Spring wheat yields on two contrasting aridic agriborolls in northcentral Montana
by Brian David Schweitzer

A thesis submitted in partial fulfillment of the requirements for the degree of MASTER OF SCIENCE in Soil Science
Montana State University
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Abstract:
Spring wheat yield data were collected on two soils of north-central Montana. The soils are Scobey and Kevin series which are both Aridic Argiborolls. These soils occur in complexes on glacial till in northern Montana. Soil plots were identified within single fields allowing examination of the soils yield performance independent of other variables such as management and climate.

Wheat grown on Scobey plots always outyielded wheat on Kevin plots. Average yield on Scobey was 262 percent of average yield on Kevin. Wheat on Scobey plots yielded an average of 4653 kg/ha and wheat on Kevin averaged 1772 kg/ha.

Wheat on the two soils utilized nearly the same quantity of water. Available P, NO3-N, CaCO3 ($p = .01$); organic matter, and extractable K ($p = .05$) were correlated with soil series. Water is usually considered to be the most yield limiting factor in Montana dryland wheat production, but in this study, yield differences between soil series ;were due to soil fertility rather than soil water.

Soil yield performance data collection procedures of this study could be adapted by the Soil Conservation Service. These procedures would be more accurate and useful than the data collection system presently used.

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by

BRIAN DAVID SCHWEITZER

A thesis submitted in partial fulfillment
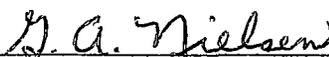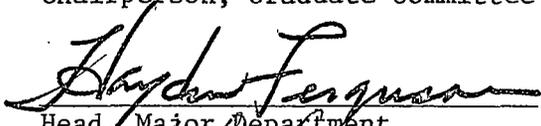of the requirements for the degree
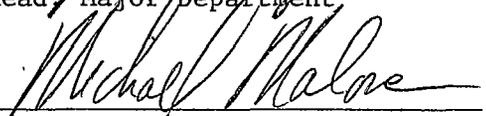
of

MASTER OF SCIENCE

in

Soil Science

Approved:

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Chairperson, Graduate Committee

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Head, Major Department

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Graduate Dean

MONTANA STATE UNIVERSITY
Bozeman, Montana

August, 1980

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ABSTRACT

Spring wheat yield data were collected on two soils of north-central Montana. The soils are Scobey and Kevin series which are both Aridic Argiborolls. These soils occur in complexes on glacial till in northern Montana. Soil plots were identified within single fields allowing examination of the soils yield performance independent of other variables such as management and climate.

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Soil yield performance data collection procedures of this study could be adapted by the Soil Conservation Service. These procedures would be more accurate and useful than the data collection system presently used.

INTRODUCTION

There is a need for detailed soil performance data. A producer cannot choose a realistic level of management inputs unless the expected yield is known. A reasonable yield goal can only be estimated by soil performance studies under known management and climatic conditions. Results of such studies can assist 1) farmers in management decisions, 2) land use planners in feasibility studies, and 3) private and public agencies in land appraisal.

The Soil Conservation Service (SCS) presently provides yield predictions in published soil survey reports. The soil survey manual (Soil Survey Staff, 1951) states that "performance judgments are based upon evidence afforded by actual yield data from sample areas of the soil mapping units", but this approach is seldom utilized.

The most useful performance data includes yield predictions for a given soil under a wide range of management and climate. For example, on a given soil, a producer could predict crop yields based upon specific management practices and climate. This information allows accurate cost/benefit predictions prior to planting.

OBJECTIVES

Objectives of this study were: 1) to collect actual field yield data from Scobey and Kevin soils, and 2) to determine the significance of these soils to crop yield by comparing spring wheat yields on two soils within one field. Management and macroclimate are nearly identical. Therefore, the yield difference must be due to soil.

REVIEW OF LITERATURE

The art of soil classification and mapping is at least 4,000 years old (Thorp, 1935). During this century, it became apparent that the mere classification of a soil does not sufficiently aid the resource manager. The next logical step was to provide recommendations about potential uses of soils for engineering and edaphological purposes. Presently, the SCS provides this information in all published soil surveys.

One of the most important applications of soil surveys is the prediction of crop yields from particular soil units. Predicted yields can help producers set realistic yield goals and link productivity to land evaluation (Soil Survey Staff, 1951).

Presently yield predictions are compiled in three manners:
1) interviews with producers and visual field observations, 2) examination of farm records, and 3) actual yield determination from sample areas of the soil unit (Odell, 1958). The last technique is the most accurate, but is seldom employed.

Yield data collection has been studied for many years. Soybeans, winter wheat, oats and corn yields were examined on Clinton Silt Loam for seven years. This central Illinois (Rust & Odell, 1957) study included records from several farms under a wide range of management. Another Illinois study employed multiple curvilinear regression

analysis of crop yields on soil units under varied management and climatic conditions. The study included data from seven hundred farm production records. The length of the production records varied from five to twenty-five years. The crop yields on each soil unit increased or decreased from year to year, up to fifty-six percent (Rust & Odell, 1957).

In one study (Henao, 1976), soil productivity ratings were based upon over thirty physical and chemical properties. The intent was to examine such factors as: percent carbon in the plow layer, plant available water holding capacity of the soil profile, bulk density in the subsoil horizons, pH by horizon, depth to the top of the calcium carbonate horizon, and assign numerical yield values contributed by each factor. Another report (deJong and Rennie, 1967) concluded, "it is impossible to assess the practical significance of specific soil physical properties in terms of wheat production on the basis of current research information."

A model was designed in Oklahoma (Allgood and Gray, 1977) to assign soil productivity ratings for yield prediction on different soils. They tried two systems. The first utilized laboratory data, field observations and published yield information. The second system was based solely on diagnostic soil characteristics included in *Soil Taxonomy*. Water was the most yield limiting factor in this study. Parameters that affected soil moisture such as slope, clay percent,

and percent organic matter were most important in predicting yield.

There are three basic components of yield soil, climate and management. Yield prediction accuracy suffers when any of these independent components is not accurately identified or held constant. To overcome this problem, some workers have compared yields on different soil units within individual fields. This approach holds management and microclimate constant so yield differences are attributed to soil alone (Ferguson & Gorby, 1966; Rennie & Clayton, 1960; Spratt & McIver, 1971). They demonstrated that yields can vary substantially, as much as 300 percent, between soils on glacial till catenas of the northern great plains when other variables are held constant. Furthermore, these investigations demonstrated that each soil responded differently to fertilizer treatments.

METHODS

Spring wheat was planted by five cooperating farm operators during May, 1979. Plots were identified and marked after the crop was seeded, but prior to germination. There were two plots per site, one on Scobey soils and one on Kevin, both within one field. Each plot measured 1.55m x 7.63m. Four farms had one site per field (1, 2, 3, 7) and one farm had three sites in one field (4, 5, 6) as can be seen in Figure 1 and legal descriptions of sites are in Table 1. Soil series chosen for this study occur on glacial till in northern Montana. The Scobey series (Figure 2) is identified as the most extensively cultivated soil in Montana (Genter, 1977). The Kevin soil series is found in complexes with the Scobey. They are both Aridic Argiborolls (Appendix IV). The Scobey is in the fine, montmorillonitic and Kevin is in the fine loamy, mixed family. Kevin contains $CaCO_3$ in the plow layer and Scobey does not.

Scobey and Kevin soils were formed on the same parent material. The differences between the two soils in the study are a result of geologic wind and water erosion moving material from the erosional or Kevin landscape positions to the depositional or Scobey positions. Due to its landscape position, these Scobey soils are deeper, more fertile and have a higher available water holding capacity than Kevin soils.
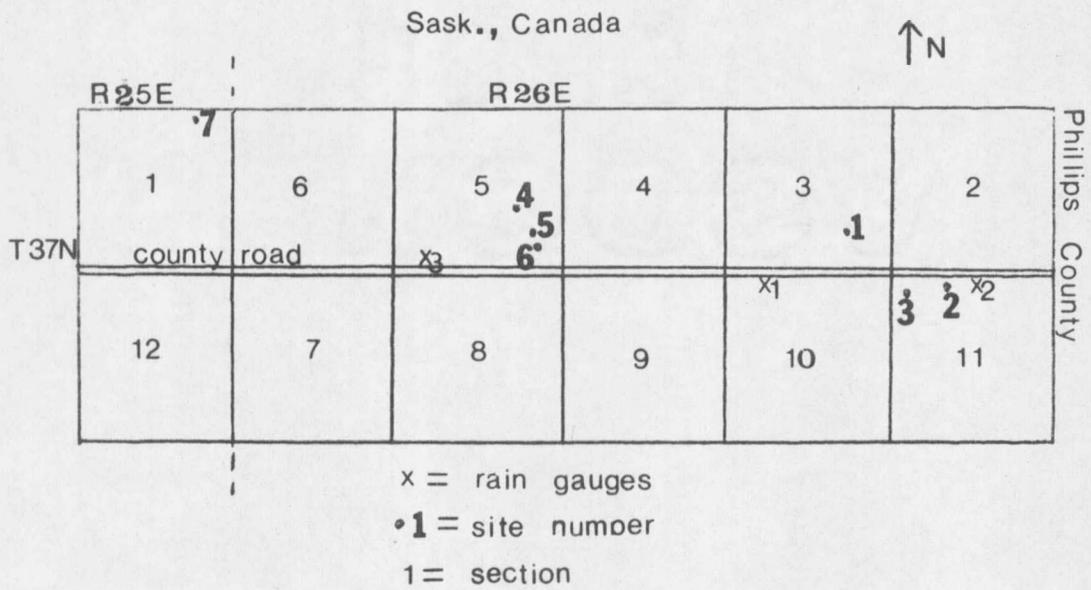
S = study area

Figure 1.   Location of Sites.

TABLE 1. QUESTIONNAIRE SUMMARY

Plot		Farm Operator	Legal Description	Seed Variety	Total Initial Water in 120cm Profile	Rainfall During Growing Season cm	Previous Crop	Summer Fallowed on Previous Year	Number of Times Tilled Prior to Planting	Stand Establishment 1 = Excellent 5 = Poor	Estimated Crop Loss Due to Weeds kg/ha	Planting Date 1979
1	S*	Walter Fouts	SE¼, NW¼, SE¼, Sec. 3 T 37N, R 26E	Bounty 309	19.8	13.04	Fallow	Yes	5	1	0	May 21
	K*	Walter Fouts	SE¼, NW¼, SE¼, Sec. 3 T 37N, R 26E	Bounty 309	4.2	13.04	Fallow	Yes	5	1	0	May 21
2	S	Glenn Hutton	NW¼, NE¼, NW¼, Sec. 11 T 37N, R 26E	Bounty 309	9.3	12.37	Fallow	Yes	3	2	67	May 24
	K	Glenn Hutton	NW¼, NE¼, NW¼, Sec. 11 T 37N, R 26E	Bounty 309	6.9	12.37	Fallow	Yes	3	2	67	May 24
3	S	Rick Glabofski	NW¼, NW¼, NW¼, Sec. 11 T 37N, R 26E	Bounty 309	6.1	12.37	Fallow	Yes	5	4	134	May 20
	K	Rick Glabofski	NW¼, NW¼, NW¼, Sec. 11 T 37N, R 26E	Bounty 309	8.7	12.37	Fallow	Yes	5	4	134	May 20
4	S	Allen Billmyer	NE¼, NW¼, SE¼, Sec. 5 T 37N, R 26E	Butte	8.5	13.30	Fallow	Yes	4	2	33	May 26
	K	Allen Billmyer	NE¼, NW¼, SE¼, Sec. 5 T 37N, R 26E	Butte	11.0	13.30	Fallow	Yes	4	2	134	May 26
5	S	Allen Billmyer	SW¼, NE¼, SE¼, Sec. 5 T 37N, R 26E	Butte	10.6	13.30	Fallow	Yes	4	2	67	May 26
	K	Allen Billmyer	SW¼, NE¼, SE¼, Sec. 5 T 37N, R 26E	Butte	9.7	13.30	Fallow	Yes	4	2	33	May 26
6	S	Allen Billmyer	NW¼, SE¼, SE¼, Sec. 5 T 37N, R 26E	Butte	9.0	13.30	Fallow	Yes	4	2	67	May 26
	K	Allen Billmyer	NW¼, SE¼, SE¼, Sec. 5 T 37N, R 26E	Butte	8.2	13.30	Fallow	Yes	4	2	67	May 26
7	S	Sid Egbert	NE¼, NW¼, NE¼, Sec. 1 T 37N, R 25E	Prodax	6.8	13.30	Crested Wheat Grass	No	5	4	33	May 29
	K	Sid Egbert	NE¼, NW¼, NE¼, Sec. 1 T 37N, R 25E	Prodax	1.28	13.30	Crested Wheat Grass	No	5	4	33	May 29

*S = Scobey
K = Kevin

Figure 2a.   Typical Scobey Landscape.   Study area is more severely undulating.

Figure 2b.   Scobey Soil Profile.

Soil Identification

The Scobey and Kevin soils were identified by extracting a core

sample and examining color, texture and pH. If a soil effervesced

when 10% hydrochloric acid (HCI) was applied to the Ap horizon, it

was identified as Kevin. When the soil effervesced only at depths of

eleven inches or greater, it was identified as Scobey. Scobey soils

are usually located in depression to midslope positions, while Kevin

soils occupy the slope and crown positions. The SCS has mapped the

complex as 60% Scobey and 40% Kevin.

Spring Soil Samples

Soil samples were collected as the plots were identified during

the week of May 20, 1979. Twenty subsamples were extracted from the

Ap horizon of each plot, mixed and subsampled to obtain a 600 gram

sample. The soil samples were analyzed by the Montana State University

Soil Testing Laboratory.

Each sample was analyzed for: pH, extractable K, available P,

organic matter percent and $CaCO_3$ percent by standard Montana State

University Soil Testing Laboratory procedures.

These procedures are: 1) available P by modified Bray #1 (Smith,

F. W. *et al*, 1957; Olsen, S. R. and L. A. Dean, 1965), 2) percent $CaCO_3$

by adding HCI and measuring CO_2 loss (Williams, 1948), 3) extractable

K by the neutral, normal NH_4OAC extraction procedure as modified by the

Montana State University Soil Testing Laboratory, 4) NO_3-N by the chromotropic acid method (Sims, J. R. and Jackson, G. D., 1971), 5) percent organic matter was determined by the simplified colormetric method (Sims and Haby, 1970), and 6) pH was determined on 2:1 water to soil paste.

Two 5.7cm diameter core samples were extracted to a depth of 120 cm because this is the spring wheat rooting depth (Israelsen and Hansen, 1962). The cores were separated into 30cm increments, frozen and analyzed for NO_3-N. Soil water content was measured gravimetrically.

Precipitation

Rain gauges were placed in three locations near study sites. Gauge 1 represents site 1, gauge 2 represents sites 2, 3 and sites 4, 5, 6, 7 are represented by rain gauge 3. The cooperating farmers recorded precipitation data. Locations of gauges are marked on the sample area map in Figure 1.

Harvest

The crop was examined during the growing season to detect any obvious disease or insect problems that would substantially reduce yield. A 0.6 x 6.1m plot was harvested from the middle of each plot on September 1, 1979. Forty random spikes from each plot were collected during harvest to determine the average number of kernels per spike. Random was defined as selecting the 40th, 80th and 120th spike from

every 5th furrow in the plot. If the designated spike was sterile,
the next spike was selected. The harvested grain was weighed to
determine total yield. Using kernels per spike data and total yield
data (yield/kernel weight x kernels per spike), stand density was
calculated. Total protein percent was analyzed using the Udy dye
method (Association of Official Agricultural Chemists, 1965).

Soil Temperature

A soil thermometer was placed at a depth of 50cm near site 1.

Fall Soil Samples

Spring soil sampling procedures were repeated on September 1,
1979. The fall samples were analyzed for: pH, extractable K, available
P, organic matter percent, NO_3-N and soil water.

Management Data Sheets

Questionnaires were prepared dealing with management of the crop.
All factors including tillage, climate, insects, disease, seed variety
and cropping history that would effect crop yield were considered. The
questionnaires are shown in Appendix I and summarized in Table 1.

Statistical Methods

The "paired t" test (Jerome, C. R., 1964) was selected to analyze
statistical differences between Scobey and Kevin. The "paired t"
allowed comparison of yield and chemical soil properties between Scobey

and Kevin plots within single sites. By comparing soils within single

sites, management and climate differences were minimized.

RESULTS

Results of spring soil sample analysis and harvested grain
are summarized in Table 2.

Yield

Wheat yield was correlated with soil series (p = .01). The
average yield on Scobey was 4653 kg/ha and Kevin soils averaged
1772 kg/ha. Wheat yield values are shown in Figure 3.

Number of Kernels per Spike

Kernels per spike were correlated with soil series (p = .05).
The average number kernels/spike on Scobey was 27.2 and 20.6 on
Kevin. Kernels/spike values are shown in Figure 4.

Stand Density

Stand density was correlated with soil series (p = .01). Stand
density on Scobey plots averaged 345 spikes/m^2 and 134 spikes/m^2 on
Kevin. Stand density values are shown in Figure 5.

Wheat Protein

Wheat protein percent was correlated with soil series (p = .05).
Wheat grown on Scobey plots averaged 14.4% protein and the average
of wheat grown on Kevin was 13.5%. Wheat protein values are shown
in Figure 6.

TABLE 2. SUMMARY OF SPRING SOIL ANALYSIS AND HARVESTED GRAIN DATA

Plot		Yield* kg/ha	Kernels/ Spike**	Stand Density m²*	Percent Protein**	Available Phosphorus, ppm*	NO₃-N kg/ha*	Extractable Potassium, ppm**	Organic Matter, %**	CaCO₃, %*	pH**
1	S	5468	22.3	407	15.5	113	382	750	3.4	0.74	6.8
	K	3398	20.6	274	15.1	29	118	310	1.7	2.13	7.8
2	S	6501	37.3	339	14.5	63	193	318	1.9	0.63	7.8
	K.	1863	23.4	129	14.1	25	39	282	0.9	5.80	8.1
3	S	3306	31.6	235	11.3	41	38	247	1.3	0.72	8.0
	K	1545	25.9	105	11.1	13	28	240	1.2	5.35	8.1
4	S	3840	22.0	292	17.2	51	121	255	1.5	0.61	8.1
	K	1377	19.8	120	15.3	14	45	216	1.0	5.08	8.3
5	S	6313	22.5	489	13.7	70	169	487	2.3	0.53	7.6
	K	1365	19.8	121	13.9	14	16	186	1.5	4.59	8.2
6	S	5009	23.7	366	15.5	57	140	454	2.0	0.70	8.0
	K	2315	20.7	131	13.4	21	61	247	1.3	4.39	8.3
7	S	2136	30.7	156	13.0	92	43	664	3.4	0.72	7.3
	K	546	14.3	59	11.0	18	30	318	1.5	3.52	8.1

S = Scobey
K = Kevin

*Significant at (p = .01) level

**Significant at (p = .05) level

Figure 3. Spring Wheat Yield on Paired Scobey (shaded) and Kevin (unshaded) Soils.

Number of Kernels per Spike

Figure 4.   Number of Kernels Per Spike in Scobey (shaded) and Kevin (unshaded) Soils.

STAND DENSITY

Figure 5. Stand Density in Paired Scobey (shaded) and Kevin (unshaded) Soils.

Figure 6.   Percent Protein of Spring Wheat in Paired Scobey (shaded)
and Kevin (unshaded) Soils.

Soil Analyses

The spring soil samples revealed distinct differences between Scobey and Kevin. Spring analyses are reported in the following section.

Fall soil analyses were similar to spring analyses, but were not statistically analyzed. Fall analyses are reported in Appendix III.

Available P

Available P was correlated with soil series (p = .01). Average available P in Scobey was 70 ppm and 19 ppm in Kevin plots. Available P values are shown in Figure 7.

Organic Matter

Organic matter percent was correlated with soil series (p = .05). The average organic matter percent was 2.3% in Scobey plots and Kevin plots averaged 1.3%. Organic matter values are shown in Figure 8.

$CaCO_3$

$CaCO_3$ was correlated with soil series (p = .01). Average $CaCO_3$ percent in the Ap horizon of Kevin plots was 4.40% and .66% in Scobey. $CaCO_3$ values are shown in Figure 9.

NO_3-N

NO_3-N was correlated with soil series (p = .01). Soil profiles

Figure 7. Available P in Paired Scobey (shaded) and Kevin (unshaded) Soils.

ORGANIC MATTER

Figure 8. Organic Matter Percent in Paired Scobey (shaded) and
Kevin (unshaded) Soils.

Figure 9. CaCO₃ Percent in Paired Scobey (shaded) and Kevin (unshaded) Soils.

in Scobey plots had an average of 169 kg/ha NO_3-N and Kevin plots averaged 48 kg/ha. NO_3-N values are reported in Figure 10.

Extractable K

Extractable K was correlated with soil series (p = .05). Scobey plots had an average of 454 ppm of extractable K and the Kevin average was 250 ppm. Extractable K values are shown in Figure 11.

pH

The pH of the Ap horizon was correlated with soil series (p = .05). Average pH of Kevin plots was 8.1 and Scobey plots averaged 7.8. The pH values are shown in Figure 12.

Water Utilization

Water utilization was defined as: total water in a 120cm profile at planting minus total water in a 120cm profile at harvest plus precipitation during the growing season. Results are tabulated in Tables 3 and 4 and shown in Figure 13.

Water utilization was not correlated with soil series. The Scobey plots used an average of 20.7cm and Kevin plots averaged 18.1cm.

Soil Temperature

Soil temperature data is reported in Appendix IV.

Nitrate Nitrogen

Figure 10. NO_3-N in Paired Scobey (shaded) and Kevin (unshaded) Soils.

Figure 11. Extractable K in Paired Scobey (shaded) and Kevin (unshaded) Soils.

pH

Figure 12. pH in Paired Scobey (shaded) and Kevin (unshaded) Soils.

TABLE 3. SUMMARY OF WATER UTILIZATION DATA

Plot		Initial H_2O in 120cm Profile	Rainfall cm	Fall H_2O in 120cm Profile	Water Utilization cm
1	S	19.8	13.04	4.44	28.4
	K	4.2	13.04	0.44	16.8
2	S	9.3	12.37	0.37	21.3
	K	6.9	12.37	0.87	18.4
3	S	6.1	12.37	0.47	18.0
	K	8.7	12.37	2.57	18.5
4	S	8.5	13.3	2.5	19.3
	K	11.0	13.3	4.0	20.3
5	S	10.6	13.3	2.7	21.2
	K	9.7	13.3	2.0	21.0
6	S	9.0	13.3	1.1	21.2
	K	8.2	13.3	3.4	18.1
7	S	6.8	13.3	4.8	15.3
	K	1.3	13.3	0.9	13.7

S = Scobey
K = Kevin

TABLE 4. PRECIPITATION DURING GROWING SEASON

Date Received	Amount Recorded, cm Site		
	1	2, 3	4, 5, 6, 7
June 3	.85	.70	.90
June 11	.11	.09	.14
June 25	.06	.08	.07
July 3	9.31	8.95	9.55
July 5	1.75	1.69	1.63
August 2	.96	.86	1.01
Total	13.05	12.37	13.30

Figure 13. Water Utilization by Paired Scobey (shaded) and Kevin (unshaded) Soils.

DISCUSSION

Wheat on Scobey plots always outyielded wheat on Kevin plots at the same site. This means that under identical management and macro-climate, these Scobey soils have a higher spring wheat yield performance than these Kevin soils. In examining the data from this study, there is little value in comparing yields and soil data between sites because there is no practical mechanism of holding management and climate constant.

Site 1

Site 1 was the most unusual site in the study. Wheat yields on the Scobey were within the standard deviation of other Scobeys, but wheat yields on the Kevin were one-third higher than the next highest yielding Kevin. Both Scobey and Kevin had high NO_3-N values relative to the rest of the sites. I cannot explain the unusually high NO_3-N soil test results. Water utilization was extremely high in 1S. This may have been due to the high NO3-N levels initiating a vigorous leaf system which increased transpiration demand.

Site 2

Scobey on site 2 had the highest yielding plot in this study. 2S had adequate NO_3-N and available P, so water probably became the limiting factor.

Site 3

Low soil fertility is largely responsible for site 3 yielding
less wheat than all but one other site. NO_3-N and available P were
lower in site 3 than any other site. In response to low NO_3-N levels,
grain protein was also the lowest in the study.

Sites 4, 5, 6

These sites were within one field. Even though management was
constant, yields and soil fertility varied greatly between repre-
sentatives of the same soil series. This variability is expected in
soils on glacial till. The churning effects of the glacier probably
caused this spacial variability. This variability is not great
enough to disqualify the soils from the Scobey or Kevin soil series,
but can have great effects on soil fertility and consequently grain
yield.

Site 7

This was the lowest yielding site in the study. The field con-
taining this site had been growing crested wheat grass for the
previous 15 years. The farmer had not summer fallowed the field and
consequently stored water was extremely low. Prior to planting, the
farmer plowed the field five times in order to prepare a seed bed.
This further depleted the soil water. Due to the low water status,
especially in the plow layer, stand density (a function of plant

population and tillering) was so low that the crop did not fully
utilize the July rainfall.

Water Utilization

Water utilization was defined as water in a 120cm profile at
planting minus water in the same profile at harvest, plus growing
season precipitation. However, Kevin occurs on erosional and Scobey
on depositional positions on undulating topography (0-4%). Therefore,
I assume that during the heavy rainfall on July 3, 1979 some water did
not infiltrate the Kevin plots and flowed onto the Scobey plots. There
was no obvious erosional indication of this occurrence, but based upon
interviews with farmers, the rain fell with great intensity.

Extractable K

K levels were correlated (p = .05) with soil series. The pro-
cedure used for extracting K (neutral, normal NH_4OAC extraction as
modified by the Montana State University Soil Testing Laboratory)
may not accurately indicate plant available K. Schaff (1979) demon-
strated that K soil test values are not correlated with winter wheat
yield response to K fertilization on Montana soils.

Differential Fertilization

The author has demonstrated contrasting soil performance for
spring yield on Scobey-Kevin complexes. A "soil complex consists of

two or more recognized taxonomic units that occur together in a
regular pattern and are so intimately associated geographically that
they cannot be separated by the boundaries at the scale used" (Soil
Survey Staff, 1951).

The Scobey-Kevin complex, as with others on glacial tills of
the Northern Great Plains, should be managed differentially. Farmers
have long recognized soil performance differences in their fields,
but have managed whole fields uniformly. An important management tool
could be "differential fertilization". Differential fertilization is
defined as fertilizing at varied rates, according to type of soil
within one field. Kevin soils can require up to 3.5 times as much
phosphorus as Scobey soils within a single field (Figure 14). When
these complexes are fertilized uniformly, fertilization rates are
too high for parts of the field and too low for others. Differ-
ential fertilization would put the fertilizer where it is needed.

A Canadian farmer was interviewed who operates a farm one mile
north of the sample area. His fields were on similar topography to
the Scobey-Kevin complex. He mentioned that prior to seeding, he
broadcast high rates of 0-46-0 on the erosional (Kevin-like) portions
of his fields and they now yield nearly as much wheat as the
depositional (Scobey-like) soils.

Although the Canadian got yield responses with additions of
broadcast P fertilizer, a more efficient response could be attained

Figure 14.   Recommended Fertilizer for Paired Scobey (shaded) and
Kevin (unshaded) Soils Based on the Montana Extension
Fertilizer Guide for Nonirrigated—Spring Wheat
(Christensen and Wilson, 1977).

with "band" applications. When P is placed in a narrow band with the
seed, lower rates are required than when broadcasting. Banding is
more efficient (Tisdale, S. L. and Nelson, W. L., 1966) because it
decreases the P-Ca contact zone which can minimize P fixation by Ca.
Cool soil temperatures early in the growing season (Russel, F. W.,
1973) also restricts uptake of P by roots. High P concentration in
bands near the seed minimizes the problem.

Equipment is not presently commercially available that will
differentially band fertilize. A farmer could modify the grain drills
to facilitate differential band fertilization for less than $1,000.

There are at least 500,000 acres in Montana where complexes,
similar to the Scobey-Kevin complex, are cultivated. Differential
fertilization would increase crop yields by at least three bushels.
If a bushel of wheat is worth $3.65, the returns from differential
fertilization in this state would be at least 5.5 million dollars
additional gross income

Collection System for Soil Yield Performance

The soil performance data collection technique discussed in this
thesis could be readily applied by the SCS and others. Scientists
employed for soil mapping or information dissemination could be shifted
to soil yield performance data collection during a week in the spring
and fall. Utilizing current personnel in this manner, data could be

-recorded without hiring additional staff.

When soil performance data has been collected on key soils for several cropping years, the entire state could benefit. The Extension Service could base fertilizer recommendations on soil test values and soil series. USDA crop harvest estimates and property tax assessments would be more accurate. Costs of urban sprawl into croplands could also be calculated more readily than is presently possible.

A soil yield performance collection technique is currently being investigated by the SCS and the Montana Cooperative Extension Service in Montana. With small modifications, youth groups such as 4-H and FFA in cooperation with the SCS and Montana Cooperative Extension Service could aid in collection of yield, climate and soil test data.

CONCLUSIONS

1. Soils within a single field can have highly contrasting wheat yield performances.

2. Soil fertility, not water, was apparently the most yield limiting factor on soils in this study.

3. Producers should investigate differential fertilization on the glacial till complexes of northcentral Montana.

5. Soil performance data can be collected both accurately and inexpensively on soils in Montana.

6. Measuring soil productivity on contrasting soils within a single field is a good method of comparing soils' yield performance because managment and macroclimate are held essentially constant.

APPENDICES

APPENDIX I

SOIL PERFORMANCE DATA SHEET FOR WHEAT PRODUCTION

Site: 1 Scobey and 1 Kevin

County: ___Blaine_____

Range & Township: ___R 26E, T 37N_____

Field Description: ___SE¼, Sec. 3_____

Manager

    Name ___Walter Fouts_____

    Address ___Turner, Montana_____

    Phone ___379-2641_____

Climate

*Initial water supply ___S = 19.8cm   K = 4.2cm_____

*Rainfall in growing season ___13.04cm_____

Estimated hail loss _____0_____

Estimated wind shatter loss ___0_____

Other climatic factors that may have contributed to or deleted from

your harvested yield ___During high intensity rainfall an unknown___

quantity of water may not have infiltrated profile on all K sites

and most S sites may have had additional run-on.

Cultural

Summer fallow - number times and implement(s) used in cultivation _5_

tool bar - duckfoot_____

Continuous cropping _____ Number of times and implement(s) used _____

_____

Condition of seedbed at planting: 1 = excellent   5 = poor <u>1</u> 2 3 4 5

Planting date ___May 21, 1979_____

Harvest date ___September 1, 1979_____

Seed variety ___Bounty 309_____

Was there good stand establishment? 1 = excellent   5 = poor <u>1</u> 2 3 4 5

How many years has this site been cropped? ___40_____

What is the cropping history for the previous 5 years? ___Fallow,_____

wheat, fallow, wheat, fallow_____

Estimate yield reduction due to:

    Weeds _____0_____ bu.

    Insects _____0_____ bu.

    Disease _____0_____ bu.

    Winter kill ____0_____ bu.

Fertility

    Attach soil test result, amount, kind, and method of fertilizer

application.

        No fertilizer applied

Soil test results are in Table 1.

SCIENTIST'S FIELD OBSERVATIONS

Soil identified at sampling site: S = Scobey   K = Kevin
(series or phase)

Soil identified by (name of soil scientist) __Brian Schweitzer__

Most recent soil map (title and year): __mapping complete, but not__

__published__

Soil map unit symbol (from the map): _____

Elevation: __2900 feet__

Slope (%): __0-4%__

        Kind: __S = 3   K = 1__
        (1=conves, 2=plane, 3=concave)

Surface drainage: __S = 1   K = 3__
(1=run-on exceeds run-off,
 2=neutral,
 3=run-off exceeds run-on,
 4=can not be evaluated)

Depth to mottles: __not in profile__

Erosion Control
     Practices applied: __2__
     (1=contour,
      2=strip crop,
      3=cover crop,
      4=no-till,
      5=min. till)

APPENDIX II

SERIES DESCRIPTION

Scobey Series

The Scobey series consists of deep, well drained soils that formed in glacial till. Scobey soils are nearly level to strongly rolling and are on glaciated plains. The mean annual precipitation is about 17 inches, and the mean annual air temperature is about 42°F.

Taxonomic Class: Fine, montmorillonitic Aridic Argiborolls.

Typical Pedon: Scobey clay loam, cultivated. (Colors are for dry soil unless otherwise noted.)

Ap--0 to 6 inches; grayish brown (10YR 5/2) clay loam, very dark grayish brown (10YR 3/2) moist; strong fine granular structure; hard, friable, sticky and plastic; many fine roots; many fine and medium pores; 10 percent pebbles; neutral (pH 6.5); clear wavy boundary. (6 to 8 inches thick)

B2t--6 to 12 inches; brown (10YR 5/3) light clay, dark brown (10YR 4/3) moist; peds coated dark grayish brown (10YR 4/2) and very dark grayish brown (10YR 3/2) moist; strong fine and medium prismatic structure that separates to strong fine subangular blocky; very hard, friable, sticky and plastic; many fine roots; many fine tubular pores; thick continuous clay films on peds and pebbles; 5 percent pebbles; neutral (pH 6.8); clear wavy boundary. (4 to 10 inches thick below Ap)

B3ca--12 to 19 inches; grayish brown (2.5Y 5/2) heavy clay loam, dark grayish brown (2.5Y 4/2) moist; strong medium prismatic structure that separates to moderate medium blocky; very hard, friable, sticky and plastic; many fine roots; many fine tubular pores; moderately thick discontinuous clay film on peds and pebbles; 5 percent pebbles; few soft masses of segregated lime and few lime-coated pebbles; strongly effervescent; mildly alkaline (pH 8.0); gradual wavy boundary. (2 to 12 inches thick)

C1ca--19 to 39 inches; light brownish gray (2.5Y 6/2) clay loam till, dark grayish brown (2.5Y 4/2) moist; weak coarse and very coarse prismatic structure that separates to weak angular blocky; very hard to extremely hard, firm, sticky and plastic; common fine roots; many fine pores; many soft masses and film of segregated lime; 10 percent pebbles; few shale and lignite chips and random distribution of few lime-coated pebbles; strongly effervescent; mildly alkaline (pH 8.3); gradual wavy boundary. (20 to 30 inches thick)

C2cs--39 to 80 inches; grayish brown (2.5Y 5/2) clay loam glacial till, dark grayish brown (2.5Y 4/2) moist; weak thick platy structure; extremely hard, firm, sticky and plastic; few roots, common fine pores; few lignite and shale chips and few pebbles; slight effervescents; mildly alkaline (pH 7.6 to 8.0).

Type Location: Blaine County, Montana; north of road, about 500 feet west and 100 feet north of SE corner of section 5, T 34N, R 24E.

Range in Characteristics: Rounded and subangular very hard pebbles, cobbles and stones comprising 2 to 15 percent by volume are randomly distributed through the soil. Fine and coarse sands comprise 20 to 40 percent of the less than 2mm soil fraction. Hues are 10YR or 2.5Y. The mean annual soil temperature ranges from 42 to 46 degrees F. The average summer soil temperature ranges from 60 to 64 degrees F. The mollic epipedon is 7 to 14 inches thick and includes all or part of the argillic horizon. Depth to the Ccs horizon is 30 inches or more. Some pedons lack a Ccs horizon.

The Ap horizon has chroma of 2 or 3. It is clay loam or loam and has less than 35 percent clay. An A1 horizon 2 or 3 inches thick occurs under native grass cover, and it has 18 to 25 percent clay. Main surface textures are loam or clay loam.

The B2t horizon has value of 4 or 5 dry, 2 or 3 moist and chroma of 2 through 4 crushed or rubbed. It averages about 40 percent clay and ranges from 36 to 45 percent. This horizon has moderate or strong prismatic or blocky structure. Some pedons have thin discontinuous silt coatings or skeletons on the faces of peds. Reaction is neutral or mildly alkaline.

The C horizon has value of 5 or 6 dry, 4 or 5 moist and chroma of 2 or 3. It is clay loam but has lenses of loam or sandy clay loam. Bulk density of the compacted till ranges from 1.6 to 1.8. This horizon is mildly to strongly alkaline.

Competing Series: These are the Acree, Ethridge, Holderness, Morop, Phillips, Tanna, and Ulric series. Acree soils have hue of 7.5YR or redder. Ethridge soils are on glacial meltwater deposits and have less than 5 percent gravel or stones. Holderness soils lack secondary calcium carbonate accumulations. Morop soils contain 15 to 30 percent stones and are formed on slopewash derived primarily from basalt. Phillips soils lack a mollic epipedon and have a thin A2 horizon. Tanna soils are underlain with bedrock at depths of 20 to 40 inches. Ulric soils lack compacted glacial till at depths of less than 40 inches.

Geographic Setting: Scobey soils are nearly level to strongly rolling and are on glaciated plains at elevations of 2,400 to 4,000 feet. They formed in calcareous clay loam, continental deposited glacial till with few rounded subangular hard rock pebbles, cobbles, and stones. The deposit is presumably of middle to early Wisconsin Age. The mean annual precipitation is 10 to 14 inches, 80 percent of which falls in spring and early summer. Mean annual temperature ranges from 40 to 45 degrees F. Mean January temperature ranges from 10 to 16 degrees F. The (32 degrees F.) growing season ranges from 100 to 135 days.

Geographically Associated Soils: These are the Acel Elloam, and Thoeny soils and the competing Ethridge and Phillips soils. Acel soils have hard and massive epipedons and a large increase in clay in the Bt horizon over that in the A horizon; also, they occur in swales

and depressions. Elloam and Thoeny soils have natric horizons.

Drainage and Permeability: Well drained; medium runoff; moderately slow permeability in the solum and slow in the underlying till.

Use and Vegetation: Used mainly for dryland farming of small grain. Some areas are used for range. The principal native grasses are western wheatgrass, needleandthread, bluebunch wheatgrass, blue grama, prairie junegrass, fringed sagewort, green needlegrass, Canby bluegrass, and forbs and shrubs.

Distribution and Extent: Scobey soils are extensive in the glaciated plains of northern Montana.

Series Established: Milk River Area, Montana, 1928.

National Cooperative Soil Survey

U. S. A.

Kevin Series

The Kevin series consists of deep, well drained soils that formed in glacial till. Kevin soils are on glaciated plains. The mean annual precipitation is about 12 inches and the mean annual air temperature is about 44°F.

Taxonomic Class: Fine-loamy, mixed Aridic Argiborolls.

Typical Pedon: Kevin clay loam, cultivated. (Colors are for dry soil unless otherwise noted.)

Ap--0 to 7 inches; grayish brown (10YR 5/2) clay loam, very dark grayish brown (10YR 3/2) moist; moderate fine gradular structure; hard, friable, sticky and plastic; many very fine roots; many fine pores; 5 percent pebbles; mildly alkaline (pH 7.6); abrupt smooth boundary. (4 to 8 inches thick)

B2t--7 to 9 inches; brown (10YR 5/3) heavy clay loam, dark brown (10YR 4/3) moist; moderate medium prismatic structure parting to moderate medium subangular blocky; very hard; friable, sticky and plastic; many very fine roots; many fine pores; moderately thick continuous grayish brown (10YR 5/2) and very dark grayish brown (10YR 3/2) moist clay films on faces of peds; 5 percent pebbles; slightly effervescent; mildly alkaline (pH 7.8); clear wavy boundary. (2 to 5 inches thick)

B3ca--9 to 19 inches; grayish brown (2.5Y 5/2) light clay loam, dark grayish brown (2.5Y 4/2) moist; moderate medium prismatic

structure parting to weak medium subangular blocky; very hard, friable; sticky and plastic; common very fine roots; many very fine pores; 5 percent pebbles with lime crusts on surface; many very fine masses of lime; strongly effervescent; moderately alkaline (pH 8.4); gradual smooth boundary. (12 to 20 inches thick)

C1ca--19 to 30 inches; grayish brown (2.5Y 5/2) light clay loam, dark grayish brown (2.5Y 4/2) moist; weak coarse prismatic structure; very hard, friable, sticky and plastic; common very fine roots; common very fine pores; 5 percent pebbles with lime crusts on surface; few lignite chips; common fine masses of lime; strongly effervescent; strongly alkaline (pH 8.6); gradual smooth boundary.

C2--30 to 44 inches; light brownish gray (2.5Y 6/2) light clay loam, dark grayish brown (2.5Y 4/2) moist; massive; very hard, friable, sticky and plastic; few roots; 5 percent pebbles; few fine masses of lime; strongly effervescent; strongly alkaline (pH 8.6); clear smooth boundary.

C3--44 to 60 inches; grayish brown (2.5Y 5/2) clay loam, dark grayish brown (2.5Y 4/2) moist; massive; very hard, firm, sticky and plastic; few roots; 5 percent pebbles; few fine lignite chips; few fine masses of lime and few fine seams of gypsum; strongly effervescent; moderately alkaline (pH 8.4).

Type Location: Cascade County, Montana; 1,400 feet north and 150 feet east of the SW corner of section 11, T 22N, R 4E.

Range in Characteristics: The depth to free lime is less than 10

inches and some cultivated pedons are calcareous to the surface. Depth

to the base of the argillic horizon is less than 10 inches. The

particle size control section is clay loam and has 27 to 35 percent

clay. Rock fragments average from 5 to 15 percent. The mean annual

soil temperature is 39° to 46°F. Hue ranges from 10YR to 5Y.

The A horizon has chroma of 2 or 3. It is clay loam, gravelly loam

or loam. This horizon is mildly or moderately alkaline.

The B2t horizon has chroma of 2 or 3. It has moderate or strong pris-

matic and blocky structure, and it is slightly or strongly efferves-

cent. The B3ca horizon has value of 5 or 6 dry, 4 or 5 moist, and

chroma of 2 or 3. It has weak to strong prismatic or blocky structure,

and has common or many soft nodules and threads of lime. This

horizon ranges from mildly through strongly alkaline.

The C horizon is mainly massive but some pedons have weak prismatic

or platy structure in the upper part. It is moderately or strongly

alkaline.

Competing Series: These are the Assinniboine, Bostwick, Cheeseman,

Duffson, Evanston, Jarre, Joplin, Marmarth, Morval, Notter, Perry-

park, Peyton, Telstad, Turret, and Villa Grove series. Assinniboine,

Bostwick, Cheeseman, Duffson, Evanston, Jarre, Marmarth, Morval,

Notter, Perrypark, Peyton, Telstad, Turret, and Villa Grove soils

are deeper than 10 inches to the base of the argillic horizon.

Joplin soils have 20 to 27 percent clay in the control section.

Geographic Setting: Kevin soils are nearly level to strongly rolling and are on glaciated plains at elevations of 2,200 to 4,000 feet. The soils formed in calcareous, clay loam, continental glacial till of an early or pre-Wisconsin glacial substage. The climate is cool, dry semiarid with long, cold, dry winters and moist springs and summers. Mean annual precipitation ranges from 10 to 14 inches, most of which falls during the spring and early summer. Mean annual temperature ranges from 40° to 49°F., mean January temperature from 8° to 20°F., and mean July temperature from 62° to 72°F. The (32°F.) growing season is 105 to 135 days.

Geographically Associated Soils: These are the Absher, Elloam, Hillon, Phillips, Scobey, Sunburst, and Thoeny soils. Absher, Elloam, and Thoeny soils have ochric epipedons and natric horizons. Hillon and Sunburst soils have ochric epipedons and no diagnostic subsurface horizons. Phillips soils have ochric epipedons. Scobey soils have the base of the argillic horizon at depths greater than 10 inches.

Drainage and Permeability: Well drained; slow to rapid runoff; moderately slow or slow permeability.

Use and Vegetation: These soils are used for nonirrigated cropland and the more strongly rolling morainic areas are used for range. The native vegetation is mainly western wheatgrass, needleandthread, green needlegrass, clubmoss, and fringed sagewort.

Distribution and Extent: Kevin soils are extensive and occur on the glaciated plains of northern Montana.

Series Established: Blaine County, Montana, 1969.

<div align="center">National Cooperative Soil Survey</div>

<div align="center">U. S. A.</div>

APPENDIX III

FALL SOIL TEST RESULTS

Site & Plot #	Total NO$_3$-N to depth of 120cm kg/ha	Available P ppm	Extractable K ppm	pH	Organic Matter %
1 S	158	87	767	6.6	2.9
1 K	33	48	398	7.8	1.5
2 S	162	85	803	7.6	2.6
2 K	15	30	209	8.0	.9
3 S	18	29	357	6.9	1.6
3 K	16	25	334	8.1	1.3
4 S	175	53	438	7.5	1.3
4 K	13	10	201	8.1	.8
5 S	67	67	570	7.3	2.0
5 K	76	12	193	8.0	.8
6 S	31	51	381	7.9	1.5
6 K	76	13	186	8.1	1.0
7 S	138	68	554	7.8	2.3
7 K	29	14	232	8.0	1.3

S = Scobey
K = Kevin

APPENDIX IV

SOIL TEMPERATURE AT DEPTH OF 50cm ON PLOT 1 S

Date Recorded 1979	Soil Temperature °C
May 25	9.4
June 3	10.0
June 11	13.3
June 18	13.3
June 25	16.7
July 4	17.2
July 5	17.2
July 17	17.8
August 2	20.6
August 14	20.0
August 19	19.4
August 24	18.9
September 1	17.2

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