum levels of P and K fertilizers were applied throughout an irrigated potato field when rates and formulations were varied by soil type (Hammond et al., 1988). Excess fertilizer would have been applied to half the field if a uniform rate and formulation were used. Fertilizer applications at levels in excess of plant needs can lead to groundwater pollution (Bidwell, 1986); avoiding excess fertilizer applications by Farming Soils, Not Fields can reduce the likelihood of groundwater contamination from agricultural chemicals.

Commercial applicators which vary fertilizer rates and formulations by soil type are being used in farming operations (Reichenberger and Russnogle, 1989). Some units can also spread fertilizer impregnated with herbicides. Similar systems are being developed for selective placement of herbicides (Russnogle, 1989).

The goal of this project was to determine if additional economic returns could result by varying fertilizer and cultivars in some fields according to soil patterns versus applying these inputs uniformly within a field. To answer this question, objectives of this study were to: 1) measure crop yield differences between contrasting soils in fields managed uniformly, and 2) compare the economics of Farming Soils, Not Fields, where fertilizer, cultivars, and fertilizer with cultivars, are varied according to soil differences, rather than applying these inputs uniformly within a field. Contrasting soils also produce varying amounts of straw within fields, so a further objective was to compare straw production and straw:grain ratios on contrasting soils in the same field. A final objective of this investigation was to determine if yield, grain protein and test weight of spring wheat and spring barley are related to soil characteristics.

LITERATURE REVIEW

Soil Variability and Fertility

Fertilizers are usually applied uniformly; that is, a single formulation and rate of fertilizer is applied throughout a field. However, many fields consist of two or more soils with different crop yield potentials and soil test levels requiring different fertilizer programs for most economical yields. Spratt and McIver (1972) found soils occupying five landscape positions at 15 locations responded differently to N and P fertilizer applications. Wheat yields ranged from 1152 kg ha^{-1} to 1932 kg ha^{-1} prior to the addition of fertilizer. Differences were generally not eliminated by fertilizer applications.

The soil fertility status of a field is often variable since many fields include several soils, each with different nutrient supplying capabilities (Ferguson and Gorby, 1966; Power et al., 1961; Rennie and Clayton, 1960). Schweitzer (1980) reported that differences in fertility levels between soils in some fields were the major cause of crop yield variability. Other researchers have suggested that fertility and other edaphic factors explained yield differences between soils in fields (Larson, 1986; Malo and Worcester, 1975).

Soil physical factors explain crop yield variation in many fields. Evans and Catt (1987) attributed yield variability to hydrologic and temperature differences. Results of several studies indicate that differences in available water largely explained yield variation between soils (Evans, 1972; Hannah et al., 1982; Yeh et al., 1986). These physical factors are related to fertilizer management since they can influence the crop yield goals which, together with soil test results, determine fertilizer recommendations.

Soil Variability and Crop Cultivars

A single cultivar is usually planted on two or more contrasting soils that occur in a field, thereby ignoring edaphic heterogeneity. Alternatively, planting a different cultivar on each soil may improve cultivar performance and thereby provide greater economic returns.

Cultivars respond differently to environmental factors. In work with peanut (Arachis hypogaeal L.), Shorter and Norman (1983) reported that cultivars from different genetic origins had different yield responses at 10 locations. Environment X cultivar interactions have also been reported for several seed quality parameters in winter wheat (Triticum aestivum L.) (Peterson et al., 1986; Baenziger et al., 1985). The data suggest that one cultivar may be more productive than another cultivar in some environments.

Soil variation explained environment X cultivar interactions for several varieties of wheat and barley (Hordeum spp. L.) grown in Kansas (Liang et al., 1966). Edaphic differences, along with precipitation and temperature variation, were important factors determining relative performance of different cultivars.

Soil variability can have a greater impact on crop yield and quality than other factors that influence crop production. For example, sugar beet yield was influenced more by soil type than by differences in cultivation, fertilizer, and cultivar (Deleenheer and Simon, 1950). Yield and quality of wheat were related to soil type in fields under uniform management (Lee and Spillane, 1970). However, relative productivity of soils was influenced by the cultivar grown, which complicated assessment of soil differences on wheat yield and quality. Ciha (1984) reported that both cultivar and soil type influenced yield components of winter wheat, but only cultivar significantly influenced test weight. The data indicate that both cultivar and soil type must be considered for production of optimum crop quality and yield in fields containing contrasting soils.

Planting different crops in parts of the same field may result in greater economic returns than planting one crop in fields containing several soils. Jones and others (1987) suggested that different crops should be planted on contrasting landscape positions in a field to maximize returns over variable costs. This might create problems with field management and harvesting. An alternative is to plant different cultivars on contrasting soils in a field.

Commercial application units are currently operated which vary fertilizer rates and formulations within a field. Fertilizer is applied in a field according to yield goals and soil nutrient status of the various soils. Planting several cultivars in a field might be possible using similar technology.

Soil Variability and Crop Residue

Wind erosion is a serious problem on much of the cropland in the Northern Great Plains, where over one billion megagrams of topsoil were removed by wind during 1982 (USDA-SCS, 1987). Without implementing several conservation practices, soil loss was expected to continue at this level. Wind erosion results in the removal of the most fertile portion of the soil, thereby lowering soil productivity (Lyles, 1975). Blowing soil particles can also damage seedlings and lower the marketability of many crops. Uncontrolled wind erosion reduces productivity to a point where cropland can neither be managed nor restored economically, and much is abandoned.

Establishing and maintaining a vegetative cover, whether living or nonliving, helps protect cropland from wind erosion. Wheat straw, for example, absorbs much of the shear stress that is applied to bare, unprotected soil by wind (Troeh et al., 1980). Straw on the surface also forms barriers, preventing soil creep and saltation (Hayes and Fenster, 1983). Soil losses can be minimized when sufficient amounts of straw are produced on formerly bare soils, as indicated from field studies in Montana (Krall et al., 1958).

Field samples can be collected to measure amounts of straw produced in fields (Whitfield et al., 1962). However, field collection is both labor and time intensive, and impractical for inventory of large areas (Aase and Siddoway, 1981). Estimates of straw production can be made on the basis of grain yields, if a constant straw:grain ratio is assumed.

Several straw:grain ratios have been determined for spring wheat from field data. Bauer and Zubriski (1978) reported an average straw:grain ratio of 1.91 for several spring wheat cultivars, with a range of 0.72 to 4.71. Deviation from the average value decreased as yield levels increased. A straw:grain ratio of 1.7 was indicated by data collected over 8 years in Nebraska (Fenster and McCalla, 1970), whereas Black et al. (1974) suggested a ratio of 1.3. Although the data indicate a considerable range in the straw:grain ratio for spring wheat, for conservation planning purposes, the Soil Conservation Service (SCS) assumes a constant straw:grain ratio of 1.6 in Montana (Nadwornick, 1989, personal communication).

Management practices influence the straw:grain ratio of small grain crops. For example, average ratios of 1.6 and 3.8 were determined for irrigated and nonirrigated wheat cultivars, respectively, in North Dakota field studies (Frank et al, 1977). Tillage operations also affect the straw:grain ratio, with a narrower range among cultivars in stubble-mulch than clean-fallow fields (Tucker et al., 1971; Zing et al., 1955, 1957). Reitz (1976) suggested that fertility and planting date influenced the straw:grain ratio.

It is unclear what influence soil type has on the straw:grain ratio of spring barley and spring wheat, even though fertility and other factors vary between many soils (Beckett and Webster, 1971). Since most fields are comprised of two or more contrasting soils, edaphic influences on the straw:grain ratio would result in overestimating residue production on some soils and underestimating on others if a constant straw:grain ratio is assumed.

MATERIALS AND METHODS

Soil Variability and Fertility

Yield Variability Study

Three locations in central Montana were selected to represent important dryland wheat-(*Triticum aestivum* L.) and barley-(*Hordeum vulgare* L.) producing regions of the state (Figure 1). During 1987, four fields containing at least two distinct soils were identified at these locations. Soil unit boundaries were first delineated using a soil survey report. Color-infrared aerial photographs or satellite images were subsequently used to modify boundaries. Producer knowledge of the field was incorporated to develop an operational soil unit management map. Soil Conservation (SCS) personnel and the researchers evaluated the maps in the field to ensure accurate delineation of the map units. The entire field was tilled and planted to barley or wheat by the farmer.

Grain samples were collected using a research combine from 10 m^2 areas along transects approximately 500-m long which crossed soil units in each field. An average of 20 samples were collected from each soil unit. Test weight and yield were determined for each sample. Returns over

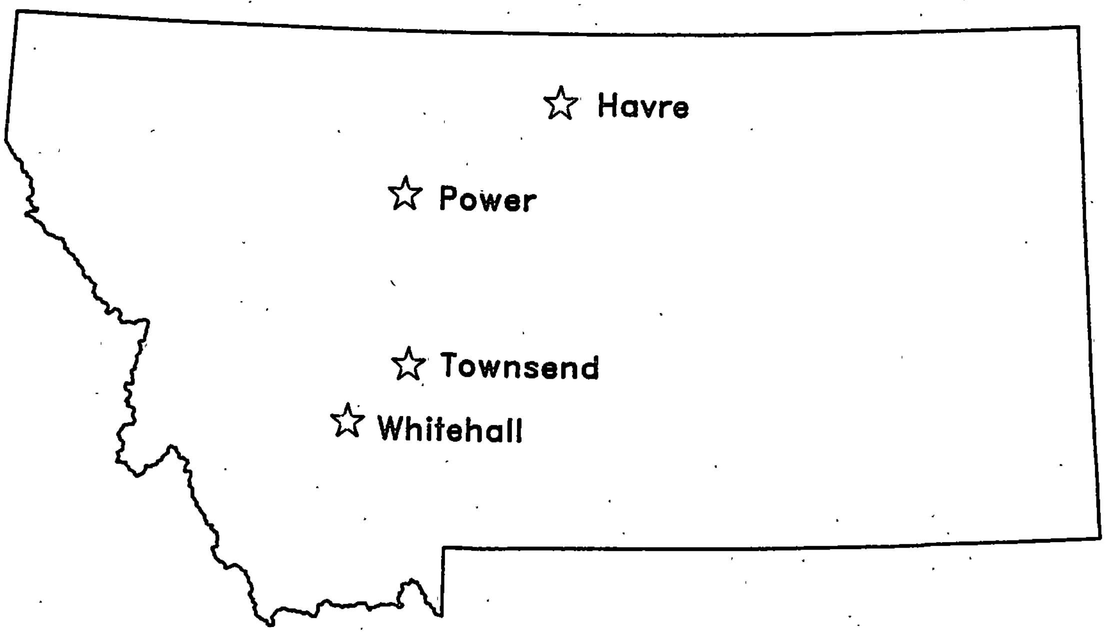

Figure 1. Location of study sites.

variable costs (returns) were calculated by subtracting actual production cost in each field from the price of the grain, which during 1987 was \$0.08 kg^{-1} for feed barley and \$0.10 kg^{-1} for spring wheat at 14% grain protein, respectively. Data were subjected to a one-way analysis of variance with soil map unit as the independent variable.

Soil Fertility Studies

Soil fertility studies were conducted in three fields during 1987 and 1988 (Table 2). Each field contained at least two different soils. Twenty soil samples were collected and mixed from each soil unit at 0 to 15 cm, 15 to 30 cm, 30 to 60 cm and 60 to 90 cm depths except at Whitehall (1987), where samples were collected at 0 to 15 cm and 15 to 60 cm depths. The 0 to 15 cm composite sample was analyzed for organic matter, using a modified Walkley-Black technique (Walkley and Black, 1934), NO_3-N by cadmium reduction (Henrikson and Selner-Olsen, 1970), NH_4OAc-extractable K (Knudsen et al., 1982), and $NaHCO_3$-extractable P (Olsen and Sommers, 1982). A 1:2 soil:water slurry was used to determine pH and electrical conductivity (USDA, 1954). Composite samples for other depths were analyzed for NO_3-N. Field average soil test values were determined by combining and mixing corresponding depth samples from all soil units. Soil test results show that the soil units in each field are different in one or more properties.

Fertilizer recommendations were made for each soil unit, based on soil test results, yield goals and Montana State University fertilizer guidelines (Bauder et al., 1986). Yield goals for soil units were initially based on SCS estimates for soil series and were then modified, based upon historical field records and grower experience. The fertilizer treatment for the field was based on soil test results for the whole field, fertilizer guidelines and a yield goal established from crop yield records for

Table 2. Soil fertility test results for soil units in six Montana fields.

Year	Location	Soil unit[1]	NO_3-N[2]	P	K
			kg ha^{-1}	--- ppm	---
1987	Havre	Evanston	25	15	390
		Phillips	50	17	350
		Telstad	40	13	260
1987	Power	Cabbart	60	13	470
		Delpoint	105	14	420
1987	Whitehall	Ethridge	10	8	410
		Varney	24	10	480
		Yawdim	10	25	510
		Yetull	20	10	460
1988	Havre	Gerdrum	130	30	620
		Joplin	40	10	260
		Phillips	40	15	360
		Telstad	45	10	295
1988	Townsend	Amesha	80	8	300
		Brocko	50	16	240
1988	Whitehall	Ethridge	30	30	330
		Varney	15	20	380
		Walbert	30	20	360

[1]Soil unit names are based upon predominant soil series.

[2]Soil test results for N were for 0 to 60 cm depths at Whitehall (1987) and 0 to 90 cm depths at other locations; soil test results for P and K were for 0 to 15 cm depths at all locations.

the field (Table 3). A different fertilizer treatment was recommended and applied for each soil unit and field except at Power and Havre (1987), where an approximation of the recommended treatment was applied along with 14 additional fertilizer treatments above and below each recommended nutrient rate.

Table 3. Yield goals and recommended fertilizer programs for soil management units in six Montana fields.

Year	Location[1]	Soil unit and field	Crop[2]	Yield goal	Recommended rate N	P	K
				----- kg ha^{-1} ------			
1987	Havre	Evanston	sw	3020	78	10	30
		Phillips	sw	2350	36	0	0
		Telstad	sw	2690	37	10	30
		Field	sw	2690	37	10	30
1987	Power	Cabbart	ww	2350	47	10	0
		Delpoint	ww	3360	63	10	0
		Field	ww	3025	63	10	0
1987	Whitehall	Ethridge	sw	2960	140	19	0
		Varney	sw	2350	66	7	0
		Yawdim	sw	1075	45	9	0
		Yetull	sw	1275	25	17	0
		Field	sw	1950	51	12	0
1988	Havre	Gerdrum	sw	3360	56	11	0
		Joplin	sw	2015	28	11	0
		Phillips	sw	1680	11	11	0
		Telstad	sw	2690	45	11	0
		Field	sw	2350	15	11	0
1988	Townsend	Amesha	sb	2150	0	36	0
		Brocko	sb	2420	8	11	34
		Field	sb	2150	0	0	0
1988	Whitehall	Ethridge	sw	3025	134	0	0
		Varney	sw	2690	121	0	0
		Walbert	sw	2150	74	0	0
		Field	sw	2690	111	0	0

[1]At Havre and Power, one of 15 established fertilizer rate combinations was used as the recommended rate based upon soil test results and yield goals.

[2]sw, spring wheat; ww, winter wheat; sb, spring barley.

Fertilizer was applied using a research drill at Havre (1987) and Power, a commercial no-till drill at

Whitehall and Townsend, and a commercial air seeder at Havre (1988). Nitrogen was applied as NH_4NO_3 (34-0-0) at all sites except Havre (1988), where N was applied as $NH_4H_2PO_4$ (11-55-0) prior to seeding and $CO(NH_2)_2$ (46-0-0) as a topdress at seeding. Potassium was applied as KCl (0-0-60) at all sites. Phosphorus was applied as H_3PO_4 (0-54-0) at Power and Havre (1987), as $NH_4H_2PO_4$ at Havre (1988), and as $Ca(H_2PO_4)_2$ (0-45-0) at other locations. Fertilizer treatments were applied in a randomized complete block design with four replications except at Whitehall (1987) where the treatments were applied in 12-m x 600-m strips, and at Havre (1988) where 12-m x 1600-m strips crossed soil units.

During 1987, 'Newana' spring wheat was seeded at Havre and 'Bronze Chief' at Whitehall. 'Norwin' winter wheat was seeded in the fall of 1986 at Power. During 1988, 'Piroline' spring barley was seeded at Townsend and 'Newana' spring wheat at Whitehall. Four spring wheat cultivars, 'Cutless', 'Lew', 'Glenman' and 'Rambo' were seeded across each fertilizer treatment at Havre. Local practices were used in seedbed preparation and weed control.

Plots at Havre (1987), Power, Townsend, and Whitehall (1988) were harvested using a research combine. Harvested plot size was 7.5 m^2 at Power and Havre, and 15 m^2 at

Townsend and Whitehall. Four 37 m^2 samples were harvested at Whitehall (1987) from each plot. Twelve 9 m^2 samples were harvested at Havre (1988) from each soil unit X fertilizer treatment (3 samples per cultivar, with 4 cultivars per soil unit). Reported data are averaged across cultivars.

Test weight and yield were determined for each sample. Percent grain protein was determined for all wheat samples using a near-infrared analyzer at the Cereal Quality Laboratory at Montana State University. Percent grain protein of barley was not determined since the crop was sold as feed and protein did not influence the price. Returns were calculated by subtracting fertilizer and application costs from gross return based on current grain prices, taking percent grain protein into account for wheat.

Average price paid for N, P, and K fertilizer was \$0.55 kg^{-1}, \$0.97 kg^{-1}, and \$0.35 kg^{-1}, respectively, during 1987 and \$0.55 kg^{-1}, \$1.37 kg^{-1}, and \$0.31 kg^{-1} during 1988. Average price received for spring wheat was \$0.10 kg^{-1} at 14 percent grain protein during 1987, with an additional \$0.002 kg^{-1} received each quarter percent up and minus \$0.004 kg^{-1} each quarter down from 14 percent to 13.5 percent, where \$0.09 kg^{-1} was received. Average price received for winter wheat was \$0.10 kg^{-1} at 11 percent grain protein during 1987, with an additional \$0.0004 kg^{-1} received each quarter percent up and down from 11 percent. During 1988, \$0.16 kg^{-1} was received for spring wheat at 14 percent grain protein, with an additional \$0.0004 kg^{-1} received each half percent up and minus \$0.0007 kg^{-1} each quarter percent down from 14 percent to 12.5 percent, where \$0.15 kg^{-1} was paid. Average price received for spring barley was \$0.08 kg^{-1}.

Data were subjected to analysis of variance using soil units and fertilizer treatments as independent variables except at Havre (1988), where cultivars were also treated as an independent variable. In fields where treatments were applied in a randomized complete block design, each soil map unit was also evaluated as a location with fertilizer treatment as the independent variable. A procedure described by Cochran and Cox (1957) was used to determine error terms in cases where variances with soils as locations were heterogenous.

Soil Variability and Crop Cultivar

Crop X Soil Studies, 1987

The study site included three contrasting soils in a 130 hectare field near Havre. Soil map boundaries were first delineated using a soil survey report, and modified using color-infrared aerial photographs. Producer knowledge of the field was incorporated to develop an operational soil unit management map.

Twelve spring wheat cultivars ('Copper', 'Cutless', 'Fortuna, 'Glenman', 'Lew', 'MT 751', 'MT 7926', 'Newana', 'NK 751', 'Pondera', 'Success', and 'Wheaton') and twelve spring barley cultivars ('Bowman', 'Clark', 'Gallatin', 'Harrington', 'Hazen', 'Hector', 'Kimberly', 'Lewis', 'MT 81161', 'MT 81616', 'Piroline', and 'Steptoe') were each established in 5 m^2 field plots on each soil unit. Field plots were arranged in a randomized complete block design with four replications on each soil unit.

Fertilizer was applied using a commercial drill at a rate of 63 kg of N ha^{-1} as $CO(NH_2)_2$ prior to final seedbed preparation, with an additional 15 kg of N ha^{-1} and 17 kg of P ha^{-1} as $(NH_4)_3PO_4$ applied at planting. Fertilizer rates were based on both soil test results and a yield goal established for the whole field from historical records. Local practices were used for pest control.

Grain from 4.5 m^2 areas was harvested from each plot using a research combine. Grain yield, test weight and protein were determined. Returns over variable costs (returns) were calculated by subtracting fertilizer and application costs from gross return based on current grain prices. Percent grain protein was taken into account for wheat, but was not for barley, since it was sold for livestock feed.

Data were subjected to analysis of variance using cultivars as the independent variable and grain yield, protein and test weight as dependent variables with each soil unit as a location. The whole field was also analyzed as a location, with soil units and cultivars as independent variables. The error term with the field as a location was determined from the pooled sums of squares with soil units as the independent variable.

Cultivar X Fertilizer X Soil Unit, 1987

Field plots of four spring wheat cultivars ('Fortuna', 'Glenman', 'Lew', and 'Newana') were established on the Evanston loam, Phillips clay loam, and Telstad loam in the field near Havre previously described. Nitrogen was applied at planting to the plots (13 m^2 each) as NH_4NO_3 at 0%, 75%, 100%, or 125% of the recommended rate based on soil tests and yield goals for each soil unit. Recommended rates of N were 63, 36, and 50 kg ha^{-1} for Evanston, Phillips-Kevin, and Telstad-Joplin soil units, respectively. Phosphorus (P) was applied to all plots at a rate of 10 kg ha^{-1} as H_3PO_4 and K at a rate of 30 kg ha^{-1} as KCl. The cultivar X fertilizer plots were arranged in a randomized complete block design with four replications on each soil unit.

Grain was harvested from 8.5 m^2 areas in each plot; grain yield, test weight, protein and returns were determined as previously described. Cultivar and fertilizer were both treated as independent variables when soil units were treated as locations during statistical analysis.

Cultivar X Fertilizer X Soil Unit, 1988

Four spring wheat cultivars ('Cutless', 'Glenman', 'Lew', and 'Rambo') were planted in 2 m x 1600 m strips that crossed four soil units in a field. Nitrogen fertilizer was applied in 12 m x 1600 m strips as $CO(NH_2)_2$ in the fall at rates of 4, 7, 20, 37, 50, and 60 kg ha^{-1}. An additional 7 kg ha^{-1} was applied at planting, along with 15 kg ha^{-1} P as $(NH_4)_3PO_4$ and 19 kg ha^{-1} K as KCl. Fertilizer was applied so that strips of all four cultivars occurred within each N fertilizer strip. A check strip (no fertilizer) was included as a treatment.

Three 8.5 m^2 samples were harvested using a research combine from each cultivar X fertilizer strip on each soil unit. Mean values for each cultivar X fertilizer treatment were used for statistical analysis. The soil unit X fertilizer treatment interaction was the error term for soil units and fertilizer treatments, and the soil unit X fertilizer X cultivar treatment was the error term for other variables and interactions.

Soil Variability and Crop Residue

Soil X Cultivar Studies, 1987

Plants were clipped at 13 cm above the soil surface from 8.5 m^2 areas in the Crop X Soil Studies plots using a research combine. Grain and straw were separated by the combine; grain was stored in a hopper and then collected in small plot sample bags. Straw was caught and collected on tarps as it was thrown from the rear of the combine. Grain and straw weights were determined, as was a straw:grain ratio, for each sample. Weight of the 13 cm of straw remaining in the plots was not measured, but based on its relation to total plant height, was estimated to weigh 15 percent of the weight of the straw which was collected.

Data were subjected to analysis of variance using cultivars as the independent variable and grain yield, straw yield, and the straw:grain ratio as dependent variables, with each soil unit as a location. The whole field was also analyzed as a location, with soil units and cultivars as independent variables. The error term with the field as a location was determined from the pooled sums of squares with soil units as the independent variable.

Soil X Fertilizer Studies, 1988

Plants were clipped at the surface from one 1 m^2 area from each plot in Soil Fertility Studies at Townsend and Whitehall using methods reported by Whitfield et al. (1962). Samples were dried at 60^o C until a constant weight was measured. A research combine was used to separate grain from straw. Grain was collected and weighed; straw weight was determined by subtracting the weight of the grain from the initial weight of the dried sample. Data were subjected to analysis of variance using soil units and fertilizer treatments as independent variables. Soil units were also evaluated as locations with fertilizer treatments as the independent variable.

Soil X Fertilizer X Cultivar Studies, 1988

Three 1 m^2 samples were collected from each Soil X Fertilizer X Cultivar strip in the field at Havre. Grain and straw weights were determined, as already described. Analysis of variance was conducted on the mean values of each cultivar X fertilizer treatment using soil unit, fertilizer, and cultivar as independent variables. The soil unit X fertilizer interaction was the error term for soil units and fertilizer treatments, and the soil unit X cultivar X fertilizer interaction was the error term for other variables and interactions.

RESULTS AND DISCUSSION

Soil Variability and Fertility

Yield Variability Study

High yielding soil units produced over twice as much grain as low yielding units (Table 4). Returns were negative on low-yielding soil units in each field. Conversely, positive returns of \$49 ha^{-1} to \$240 ha^{-1} were generated on the high-yielding soil units except at Power, where grasshopper damage was severe. The data suggest that overall returns would have been improved by taking low yielding soil units out of production during 1987. Soil units at every location produced significantly different ($P < .05$) grain yield and returns.

Soil Fertility Studies

Soil units differed in grain yield and in returns over variable costs except at Whitehall (1987) (Table 5). An average yield difference of 1650 kg ha^{-1} occurred between low-yielding and high-yielding soil units in the same field; returns varied an average of \$133 ha^{-1}. Fewer grain samples were collected from soil units at Whitehall (1987) than in other fields and may explain lack of significant differences in grain yields between the soils.