The Impacts of Soil Degradation on Crop Yields

in the Canadian Prairies:

An Annotated Bibliography

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PREFACE

The Land Resource Division of the Centre for Land and Biological Resource Research conducts research on soil degradation, land use and land management practices in Canada. The Soil Quality Evaluation Project (SQEP) within the National Soil Conservation Program (NSCP), currently provides a focus for much of this research. The main objective of one of the SQEP sub-project was to collect information regarding the impacts of soil degradation on crop yields and to assess the completeness of this information.

The literature review and annotated bibliography contained in this report are the results of the first phase of information collection. The next phase of this soil degradation study involves gathering and interpreting expert opinions. The final step will integrate the literature review results and the expert opinions into a dynamic knowledge base.

This document is divided into three parts. The first part, the literature review, reports on significant findings of the annotated citations that examined the impact of soil degradation on crop yields that are relevant to the Canadian prairies. The results are divided by four degradation types: soil erosion (wind and water), compaction, salinization, and acidification. The annotated citations are found in the second part. These 85 citations were selected from 242 references based on their relevance to agricultural conditions in the Canadian prairies and are grouped by crop within degradation type. The final part of this report lists the 85 annotated citations and the remaining 157 references reviewed. Both lists are arranged by author rather than crop or degradation type.

PRÉFACE

La Division des terres du Centre de recherches sur les terres et les ressources biologiques mène actuellement des études sur la dégradation des sols, sur l'utilisation des terres et sur les pratiques de gestion des terres au Canada. Le gros de ces recherches se font dans le cadre du Projet d'évaluation de la qualité des sols (PEQS), qui s'inscrit dans le Programme national de conservation des sols (PNCS). L'un des sous-projets du PEQS vise principalement la cueillette de renseignements concernant, d'une part, l'incidence de la dégradation des sols sur les rendements culturaux et, d'autre part, l'évaluation de l'intégralité de cette information.

Avec le dépouillement de la documentation et la production de la bibliographie commentée que contient le présent rapport prend fin le premier stade de cueillette de l'information. La prochaine étape de l'étude sur la dégradation des sols consistera à recueillir et à interpréter les opinions des experts. Au dernier stade, l'information tirée des deux premiers sera intégrée en une base de données interactive.

Le présent rapport se divise en trois parties, dont la première (dépouillement de la documentation) porte sur les résultats d'intérêt pour les Prairies canadiennes, qui sont tirés des citations annotées ayant trait aux répercussions de la détérioration des sols sur les rendements culturaux. Les résultats sont ventilés selon quatre types de dégradation, soit : l'érosion des sols par le vent et par l'eau, la compaction, la salinisation et l'acidification. Les citations annotées (85) se trouvent dans la seconde partie; elles ont été choisies parmi 242 références en raison de leur pertinence à l'égard des conditions agricoles dans les Prairies canadiennes; elles sont regroupées par culture et par type de dégradation. Le dernier volet du rapport contient les 85 citations annotées et le reste des références dépouillées. Les deux répertoires sont présentés par auteur plutôt que par culture ou par type de détérioration des sols.

SOIL DEGRADATION LITERATURE REVIEW SUMMARY

Introduction

This Annotated Bibliography is the result of an extensive literature search. The scope of this search included all forms of degradation that may be present in the Prairie region of Canada. Studies done in the Midwestern United States were considered similar to the Prairies and thus included in the bibliography if no comparable Canadian study existed. All the major crops of the three Prairie provinces were to be represented in this review.

Generally, most citations dealt with the impacts of a single type of degradation on crop yields. A majority of the studies cited dealt with erosion (approximately 55%). The remaining studies focused mainly on compaction and soil salinity. There are 242 citations in the bibliography. Of these, 85 were annotated to include the following information:

1. Methods
2. Degradation
3. Crop
4. Soil
5. Land Management
6. Location
7. Impact
8. Results
9. Productivity Abstract, and
10. Key Words

The 85 annotated citations were divided into four degradation categories such that there were:

- 54 erosion (wind and water) studies (64%);
- 19 compaction studies (22%);
- 10 salinization studies (12%); and,
- 2 acidification studies (2%)

For the purpose of this summary, the citations were also assigned to one of several study types. These types include field studies, models, regression analysis, greenhouse experiments, and literature reviews and summaries. The field experiments were usually short term studies (3 to 5 years) whereas the models simulated degradation over the longer term (25 to 200 years). Regression analysis focused on the definition of a yield response curve, with some measurement of degradation as the regressor.

This summary describes the Annotated Bibliography by presenting some of the study highlights and identifying where further information may be helpful. Soil degradation, for the purpose of this review, was divided into four areas:

1. erosion, both wind and water;
2. compaction;

3. salinization; and,
4. acidification

Review Results

Erosion Studies
There were many studies that dealt with the effects of erosion on crop productivity. Over 60% of the citations annotated reported on erosion studies. A wide range of soils and climatic conditions were included. All crops and study types were represented in this degradation category. Table 1 summarizes a majority of these studies, with a particular focus on field studies and regression analysis that were crop specific.

Crops
The crop which was studied most often was corn. It was used to validate and/or calibrate the various models as well as in field studies. Wheat was the second most frequently studied crop. Other crops that were studied included soybeans, barley, oats, and canola (there was a single canola study).

Soil types
Almost all of the citations had fairly comprehensive soil descriptions. The following is a list of all the soils which were described in detail:

Ultic Agrixeroll*Typic UdorthentUltic Haploxeroll*
Typic Hapludalf*Udic Haploboroll*Typic Haplustoll
Typic ArgiustollTypic Fragiudalf*Xeric Argialboll
Aquollic Hapludalf*Typic Argiudalf*Typic Hapluboroll*
Typic Argiudoll*Typic OchraqualfTypic Haplorthent
Aquic HapludollCumulic HapludollTypic Hapludoll*
Typic ArgilborollAquic HapluborollAeric Ochraqualf*
Udic AgriborollAridic ArgiustollAquic Argiudoll*
Durixerollic Calciorthid

* soil was used in more than a single erosion study.

Geographic coverage
The location of the various studies were:

- U.S.: Minnesota,Iowa, Nebraska, Indiana, Illinois, Idaho (Palouse), Kansas, Missouri, South Dakota, North Dakota, Wisconsin, Colorado, Washington State (Palouse);
- Canada: Manitoba, Saskatchewan, Alberta; and,
- International: Sweden, Egypt, Nigeria, Soviet Union (formerly).

The international studies were included if the crop was of importance in the prairies or the study type was a greenhouse experiment.

Study types

Field studies were rarely longer than 5 growing season and in many cases, at least one year had climatic conditions that eclipsed the effects of erosion on crop yields. Erosion levels were simulated by adding topsoil, removing topsoil, and measuring the topsoil depth of various field locations. Yields from different erosion phases were compared using analysis of variance.

Corn and wheat both had significant yield reduction when 10-15 cm of topsoil was removed or added in many of the erosion field studies (Corn: 26,32 Wheat: 8,9,11,13,15,19). The yield response of soybeans to erosion was reported to increase significantly at all levels of topsoil depth (26). Corn and soybeans were both examined in this study. It was noted that corn yield increased only when 15 cm of topsoil was added while soybeans continued to increase when a further 15 cm was added. Oat yields were significantly increased when 20 cm of topsoil was added (32).

Regression analysis was used to determine the relationship between topsoil depth and crop productivity. The exact shape of the resulting yield response curve was dependent on soil and landscape characteristics. Generally, it is accepted that this relationship is best described by a Mitscherlich-Spillman function. Christensen and McElyea (1988) define four elements of agronomic response which should be included in the development of a yield response curve:

1. conform to the law of diminishing returns;
2. when topsoil depth is zero, some yield should still be possible;
3. there should be a finite maximum yield; and
4. topsoil depth in excess of the rooting zone should not decrease yields.

Response curves for several crops were developed using non-linear functions (Wheat: 4,5,6,17,22 Sweet corn: 5 Barley: 5). Equations were different for a single crop and this may have been due to the differences in soil series and landscapes from one study to the next. Two wheat yield response curves illustrate this:

1. $Y=-57.17 + 37.23 \ln x$ where x=topsoil depth
2. $Y=84+2808(1-0.634^{SD})(1-0.926^{SM})$ where, SD=topsoil depth and SM=soil moisture.

The first equation was developed from wheat yields in Idaho on a Durixerollic Calciorthid soil and the second was from wheat yields in Saskatchewan on a Brown soil. The locations of these two studies have different soils and landscapes (steeper slopes in Idaho).

The descriptions of several erosion-productivity models such as EPIC, NTRM, PI model and the Y-SLS were included in the literature. These models were developed in the United States to estimate the long term effects of erosion on crop productivity. The individual models have slightly different applications. EPIC was designed to assist in national crop productivity assessment and conservation planning. The NTRM model has a function similar to EPIC, but on a more local scale with an emphasis on conservation practises. The PI model specifically considers the effect of erosion on subsoil characteristics and how any changes may impact crop yields. The Y-SLS was one of the first models to be developed and it also estimates yield losses at the national (U.S) level.

Results of these models indicated that there would be an average loss of productivity over the entire cropland of the U.S. of approximately 8% over the next 100 years (24,44,47) if erosion continued at the 1977 rates. Certain portions of a landscape that have steeper slopes were estimated to have a much higher or total loss of productivity (35).

The PI model examined the productivity of a specific soil in specific locations. This index was validated, in most studies, with corn yields. Subsoil characteristics of each horizon within a soil profile were used to determine the index value rather than topsoil depth. The model is defined by this equation:

$PI = \sum (A_i \times C_i \times D_i \times WF)$ where,
A_i = available soil water capacity
C_i = bulk density
D_i = pH
WF = is a weighting factor which corresponds to the proportion of each horizon within the soil profile.

Soil profiles with favourable subsoils have a higher soil loss tolerance (36,47,48). The productivity of specific soil series in Minnesota were compared by Pierce et al. in 1984. The Monona silt loam has both a favourable surface and subsoil with an erosion rate of 33.9 t/ac. The estimated PI reduction was only 3% over 100 years. Kenyon loam (Typic Hapludoll) soil has a favourable surface but an un-favourable subsoil. The initial PI for this soil series was lower than the Monona soil at .92. After 100 years of erosion at a rate of 7.6 t/ac per year there was a 4% reduction in PI. The last soil series, Rockton loam, has a favourable surface but has a consolidated or coarsely fragmented subsoil. This soil has an initial PI of .76 and after 100 years of erosion (11.1 t/ac per year) had a 17% reduction in PI. These results prompted a further investigation of soil loss tolerances (43,47). It was obvious that some soils could accommodate a much higher rate of erosion than other soils. Subsoil characteristics were used as the basis to determining a soil's vulnerability to productivity losses.

A Canadian model that is being developed by Greer et al. (10) estimates yield losses over a 30 year period that has a constant rate of soil erosion (130 T/ha). The yield losses are attributed to the reduction in soil organic matter content and available nitrogen that occurs as topsoil is removed. This model differs from models such as EPIC in that it assumes a fairly high erosion rate over a much shorter time span. The initial results of have shown that yields begin a rapid decline when approximately 10 cm of topsoil is lost. Yields are reduced to zero when erosion reduces the topsoil depth to zero. The non-linear relationship between topsoil depth and yield estimated by this model is consistant with several regression and field studies.

The last study type was the group of citations that were literature reviews or research summaries (1,3,24,27,43,29,30,31,45,46,50,52). Each review concluded with suggestions for future research. The most recent review was completed in 1991 by F. J. Pierce (46). The past 50 years of erosion research were summarized into the following observations:

1. Yields from field studies were lower relative to actual production values;
2. Restoration of yields by increased use of fertilizer is dependent on subsoil properties;

3. There were many studies where yields were related linearly to topsoil depth;
4. There is no method to determine if productivity losses are permanent;
5. Uneroded sites are becoming harder to find;
6. Some effects of erosion have yet to be studied;
7. Technology can mask the gradual productivity losses over the long term and make it difficult to detect the yield decreases immediately; and
8. Spatial relationships and soil variability within a landscape have generally been ignored.

Table 1. Summary of erosion studies

Crop	**Soil**	**Date**	**Study Type***	**Location**	**Impact**	**Authors**
Corn	Typic Ochraqualf	1984	F	Missouri	Significant yield increases at the 12.5 cm topsoil depth-62% greater than no topsoil.	Gantzer, McCarty
Corn	Typic & Aquic Hapludoll	1985	F	Iowa	Significant yield increases when 15cm top soil was added.	Henning, Khalaf
Corn	Aquic Argiudolls Typic Hapludolls Typic Udorthents	1982	R	Midwest U.S.A	As topsoil was removed: Deep medium textured soils- 8-30% yield reductions. Shallow medium to coarse textured soils- 36-44% yield reduction.	Langdale, Shrader
Corn	Mollisols Alfisols Ultisols	1985	M	Cropland U.S.A.	Marshall soils: yields from severely eroded soils- 8% less than soils slightly eroded. Seymore soils: yields from severely eroded soils- 17% less than soils slightly eroded.	Larson, Fenton, Skidmore, Benbrook
Corn	Alfisols Ultisols Vertisols Mollisols	1985	M	North Central U.S.A.	Initially: 77% of soils had PI>=.6 25cm topsoil removed: 70% of soils had PI>=.6 50cm topsoil removed: 59% of soils had PI>=.6	Larson, Pierce, Dowdy
Corn		1975	M,F	Kansas Ohio Iowa Wash. Oregon	Average yield reduction per inch of topsoil lost: 6.3%. Erosion is due to wind.	Lyles
Corn	Typic Ustorthent Udic Haplustoll		F	Nebraska	100 and 200mm of soil added significantly increased yield.	Mielke, Schepers
Corn	Typic Hapludalf Aquic	1985	R	Iowa Ohio Indiana	Iowa: severely eroded yields 80-88% of base yields (slightly eroded). Ohio:severely eroded yields 77-88%	Mannering, Franzmeier, Shertz,

Crop	Soil	Date	Study Type*	Location	Impact	Authors
	Hapludoll			Illinois	of base yields. Indiana: severely eroded yields 72-92% of base yields. Illinois: severely eroded yields 74-85% of base yields.	Moldenhauer , Norton
Corn	Aquic Argiudolls Typic Fragiudalf Aquollic Hapludalf Typic Hapludalf Typic Argiudalf	1990	F	Illinois	Root restricted soils: Clarence-35% reduction in yield on severely eroded soil. Grantsburg-21% reduction in yield . Hoyleton-16% reduction in yield. No restrictive subsoil: Rozetta-5% reduction in yield. Tama-8% increase in yield.	Olson, Carmer
Corn	Typic Fragiudalf Aquic Argiudoll Aquollic Hapludalf Typic Argiudoll Typic Hapludalf	1988	F	Illinois	Root restricting subsoils that had severely eroded surfaces had yields 24% less than moderately eroded surfaces.	Olson, Nizeyimana
Corn	Miami silt loam	1985	M	Illinois	Convex landforms is the most vulnerable to productivity losses When deposition increases yield: after 200 yrs-78% of initial productivity. When deposition does not increase yield: after 200 yrs-67% of initial productivity.	Perrons, Foster, Beasley
Corn	Soils of the Corn Belt	1984	M	Corn Belt, USA	8% decrease in PI over 100 yrs of erosion. Changes in PI are variable throughout the region depending on the vulnerability index.	Pierce, Dowdy, Larson, Graham
Corn	Typic Hapludalf Typic Argiudoll	1985	M NTRM	Minn. Iowa Wis.	Fayette soil: lowest yield reduction due to erosion. Dubuque soil: only recovered productivity with intensive management inputs. Dakota soils: best yield recovery when irrigated.	Shaffer
Corn	Typic	1982	RA	Iowa	Technological advances mask the	Spomer,

Crop	Soil	Date	Study Type*	Location	Impact	Authors
	Hapludolls Typic Haplorthent Cumulic Hapludoll				effects of erosion over the long term. Yields were from 1930-1980.	Piest
Corn	Typic Hapludalfs	1987	RA	Wisconsin	Erosion - yield response function was defined as linear with 1983 yields having the greatest decline due to decreased topsoil depth. % differences in yields: 1981- no difference 1982- 2 1983- 34 1984- 11 1985- 14	Swan, Shaffer, Paulson, Peterson
Corn to calibrate and validate	Aeric Ochraqualf	1986	RA,M	New York	The erosion-yield response relationship was non-linear. Matoon soil - immediate response to soil erosion. Niagara soil - yields began to decline when soil depth was less than 70cm. The limiting factor in this model was soil moisture.	Timlin, Bryant, Snyder, Wagenet
Corn	Miami silt loam	1985	M EPIC	Indiana	The EPI ratio is explained. It is the yield with erosion divided by the yield without erosion. Over 100 years of erosion this ratio decreases. This decrease occurs rapidly in the beginning and then slows as most of the topsoil is eroded away.	Williams, Putman, Dyke
Wheat	Ultic Argrixeroll Ultic Haploxeroll	1985	F	Palouse region Idaho	Yield increases as topsoil depth increases. This relationship was linear in 1981 and non-linear in 1983.	Bramble-Brodahl, Fosberg, Walker, Falen
Wheat	Ultic Haploxeroll Ultic Agrixeroll Xeric Argiaboll	1985	RA	Wash. State	Response function was assumed to be a Mitscherlich-Spillman function. 30cm topsoil yields compared to 0cm topsoil yields: Palouse - 28-34% increase Thatuna - 46-50% increase Naff - 21-27% increase	Busacca, McCool, Papendick, Young
Wheat	Durixerollic Calciorthid	1985	F,RA	Idaho	The wheat response curve was defined by the following equation: $Y = -57.17 + 37.23 \ln x$, where x is the topsoil depth. Maximum yields were obtained when topsoil depth was 65cm.	Carter, Berg, Sanders

Crop	Soil	Date	Study Type*	Location	Impact	Authors
Wheat	Brown Soil	1988	R,RA	Sask.	Topsoil depth-yield response function was of the Mitscherlich-Spillman form: $Y= 84+2808(1-0.634^{SD})(1-0.926^{SM})$ where SD=soil depth SM=soil moisture Yield decreases began when there was less than 8 inches (20cm) of topsoil. Yield data was obtained from the Innovative Acres Program.	De Jong
Wheat	Typic Hapluboroll	1988	F	Alberta	In the non-fertilized plots, there were significantly lower yields when 46 cm of topsoil was removed.	Dormaar, Lindwall, Kozub
Wheat	Dark Brown Chernozem (Typic Hapluboroll)	1986	F	Alberta	Yield were significantly reduced when 46cm of topsoil was removed: undisturbed plot: 1790 kg/ha 46cm+ cut plot : 736 kg/ha These yields were from unfertilized plots. Maximum yields for all fertilizer treatments were obtained in the plots where 8-10cm of topsoil was added.	Dormaar, Lindwall, Kozub
Wheat	Palouse soils	1982	RA	Washington State	Historical yield records were analyzed and it was determined that technological advances increased yields by 1446 kg/ha. Adjusted yield increases (yield increase due to technology + yield decrease due to erosion) were calculated. On average there would be 720 kg/ha increase. Land classes IV and VI experienced yield losses even with the technological increases.	Krauss, Allmaras
Wheat	1. Aquic Haploboroll 2. Udic Haploboroll 3. Udic Agriboroll	1987	F	Manitoba	Not all yield reductions were significant as topsoil was removed, however there was always a downward trend. Year Soil Topsoil removed % reduction in yield 83 1 10cm 13 2 10cm 26 1 20cm 64 2 20cm 41 84 1 10cm 32 2 10cm 19 3 10cm 4 1 20cm 53	Ives, Skayhewich

Crop	Soil	Date	Study Type*	Location	Impact	Authors
					x 2 20cm 19 3 20cm 50 Soil 2, the Newdale series, was least affected by topsoil removal.	
Wheat	Aquic Argiudoll Typic Hapludoll Typic Udorthent	1982	R	Midwest U.S.A	Yield losses due to topsoil removal: Deep medium textured soils 11-24% Shallow medium to coarse textured soils 22-34%.	Langdale, Shrader
Wheat	Brown and Dark Brown Chernozemic	1991	F	Alberta	There is a quadratic relationship between topsoil losses and yield reductions on plots which simulate wind erosion.	Larney, Janzen, Olson, Lindwall
Wheat		1975	M,F	Kansas Ohio Iowa Wash. Oregon	Average yield reduction per inch of topsoil lost: 5.3%. Erosion is due to wind.	Lyles
Wheat	Haploxeroll Torriorthent	1985	F	Idaho	Yields increased when 15cm of topsoil was added and decreased when 15 cm was removed. Soil T/ment Nitrogen added Yield response +15cm 0 kg/ha +68% +15cm 34 kg/ha +45% +15cm 68 kg/ha +34% -15cm 0 kg/ha -46% -15cm 34 kg/ha -22% -15cm 68 kg/ha -13% -30cm 0 kg/ha -61% -30cm 34 kg/ha -27% -30cm 68 kg/ha -21%	Massee, Waggoner
Wheat	Dark Brown and Black Chernozemic	1986	M	Alberta 4 regions: Southern Red Deer Barrhead Vermillion	Yields were significantly lower on the severely eroded soils compared to the slightly eroded soil: Region Yield Cropping reduction practice Southern 21% Red Deer 37% fallow Red Deer 22% stubble Barrhead 37% fallow Barrhead 37% stubble Vermillion 37% fallow Vermillion 37% stubble The solonetzic soil zone had the highest yield losses when 50% of	Narayanan

Crop	Soil	Date	Study Type*	Location	Impact	Authors
					the topsoil is eroded (yields were estimated to be only 40% of the uneroded soils).	
Wheat	no soils specified	1986	R	Alberta Sask. Manitoba	Over the long term yield losses would be: Alberta - 50% reduction Saskatchewan - 70 kg/ha/cm of soil eroded Manitoba - 10% reduction due to wind erosion, 25% reduction due to moderate water erosion, 50% reduction due severe water erosion.	Rennie
Wheat	Typic Argilboroll	1989	F	Montana	Three amounts of topsoil were removed resulting in yield reductions of: Topsoil removed / Yield reduction % 0.06m 7 0.12m 39 0.18m 44	Tanaka, Aase
Wheat	Dark Brown soil	1989	M,RA	Sask.	Critical topsoil depth was determined to be 12.5cm. At the time of this study only 17% of cropland has less than 12.5cm of topsoil. In 35 years, it was estimated that this would increase to 25% of cropland. When topsoil depth is 5-10cm there was a marginal loss of 24.1 kg/ha per cm of soil eroded. In 35 years the amount of cropland in the 5-10cm category was estimated to increase from 6.2 to 8.2%.	Van Kooten, Weisensel, De Jong
Wheat	Dark Brown soil	1990	F	Sask.	45-58% increase in yield when 50 mm of topsoil was added to an eroded upper slope. Adding 100 and 200mm of topsoil did not result in yields significantly higher than when 50mm of topsoil was added.	Verity, Anderson
Wheat	Palouse soils	1985	RA	Wash. State	Yield response functions developed from historical yields were compared. Two time spans were examined, 1952-53 and 1970-75. The slopes of these curves were significantly different indicating the multiplicative effect of technology	Young, Taylor, Papendick

Crop	Soil	Date	Study Type*	Location	Impact	Authors
					on yields.	
Soy Beans	Typic & Aquic Hapludoll	1985	F	Iowa	Significant yield increases when both 15 and 30cm of top soil was added.	Henning, Khalaf
Soy Beans	Aquic Argiudoll Typic Hapludoll Typic Udorthent	1982	R	Midwest U.S.A	Yield losses due to topsoil removal: Deep medium textured soils 20-40%. Shallow medium to coarse textured soils 22-47%.	Langdale, Shrader
Soy Beans	Typic Argiudoll Typic Hapludalf	1989	F	Indiana	Severe erosion can reduce yields by 24%. Climate stress increases this effect. Not all yields were significantly reduced by erosion but the trend in yield was consistently downward.	Schertz, Moldenhauer, Livingstone, Weesies, Hintz
Barley	Durixerollic Calciorthid	1985	F,RA	Idaho	The barley response curve was defined by the following equation: $Y= - 2.90 + 23.59 \ln x$, where x is the topsoil depth. Maximum yields were obtained when topsoil depth was 65cm.	Carter, Berg, Sanders
Barley	Dark Brown and Black Chernozemic	1986	M	Alberta 4 regions: Southern Red Deer Barrhead Vermillion	Yields were significantly lower on the severely eroded soils compared to the slightly eroded soil: Region — Yield reduction Southern — 34% Red Deer — 37% Barrhead — 37% Vermillion — 37% The solonetzic soil zone had the highest yield losses when 50% of the topsoil is eroded (yields were estimated to be only 40% of the uneroded soils).	Narayanan
Oats	Typic Ustorthent Udic Haplustoll		F	Nebraska	Adding 200mm of topsoil significantly increased yield.	Mielke, Schepers
Canola	Dark Brown and Black	1986	M	Alberta 3 regions: Red Deer	Yields were significantly lower on the severely eroded soils compared to the slightly eroded soil:	Narayanan

Crop	Soil	Date	Study Type*	Location	Impact	Authors
	Chernozemic			Barrhead Vermillion	Region Yield reduction Red Deer 11% Barrhead 43% Vermillion 43% The solonetzic soil zone had the highest yield losses when 50% of the topsoil is eroded (yields were estimated to be only 40% of the uneroded soils).	

*Study types:F=field study, M=model, R=literature review and summary, RA=regression analysis, GH=greenhouse experiment

Compaction studies

This was the second most common type of degradation in the annotated bibliography. None of these studies were done in the Canadian prairies. The northern Corn belt was considered to be fairly similar to the Canadian prairies.

Crops
Again, the main crop was corn. Unlike erosion, soybeans (rather than wheat) were the second most important crop in compaction studies. Wheat, oat, and barley yields were also studied.

Soil types
The soil types identified in the compaction studies included:

Typic Haplustoll	Typic Argiaboll	Typic Hapluquoll
Typic Argiaquoll	Typic Hapludalf*	Typic Haplaquoll*
Udic Haplustoll	Udic Argiboroll	Aridic Argiustoll
Aquollic Hapludalf	Aquic Hapludoll	

* soil was used in more than a single compaction study.

Geographic coverage
Almost all citations were from the U.S. Corn Belt region, with the exception of a few international studies. The U.S. locations included Nebraska, Minnesota, Iowa, Ohio, Wisconsin, North Dakota, and Illinois. The international studies were from Morocco, Sweden and the Soviet Union.

Study types
Almost all compaction studies were field trials that took place over 2 to 5 growing seasons. Table 2 summarizes the field studies and the greenhouse experiments. Varying amounts of tractor traffic were used to simulate compaction levels. Bulk density and penetrometer readings were used as measurements of soil compaction. Very few field studies distinguished between surface and subsoil

compaction (71). Subsoil compaction was said to occur when axle weights were greater than 5 ton/axle (68,71). A recent study by Voorhees et al., 1989, identified a difference between corn yield responses to surface and subsoil compaction. Annual surface compaction over 5 years had no significant negative effect and was very dependent on soil moisture conditions. Subsoil compaction was applied only at the beginning of the 5 year period. Yield reductions persisted into the third year after the subsoil compaction.

Many of the field studies noted a difference in yield response to compaction depending on the amount of precipitation during the growing season (55,56,60,61,62,67,69,71). Soybean yields from a compacted plot were 15% higher than yields from a non-compacted plot in a dry year (Lindemann et al., 1982) whereas yields were reduced by 6% due to compaction in a wet year.

There were two greenhouse studies (57,70) that applied weights to potted soil to create gradients of compaction. Bulk density was used as the measure of compaction. Both these studies used different crops (wheat and soybeans) as productivity indicators. Soybeans had significant yield reductions when the soil bulk density was greater than 1.4 g/cm^3.

The use of models in compaction studies was very rare. Only one study attempted to mathematically define the effect of compaction on yield. A bell shaped, Gaussian curve was proposed to represent yield response to different levels of compaction (Matsepuro,1982). Soil moisture was used as one of the key soil characteristics to develop this model.

Several reviews of compaction research have been completed but only one is included in this annotated bibliography (Giles, 1983). This review refers to a soybean field study which compares track and non-track yields. Compaction studies have been limited to very few crops grown on a small number of soils.

Future research in compaction should include a thorough investigation of soil-climate interaction over a broader range of soil series and crops. Results from models or longer field trials (10+ years) are needed to define the impact of compaction on crop yields.

Table 2. Summary of compaction studies

Crop	Soil	Date	Study Type*	Location	Impact	Authors
Corn	Typic Haplustoll	1985	F	Nebraska	Severely compacted yields were 62% lower than slightly compacted yields.	Anderson, Peterson
Corn	Nicolett Webster	1985	F	Minnesota	Root density was lower in trafficked rows than in the seedbed rows.	Bauder, Randall, Schuler
Corn	Sharpsburg Fillmore	1983	F	Nebraska	Periodic use of the moldboard plow can result in statistically higher yields as compared to continuous no-till. A relationship between cone penetrometer index and yield indicates a trend toward lower yield with higher index values with continuous no-till having the	Dickey, Peterson, Gilley, Mielke

Crop	Soil	Date	Study Type*	Location	Impact	Authors
					highest index.	
Corn	Typic Argiabolls	1987	F	Nebraska	In 1985, the compacted plots had yields that were 61% less than the usual field condition yields. In 1986, there were no differences between yields. Subsoiling the compacted plots contributed to yield recovery but not in the first year.	Dolesh, Jasa, Dickey
Corn	Typic Hapluquoll	1986	F	Iowa	Wheel tracks caused an average yield reduction of 11%.	Erbach, Melvin, Cruse, Janzen
Corn	Typic Argiaquoll	1984	F	Ohio	Tracked plot yields were 11% lower than non-tracked plots.	Fausey, Oylla
Corn	Typic Hapludalf	1986	F	Wisconsin	Compaction occurred in 1983. The first soil (Rozetta) had yield reduction of 14 and 9% in 1983 and 1984, respectively.	Schuler, Lowery
Corn	Typic Haplaquoll Udic Haplustoll	1989	F	Minnesota	Webster soil - there was a 30% yield reduction in the first year after subsoil compaction and recovery to non-compacted yield levels in the next year. Ves soils had no significant yield reductions. Surface compaction applied annually had no significant negative effect. The effect of compaction on yields depends on the available soil moisture.	Voorhees, Johnson, Randall, Nelson
Corn	not specified	1986	F	Iowa	No-till plots had higher yields than the tillage plots. Traffic on both sided of crop rows had an undesirable effect on yield.	Sial, Marley, Erbach
Wheat	Udic Argiboroll	1985	F	Minnesota	The grain yield was 27 % lower in the wheel tracked soil compared to the non wheel tracked soil in 1975. In drier conditions, the wheel tracked yields were increased by 53%. In 1977 the wheel tracked yields were only 8% less than the non-tracked yields.	Voorhees, Evans, Warnes
Wheat	Aridic Argiustoll	1988	GH	Nebraska	High soil densities significantly reduced above ground growth.	Wilhelm, Mielke
Soy Beans	Bearden silty loam	1983	F	North Dakota	Yields from the wheel track were 50 % less than yields from the non-track area of the field. Since the wheel tracks only cover 11% of the field, the whole plot yield would be 5% less than a field	Giles

Crop	Soil	Date	Study Type*	Location	Impact	Authors
					without wheel tracks.	
Soy Beans	Typic Haplaquoll	1986	F	Illinois	Corsoy variety: yield from compacted plots were reduced 27% in 1983 and 49% in 1984. Corsoy 79 variety: yield from compacted plots were reduced 4% in 1983 (not significant) and 25% in 1984.	Gray, Pope
Soy Beans	Typic Haplaquoll	1982	F	Minnesota	The greatest mean yield was obtained in the non-compacted soil (4117 kg/ha). Yields decreased as compaction increased in wet years. In dry years, yields increased with increases levels of compaction.	Lindemann, Ham, Randall
Soy Beans	Aquollic Hapludalf Typic Hapludalf	1982	GH	Illinois	In all instances, yields of plants grown in soil compacted to 1.4 g/cm^3 out-yielded plants grown in soils compacted to approximately 1.6 g/cm^3. Yields were 37% less in the pots that were severely compacted compared to the pots with no compaction and 27% less than the moderately compacted yields. Moderately compacted yields were 14% less than the no compaction yields.	Stuckey, Lindsey
Soy Beans	Aquic Hapludoll Typic Hapaquoll	1986	F	Iowa	There were significant reduction in whole plot yield due to tractor traffic in both 1980 and 1981 for 2 of the 3 cultivars compared to the control plot. The third cultivar had a significant reduction in yield only for the traffic treatment that occurred in the last stage of development averaged over the two years.	Wilkens, Whigham
Barley	Sod Podzolic Ordinary Chernozem Chestnut	1982	F	Russia	Grain yields were significantly reduced when bulk density was greater than 1.40 g/cm^3 in the Sod-Podzolic soil. The ordinary Chernozem was much more sensitive to compaction in that yields were reduced when bulk density was only 1.11 g/cm^3. The irrigated Chestnut soil yields were significantly reduced when bulk density was 1.30 g/cm^3.	Sheptukhov, Voronin, Shipilov

*Study types: F=field study, M=model, R=literature review and summary, RA=regression analysis, GH=greenhouse experiment

Salinization and Acidification studies

There are 10 salinization and 2 acidification studies included in the annotated bibliography. Salt tolerances were determined almost exclusively for different small grains (wheat,barley,oats). Field studies were the dominant form of research. No reviews of these types of degradation were annotated. Table 3 summarizes the studies from both these types of degradation.

Crops

Barley and wheat were the two main crops studied in the salinization research. Other crops included oats, rye and canola. Both acidification studies involved wheat growth or yields.

Soil types

The soils of the Canadian prairies were well represented in the salinization studies including:

Dark Brown (Carmangay)
Black Chernozemic
Orthic Brown Chernozemic
Holtville silty clay
Brown Solonetzic
Dark Gray Chernozemic
Lacustrine clay or clay loam

Only one soil series, Typic Hapludult, was examined in the acidification studies.

Geographic coverage

Most of the salinization studies that were annotated were located in either Alberta or Saskatchewan. A California field study and an Egyptian greenhouse experiment were the only non-Canadian studies annotated. Acidification studies were done in Virginia (greenhouse experiment) and Georgia (field study).

Study types

The field studies revealed that barley, particularly 6-row cultivars, had the highest salt tolerance of all the small grains being studied (74,83). Saline levels were determined by the percent salt in dried soil or electrical conductivity of soil samples (dS/m,mS/cm). Increasing saline levels generally decreased wheat yields. Fowler and Hamm (1980) found that wheat yields decreased 11.5% per unit increase of salt. Rye and canola had similar reactions to increased saline levels. Barley and oat yields decreased 6.7 and 7.9%, respectively per unit increase of salt. In another study (McKenzie, Sprout and Clark, 1983), barley yields were reduced 8.8% per unit increase of saline paste.

Only one study (Johnson and Ohki, 1984) described the impact of increased acidity of soils on crop yields. Wheat yields from soils with high pH values (6.1) were 44% higher than wheat yields from soils with low pH values (5.2).

Table 3. Salinization and acidification studies

Crop[1]	Soil	Date	Study Type[2]	Location	Impact	Authors
Wheat (S)	Dark Brown Carmangay	1979	F	Alberta	Wheat grown on saline soil had yields that were 41 % of the same wheat grown on non-saline soils.	Bole, Wells
Wheat (S)	Brown Solonetzic	1986	F	Alberta	The yields from the irrigated fields were generally higher and less variable than the yields from the non-irrigated fields. The levels of salinity were lower in the irrigated fields.	Chang, Sommerfeldt, Schaalje, Palmer
Wheat (S)	Black and Dark Gray Chernozem	1980	F	Sask.	Winter wheat had yield decreases of approximately 11.5 % per unit increase of salt.	Fowler, Hamm
Wheat (S)	Sand cultures	1986	GH		Grain yields were decreased the most when salinity was increased during the vegetative stage of growth. Probred variety - 70% yield reduction. Aldura Variety - 77% yield reduction.	Maas, Poss
Wheat (S)	no soil type	1985	GH	Egypt	There was an initial increase in dry matter yield at the first level of salinity and a decline in yields at all the higher salinity levels. This was the case for all moisture contents. Moisture Yield treatmentreduction 1 55% 2 90% 3 37% Yield reduction were determined by comparing the yields from the S1 and S3 salinity treatments (0.3% vs 0.9% saline).	Rabie, Matter, El-Maksoud, Khamis, Mostafa
Barley (S)	Dark Brown Carmangay	1979	F	Alberta	Six row barley was the least effected by the increased salinity of the soil. The yield from the saline soil was 62% of the yield from the non-saline soil. The mean yield of 2-row barley was only 40% of the yield obtained from non-saline soils.	Bole, Wells
Barley (S)	Black and Dark Gray Chernozem	1980	F	Sask.	Barley had the lowest yield decreases per unit increase of salt (6.7%) compared to the other crops in this study.	Fowler, Hamm
Barley (S)	Orthic Brown Chernozem	1988	F	Alberta	Barley yields decrease as salinity increases.	Janzen
Barley	Solonetzic	1987	GH	Alberta	Yields declined significantly when the	Janzen,

Crop[1]	Soil	Date	Study Type[2]	Location	Impact	Authors
(S)					electrical conductivity of the soil was 6 dS/M (saline level). Yields were reduced by 50% when the saline level was approximately 11.7 dS/M.	Chang
Barley (S)	Lacustrine clay or clay loam	1983	F	Alberta	There was an 8.8% decrease in yield per unit increase of saline paste. The flood irrigated barley yields were affected more by increased levels of soil salinity than were the yields from the centre pivot irrigation.	McKenzie, Sprout, Clark
Barley (S)	Dark Brown and Black soil	1983	F,RA	Sask.	Yield increases due to fertilizer N were reduced rapidly as soil salinity levels increased. Rosthern barley yields were used in regression analysis to determine the following values for two different fertilizer treatments (N and N-P): Maximum yield - N 2200 kg/ha - N-P 3012 kg/ha Zero salinity yield - N 2756 kg/ha - N-P 5439 kg/ha Yield decrease per unit increase salinity - N 197.7 kg/ha - N-P 436.6 kg/ha % yield decrease/unit increase salinity - N 9.0% - N-P 14.5% Salinity at maximum yield - N 2.8 mS/cm - N-P 5.6 mS/cm Salinity at zero yield - N 13.9 mS/cm - N-P 12.5 mS/cm Salinity at 50% maximum yield - N 8.4 mS/cm - N-P 9.0 mS/cm	Peters
Oats (S)	Dark Brown Carmangay	1979	F	Alberta	Oat yields on saline soils were only 25% of the oat yields from non-saline soils.	Bole, Wells
Oats (S)	Black and Dark Gray Chernozem	1980	F	Sask.	Oats had the second lowest yield decrease per unit increase of salt (7.9%) compared to the other crops in this study.	Fowler, Hamm
Rye (S)	Black and Dark Gray Chernozem	1980	F	Sask.	Spring rye had yields decreases of approximately 11.5 % per unit increase of salt	Fowler, Hamm

Crop[1]	Soil	Date	Study Type[2]	Location	Impact	Authors
Rye (S)	Holtville silty clay	1989	F	California	When the salinity level was equal to or greater than 11.4 dS/M, yields decreased 10.8% per unit increase of salinity. Temperature seemed to effect the crop response to salinity in that there were higher salt tolerances when there were cooler temperatures.	Francois, Donovan, Lorenz, Maas
Canola (S)	Black and Dark Gray Chernozem	1980	F	Sask.	Rapeseed (canola) had yields decreases of approximately 11.5 % per unit increase of salt.	Fowler, Hamm
Wheat (A)	Typic Hapludult	1987	GH	Virginia	As the pH was increased, the top dry weight of both cultivars also increased.	Foy
Wheat (A)	Typic Hapludult	1984	F	Georgia	Low pH significantly reduces grain yield. At the high pH, yields were 44% higher than the yields from the low pH soils.	Johnson, Ohki

[1]The letter in brackets indicates the type of degradation, S=salinization and A=acidification
[2]Study types: F=field study, M=model, R=literature review and summary, RA=regression analysis, GH=greenhouse experiment

Conclusions

The Annotated Bibliography contains results of many studies that were designed to determine the effect of soil degradation on crop yields. Yet, further investigation is still needed, particularly in how salinization and acidification affect crop yields. Erosion studies are fairly encompassing as models and regression analysis allow for long term yield predictions. Still, more work on soil erosion effects is necessary. The effect of wind erosion is still largely unexplained. There is a total lack of compaction studies in the Prairies. Specific information needed may include:

1. The study of the effects of all types of degradation on the various oilseed crops grown in the Prairie provinces;
2. The effects of varying levels of temperature and precipitation and the timing thereof within each type of degradation;
3. The development of yield response curves for increased levels of salinity and acidity;
4. A more localized topsoil depth-yield response relationship to typify the prairie soils and landscapes;
5. How different types of soil degradation may be interrelated; and,
6. The determination of the seriousness of surface and/or subsoil compaction in the prairies.

ANNOTATED CITATIONS

Section 1: Soil Erosion

Small Grain Cereals

1 Anderson, D. W. and Gregorich, E. G. 1983. **Effect of soil erosion on soil quality and productivity.** Pages 105-113 in Soil Erosion and Land Degradation, Saskatchewan Institute of Pedology, Saskatoon, Saskatchewan.

Erosion, the gradual wearing away of soil and rock by water or wind is a natural process that is part of the long-term geological changes to the surface of the earth. It is well known that the erosional process can be markedly increased by agricultural practices which remove the protective cover of vegetation or plant residues and loosen the soil. Where the loss of soil by erosion is greater than rates of soil development or rejuvenation the quality of the soil resource deteriorates, resulting in lost crop productivity. The many factors which influence productivity, particularly inputs of improved technology, make it difficult to determine the effects of different management strategies on lands of differing properties. Knowledge in this area is critical to determining the seriousness of the problems and to attract public concern and funds to their solution.

Summary

Methods:	Summarizes the effect of soil erosion on soil quality and productivity, by describing: the ways in which erosion reduces productivity; synergistic effects; and estimates of erosion effects.
Degradation:	Erosion
Crop:	Wheat, corn
Soil:	
Land Mgmt:	
Location:	
Impact:	Wheat studies in the Palouse region are cited. The yield loss was estimated to be 725 kg/ha over a 90 year period. In corn studies, when 30 cm of topsoil was removed (in Minnesota) corn yield was reduced from 3.6 t/ha to 2.5 t/ha. Fertilizer restored the yields to 3.0 t/ha but this was still significantly lower than the yield from undisturbed soil.

Results:

Productivity Abstract:	This article concentrates on the effect of erosion on soil quality parameters and does not summarize the effects of erosion on productivity except in a general sense.

Keywords:	Erosion, summary, soil quality, productivity, wheat, corn

2. Bramble-Brodahl, M., Fosberg, M. A., Walker, D. J. and Falen, A.L. 1985. **Changes in soil productivity related to changing topsoil depths on two Idaho Palouse soils.** Pages 18-27 in Erosion and soil productivity: Proceedings of the National Symposium on Erosion and Soil Productivity, December 10-11, 1984, New Orleans, Louisiana.

The impact of erosion on winter wheat productivity on two Idaho Mollisols - an Ultic Argixeroll belonging to the Naff series, and a Pachic Ultic Haploxeroll belonging to the Palouse series, respectively, was investigated during 1982-1983. The soils were sampled in similar landscape positions on south slopes with approximately 10 to 25% slopes. The two soils differed in that one had an argillic subsoil (an increase in clay and in soil structure), the other had a subsoil texturally similar to the surface horizons and not as strongly structured. The data were collected on fields where the 2 year crop rotation was Stephens winter wheat with dry peas or lentils. On both soils, yield response to changes in topsoil depth was linear in 1982 and nonlinear in 1983. On Naff soils in 1983, a change in yield was associated with a change in topsoil depth over most of the depths sampled, while on Palouse soils the yield changed very little as topsoil depth increased beyond 30 cm (yield close to the asymptotic upper limit). Finally, the soil profile factors influencing yield appeared to differ between the two soils because of the type of subsoil. Yield was related to changes in organic matter and bulk density on Naff soils, but was related only to changes in organic matter on Palouse sites. On Naff sites, the results suggest that, even in a favourable growing season, yields will be affected by topsoil loss over much of the range of existing topsoil depths. On Palouse soils there was a greater difference in yield response between the two years, which may indicate a generally more variable yield-topsoil depth relationship; the average yield response to erosion on this soil may depend on the prevalent growing season conditions.

Summary

Methods:	Five cooperator farms. Samples were taken on the south slopes at the ridge shoulder and side slope positions (10 to 25% slope). Data collected included the thickness of the mollic epipedon, on Naff soil the depth to argillic horizon, per cent organic matter, wheat yields, and bulk density. Both linear and non- linear regression analysis was performed on data to attempt to best define the relationship between yield and topsoil depth. The cost of erosion was also estimated for each soil type.
Degradation:	Erosion, as represented by different depths of topsoil
Crop:	Wheat.
Soil:	Naff, fine, silty, mixed, mesic Ultic Argrixeroll Palouse, fine, silty, mixed, mesic Ultic Haploxeroll
Land Mgmt:	
Location:	Genesee area in Idaho (rolling loess hills)
Impacts:	Wheat yields: Increase with an increase in the thickness of topsoil. This relationship was linear in 1982 and non-linear in 1983 for both soils.

Results

Table 1.Mean and ranges of data for Naff and Palouse soils in 1982 and 1983.

	n	mean	1982 min-max	n	mean	1983 min-max
Naff						
yield kg/ha	32	4950	2856-7278	48	7930	4402-10367
molldep cm	32	27.1	0-61.0	48	28.2	0-66.0
depby cm	32	45.0	10.2-81.3	48	39.4	0-114.3
om %	32	2.330.	78-3.74	47	2.30	0.85-1.71
bd g/cc	32	1.35	1.17-1.65	48	1.38	1.08-1.71
Palouse						
yield kg/ha	27	5077	2354-7088	31	8405	6289-10054
molldep cm	27	43.4	0-88.9	31	38.6	0-114.3
om %	27	2.26	.78-3.77	31	2.48	.85-4.10
bd g/cc	27	1.28	1.09-1.50	31	1.27	1.06-1.40

yield = Yield of Stephens soft winter wheat
molldep = thickness of the mollic epipedon
depth = depth to argillic horizons
om = per cent organic matter in a mix of the top 30 cm of soil
bd = bulk density at 30 cm
n = number of samples

Yield response curves

1. Linear Yield=L0+L1
   L0 - intercept, yield at 0 cm topsoil depth
   L1 - increase in yield per cm increase in topsoil depth

2. Non linear Yield=B0+B1(1-exp(-B2))
   B0 - yield at 0 cm topsoil depth
   B1 -difference between yield at 0 cm depth and its maximum yield
   B2 - rate at which the maximum yield is approached as depth is increased.

Economic consequences

Naff erosion cost equation: Yield=4105+5128(1-exp(-.016))
Palouse erosion costs equation: Yield=5050+3473(1-exp(-.019))

These equations were developed under the following assumptions:

1. annual soil loss - 23.3 Mg/ha.

2. topsoil depth 38 cm.
3. wheat price of $0.13/kg.
4. 75 yr time horizon over which damage from current erosion is estimated
5. 4% real rate of discount
6. a proportional rate of technical progress of 1.7% annually, the rate occurring over the last 50 years in Palouse.

The annual costs were estimated for each soil type:

Naff	$40.28/ha.
Palouse	$28.66/ha.

Productivity Abstract
Soil type is highlighted as an important variable when determining the impacts of soil loss in this study. Organic matter percentages and bulk density were considered key physical characteristics that are affected by soil loss. In the regression models, changes in organic matter percentages had similar and significant influences on the yields from both soils. Changes in bulk density only had a significant influence on the Naff soil. Naff soils were considered more difficult to repair after erosion occurred because of this bulk density influence. The annual cost of erosion also reflects this.

Keywords: Erosion, regression models, non linear, wheat yields, erosion cost, Palouse Naff.

3. Burnett, E., Stewart, B. A. and Black, A. L. 1985. **Regional effects of soil erosion on crop productivity - Great Plains [USA].** Pages 285-304 in Follett, R. F. and Stewart, B. A. eds. Soil erosion and crop productivity. American Society of Agronomy, Madison, Wisconsin

Severe erosion, particularly wind erosion, continues in many parts of the Great Plains, USA. This affects crop productivity, removing nutrients, reducing infiltration and topsoil thickness. Improved technology (improved cultivars, increased fertilizer use, pesticides and machinery) has masked the effect of erosion, without which crop yields would probably have declined.

Summary

Methods:	The effects of topsoil removal (simulated erosion) are summarized for dryland agriculture. Fertilizer treatments are combined with various levels of erosion. Tables from several studies are cited.
Degradation:	All levels of erosion
Soil:	Gardena coarse-silty, mixed, Pachic Udic Haploboroll Beadle silty clay loam, Typic Argiustoll
Crop:	Wheat, sorghum, corn
Land Mgmt:	Variable rates of fertilizer application
Location:	Upham, North Dakota and Madison, South Dakota
Impact:	If sub-soil horizons are markedly different from topsoil in either chemical or physical characteristics, crop yields are reduced. Current trends include an increased use of fertilizer to increase yields. If poor physical conditions exist in the sub-soil, it is very difficult to restore productivity with fertilizer.

Results

Table 1. Effects of topsoil removal with and without replacement of 15 cm of topsoil and fertilizer treatments on corn grain yields on Beadle silty clay loam cut 0, 30, and 45 cm, Madison, SD (Olson, 1977).

Fertility Treatment N-P-K+Zn (kg/ha)	Grain yield for three levels of topsoil removed (cm): 0	30	45
	------kg/ha------		
No topsoil replaced			
56-22-0 + 9	3625	2988	2827
168-44-37 + 9	3724	3092	3016
15 cm topsoil replaced			
56-22-0	4308	4595	3933
56-22-0 + 9	4689	4741	4146
168-44-0	4579	4686	4568

Table 3.Effect of topsoil removal and fertilizer treatments on corn grain yield on Gardena fine sandy loam soil at Upham, ND, 1954 and 1956 (Carlson et al., 1961)

1954 fertilizer treatment N	P	Zn	Grain yields 1954 C+	U++	1956 C	U
------kg/ha------						
0	0	0	280	2885	1280	3945
0	50	17	480	3375	1345	4065
200	50	0	2020		2150	
200	0	17	1680	3535	1505	3625
200	50	17	3825	3615	1625	3765

\+ C=area from which 30 cm surface soil was removed.
++ U=area from which no surface soil was removed.

Table 4.Estimated crop yield reduction per centimetre of topsoil loss at several Great Plains locations (Lyles, 1975)

Location	Wheat yield reduction per cm of topsoil loss kg/ha	%	Grain sorghum reduction per cm of topsoil loss kg/ha	%
Geary Co., KS	0.3	6.2		
Manhatten, KS	0.3	4.3		
Akron, CO	1.3	2.0		
Bushland, TX				

(irrigated)	0.7	5.2
(preseeding irrig.)	0.5	4.1
Temple, TX		
(nonirrigated)	0.5	5.7

Table 6.Estimated annual reduction in wheat and grain sorghum yields resulting from wind erosion under various crop rotations in the Great Plains (Lyles, 1977)

Location	Wind erodibility groups 1	2	3-4L	5	6	7
	------------------kg/ha					----------------
Wheat-fallow rotation						
Northern Plains*	15.1	5.2	2.8	1.6	1.2	0.8
W.Kans-E.Colo.	60.3	19.5	10.7	6.0	4.8	3.6
W.Texas	118.3	33.0	17.1	9.1	7.5	5.2
Wheat-sorghum-fallow rotation (wheat)						
Nebr.-S.Dak.	36.1	13.5	7.5	4.4	3.2	2.4
W.Kans-E.Colo.	92.1	34.9	20.2	11.9	9.5	7.1
W.Texas	136.6	44.1	24.2	13.9	11.1	8.7
Wheat-sorghum-fallow rotation (sorghum)						
Nebr-S.Dak.	54.0	20.2	11.3	6.5	4.7	3.6
W.Kans-E.Colo.	137.6	52.2	30.2	17.8	14.2	10.7
W.Texas	204.0	65.8	36.2	20.8	16.6	13.0

* includes N.Dak., S.Dak., Nebr., Mont., and Wyo.

Productivity Abstract:
This chapter reviews previous erosion field studies mainly completed in the 1960s for in the great plains. It is noted that most of these studies may be underestimation of the effects of erosion due to the assumption that the topsoil thickness-yield relationship is linear. Since the time of this report more work has been done to refine the topsoil thickness-yield relationship. The authors also stress the importance of differences in subsoil properties in future studies. The harsh climate is another element in the Great Plains that may accentuate the erosion problem.

Keywords: corn, wheat, erosion, Great Plains, North and South Dakota, topsoil thickness, field studies.

4. Busacca, A. J., McCool, D. K., Papendick, R. I. and Young, D. L. 1985. **Dynamic impacts of erosion processes on productivity of soils in the Palouse.** Pages 152-169 in Erosion and soil productivity: Proceeding of the National Symposium on Erosion and Soil Productivity, December 10-11, 1984, New Orleans, Louisiana.

The soil-landscapes of the Palouse are complex for a number of reasons: (1) the topography is complex, (2) the macro- and micro-climate have strongly influenced soil development, and (3) buried paleosols occupy part or all of the rooting zone in at least 30 percent of the upland soils. The Risbeck and Endicott soils in the Walla Walla soil association have duripan fragments and duripans within the rooting zone, and the Naff and Garfield soils in the Palouse-Thatuna-Naff soil association have strong argillic horizons at shallow depth. These and other similar soils in the Palouse will be more severely affected by continued erosion than will the very deep, uniform Walla Walla and Palouse soils, because of reduction in effective rooting depth, loss of water and nutrient storage capacity, and increased rainfall runoff. USLE water erosion estimates are presented here, which although approximate, are nevertheless, based on measured hill shapes and soil distributions. The projections of soil loss over a 50-yr period allow for direct gauging of the magnitude of the loss. The estimates differ by almost a factor of ten (8.7 t/ha-yr to 74.6 t/ha-yr) between soils, depending on slope position, tillage practice, precipitation zone, and aspect. Tillage erosion on hilltops, estimated for a single deep plowing, is of a similar magnitude (29 t/ha-yr vs. 11.2 to 36.8 t/ha-yr) to the annual water erosion from the same upper hill segment, and this segment is where paleosol horizons are generally nearest the surface. At the rates of water and tillage erosion projected for conventional tillage over a 50-yr period, all of the topsoil will be removed from the Naff, Garfield, and Risbeck soils, exposing paleosol B horizons at the surface. One-third to two-thirds of the topsoil will be removed from the Walla Walla, Palouse, and Thatuna soils in this 50-yr period. Based on the projected erosion rates, and analysis of the relationship between topsoil depth and wheat yield for selected soils, crop yields will be reduced on soils in both the Walla Walla and Palouse-Thatuna-Naff associations and may be reduced by up to 25 percent on the severely eroded sites of the Thatuna series over 50 years. Even allowing for technical progress, the impacts of erosion still represent reductions in yield growth.

Summary

Methods: Levels of erosion were calculated based on soil profile and landscape position. The procedure used was based on the USLE. Regression models were used to determine the topsoil thickness-yield relationship. (Mitscherlich-Spillman response function)

Degredation: Erosion

Crop: Winter wheat

Soil: Palouse, Pachic Ultic Haploxerolls Thatuna, Xeric Argialbolls Naff, Ultic Argixerolls

Land Mgmt: Convential tillage assumed.

Location: Colfax, Washington

Impact: Soil erosion leads to potential yield decline of winter wheat. Different soil series respond to different degrees.

Results

Table 2.Predicted average annual winter wheat yields in the Eastern Palouse for varying topsoil depths, by soil series and capability class.

	Predicted yields (t/ha)					
Topsoil	Palouse series		Thatuna series		Naff series	
depth (cm)	Class III	Class IV	Class III	Class IV	Class III	Class IV
0	2.96	2.41	2.36	1.81	2.36	1.81
15	3.41	2.86	2.94	2.39	2.63	2.08

30	3.79	3.24	3.44	2.88	2.86	2.30
45	4.11	3.56	3.85	3.30	3.05	2.49
60	4.38	3.83	4.20	3.65	3.21	2.66
75	4.61	4.06	4.50	3.95	3.34	2.79
90	4.81	4.26	4.75	4.20	3.46	2.91

Product Abstract:
This study distinguishes between 3 soil series by using linear extrapolation of yields versus topsoil depth. The Palouse yields were higher at the zero topsoil level than the other two soils. The Naff soil had the smallest decline in yield but this may be due to its initial lower yield potential. Thatuna wheat yields at the zero topsoil level were estimated to be the same as the Naff yields. However, figure 4 illustrates that the Thatuna soil has a greater positive response to the thickness of topsoil. The R^2 for the response function was 0.48. The authors state that there is a lack of information concerning management practices and this may represent the residual variability.

Keywords: erosion, regression models, wheat, topsoil thickness, yield estimates, Palouse.

5.Carter, D. L., Berg, R. D., and Sanders, B. J. 1985. **The effect of furrow irrigation erosion on crop productivity.** Soil Sci. Soc. Am. J. 49: 207-211.

Furrow irrigation erosion redistributes topsoil by eroding upper ends of fields and depositing sediment on downslope portions causing a several fold topsoil depth difference on individual fields. This investigation was conducted to evaluate the effects of this erosion and deposition process on crop yield and to develop crop yield-topsoil depth relationships. Studies were conducted on 14 farmer-operated fields and on field plots with a continuous topsoil depth gradient from 10 to 66 cm. Severe erosion on the upper ends of fields combined with tillage has mixed light-coloured subsoil with topsoil and caused these areas to become whitish in colour. Crop yields have sharply decreased on these whitish areas compared to areas where the topsoil depth is 38 cm, or the original depth. Yields were increased, but less sharply, where sediment deposition has increased topsoil depth above 38 cm up to a depth of about 66 cm. Yield-topsoil depth relationships followed the equation $Y = a+b \ln X$ with significant correlation coefficients for wheat (Triticum aestivum), sweet corn (Zea mays), barley (Hordeum vulgare), alfalfa (Medicago sativa), dry beans (Phaseolus ssp.) and sugarbeets (Beta vulgaris). Yield decreases per unit loss of topsoil were greatest for wheat and sweet corn and least for sugarbeets. Yields on whitish soil areas could not be improved more than indicated by these relationships by adding additional fertilizer phosphorus or potassium.

Summary

Methods: The yield data was collected from farmer operated fields and experimental plots. The original depth of topsoil was determined to be 38 cm. Topsoil depth ranged from 10 to 65 cm. Yield results were analyzed using non-linear regression equations.
Degredation: Water erosion
Crop: Wheat, dry beans, sugar beet, potatoes, sweet corn.
Soil: Portneuf silt loam, Durixerollic Calciorthid
Land Mgmt: All of the fields had been furrow irrigated for at 60 years. A blanket fertilizer application of 112 kg N, 67 kg P, and 11 kg Zn per hectare was made in the spring. The furrow plots were irrigated frequently to avoid water stress.

Location: Idaho
Impact: Wheat and sweet corn were most sensitive to soil loss. Sugar beets had the lowest yield decreases.

Results

Figure 2 illustrates the results of the regression analysis. The percent of maximum yield was plotted against topsoil depth. The regression equations for each crop were as follows:

Wheat	$Y=-57.17 + 37.23 \ln x$	$R^2=0.518$
Sweet corn	$Y=-65.66 + 39.26 \ln x$	$R^2=0.799$
Dry beans	$Y=-46.98 + 33.68 \ln x$	$R^2=0.685$
Barley	$Y= -2.90 + 23.59 \ln x$	$R^2=0.765$
Alfalfa	$Y= 7.94 + 19.28 \ln x$	$R^2=0.389$
Sugar beets	$Y= 45.25 + 11.68 \ln x$	$R^2=0.529$

Productivity Abstract:
The purpose of this study was to quantify the effects of furrow irrigation erosion on crop yields. The format of the non-linear regression equations was $Y=a + b \ln x$, where x is the topsoil depth. Yield increases that occurred in all crops when topsoil was added to the 38 cm depth indicated that maximum yields were not possible at the original soil depth. The authors suggest that the maximum yields were obtained when the topsoil thickness was near 65 cm. The 38 cm thickness may in fact be a point of inflection where the rate of yield loss begins to slow.

Keywords: Erosion, wheat, sweet corn, barley, regression analysis, non-linear, Idaho, furrow irrigation, topsoil thickness, field data.

6. De Jong, E. 1988. **Soil erosion.** Pages 57-69 in Land Degradation and Conservation Tillage: Partial Proceedings, 34th Annual CSSS/AIC Meeting, August 21-24, 1988, Calgary, Alberta.

Summary

Methods: This article begins with a historical overview of the study of erosion. Studies on soil redistribution are summarized and then the implication of soil loss is discussed in terms of its effect on crop yields or soil productivity.
Degradation: Erosion
Crop: Wheat
Soil: Brown soil zone
Land Mgmt:
Location: Saskatchewan
Impact:

Results

Data from the Innovative Acres program was used to establish the following Mitscherlich-Spillman equation:

$Y = 84 + 2808\ (1-0.634^{SD})(1-0.926^{SM})$ where,
SD = topsoil depth in cm
SM = spring available soil moisture

From this equation a threshold of 8 inches of topsoil was determined. Yields did not increase if more topsoil was present and the first increment of soil loss resulted in only minimal yield losses.

Productivity Abstract:
The cost of erosion has been measured by several different methods. Although each method estimates costs differently, the common thread is that on farm costs are very difficult to estimate in the short term. Features of the Prairie landscape such as the hummocky terrain present special problems. Erosion does not often occur uniformly across a field but the practices to control erosion are performed on the entire field. This may not be considered when estimating the costs of erosion. Climatic variability is another factor that complicates management decisions to control erosion and the estimation of the effect of erosion on yields.

Keywords: Erosion, wheat, costs, topsoil thickness, non-linear relationship, Saskatchewan, review.

7. Dormaar, J. F., Lindwall, C. W., and Kozub, G. C. 1988. **Effectiveness of manure and commercial fertilizer in restoring productivity of an artificially eroded Dark Brown Chernozemic soil under dryland conditions.** Can. J. Soil Sci. 68: 669-679.

A field was artificially eroded by levelling in 1957. Continuous cropping to barley for 7 yr followed by a wheat-fallow rotation for 14 yr without nutrient application did not significantly improve the soil productivity of severely 'eroded' land. Subsequently, a wheat-fallow experiment was conducted from 1980 to 1985 to determine the effects of 30 Mg/ha feedlot manure or 150 kg commercial fertilizer N (as urea) + 150 kg commercial fertilizer P (as triple superphosphate)/ha on restoring productivity to soil from which 10-20 cm or 46 + cm of soil had been removed. The manure and commercial fertilizer treatments restored productivity within the first year, as measured by wheat yields, regardless of severity of erosion. During years of drought stress, the manure application on the 'eroded' soil treatments resulted in yields greater than those on check or fertilized plots. The manure significantly increased the organic matter, total N, NO_3-N, available P, and water-stable aggregate status of the soil. There was a decrease in the difference in carbohydrates between undisturbed and 'eroded' plots from 1982 to 1984.

Summary

Methods: Three soil erosion treatments were defined for this study. The plots were located within the artificially eroded field of a previous study (Dormaar et al.,1986). The erosion treatments were undisturbed, 10-20 cm cut, and more than 46 cm cut. There

	were 3 fertilizer treatments, check, feedlot manure (30 Mg/ha), and commercial fertilizer (150 kg N and 150 kg P)
Degradation:	Erosion
Crop:	Spring wheat
Soil:	Calcareous Dark Brown Chernozemic (Typic Haploboroll)
Land Mgmt:	The plot was continuously cropped with barley from 1958 to 1964. The next 14 years the field was cropped in a wheat-fallow rotation with no fertilizer application. Precipitation was quite variable over all the growing seasons but was consistently below average during the last three growing seasons.
Location:	Lethbridge, Alberta
Impact:	After 28 years and 17 crops, yields from the 46 cm cut erosion treatment were only 60 % of those from the undisturbed plots. Fertilizer and manure treatments restored yields from the severely eroded plots to the level of the undisturbed plots in every year of the study. In 1981, the fertilizer and manure treatment yields from all erosion treatments were significantly higher than the undisturbed check yields.

Results

Table 5.The effect of erosion treatment on wheat yields in response to commercial fertilizer and manure treatments (1981-1985).

			Wheat yield	
	Erosion	Check	Fertilizer	Manure
Year	treatment	------------	kg/ha	-----------
1981	Undisturbed	2372cA	2784bA	3202aA
	10-20 cm cut	1737cA	2728bA	3216aA
	46+ cm cut	1444bA	2637aA	2805aA
	SE1++		469	
	SE2#		195	
	Pe##		NS	
	Pf		**	
	Pexf		NS	
1983	Undisturbed	2014aA	2318aA	2374aA
	10-20 cm cut	1333bB	1305bB	2386aA
	46+ cm cut	1277bB	1270bB	1919aA
	SE1		214	
	SE2		174	
	Pe		**	
	Pf		**	
	Pexf		**	
1985	Undisturbed	1520aA	1582aA	1553aA
	10-20 cm cut	914bB	1236aA	1478aA
	46+ cm cut	838bB	1123aA	1318aA
	SE1		235	
	SE2		118	
	Pe		NS	
	Pf		**	
	Pexf		*	

```
++SE1 = Standard error of a difference between two erosion treatment means for
      the same or different fertilizer treatments.
#SE2 = Standard error of a difference between two fertilizer treatment means
      within an erosion treatment.
##Pe, Pf, Pexf refer to the significance of erosion, fertilizer, and erosion x
      fertilizer effects, respectively.
*,** = P<0.05, and P<0.01, respectively.
NS Not significant
a-cMeans followed by the same letter within an erosion treatment X year
      combination are not significantly different (P>0.05)
A-CMeans followed by the same upper case letter within a fertilizer X year
      combination are not significantly different (P>0.05).
```

Productivity Abstract
The productivity of severely eroded soil was restored in the first year of fertilizer or manure application. The amount and timing of precipitation varied from year to year. Erosion had a greater effect on yields in the drier years. In this study, 1985, typifies a drier year in that all yields are lower and the difference between the yields from the undisturbed plots and the eroded plots are magnified. Even the application of fertilizer or manure to the eroded plots did not fully restore yields to the undisturbed levels. Fertilized plot yields and manure plot yields were only 74 and 86% of the undisturbed, check plot yields, respectively. Soil nutrients (organic carbon, total N, NO_3-N and available P) which were lost when topsoil was removed were replaced. This study focused on the importance of organic matter in the topsoil layers and suggests that annual manure application and continuous cropping may maintain soil productivity levels during the natural soil rebuilding process.

Keywords: Erosion, Alberta, artificially eroded, wheat yield, fertilizers, field study.

8. Dormaar, J. F., Lindwall, C. W., and Kozub, G. C. 1986. **Restoring productivity to an artificially eroded Dark Brown Chernozemic soil under dryland conditions.** Can. J. Soil Sci. 66: 273-285.

A field was artificially eroded by levelling in 1957 and then continuously cropped to barley for 7 yr. Subsequently, a wheat-fallow experiment was conducted from 1965 to 1979 to determine the effects of four fertilizer treatments and green manure (yellow sweet clover) on restoring the productivity to soil that had been "eroded" to various depths. After 22 yr and 14 crops, the productivity of the land from which soil was removed had been improved but not fully restored. Although green manuring with yellow sweet clover improved soil structure, wheat yields were not improved because of competition for soil moisture and poorer in-crop weed control in this part of the rotation. The addition of 45 kg N plus 90 kg P_2O_5 per hectare in each crop year to sites from which 8-10, 10-20, or 46+ cm of soil had been removed resulted in yield increases of 18, 46, and 70%, respectively, over the unfertilized check of each treatment; the average yields were 104, 91, and 70%, respectively, of the undisturbed, unfertilized (check) treatment. On "erosion" treatments where only 8-10 cm of soil were removed, 45 kg N plus 22 kg P_2O_5 per hectare were sufficient to restore the productivity. Precipitation apparently had a greater effect than fertilizer application on wheat yields. The loss of organic matter and associated soil structure characteristics seemed to be critical factors contributing to yield losses associated with soil erosion. These results show that it is more practical to use management practices that prevent soil erosion than to adopt the practices required to restore eroded soil.

Summary

Methods:	This field study had 6 erosion treatments and four levels of fertilizer. Erosion was simulated by addition and removal of different amounts of topsoil. Soil moisture before seeding and after harvest, % organic matter, and water stable aggregates were also recorded throughout the 14 year study
Degradation:	Erosion
Crop:	Spring wheat
Soil:	Calcareous Dark Brown Chernozemic
Land Mgmt:	There were 7 two year wheat-yellow sweet clover fallow rotations. Cultivation was done using a wide blade cultivator.
Location:	Lethbridge, Alberta
Impact:	Yields averaged over fertilizer levels generally decreased as the depth of topsoil was decreased. The magnitude of these differences from year to year depended on the growing season precipitation. Field 2 had lower overall differences between yields of different erosion treatments.

Results

Table 3.The effect of erosion treatment on available soil moisture, soil moisture depletion, and wheat yield in response to fertilizer treatment on fields without (field 1) and with (field 2) sweet clover. (1967-1979)

	Soil moisture (1.2 m depth)		Wheat yield Fertilizer			
Erosion treatment	Available	Depletion	0-0	45-22	45-45	45-90
	----------mm----------		----------kg/ha----------			
Field 1						
30+cm fill	123	103	1967	1861	1860	1912
8-10 cm fill	129	101	2048	2053	2022	2035
undisturbed	131	99	1790	1867	1876	1855
8-10 cm cut	151	113	1576	1880	1886	1860
10-20 cm cut	157	110	1122	1365	1469	1632
46+ cm cut	99	62	736	1015	1092	1251
SE	13.5	6.2			47++	
df	18	18			54	
P	NS	**			**	
Field 2						
30+cm fill	116	96	1928	1698	1788	1715
8-10 cm fill	116	91	1846	1756	1497	1716
undisturbed	106	81	1609	1568	1618	1610
8-10 cm cut	105	82	1437	1380	1503	1568
10-20 cm cut	102	71	1076	1100	1288	1122
46+ cm cut	91	78	1044	1111	1232	1270
SE	18.9	7.6			67	
df	18	18			54	
P	NS	NS			**	

```
++Standard error for a fertilizer mean within a soil treatment.
*,** Significant effect at P<= 0.1 and P<=0.01, respectively,
NS   Not significant
```

Productivity Abstract

This is one of the most extensive erosion studies done in Alberta. There were two main objectives to this study. The first objective dealt with the measurement of the effect of erosion of wheat yield and soil properties. The second objective measured the restorative ability of fertilizer at various levels of erosion. The seven cycles of wheat-fallow or wheat clover rotation still have high levels of year to year variation due to climatic factors. Under low rainfall conditions, the effects of erosion are more severe. Losses of organic matter and nutrients were noted throughout the study; however, some of these losses can be regained through higher levels of fertilizer application.

Keywords: Erosion, wheat, Alberta, soil properties, field study.

9. Greb, B. W. and Smika D. E. 1985. **Topsoil removal effect on soil chemical and physical properties.** Pages 316-327 in S. A. El-Swaify, W. C. Moldenhauer, and A. Lo (eds). Soil erosion and conservation. Soil Conservation Society of America, Ankeny, Iowa.

The amount of native topsoil removed resulted in marked differences in physical and chemical properties of the new surface soil. In the 0 to 5 cm depth, clay content increased as much as 15 percent, bulk density decreased as much as 0.25g/cm3, and the erodible soil fraction decreased by 11 percent. Chemical property changes in the same 5 cm profile segment included an increase in lime content of 5.3 percent, a total N decrease of 0.025 percent, and a labile P decrease of 21 kg/ha. Although labile P was very low in the newly exposed soil, there was a gradual increases during the first 8 years after soil removal. The crop grown had some influence on labile P, with sudan grass more favourable for P increase than wheat. Regardless of crop grown, yield decreased with increasing depth of soil removed. The application of N or N and P tended to overcome the yield decrease of cultivated crops and grasses grown (Russian wildrye and crested wheatgrass) during the years fertilzer was applied. However, the residual effects of the fertilizer were short for the grasses.

Summary

Methods: This 7 year field study had 5 soil exposure depths:
- 0 to 7.6 cm;
- 0 to 15.2 cm;
- 0 to 22.8 cm;
- 0 to 30.4 cm; and
- 0 to 38.1 cm.

Three fertilizer treatments were also used:
- no fertilizer;
- N only; and
- N and P.

Soil chemical and physical properties were recorded along with some yield reduction information.

Degradation: Erosion (wind and water)

Soil: Aridic Paleustoll
Crop: winter wheat, Russian wildrye, sudangrass
Land Mgmt: The fallow period between wheat crops was 14 to 18 months. During this time the plot was tilled five times to control weed growth.
Location: Akron, Colorado, USA
Impact: All crop yields decreased as the amount of topsoil removed was increased.

Results

Table 5.Yield of wheat grown on fallow as influenced by depth of soil removal and fertilization, average of 1958, 1960, and 1962.

Soil Removal	Fertilizer Treatment*	Yield Grain	Yield Straw	Total Dry Matter	Grain Protein
		----------- kg/ha		-----------	(%)
	0	1530a+	2830a	4360a	16.1a
R1	N	1460a	2880a	4340a	17.3b
	N + P	1450a	2930a	4380a	17.0b
Average		1480xy	2880xy	4360y	16.8z
	0	1530a	2870a	4400a	15.3a
R2	N	1510a	2930a	4440a	16.8c
	N + P	1590a	3230a	4820b	15.9b
Average		1540xy	3010y	4550y	16.0y
	0	1490a	2830a	4310a	13.9a
R3	N	1490a	2930a	4420a	15.7b
	N + P	1440a	3050a	4490a	15.5b
Average		1470xy	2930xy	4400y	15.0y
	0	1460a	2830a	4290a	12.1a
R4	N	1460a	3020a	4480a	14.1b
	N + P	1750b	3390b	5140b	14.2b
Average		1560y	3080y	4640y	13.5x
	0	1220a	2460a	3680a	11.7a
R5	N	1260a	2690ab	3950ab	14.7b
	N + P	1550b	3050b	4600b	15.0b
Average		1340x	2730x	4070y	13.8x
	0	1440a	2770a	4210a	13.8a
All depths	N	1440a	2900a	4340a	15.7b
	N + P	1550b	3140b	4690a	15.6b

*Applied 40 kg N /ha per crop and 50 kg P/ha applied in 1956 and 100 kg P/ha applied in late 1960.
+Values within columns within each soil removal depth accompanied by different letters are significantly different at the 95% level of probability. Soil removal average values within columns accompanied by different letters are significantly different at the 95% probability.

Productivity Abstract
This study focusses mainly on the changes in soil chemical and physical properties as soil depth decreases. The yield results for winter wheat illustrated that decreased soil depths had a negative effect on both grain and straw yields. A significant decrease in grain yield was indicated only in the R5 soil removal treatment (38.1 cm removed).

Keywords: Erosion, field study, Colorado, USA, winter wheat, soil removal, chemical and physical properties, fertilizer.

10. Greer, K. J., Hilliard, C. R., Schoenau, J. J., and Anderson, D. W. 1992. **Developing simplified synergistic relationships to model topsoil erosion and crop yields.** Pages 198-205 in Proceedings of the Soils and Crops Workshop; Saskatoon, Saskatchewan. (In press).

Topsoil is highly enriched with organic matter, which provides a valuable source of plant nutrients as well as a favourable rooting environment. Over time, erosion processes selectively remove the organic matter-rich fine fraction which causes a measurable reduction in soil productivity. Assessments of past erosion are of little value in predicting future losses in productivity since the synergistic lowering of soil organic matter through lower residue inputs is not considered. Dynamic computer models, which simulate the plant/soil system, can project the long run future costs of soil erosion on crop yield. A simplified erosion-crop yield model was developed by first defining the most important soil productivity variables, then quantifying the effect of erosion on each variable. The model predicted a declining trend in grain yields similar to that observed on soil scalping experiments.

Summary

Methods:	This erosion model uses the temporal modelling environment STELLA II. Soil organic matter content and available N were considered the limiting productivity variables.
Degradation:	Erosion
Crop:	Wheat
Soil:	Not specified
Land Mgmt:	
Location:	
Impacts:	Grain yields decline rapidly when 7 to 10 cm of topsoil is lost.

Results

Figure 7 plots the results of simulated changes in soil depth and grain yield over thirty years. The topsoil depth decreases at a constant rate of 1 cm per year. Grain yields begin to decrease rapidly after 5 cm of topsoil is lost. This rate of decline continues until approximately half the topsoil has been lost. By this time, the grain yield was estimated to be less than 25% of the grain yield before any erosion occurred.

Productivity Abstract
Grain yield losses were estimated based on the changes in soil organic matter content and available nitrogen. The first run of the model did not account for the differential rate of N mineralization throughout a soil profile. Subsequent runs incorporated a soil depth factor which resulted in an accelerated grain yield loss. This simple model obtained results that were similar to field scalping studies and indicated that the topsoil loss-yield reduction relationship was non-linear.

Keywords: model, grain yield, topsoil depth, available N, productivity, erosion, wheat, soil organic matter.

11. Ives, R. M., and Shaykewich, C. F. 1987. **Effect of simulated soil erosion on wheat yields on the humid Canadian prairie.** J. Soil Water Conserv. 42: 205-208.

Effects of simulated soil erosion on wheat yields were studied on a Reinland loamy very fine sand, a Newdale clay loam, and a Pembina clay loam in Manitoba. Erosion was simulated by scalping 0, 5, 10, and 20 cm of Ah horizon with a road grader. Each soil removal treatment was split into three levels of fertilizer application control, soil test recommendation, and a high rate. The amount and kind of nutrient added in each fertilizer treatment was based on soil test. Wheat yields, averaged over all fertilizer treatments, decreased consistently with increasing amounts of topsoil removed. The data showed the detrimental effects of soil erosion on productivity and how technology can mask these effects. With no fertilizer, yields differed vastly between the plots with 0 and 20 cm of topsoil removed. However, for the higher than recommended fertilizer level, there was no significant difference in yield for the same two topsoil removal treatments. An attempt was made to estimate the cost of soil erosion by determining the cost of fertilizer required to restore production. In some cases, as much as $90/ha for fertilizer was required to restore productivity. In other cases even a very high rate of fertilizer did not produce a yield equal to the control without fertilizer. In most instances nutrient content in the grain was not affected by topsoil removal treatment. Thus, the major nutritional effect of topsoil removal was a yield reduction.

Summary

Methods:	Topsoil removal and different rates of fertilizer application for each level of removal.
Degradation:	Erosion
Crop:	Wheat
Soil:	Reinland (Aquic Haploboroll), Newdale (Udic Haploboroll), Pembina (Udic Agriboroll)
Land Mgmt:	
Location:	Gladstone, Minnedosa, and Altamont, Manitoba
Impacts:	Wheat yields, averaged over all fertilizer treatments decreased consistently with increasing amount of topsoil removed.

Results

Table 2.Wheat yield for each level of topsoil removal, averaged over all fertilizer treatments

Year and Depth of Topsoil Removed (cm)		Wheat Yield (t/ha) Reinland	Newdale	Pembina
1983	0	1.603a*	2.768a	
	5	1.708a	2.231a	
	10	1.389a	2.040a	
	20	0.575b	1.633a	
1984	0	2.297a	2.785a	2.986a
	5	1.911ab	2.306a	3.043a
	10	1.551ab	2.269a	2.876a
	20	1.073b	2.263a	1.498b

*Tukey's procedure. Within site year means followed by the same letter are not significantly different at P = 0.05.

Table 3.Wheat yield for various soil-removed and fertilizer-rate combinations over the study period.

Year and Topsoil Removed		Wheat Yield (t/ha) Reinland Fertilizer Treatment			Newdale Fertilizer Treatment			Pembina Fertilizer Treatment		
		A	B	C	A	B	C	A	B	C
1983	0	1.5ab*	1.7ab	1.6ab	2.9a	2.8a	2.6a			
	5	1.7a	1.6ab	1.8a	1.9a	2.6a	2.3a			
	10	1.6ab	1.3ab	1.3ab	1.8a	2.3a	2.1a			
	20	0.6ab	0.5b	0.6ab	1.7a	1.8a	1.5a			
1984	0	2.4a	2.2a	2.3a	2.6a	2.6a	3.1a	2.3abc	2.8ab	3.8a
	5	1.8abc	1.9ab	2.1a	2.1a	2.2a	2.6a	2.8ab	3.2a	3.1a
	10	1.2abc	1.5abc	2.0a	2.2a	2.1a	2.7a	2.7ab	2.2abc	3.7a
	20	0.6c	0.7bc	2.0a	1.8a	2.1a	2.9a	0.7c	1.2bc	2.3abc

*Tukey's w-procedure. Within site year means followed by the same letter are not significantly different at P = 0.05.

Productivity Abstract

This is one of the only studies that deals with erosion in Manitoba. Fertilizer can restore yields to approximately the pre-erosion levels but, in some cases, the cost of this practice is very high (over $90 an acre). The effects of erosion were dependent on soil type. The productivity of Pembina and Reinland soils was effected more by topsoil removal than the Newdale soil.

Keywords: Simulated erosion, topsoil removal, Manitoba, field study, wheat yield.

12. Krauss, H. A., and Allmaras, R. R. 1982. **Technology masks the effects of soil erosion on wheat yields - a case study in Whitman County, Washington.** Pages 75-86 in B. L. Schmidt, ed. Determinants of Soil Loss Tolerance. American Society of Agronomy, Madison, Wisconsin.

The separation of technology and soil productivity involved the use of long-term wheat yields, measured wheat response to remaining epipedon, historical soil erosion rates, and landscape distributed soil erosion rates. Current wheat yield in Whitman County increased approximately 36.1 kg/ha (0.54 bu/acre) per year as an average for the whole landscape; meanwhile annual soil erosion losses average 21.1 metric tons/ha (9.4 tons/acre) on a cropland base of 421,200 ha (1,040,000 acres). The soil productivity decrease from an average epipedon loss of 13.4 cm (5.3 in) in a 90-year period was 725 kg wheat/ha (10.8 bu/acre). An average erosion rate, however, does not reveal the true impact on productivity. Isolation of the soil productivity change component by land capability subclass showed that the net increase in yield on IIe and IIIe land (67% of the cultivated cropland) has masked a significant decline in productivity of subclasses IVe and VIe land (18% of the cultivated cropland) in the 90-year period of intensive cultivation. The average soil erosion rate in Whitman County over the 1940 to 1978 period has been nearly twice the tolerance value of 11.2 metric tons/ha (5 tons/acre) per year. Average annual soil erosion at the soil-loss tolerance (T value) level is expected to expose the subsoil of IVe land (about 12% of the cultivated cropland) in about 128 years.

Summary

Methods:	Historical yields were used to indicate that there has been an increase in yield over time in this area. The relationship between yield and topsoil depth was defined as the linear model developed by Wetter (1977). Four land capability subclasses were compared with respect to wheat yields. Erosion rates were calculated using the USLE. An adjustment for technology inputs was defined and applied to current yields.
Degredation:	Erosion
Crop:	Wheat
Soil	
Land Mgmt:	Not documented
Location:	N:Whitman County, Washington
Impact:	The net increase in yield on IIe and IIIe land has masked the significant decline in the productivity of the subclass IVe and VIe land.

Results

Table 1.Wheat yields in Whitman Co., Washington for each decade since 1936.

Decade	Wheat yield (kg/ha)
1936-1945	2029
1946-1955	2305
1956-1965	2984
1966-1975	3474
40 year increase	1445
Annual increase	36.1

Table 3.Soil erosion losses and wheat productivity changes (from epipedon loss and technology input) in cultivated cropland as related to soil capability subclass in Whitman County.

Characteristic	Land capability subclass IIe	IIIe	IVe	VIe	Average
Avg. erosion rate (t/ha/yr)	11.2	15.7	44.8	96.3	21.1
Years to lose 1 cm	12.6	9.0	3.1	1.6	6.7
Years to lose remaining epipedon++	768	345	32	80	--
Soil loss in 90 yrs(cm)	7.1	10.0	29.0	56.0	13.4
Productivity change in 90 yrs (kg/ha)*	-385	-541	-1569	-3040	-725
	(58)#	(100)	(290)	(600)	(134)
Net productivity after adjusting for 1446 kg/ha increase due to technology (kg/ha)	1061	904	-124	-1595	720
	(58)	(100)	(290)	(600)	(134)

++See fig. 3 for average remaining depth of epipedon in each land capability subclass for a typical Palouse hill.

*The 90 year period is based on the following quotation in USDA and Washington State (1979): "Summerfallow became a well established practice on most Palouse farms by the early 1890's. Washington and Idaho Experiment Stations began to recognize erosion as a problem." Productivity change is based on an average yield loss of 54.1 kg/ha per cm loss of topsoil (2.04 bu/ac per inch of topsoil).

#A value in parenthesis is the standard error of the value just above in the same column.

Productivity Abstract:
Historical records show that wheat yield increased linearly over a period of 90 years. These increases occurred despite an erosion rate (21.1 t/ha) which is higher than the soil loss tolerance rate (11.1 t/ha). Technology inputs explain some of this increase along with the availability of suitable farm land. The authors believe that technology will not be able to mask erosion effects to the same extent in the future, and that the availability of prime farm land in this region is decreasing. The poorer lands (subclass IVe and VIe) were only 18% of the cultivated cropland but experienced 52% of the erosion. If controls are not effective, the better croplands will no longer be able to compensate for the high erosion rates in the lower subclass land.

Keywords: Erosion, wheat, historical records, USLE, field study, land capability subclass, Palouse, Wash.

13. Larney, F. J., Janzen, H. H., Olson, B. M., and Lindwall, C. W. 1991. **The impact of simulated erosion on soil productivity and methods for its amendment.** Pages 277-285 in: Proceedings of the 28th Annual Alberta Soil Science Workshop; February 19-21, 1991. Lethbridge, Alberta.

Wind erosion is a major soil degradation phenomenon on the Canadian prairies but its effect on soil productivity are not well quantified. The immediate effectiveness and longevity of restorative amendments also need examination. In the spring of 1990, incremental depths of soil (0, 5, 10, 15, and 20 cm) were removed with an excavator to simulate wind erosion at three sites (two dryland and one irrigated) in southern Alberta. Three amendment treatments (optimum rate of N plus P fertilizer, reapplication of 5 cm of topsoil or 50 Mg/ha of feedlot manure) and a check were superimposed on each of the desurfaced treatments. Highly significant relationships were found between depth of desurfacing and subsequent spring wheat yields showing that simulated erosion drastically reduced soil productivity. Feedlot manure proved to be the best amendment for restoring productivity to the artificially eroded surfaces, with N plus P fertilizer being the worst. Topsoil reapplication was intermediate in its restorative powers. Treatment effects at the irrigated site followed the same trend as the dryland sites illustrating that topsoil loss cannot be compensated by adequate soil moisture.

Summary

Methods:	This field study had 4 levels of simulated erosion plus a check plot erosion treatment (0 cm, 5 cm, 10 cm, 15 cm, and 20 cm) and four amendment treatments (check, an optimum rate of N and P fertilizer, reapplication of 5 cm of topsoil, and 50 kg/ha of feedlot manure) for each erosion treatment.
Degradation:	Wind erosion
Crop:	Wheat.
Soil	Brown Chernozemic - clay loam texture Dark Brown Chernozemic - silty clay loam texture
Land Mgmt:	Seedbed preparation consisted of 1 pass of the rotary cultivator with packers. The irrigated site received 17.5 cm of water to ensure that soil moisture was not a limiting factor.
Location:	Lethbridge, Alberta
Impacts:	As the depth of desurfacing increased, grain yield decreased quadratically (R^2 = 0.94 for Lethbridge Dryland, 0.99 for Lethbridge Irrigated, and 0.92 for Taber Dryland).

Results

Table 1.Grain yield (kg/ha) on cut X check treatments and yield loss per scalping increment (kg/ha/cm) at three sites, 1990.

	Leth. Dryl.	Taber Dryl.	Leth. Irr.
0 cm Cut-check	1205	1146	2507
5 cm Cut-check	1061	877	1588
10 cm Cut-check	397	646	809
15 cm Cut-check	154	698	369
20 cm Cut-check	58	417	159
0 - 5 cm	29	54	184
5 - 10 cm	133	46	156
10 - 15 cm	49	(10)	88
15 - 20 cm	19	56	42
Average (0-20 cm)	57	36	117
Total loss	1147	729	2348

Productivity Abstract
The results from this field study demonstrated that soil productivity losses occurred as topsoil depth was reduced by wind erosion. This relationship was considered to be non-linear or quadratic in nature. It is interesting to note the comparison between the dryland and irrigated results in that both sets of yields decline in similar patterns regardless of the difference in yields on the noneroded plots (the irrigated plot yield was 2507 kg/ha and the dryland plot yield was 1205 kg/ha).

Keywords: wind erosion, wheat, Alberta, field study, amendment practices, dryland, irrigation.

14. Lyles, L. 1975. **Possible effects of wind erosion on soil productivity.** J. Soil Water Conserv. 30: 279-283.

I propose a procedure for evaluating the effects of wind erosion on soil loss and subsequent crop yields. The procedure uses the wind erosion equation to predict potential annual soil loss, which is converted to the crop yield reduction per inch of erosion for corn, grain sorghum, and wheat. When applied in 13 southwestern Kansas counties, the procedure resulted in estimated annual yield reductions of 339,000 bushels of wheat and 543,000 bushels of grain sorghum on 1.2 million acres of sandy surface soils.

Summary

Methods: The Wind Erosion Equation was used to estimate the amount of topsoil lost due to wind. The equation is:
E = f(I,K,C,L,V) where,
E =potential annual soil loss rate
I = soil erodibility
K = soil ridge roughness
C = climate factor
L = unsheltered distance across a field along the prevailing wind erosion direction
V =equivalent vegetative cover.
Yield loss was linearly related to topsoil depth. Yield data were obtained from various topsoil depth-yield response studies.
Degradation: Erosion (wind)
Crop: Corn, wheat, grain sorghum
Soil: As noted in tables 5 and 6.
Land Mgmt:
Location: Kansas, Ohio, Iowa, Washington, Oregon
Impact:

Results

Table 1. Effect of topsoil thickness on wheat yields

Location	Yield reduction per inch of Topsoil (bu/ac)	Yield reduction per inch of Topsoil (%)	Remarks
Wooster Ohio	1.7	9.5	virgin soil
Columbus, Ohio	1.3	5.3	cropped soil
Oregon	1.0	2.2	deep soil
Oregon	2.5	5.8	thin soil
Oregon	2.0	6.4	thin soil
Wooster, Ohio	1.5	6.2	
Geary Co., Kansas	1.3	6.2	
Palouse, Wash.	1.6	6.9	loss of top 5 in.
Palouse, Wash.	1.8	5.3	loss of top 11in.
Pullman, Wash.	1.4	2.9	
Manhattan, Kansas	1.1	4.3	Smolan silty clay loam
Akron, Colorado	0.5	2.0	Weld silt loam
Average	1.5	5.3	
S =	0.5	2.1	

Table 2. Effect of topsoil thickness on corn yields

Location	Yield reduction per inch of Topsoil (bu/ac)	Yield reduction per inch of Topsoil (%)	Remarks
Geary Co., Kansas	3.5	7.5	
Bethany, Missouri	3.0	6.4	Shelby & Grundy silt loams
Bethany, Missouri	4.0	6.0	Shelby & Grundy silt loams
Fowler, Indiana	4.0	4.3	Fowler, Brookston & Parr
Fowler, Indiana	3.8	5.5	silt loam
Shenandoah, Iowa	6.1	5.1	Marshall silt loam
Greenfield, Iowa	3.2	5.0	Tama silt loam
Greenfield, Iowa	3.1	6.3	Shelby silt loam
Coshocton, Ohio	5.2	8.7	
Clarinda, Iowa	4.0	5.1	Marshall silt loam
Upham, N.D.	3.4	7.4	
Wooster, Ohio	4.8	8.0	Canfield silt loam
Columbus, Ohio	3.0	6.0	Celina silt loam
E. Cental Illinois	3.7	6.5	Swygert silt loam
Average	3.9	6.3	
S =	0.9	1.3	

Table 8.Estimated annual reduction in wheat yield (bu/ac) resulting from wind erosion under two kinds of residue management in the Great Plains.

	Wind Erodibility Group (WEG)					
Location	1	2	3,4,4L	5	6	7
	Wheat residue management					
Northern Plains	0.45	0.14	0.07	0.04	0.03	0.02
Western Kansas	1.47	0.47	0.25	0.14	0.10	0.07
West Texas	2.52	0.89	0.50	0.28	0.22	0.17
	Grain sorghum residue management					
Northern Plains	0.88	0.34	0.20	0.11	0.09	0.06
Western Kansas	1.97	0.76	0.44	0.26	0.21	0.15
West Texas	2.69	1.03	0.60	0.35	0.29	0.22

Productivity Abstract:
Many of the topsoil depth-yield response studies concentrate on water erosion and do not include an estimate for wind erosion. The author uses Wind Erodibility Groups (WEG) to divided an area into different wind erosion potential zones and then estimates the yield losses due to wind erosion. Two different residue management scenarios are examined. A caution is given that the yield data used in this study is from a very limited range of soils (fine textured). Other soil types and crops should be investigated to test the Wind Erosion Equation. Fertilizer effects are also not considered. This 1975 study is based on the assumption that there is a linear relationship between topsoil depth and yield response.

Keywords: Wind erosion, wheat, corn, Mid-western U.S., model, topsoil depth, fine textured soils.

15. Massee, T. W. and Waggoner, H. O. 1985. **Productivity losses from soil erosion on dry cropland in the intermountain region.** J. Soil Water Conserv. 40: 447-450.

Soil erosion substantially reduces productivity of deep loessial soils on dry cropland in the intermountain region. The eroded areas usually coincide with steeper slopes where runoff is a problem. Reduced soil moisture limits crop growth, although the eroded soils also have fertility limitations. Where erosion was simulated by removing various amounts of topsoil from more level land, similar stored moisture readings were obtained on all plots. On these plots, however, added fertilizer did not fully replace lost topsoil for maintaining production. Also, poor soil profile moisture extraction by crops led to reduced infiltration and increased runoff during fallow. Erosion thus seems to be somewhat self-perpetuating, and there is no simple remedy once it has occurred.

Summary

Methods: Artificial erosion plots were defined where different amounts of topsoil were removed (0, 15, and 30 cm). Also 15 cm of topsoil was added to the original level. Different amounts of fertilizer were applied. Farm field plots were also used to measure the impact on yield. Efficiency of moisture use is also examined.
Degradation: Erosion
Crop: Wheat
Soil: Lanoak Rexburg Newdale Wheelerville association: Haploxerolls and Torriorthents

Land Mgmt: Fallow-wheat cropping sequence. Ammonium nitrate was the primary source of nitrogen.

Location: Albion Idaho.

Impacts : Topsoil additions and removal caused large and significant yield differences. The yields ranged from 710 kg/ha when 30 cm of topsoil was removed to 3050 kg/ha when 15 cm of topsoil was added. This was the yield range for 0 N application. The high yields obtained when topsoil was added could not be duplicated simply by adding fertilizer.

Results

Table 2.Average wheat yields on artificial erosion plots and abbreviated analysis of variance

Artificial Erosion Treatment	Yields with Various N Applications		
	0 kg/ha N	34 kg/ha N	68 kg/ha N
	-------------------kg/ha--------------------		
15 cm soil added	3050	2920	3180
Untreated	1810	2010	2370
15 cm soil removed	970	1560	2070
30 cm soil removed	710	1460	1880

LSD(Interaction, for all possible row, column comparisons) at 0.01=490 kg/ha
LSD(Interaction, for all possible row, column comparisons) at 0.05=370 kg/ha

Analysis of Variance

Source of Error	Degrees of Freedom	Calculated F
Main plots (erosion N)	11	35.5**
Erosion	3	101.6**
N	2	31.7**
Erosion x N interaction	6	3.86**
Location		
Rexburg vs Newdale soil	1	NS
Phosphorus fertilization	1	NS
Main plots x Location	11	NS
Pooled Error	58	
Total	95	

Table 3.Average soil profile moisture (to 152 cm) available in the spring of the crop year and crop yields from eroded and uneroded soils without (-N) and with (+N) fertilizer N on trial farm plots.

	Eroded Soils			Comparative Uneroded Soils		
	Profile Moisture (cm)	Yield (kg/ha) -N	+N	Profile Moisture (cm)	Yield (kg/ha) -N	+N
All plot average	12.2	1230	1540	16.3	1640	2160
Low moisture						

plots	3.8	700	780	8.6	1360	1370
High moisture plots	23.9	1890	2410	21.3	3190	4190

Productivity Abstract:
This study used both simulated erosion (topsoil removal) and actual field topsoil depths to measure yield response to topsoil depth. The results from the artificially eroded plots indicate that the critical topsoil depth is 15 cm. The addition of 15 cm of topsoil improved yield significantly which led the authors to believe that the amount of topsoil in this region is already insufficient. The farm field plots had similar results to the artificially eroded plots. The main difference was that the eroded plots contained less soil-stored moisture as these plots were generally steeper and experienced greater runoff. Both the artificially and farm eroded fields reacted similarly to fertilizer. Yield recovery occurred when moisture was not limited. When moisture was limited, yields did not return to the levels before erosion.

Keywords: Erosion, soil moisture, Idaho, field study, wheat, topsoil removed, artificial erosion.

16. Narayanan, A. V. S. 1986. **Long-term on-farm economic effects of cropland erosion in the black soil zone of Alberta.** Can. Farm Econ. 20: 27-37.

The on-farm impact of average long-term cropland erosion in the black soil zone of Alberta on crop productivity in terms of net returns and land values is measured for existing and selected alternative conservation-oriented management systems. The study uses a recently developed Soil Conservation Economics (SOILEC) model designed to simulate long-run (50 years) physical and financial consequences of soil erosion under alternative production management systems. The model first estimates the long-term average annual soil loss by weight per unit area through water erosion using the Universal Soil Loss Equation (USLE). The estimate is then translated into average annual productivity loss. The average annual loss of topsoil varies from 3-5 t/ha, doubled if the wind erosion component is added. In all, 54 Mt of topsoil loss is estimated annually, 31 Mt through water erosion and 23 Mt through wind erosion. Under the short-term (1 year) planning horizon, the existing management system obtained $5.36/ha more of annual present-value net returns and $50/ha more of land value than the conservation-oriented system, primarily due to higher variable costs associated with the conservation system. Economic benefits from soil conservation are clear, but on-farm economic incentives for farmers in the black soil zone to adopt erosion control measures are weak and insufficient both in the short- and the long-run. The conclusions relate directly to the black soil zone, although a few broad generalizations are also noted.

Summary

Methods: The USLE model is used to estimate erosion rates. The SOILEC model translates soil loss into productivity losses. Four erosion phases were defined:
1) no erosion - A & B horizons remain intact;
2) Medium erosion - 10cm of A horizon remains;
3) severe erosion - No A horizon remains; and
4) very severe erosion - No A or B horizon remains.

This does not include wind erosion estimates.
Degradation: Erosion
Crop: Wheat, barley, canola
Soil: Dark Brown and Black Chernozemic
Land Mgmt: The management practices for each mapping unit are outlined in Table 4. Both continuous and fallow cropping practices were used for all crops except canola.
Location: Four cropping regions in Alberta: Lethbridge, Red Deer, Barrhead, and Vermillion.
Impact:

Results

Table 5.Estimated effects of erosion on yields in four soil zones (relative productivity %)

Crop	Topsoil eroded 100% loss	50% loss	Not eroded
Brown Chernozemic			
Wheat	50	80	100
Barley	50	80	100
Dark brown-black chernozemic			
Wheat	70	90	100
Barley	70	90	100
Canola	50	80	100
Gray and dark gray Luvisol			
Wheat	40	70	100
Barley	40	70	100
Canola	20	50	100
Solonetzic			
Wheat	10	40	100
Barley	10	40	100
Canola	0	30	100

Table 6.Average yield by erosion phases in the major crop regions, Black soil zone.

Crop region	Crops specified	Yields by erosion phases (t/ha) Phase 1	Phase 2	Phase 3	Phase 4
Southern	Wheat on stubble	2.01	1.99	1.85	1.59
	Barley on stubble	2.34	2.31	2.17	1.47
	Tame hay	1.07	1.07	1.00	1.00
Red Deer	Wheat on fallow	3.35	3.30	3.13	2.11
	Wheat on stubble	2.82	2.77	2.61	1.78
	Barley on stubble	3.17	3.12	3.00	1.99
	Canola on fallow	1.20	1.17	1.03	1.07
	Tame hay	2.11	2.05	1.98	1.58
Barrhead	Wheat on fallow	2.92	2.85	2.71	1.84
	Winter wheat on stubble	2.92	2.85	2.71	1.84
	Barley on stubble	2.41	2.35	2.23	1.52
	Canola on fallow	0.84	0.80	0.73	0.48
	Tame hay	2.11	2.05	1.98	1.58
Vermilion	Winter wheat on stubble	2.70	2.63	2.48	1.70
	Barley on stubble	2.14	2.09	1.98	1.35

Canola on fallow	1.20	1.14	1.04	0.68
Wheat on fallow	2.70	2.63	2.48	1.70
Tame hay	1.46	1.40	1.32	0.90

Productivity Abstract:
Yields reported in this study are area average yields that were not differentiated by management practice (other than continuous vs fallow) or erosion phase. The main purpose of this study is to illustrate that yield losses are occurring in Alberta and these losses negatively affect the producer's net income. The short term impact of erosion is not severe but over the long term farmers will benefit from suggested conservation practices.

Keywords: Erosion, costs, SOILEC model, Alberta, long term effects, conservation, wheat, barley, canola, fallow, stubble.

17. Papendick, R. I., Young, D. L., McCool, D. K., and Krauss, H. A. 1985. **Regional effects of soil erosion on crop productivity -The Palouse area of the Pacific Northwest [USA].** Pages 305-320 in Follett, R. F. and Stewart, B. A. eds. Soil erosion and crop productivity, American Society of Agronomy, Madison, Wisconsin.

Wheat yields are projected to increase from technological progress in the foreseeable future. This yield growth will essentially mask the adverse effect of erosion on productivity. However, on land classes where the topsoil was originally thin or lost by accelerated erosion, projected yields will level off or even decline with continuing erosion because successively shallower topsoils become less productive and respond less to technological advances. Thus, future wheat yields and yield growth in the Palouse and other areas of the Northwest wheatlands that are subject to erosion will depend more and more on how well erosion is controlled.

Summary

Methods: Historical yield records from 1934 to 1976 were used to show how technological advances have masked the effects of erosion on productivity. The impacts of technological advances on yield are both additive and multiplicative. Topsoil depth-yield response relationship determination is also discussed.
Degradation: Erosion
Crop: Wheat
Soil:
Land Mgmt: Historical yield data did not include management practice information other than fertilizer application rates and the use of new seed varieties.
Location: Whitman County, Washington
Impact: The impact of technology was determined to be multiplicative as the 1970-75 yield response curve had a significantly steeper slope than the yield response curve developed from the 1952-53 yield data.

Results

Table 3.Projected wheat yield loss from soil erosion for two 25-year periods.

Land class	Period 1950-1975	1975-2000	Total (50 yrs)
	----------------kg/ha-----------------		
II	241	931	1172
III	649	2402	3051
IV	7812	28644	36456
VI	4094	20379	24473
Weighted average all classes	1936	7494	9430

Productivity Abstract:
Various projects which have been done in the Palouse region were summarized. The focus is on the impact of technological advances on crop yields. The topsoil depth-yield relationship has been described in many ways from a linear function to the non-linear Mitscherlich-Splillman function. The authors adopt the latter functional form when illustrating the difference between additive and multiplicative impacts of technology on yield. Different land classes reacted differently to erosion because of differences in the amount of erosion that had already occurred, and the existing topsoil depths. Technology has a greater positive impact on those land classes with less erosion. The marginal effect of topsoil loss is much lower in deep-soiled land classes. Land classes IV and VI illustrate this difference between the yield response of highly erosive shallow soils and deeper less erosive soils. The yields from Class IV had already levelled off by 1950 and will decline as erosion continues. Land Class VI yields are shown to level off by the 1980s. Classes II and III continue to increase in a linear fashion because of the deep topsoil and lower erosion rates.

Keywords: Erosion, wheat, historical yields, technology impacts, Idaho, topsoil depth, model, review.

18. Rennie, D. A. 1986. **Soil degradation, a Western perspective.** Can. J. Agric. Econ. 33: 19-29.

The article examines the types and impact of soil degradation in Canada's 4 western provinces and assesses the costs. Seen in a variety of forms, including erosion (mainly water erosion),man- made salinization, organic matter loss, acidification, drainage, compaction and subsidence, the costs of soil degradation in British Columbia, Alberta, Saskatchewan and Manitoba total around $1500 million annually, to be borne primarily by the agricultural sector and the Canadian consumer. Although the processes leading to soil degradation are well understood, much more investigation is needed before proper assessment of the processes on Canada's highly complex soil types can be made. It is clearly important to farmers, however, that the trend in soil quality be reversed and that soil conservation practices be introduced. The present problem of an unacceptably low allocation of soil research resources must therefore be remedied.

Summary

Methods: This paper documents the impact and assesses the costs of all types of soil degradation in the Prairie provinces.
Degradation: erosion, salinization, acidification.
Crop: Wheat
Soil:
Land Mgmt:
Location: Canadian prairies
Impact:

Results

Table 7. Costs of soil degradation, Alberta.

Process	Justification	Costs $ x million
Salinity	0.67 M ha of man made salinity; yield loss = 800 kg/ha; wheat worth $150/t, does not include loss on 0.34 M ha of pedogenic salinity	80.4
Soil organic matter - N	Equivalent to 80% of N consumption OR 240000 t N; cost=$0.6/kg N	144.0
Acid soil	a) 0.34 M ha st. acid soil; yield return = 15% or 300 kg/ha; wheat price = $150/t	
	b) cost of maintaining pH on soils with pH < 6.0; area=1.6 M ha; 3.5 kg lime required/1 kg N used; lime priced at $35/t	4.8
Erosion	Equivalent to total loss of topsoil on 1.8 M ha; 50% yield reduction	200.0
	TOTAL	429.2

Table 8.Estimated annual cost of soil degradation in Saskatchewan

Cause	Basis of estimate	Annual cost $ million
Salinity	1.0 M ha of slightly to moderately saline soils (due to poor management). Estimated yield loss 800 kg/ha wheat prices at $150/t	120
Erosion	11 M ha seeded: 30% upper and mid slope. Average of cm topsoil lost in 110 years. Yield loss 70 kg/cm topsoil.	220

Acidity	1.14 M ha with pH < 5.5. On these soils there is a yield loss of 15%	50
Nitrogen	Of 0.23 M tonnes of N applied, 60% is needed due to soil loss of N	80
	Gaseous loss of 6 M ha. N losses average 25 kg/ha/yr. N costs $0.60/kg	90
	Total	560

Table 9. Annual costs of soil quality deterioration - Manitoba

Cause	Basis of estimation	Annual costs
Erosion		
wind	14130 ha of moderately eroded soils with yield reductions of 10%	$5,123,000
water	37500 and 9400 ha of moderately and severely eroded soils with 25 and 50% yield losses, respectively	4,655,300
Salinity	243000 ha cultivated land with 15% yield loss	12,000,000
	120000 ha uncultivated land with up to 100% yield loss	22,000,000
	Total	43,778,300

Productivity Abstract:
The costs that are summarized in this paper exceed previous estimates. The productivity changes are not discussed in any detail as the only crop considered in all three provinces is wheat. No specific soil series are discussed.

Keywords: degradation costs, erosion, salinity, acidity, Manitoba, Saskatchewan, Alberta, wheat.

19. Tanaka, D. L. and Aase, J. K. 1989. **Influence of topsoil removal and fertilizer application on spring wheat yields.** Soil Sci. Soc. Am. J. 53: 228-232.

Topsoil loss by wind and water erosion has reduced crop productivity and created soil management problems. Crop yield-soil loss relationships vary, depending on soil, climate, crop, and management practices. The purpose of this study was to determine the relationships among the surface soil removal and additions of nitrogen (N) and phosphorus (P) fertilizer on spring wheat yields and yield components. Soil was mechanically removed from the surface of a Williams loam (fine-loamy mixed, Typic Argiboroll) to 0.00-, 0.06-, 0.12-, and 0.18-m depths in a spring wheat (Triticum aestivum L.)-fallow rotation. Three levels of N (0, 35, and 70 kg ha^{-1}) and three levels of P (0, 20, and 40 kg ha^{-1}) were applied in all combinations to each soil removal treatment prior to seeding a spring wheat crop. In 3 of 5 years, soil removal treatments reduced spring wheat yields an average of 9, 28, and 45% for 0.06-, 0.12- and 0.18-m soil removal treatments, respectively, when averaged over all fertilizer treatments compared to 0.00-m soil removal treatment. The other 2 years were water limiting and soil removal treatments were not a factor. Application of 20 and 40 kg ha^{-1} of P fertilizer increased grain yields 75 to 400 kg ha^{-1} with yield increase associated with in increase in heads m^{-2} and kernels $head^{-1}$. Phosphorus application tended to decrease grain N concentration because grain yields were increased which caused a dilution in grain N concentrations. Application of 35 and 70 kg ha^{-1} of N, in combination with either 20 or 40 kg ha^{-1} of P, resulted in greater grain yield increases when compared to N application without P. Generally 70 kg ha^{-1} of N and 20 kg ha^{-1} of P increased grain yields on 0.06-, 0.12-, and 0.18-m soil removal treatments to at least the same yield as 0.00-m soil removal treatment without N or P fertilizer. These data suggest P was the most limiting nutrient and additions of N fertilizer without P resulted in small yield increases.

Summary

Methods:	Topsoil was removed to create four levels of erosion (0.0, 0.06, 0.12, and 0.18 m. There were also three levels of fertilization (N:P - 0:0, 35:20, and 70:40)
Degradation:	Erosion
Crop:	Spring wheat
Soil:	Williams loam - fine-loamy, mixed Typic Argilboroll
Land Mgmt:	
Location:	Sidney, Montana
Impacts:	Yields obtained from the non fertilized plots were reduced by 7, 39, and 44 % respectively when 0.06, 0.12, and 0.18 m of topsoil was removed.

Results

Table 3.Treatment means,analysis of variance, and single degree of freedom comparisons for spring wheat grain yield.

	Grain yield (kg/ha)				
Treatments	1982	1983	1984	1985	1986
Soil removal					
S1	1204	1604	1756	1179	3002
S2	1041	1506	1673	1200	2725
S3	877	1000	1594	1196	2286
S4	573	703	1431	1194	1937
Phosphorus					
P1	756	1049	1283	1016	2161
P2	954	1226	1715	1243	2540
P3	1061	1336	1842	1317	2762
Nitrogen					
N1	859	1156	1572	1171	2066
N2	956	1222	1633	1181	2570
N3	957	1233	1636	1225	2827
Soil removal	*	*	NS	NS	*
S1 vs rest	*	*	NS	NS	*
S2 vs S3 & S4	*	*	NS	NS	*
S3 vs S4	*	*	NS	NS	*
Phosphorus	*	*	*	*	*
P1 vs rest	*	*	*	*	*
P2 vs P3	*	*	*	*	*
P X S	NS	*	*	NS	NS
Nitrogen	*	NS	NS	NS	*
N1 vs rest	*	*	NS	NS	*

N2 vs N3	NS	NS	NS	NS	*
N X P	NS	NS	NS	NS	*

*= significant at 0.05 probability level; NS = not significant
S1 = 0.0m soil removal; S2 = 0.06m soil removal; S3 = 0.12m soil removal;
S4 = 0.18m soil removal; P1 = 0 kg/ha of P; P2 = 20 kg/ha of P;
P3 = 40 kg/ha of P; N1 = 0 kg/ha of N; N2 = 35 kg/ha of N; N3 = 70 kg/ha of N.

Productivity Abstract:
There were significant differences in yields when no fertilizer was added and various amounts of topsoils removed. Two years were exceptions, 1984 and 1985. This was attributed to limited amounts of water. All levels of soil removal produced significant differences in yield. The three year average (1982, 1983, and 1986) yield reductions the three levels of soil reductions were 9, 28, and 45 % of the yield from plots that had no topsoil removed.

Keywords: Erosion, field study, wheat, Montana, USA, topsoil removal.

20. Van-Kooten, G. C., Weisensel, W. P., and De-Jong, E. 1989. **Estimating the costs of soil erosion in Saskatchewan.** Can. J. Agric. Econ. 37: 63-75.

This paper is a contribution to the debate regarding the measurement of the costs of soil erosion. It appears that many of the earlier studies which purported to estimate the on-farm costs of soil erosion have inadvertently measured user cost and not opportunity cost. In addition to shedding light on the problem of erosion-cost estimation, an empirical yield-soil depth response function is employed to re-estimate the user costs of soil erosion, using methodologies similar to those of the earlier studies. The results indicate that the user-cost measures are highly sensitive to the assumptions employed.

Summary:

Methods: This study describes a possible methodology or economic model determining the costs of soil erosion. The data used as the yield component in this study was from the Innovative Acres Program in Saskatchewan. The Mitscherlich- Spillman functional form was used to determined the yield response function.
Degradation: Erosion
Crop: Spring wheat
Soil: Dark Brown soil zone
Land Mgmt:
Location: Saskatchewan
Impact: Expected yield when the topsoil depth and soil moisture is zero is 84 kg/ha. The maximum yield is 2612 kg/ha.

Results

Table 2.Yield loss at various levels of solum depth and distribution of solum depth, Dark Brown soil zone, Saskatchewan.

Solum Depth cm	Marginal yield loss kg/cm/ha	Current year Pro-portion	Current year Area affected (000 ha)	In 35 years Pro-portion	In 35 years Area affected (000 ha)
0-5	235.493	0.025	105	0.087	365
5-10	24.123	0.062	260	0.082	344
10-15	2.471	0.082	344	0.089	374
15-20	0.253	0.089	374	0.089	374
20-25	0.026	0.089	374	0.084	353
25-30	0.003	0.084	353	0.077	323
30-35	0.000	0.077	323	0.069	290
> 30	0.000	0.492	2067	0.423	1777

Productivity Abstract:
Yield loss due to erosion is only a part of the total cost of erosion. The authors' estimates of long term soil loss (in 35 years) indicate a potential increase in yield loss. The critical topsoil depth is approximately 12.5 cm. Currently, only 17% of the cropland in Saskatchewan has less than 15 cm of topsoil. In 35 years the acreage could increase to 25% of the cropland. An important source of information used in this study is the Innovative Acre program.

Keywords: Erosion, cost analysis, topsoil depth, Saskatchewan, long term erosion effects.

21. Verity G. E. and D. W. Anderson. 1990. **Soil erosion effects on soil quality and yield.** Can. J. Soil Sci. 70: 471-484.

This study examines the cumulative effect of erosion on soil properties that are important to productivity, and estimated the effects of erosion on grain yields. Experiments were located in central Saskatchewan on Dark Brown soils of the Weyburn Association. The relationship between yields and the relative distance down eroded hillslopes was best described by a third order polynomial equation. Grain yields were the lowest on the upper slopes and increased steadily through the mid-slopes to maximum values that were often double the upper slope yield on the lower or foot slope, then decreased again in the more level parts of the field away from the slope. The impact of varying degrees of erosion on productivity was estimated by adding back incremental depths of topsoil to eroded knolls. Grain yields were increased by 45-58% by adding 50 mm of topsoil, with additional topsoil (100 mm or 150 mm) generally increasing yields slightly, but at a decreasing rate. Changes in soil quality with increasing erosion were measured on otherwise similar soils on eroded knolls, with a period of cultivation ranging from 0 (native) to 75 yr. Reduction in the amount of Cs^{137} in surface horizons with increasing periods of cultivation indicated the cumulative effect of erosion, with general soil losses of 20 to 30 Mg ha^{-1} yr^{-1}. Consistent reductions in silt plus very fine sand fractions with time suggested that wind erosion had been dominant. Organic C and P, total N and S decreased with increasing erosion. Potentially mineralizable N decreased at a faster rate than total N. The $CaCO_3$ content of the surface horizons increased and inorganic P remained constant with increasing degrees of erosion.

Summary

Methods: Topsoil was added to eroded sites such that there were four treatments: no topsoil added, 50 mm, 100 mm, and 150 mm. Catena samples were taken along a down hill slope.
Degradation: Severe erosion (wind).
Crop: Wheat (spring).
Soil: Dark Brown - Weyburn Association
Land Mgmt: Herbicide was applied to control grassy and broad leafed weeds. The seeding rate was 36 kg ha^{-1}. The fertilizer (ammonium dihydrogen phosphate) rate at seeding was 100 kg ha^{-1}
Location: Central Saskatchewan
Impacts: 45-58% increase in yield when 50 mm of topsoil was added.

Results

Table 1. Mean dry matter yields (kg/ha) associated with topsoil addition in 1986 and 1987.

Topsoil addition	Grain		Straw	
(mm)	1986	1987	1986	1987
0	914a	1143a	1290a	2030a
50	1343b	1627b	2094b	2389a
100	1443b	2150b	2187bc	2938bc
150	1327b	1964b	2369b	2917bc
fert. treatment	1068	1955	1857	2700

a-c means in the same column followed by different letters are significantly different at P <=0.05.

Statistical comparisons do not include fertilizer treatment.

Productivity Abstract:
This study compares yield increases that resulted from the addition of topsoil to the eroded upper slope of the same plots. Experiments were located in central Saskatchewan on hillslopes of Dark Brown soil. Grain yields were increased by 45-58% by adding 50 mm of topsoil. Further additions of topsoil resulted in yield increases which were not significantly different from the yields obtained when 50 mm of topsoil was added. Other studies were cited which indicated that there would be a 10 % yield loss due to erosion in hilly or hummocky fields.

Keywords: soil erosion, productivity, Saskatchewan, wheat, field study, topsoil added.

22. Young, D. L., Taylor, D. B., and Papendick, R. I. 1985. **Separating erosion and technology impacts on winter wheat yields in the Palouse: a statistical approach.** Pages 130-142 in Erosion and soil productivity: Proceedings of the National Symposium on Erosion and Soil Productivity, December 10-11, 1984, New Orleans, Louisiana.

Despite the doubling of wheat yields in this region over the last fifty years, yields would have been considerably higher in the absence of topsoil erosion. A statistical comparison of two topsoil depth - wheat yield response functions estimated with data collected in the eastern Palouse during the 1950s and 1970s suggests that technology has increased wheat yields by greater absolute amounts on deeper topsoil. However, the authors freely admit to the use of a sparse amount of data in this study and to the fact that it was based on certain unconfirmed assumptions.

Summary

Methods:	A crop yield response function to topsoil depth is used to disaggregate the influence of technical progress and topsoil erosion on crop yields through time. The theoretical examination of additive vs multiplicative interaction between technology and topsoil erosion influences measures the erosion damage on crop productivity. Statistical tests were used to investigate these theories.
Degradation:	Erosion
Crop:	Wheat was used as a sample crop.
Soil:	
Land Mgmt:	
Location:	Whitman County, Washington
Impact:	The yield response to topsoil thickness is assumed to be a concave non-linear function

Results

Two different regression equations developed from data from 1952-53 and 1970-75 were used to identify how technical advances have influenced yields.

Regression equations:

1953-53: $Y= 26.4 + 35.1\ [(1-0.90^{D})(1-0.60^{H})]$

Y= predicted wheat yield

D= topsoil depth

H=percentage organic matter in the top 6 inches of soil.

1970-75: $Y=38.92 + 40.50\ (1-0.9^{D})$

Productivity Abstract

Through the use of the t-statistic it was found that the slope coefficients of the two regression equations were significantly different. This indicated that there was a non-uniform multiplicative effect of technology over time. If the slope coefficients were not different then technology would have had an additive effect on yield. The complementary relationship between topsoil depth and technology implies that continued high rates of erosion in this region will stunt future yield payoff due to technical progress. This reinforces the economic justification for soil conservation. The limited information about management practices over time introduced some question as to the homogeneity of the data used in this study.

Keywords: erosion, regression, wheat, topsoil depth, technology.

Corn and Soybeans

23. Craft, E. M., Carlson, S. A., and Cruse, R. M. 1985. **A model of erosion and subsequent fertilization impacts on soil productivity.** Pages 143-151 in Erosion and soil productivity: Proceedings of the National Symposium on Erosion and Soil Productivity, December 10-11, 1984, New Orleans, Louisiana.

A Potential Yield Index (PYI) model was developed to estimate soil productivity based on simulated root growth and potential nutrient and water uptake for a corn crop through the growing season. The simulated root growth was sensitive to the soil environment. A new soil environment is encountered when topsoil is lost due to erosion. This may alter the root system and subsequent nutrient and water uptake. PYIs for 45 soils from 16 major soil associations in Iowa were predicted. The impact of soil erosion on soil productivity was estimated by evaluating changes in the PYI of these soils as 6 and 12 cm of soil were removed from the soil surface. The impact of fertilizer applications on soil productivity was evaluated by restoring the original levels of phosphorus and potassium fertility following erosion. When simulating 6 cm erosion without fertility restoration, PYI predictions on four of the soils remained within 5% of the original PYI, 23 soils had PYI predictions of 5-10% of the original PYI, and 15 soils had PYI predictions of 10-15% of the original PYI. When the original fertility was restored all but seven soils had PYI predictions within 5% of the original PYI. Doubling the soil erosion loss, simulating 12 cm erosion, resulted in further reductions in the predicted PYIs. Only 12 of the 45 soils were within 15% of the original PYI and 18 of the 45 soils were within 20-30%. When the original fertility was restored, 27 of the soils maintained PYIs within 5% of the original PYI.

Summary

Methods:	A potential yield index (PYI) was developed to estimate soil productivity using a crop growth model.
Degradation:	Erosion
Crop:	Corn
Soil:	Forty-five soils from 16 major soil associations
Land Mgmt:	Conventional tillage assumed with maintenance of moderate fertility levels assumed. Maximum profile depth was 150 cm.
Location:	Iowa
Impact:	Six cm eroded: without fertility restored, 90% of the 45 soils exhibited at least a 5-10% reduction in PYI. When fertility was restored 73% of the 45 soils had less than a 5% reduction in PYI.

Twelve cm eroded: without fertility restored, 97% of the 45 soils exhibited at least a 10-15% reduction in PYI. When fertility was restored 40 % of the soils had 5-10% reductions in PYI.

Results

Table 2.Percentage reduction in PYI for 45 soils after 6 and 12 cm erosion and under two levels of fertility management.

Reduction in PYI	6 cm erosion				12 cm erosion			
	no fertility restored		original fertility restored		no fertility restored		original fertility restored	
%	No.	%	No.	%	No.	%	No.	%
+5-10			5	11			4	9
0-5	4	9	33	73			23	51
5-10	23	51			1	2	16	36
10-15	15	33			11	24	1	2
15-20	2	4			11	24	1	2
20-25	1	2			12	27		
25-30					6	13		
30-35					3	7		
35-40					1	2		

Productivity Abstract

This study illustrates that the impact of erosion on soil productivity is largely determined by subsoil properties as they affect root growth and soil available water. Specific results were not given for each soil association. The authors note that their results confirm the concept that technology masks the erosion effects on yield.

Keywords: erosion, potential yield index model, corn, subsoil properties.

24. Crosson, P. R. and Stout, A. T. 1983. **Effects of erosion on productivity.** Pages 41-58 in Productivity Effects of Cropland Erosion in the United States. Resources for the Future, Washington, D. C.

This study is a contribution toward better understanding of the erosion threat to productivity. We have sought to achieve this by sorting through the literature in search of answers to four basic questions:

1) What do we presently know about the quantity of soil eroded from the nation's cropland?
2) What do we presently know about the effects of this erosion on the productivity of the soil, measured by national average crop yields (annual output per acre)?
3) For the nation as a whole, what is the economic cost of the loss of productivity?
4) What standard should we use in judging when the erosion induced loss in productivity is sufficient to justify national policies to reduce erosion?

Note that each of the four questions concerns national aspects of erosion amount, impacts, and policies. This is because our fundamental concern is with the threat of erosion to the nation's capacity to meet future demands for crop production at a reasonable cost. However, we believe that much of what we have to say is relevant to the interests of soil conservationists in their work with farmers.

Summary

Methods: Chapter 5 of this paper reviews and summarizes the information available concerning erosions impact on soil productivity. Studies are divided into Micro (short term field studies) and Macro (long term model simulations) studies.
Degradation: Erosion
Crop: Wheat, corn
Soil:
Land Mgmt:
Location:
Impact

Results

A) Microstudies

Table 5-1. Effect of topsoil thickness on wheat yield.

Location	Yield reduction per inch of topsoil bu/ac	percent	Remarks
Wooster, Ohio	1.7	9.5	virgin soil
Columbus, Ohio	1.3	5.3	cropped soil
Oregon	1.0	2.2	deep soil
Oregon	2.5	5.8	thin soil
Oregon	2.0	6.4	thin soil
Wooster, Ohio	1.5	6.2	
Geary Co., Kansas	1.3	6.2	
Palouse, Washington	1.6	6.9	loss of top 5 inches
Palouse, Washington	1.8	5.3	loss of top 11 inches
Pullman, Washington	1.4	2.9	
Manhattan, Kansas	1.1	4.3	Smolan silty clay loam
Akron, Colorado	0.5	2.0	Weld silt loam

From L. Lyles "Possible effects of wind erosion on soil productivity" (1975)

Table 5-2. Effect of topsoil thickness on corn yield

Location	Yield reduction per inch of topsoil bu/ac	percent	Remarks
Geary Co., Kansas	3.5	7.5	
Bethany, Missouri	3.0	6.4	Shelby and Grundy silt loam
Bethany, Missouri	4.0	6.0	Shelby and Grundy silt loam
Fowler, Indiana	4.0	4.3	Fowler, Brookston, and Parr silt loam
Fowler, Indiana	3.8	5.5	
Shennandoah, Iowa	6.1	5.1	Marshall silt loam
Greenfield, Iowa	3.2	5.0	Tama silt loam
Greenfield, Iowa	3.1	6.3	Shelby silt loam
Coshocton, Ohio	5.2	8.7	
Clarinda, Iowa	4.0	5.1	Marshall silt loam
Upham, North Dakota	3.4	7.4	
Wooster, Ohio	4.8	8.0	Canfield silt loam
Columbus, Ohio	3.0	6.0	Celina silt loam
E.Central, Illinois	3.7	6.5	Swygert silt loam

From L. Lyles "Possible effects of wind erosion on soil productivity" (1975)

B) Macrostudies

Three models were considered the current macrostudies:

1) The Yield-Soil Loss Simulator (Y-SLS)
2) The Productivity Index (PI) model from the University of Minnesota
3) The Resources for the Future regression model.

Each is discussed in some detail, including a summary of recent results.

1) Y-SLS. There are 210 yield-soil loss equations in this simulator. Crop yield was made a function of topsoil depth, subsoil depth (two horizons), average slope of land, land suitability subclass, soil texture, whether the land was irrigated or rainfed and the producing area within the water resource region. Yield losses were estimated over a period of 50 years. The overall results were that if erosion continued at the 1977 rate, there would be an 8% reduction in yields over a 50 year time period.Because it was the first model of its kind, there were problems validating all assumptions that were made during its development. The results, however, seem to be consistent with the other two macrostudies.

2) PI model. This model used a modification of the Kiniry crop rooting model. Yield was related to four soil characteristics, bulk density, available water capacity, pH, and permeability. Each of these characteristics were considered to a depth of 1 meter (3 soil layers or horizons). The top layers is given the most weight when calculating the index, as that is where the root density is the highest. The PI has a value that ranges from 1 to 0, with the most productive soil having an index of 1.0. Using the 1977 erosion rates, long term losses in productivity were calculated for three important crop regions. Major Land Resource Areas (MLRAs) 105 (Minnesota), 107 (Iowa), and 134 (Arkansas,Louisiana) were used.

	Percentage yield loss	
MLRA	50 years	100 years
105	3	5
107	2	3
134	3	5

These losses were averaged over all slope classes. Maximum yield losses typically occurred when the slope was greater than 6%.

3) RFF regression study. This study attempts to determine the effects of erosion on past yields. Table 9 summarizes the results of the regression analysis done using different sample sizes and parameters. The regression variables included:

Slope = the trend value of the county yields of corn, soybean, and wheat found by fitting the a simple least squares equation to the annual yield data (1950-1980). This is a dependent variable.
USLE = annual erosion in tons per acre of land in each crop in each county, taken from the 1977 NRI.

RKLS = potential annual erosion in tons per acre of land in each crop in each county, taken from the 1977 NRI. This is erosion that would occur on land in bare fallow. It is always more than actual erosion measured by USLE, the amount of difference depending on the strength of the C and P factors in reducing erosion.

Y52 = average yield in each county in 1950-1954 in bushels per acre.

ACD = a dummy variable; for counties in which land in the crop between 1950 and 1980 was never less than 5000 acres ACD=1. For all other counties ACD=0. Data were from state crop reporting services.

IRD = a dummy variable; for all counties in which 2 percent or more of land in crop was irrigated in 1977 IRD=1. For all other counties IRD=0. Data were from the 1977 NRI.

Table 9.Estimated effects of erosion on the trend of crop yields, 1950-80.

	Regression number	Reduction in yield trend because of erosion as a % of mean yield trend
Corn (616 co.)		
All USLE	1	4a
Corn (341 co.)		
All USLE	3	1
USLE > 5	5	3b
10<=USLE<=20	7	18c
USLE > 20	8	3
Soybeans (299 co.)		
All USLE	9	4a
USLE > 5	11	4b
10<=USLE<=20	13	22
USLE > 20	14	2
Wheat (191 co.)		
All USLE	15	1
USLE > 5	18	d

a) Regression coefficient for USLE significant at 1 percent probability
b) Regression coefficient for USLE significant at 10 percent probability
c) Regression coefficient for USLE significant at 5 percent probability
d) Less than 1 percent

When the USLE is used to estimate erosion, both corn and soybean annual trends are significantly reduced. Wheat trends, however, do not appear to be affected by the erosion estimated by USLE. This may be due to the exclusion of wind erosion and snow meltoff erosion effects.

Productivity Abstract
This document discussed many issues that are of importance when discussing soil degradation, specifically soil erosion. Chapter 5 dealt only with soil erosion-soil productivity research issues. Questions of measuring the physical processes of erosion, policy decisions, and technology transfer

were also discussed in this comprehensive report. The macrostudies do not include very much information about management practice or soil type. As a result, the yield response to erosion is not fully explained by any single model. A combination of the principles explored to date may be in order. This study was done prior to the completion of EPIC.

Keywords: Erosion, corn, soybeans, wheat, review, models, historical yields, USLE, Y-SLS.

25 Daniels, R. B., Gilliam, J. W., Cassel, D. K., and Nelson, L. A. 1987. **Quantifying the effects of past soil erosion on present soil productivity.** J. Soil Water Conserv. 42: 183-187.

Most research relating crop productivity to soil erosion has been based on two assumptions: all soil properties of the experimental site were similar when first cultivated and the productivity of the site was uniform until erosion occurred. This approach relates reduction in yield on eroded sites to erosion severity. Both assumptions are usually false because soil variability is high in landscapes subject to moderate to severe erosion when cultivated. Most gently rolling landscapes were shaped by erosion (geologic) even before they were cultivated. Within such landscapes, soil properties differ in texture from the original soil material, as well as duration of weathering. Soil surface shape and position with respect to other elements of landscape can lead to differences in the amount of water available during the growing season. Few, if any, soil erosion-productivity studies have adequately accounted for the effect of natural soil variability in erosional landscapes on soil productivity. Baseline data from virgin soils are lacking in most areas.

Summary

Methods: Reports on the different sources of soil variability and how each may effect crop yield. Each of these sources should be considered when test sites for the effect of erosion on crop yields are being chosen.
Degradation: Erosion
Crop: Corn, soybeans
Soil:
Land Mgmt:
Location:
Impacts:

Results

Productivity Abstract
This article discusses elements of plant production and different soil characteristics which should be considered when trying to quantify the effects of erosion on crop yields. Most studies do not include soil variability in the analysis of yield differences. The variability of soil materials in a field (particle size, past weathering, permeability, and potential to produce or receive runoff, landscape position) almost precludes the possibility that all soils in a field were of equal productivity when first cultivated. Regression analysis may be the best method of dealing with all these factors. However, regression analysis will not determine if there was a difference in productivity of the soils before erosion occurred.

Keywords: review, erosion, quantifying effects, soil variability.

26. Gantzer, C. J., and McCarty, T. R. 1985. **Corn yield prediction for a claypan soil using a productivity index.** Pages 170-181 in Erosion and soil productivity: Proceedings of the National Symposium on Erosion and Soil Productivity, December 10-11, 1984, New Orleans, Louisiana.

An on-site evaluation of Soil Productivity Index (SPI) for a silt loam claypan soil (Mexico series) was carried out in Boone County, Missouri. To simulate the effect of different degrees of erosion, depths of topsoil of 0.0, 12.5, 25 and 37.5 cm were selected for study. A preliminary survey of soil depth was made prior to construction of the plots. Location of the interface between A and B horizons was found to be 25+3 cm making the 25 cm depth the check treatment. Actual construction of the plots was done by using an elevating scraper to remove 12.5 cm of soil from randomly selected plots for the 12.5 cm treatments. Measurements from the original ground level were made in order to determine when 12.5 cm of soil had been removed. This soil material was then added to randomly assigned plots in order to produce the 37.5 cm treatment plots. All topsoil was removed from the zero topsoil treatment plots and stockpiled off site. The results suggest that the date for root water extraction to reach a given depth was progressively delayed for treatments with lesser amounts of topsoil. Significantly less water depletion occurred with a 0.0 topsoil treatment for depths from about 50 to 100 cm in the profile. Highly significant linear and quadratic treatment effects for yield were present; however, the majority of yield reduction was found between the 0.0 and 12.5 cm topsoil treatments. Yield results suggest that for these soils a significant improvement in the SPI could be achieved through incorporation of a quadratic component into the index.

Summary

Methods: Yields were measured from artificially eroded experimental plots known as ERASE plots (Erosion Recovery and System Evaluation). Topsoil was removed and added to define 4 levels of topsoil: 0.0, 12.5, 25.0 and 37.5 cm. Extensive data for precipitation, evapotranspiration and plant physiology were also collected.
Degradation: Erosion
Crop: Corn
Soil: Mexico, fine, mesic, Typic Ochraqualf
Land Mgmt: All plots were fertilized at high levels, reducing the significance of differential fertility on crop yield.
Location: University of Missouri experimental fields, Columbia, Missouri
Impacts: Yields increased significantly at the 12.5 cm topsoil level. Further additions of topsoil did not increase the corn yields significantly.

Results

Table 4.Analysis of corn yields from ERASE plots, Columbia Mo 1984

Source	PR>F	Topsoil Depth cm	Mean Yield kg/ha

Rep	0.31NS	0.0	3637
Treatment	<0.01	12.5	5892
linear	<0.01	25.0	6017
quadratic	0.02	37.5	6140
	R squared=0.78	Average	5421

Table 5.Predicted and observed corn yield for the ERASE plots, Columbia, MO 1984, using the linear regression model:

$$Yield(kg/ha) = -3186 + 12{,}195\ PI + e$$

Depth of Topsoil	PI	Observed Yield	Predicted Yield	Residual Yield
cm	%	--------------	kg/ha	--------------
0.0	0.615	3637	4315	-678
12.5	0.679	5892	5095	797
25.0	0.725	6017	5656	361
37.5	0.804	6140	6620	-480

Table 6.Predicted and observed corn yield for the ERASE plots, Columbia, MO, using polynomial regression model:

$$Yield(kg/ha) = -71{,}387 + 205944\ PI - 136{,}302\ PI^2 + e$$

Depth of Topsoil	PI	Observed Yield	Predicted Yield	Residual Yield
cm	%	--------------	kg/ha	--------------
0.0	0.615	3637	3715	-78
12.5	0.679	5892	5608	284
25.0	0.725	6017	6278	-261
37.5	0.804	6140	6084	56

Productivity Abstract

The authors suggested that the soil productivity index could be improved through the incorporation of a quadratic component into the index. The soil series and plots used were very well described. The residuals from the regression models support this in that they are lower than the residuals from the linear equation (see tables 5 and 6).

Keywords: regression model, corn yield, topsoil depth, ERASE plots, productivity index model, erosion.

27. Heimlich, R. E. 1989. **Productivity and erodibility of U.S. cropland.** USDA, Econ. Res. Service, Report No.604. 21 pp.

Soil erosion policy aiming to remove highly erodible land from production to reduce soil erosion may be dealing with some of the most productive and valuable U.S. cropland. If so, greater incentives for farmer to retire that land may be needed. The land capability classification system and the USDA's prime farm land definition, used to measure the suitability of land for agricultural uses, do not provide enough information for decisions on whether highly erodible are less or more productive than less erodible soils. As a result, some highly erodible lands that are also highly productive may have higher opportunity costs than commonly thought and thus may need greater incentives for retirement. Opportunity costs measure the earning power of an input, soil in this case, in its best alternative use.

Summary

Methods: National soil databases were used as input to determine:

1) where and to what degree cropland is erodible in the U.S.;
2) measures of soil productivity (crop yields, field crop revenues);
3) the erodibility of various soil landscapes; and
4) the land capability class.

There were four levels of erodibility: highly; moderately; wind; and nonerodible. Actual erosion levels are not defined.

Degradation: Erosion

Crop: Corn

Soil:

Land Mgmt:

Location: Cropland USA

Impact: The highly erodible soils in Land Capability classes IV-VIII are more productive than the nonerodible soils in the same classes. Corn grain yields are 7 % greater in the highly erodible soils than in the nonerodible soils.

Results

Table 5.Corn grain yield by erodibility and land capability class, 1982*

Land capability class	Erodibility class: Non erodible	Moderately erodible Below T	Moderately erodible Above T	Highly erodible	Wind erodible	All crop land
	bu/ac**					
I-III	99	92	96	88	82	94
IV-VIII	69	70	71	74	64	71
All	97	91	95	84	79	92

*Area weighted averages of nonirrigated cropland exclude missing corn yields
**Mean yields for erodibility groups and land capability classes are statistically different according to the Waller-Duncan k-ratio test, with k equalling 100, approximately equal to the 0.05 significance level.

Table 6.Corn grain yield by erodibility and prime farmland definition, 1982.*

Prime farmland definition	Erodibility class: Non erodible	Moderately erodible Below T	Moderately erodible Above T	Highly erodible	Wind erodible	All crop land
	bu/ac**					
Prime	106	96	99	93	86	99
Nonprime	76	80	83	82	69	79
All	97	91	95	84	79	92

*Area weighted averages of nonirrigated cropland exclude missing corn yields
**Mean yields for erodibility groups and land capability classes are statistically different according to the Waller-Duncan k-ratio test, with k equalling 100, approximately equal to the 0.05 significance level.

Productivity Abstract
Land classified as highly erodible is not necessarily less productive than nonerodible land. Thus, differences in yields by erodibility classes were not dependent on land capability class. There is a lack of little yield data from the nonerodible land category. This lack of relationship between yields, erodibility and land capabilities classes presents problems for policy makers when land that is highly erodible and also highly productive. The current classification system regards highly erodible land as non-productive land. Current productivity and long term productivity potential estimates should be included in the development of land classification.

Keywords: Erosion, erodibility, policy, corn yield, regression, national databases, US cropland.

28. Henning, S. J., and Khalaf, J. A. 1985. **Topsoil depth and management effects on crop productivity in north central Iowa.** Pages 59-65 in Erosion and soil productivity: Proceedings of the National Symposium on Erosion and Soil Productivity, December 10-11, 1984, New Orleans, Louisiana.

A loam topsoil (Hapludoll) was removed from a site in north central Iowa, and after further removal of large quantities of subsoil, the topsoil was replaced at depths of 0, 15 or 30 cm. Selected management practices such as the growth of alfalfa and the use of fungicide on soybeans were included to determine if they would lessen the loss of productivity where topsoil thickness was diminished. Corn and soybean production were initiated (1) immediately and (2) after two years of alfalfa growth following the restoration of topsoil. Corn yields were increased by the replacement of topsoil, but there was no significant difference between 15 or 30-cm depths. Soybean yields increased as topsoil thickness increased. Alfalfa growth before initiation of row crop production did not increase corn yields but did increase soybean yields. Previous alfalfa growth increased the survival of soybean plants as did the fungicide treatment.

Summary

Methods: Topsoil was removed to expose a calcareous, un-weathered subsoil. Topsoil was then added back to the plots in two amounts, creating three topsoil depths, 0, 15, and 30 cm. There were also two alfalfa treatments: no previous alfalfa growth; and two years growth of alfalfa prior to row crop production. Soil properties such as pH, bulk density, available P, and available K were recorded at different soil depths during the experiment.
Degradation: Erosion
Crop: Corn, soybeans
Soil Nicollet loam, Aquic Hapludoll Clarion loam, Typic Hapludoll
Land Mgmt: The corn planting rate was 51600 seeds/ha and the soybean planting rate was 67.2 kg/ha. Fertilizer was applied such that nutrients would not be a limiting factor. Fungicide was applied to the soybeans plots. All plots were chisel ploughed and disced in the fall.
Location: Hamilton County, Iowa
Impact: Corn yields were significantly increased when 15 cm of topsoil was added. Yields did not increase further when more than 15 cm of topsoil was added. Soybean yields, however, were significantly increased by the addition of 15 cm of topsoil and also

the addition of 30 cm of topsoil.

Results

Table 4.Corn yield response to topsoil depth and alfalfa treatments

Topsoil depth	Year			
	1979	1980	1981	1982
cm	kg/ha			
	No alfalfa			
0	4733	4720	6806	5205
15	8554	5020	7471	4956
30	7831	4620	8561	5030
	Alfalfa			
0			7135	4412
15			7895	4324
30			8420	5851

Table 5.Soybean yield response to topsoil depth and alfalfa treatments.

Topsoil depth	Year			
	1979	1980	1981	1982
cm	kg/ha			
	No alfalfa			
0	1270	1020	514	986
15	2602	2130	1470	1916
30	2732	1950	1893	2040
	Alfalfa			
0			1706	1221
15			2414	2224
30			2884	2436

Table 7.Analysis of variance of row crop yields to topsoil depth, alfalfa and fungicide treatments.

Source	df	Year			
		1979	1980	1981	1982
		Corn			
topsoil depth	2	**	NS	**	NS
0 vs 15 & 30 cm	1	**	NS	**	NS
15 cm vs 30 cm	1	NS	NS	NS	NS
Alfalfa	1	--	--	NS	NS
		Soybeans			
topsoil depth	2	**	**	**	**
0 vs 15 & 30 cm	1	**	**	**	**
15 cm vs 30 cm	1	NS	NS	**	**
Alfalfa	1	--	--	*	*
fungicide	1	--	--	--	NS

**,*,NS significant at 1 and 5% levels and not significant, respectively.

Productivity Abstract

Soil characteristics and management records are well documented in this study. The key result was that corn yields only exhibited significant differences in yield when 15 cm of topsoil was added to the subsoil. Further topsoil additions did not increase yields. Stressful climatic conditions in 1980 and 1982 depressed all yields and there were no significant differences at any level. Soybean yields, however, did exhibit increases when more than 15 cm was added in 1981 and 1982. Corn yields were not improved by the alfalfa treatments while soybeans showed significant improvements with the alfalfa treatment at all levels of topsoil.

Keywords: erosion, topsoil depth, corn, soybeans, Iowa, field study.

29. Langdale, G. W. and Shrader, W. D. 1982. **Soil erosion effects on soil productivity of cultivated cropland.** Pages 41-55 in B. L. Schmidt ed. Determinants of Soil Loss Tolerance. American Society of Agronomy Special, Madison, Wisconsin.

Soil erosion always increases the cost of crop production and causes potential environmental hazards as well as human suffering. Erosion of soils by water reduces crop yields principally through the loss of nutrients and available water. Exposed subsoils caused by severe soil erosion also exhibit many adverse properties with respect to soil management for economic crop production. Agronomic implications of soil erosion by water in the United States have been derived mainly from limited research on Mollisols, Alfisols, and Ultisols. Because cultivated Ultisols of the southeastern USA are thinner and suffer problems associated with subsoil acidity, crop yield reductions appear more permanent and more difficult to restore. The permanency of soil erosion on crop yield reductions on many Mollisols soils appears ephemeral, because only additional quantities of N, occasionally P, and micronutrients are required to restore crop yields. Additional research is urgently needed to quantify crop yield losses associated with soil erosion and reduce the cost of restoring crop production to an economic competitive level on eroded landscapes. Research of this nature would also provide insights for controlling unacceptable soil erosion levels.

Summary

Methods:	Soil erosion-crop productivity research is reviewed.
Degradation:	Erosion
Crop:	Corn, soybeans, small grains
Soil:	Aquic Argiudolls, Seymour silt loam Typic Hapludolls, Marshall silty clay loam and Monona silt loam Typic Udorthents, Ida silt loam
Land Mgmt:	
Location:	Midwestern United States
Impact:	

Results

Table 3.Estimated percent crop yield reduction following topsoil removal.*

Soil series	Corn	Cotton	Soybeans	Small grains	Forages
Deep medium textured soils					
Beadle(Olson,1977)**	17	--	--	--	--
Chama(Black,1968)**	--	--	--	14	--
Gardena(Carlson,1961)**	19	--	--	--	--
Ida(Spomer,1973)**	8 to 30	--	--	--	--
Marshall(Engelstad,1961)	13 to 17	--	--	--	--
Monona(Spomer,1973)**	8 to 30	--	--	--	--
Grenada(Buntley,1976)	26	20	40	24	17
Memphis(Buntley,1976)	9	12	20	11	5
Shallow medium to coarse textured soils					
Brandon(Buntley,1976)	44	35	47	22	25

Cecil(Adam,1949;Langdale,1979)	40	38	22 to 31+	34	22
Groseclose(Batchelder & Jones,1972)**	36	--	--	--	--

*Assumed plant nutrients were supplied in sufficient quantity to eliminate nutrient stress for surface horizons.
**Studies associated with land forming disturbances.
+Minimum (inrow chisel) and conventional tillage, respectively.

Table 4b.Crop yield estimates associated with various levels of erosion in midwestern USA.

Degree of erosion	Crop yield+ Corn	Soybeans	Small grain	Forage
	q/ha			
Seymour silt loam (Aquic Argiudolls) 2.5 to 6.0% slope				
None	--	--	--	--
Slight	52	22	16	78
Severe	43	17	13	63
Marshall silty clay loam (Typic Hapludolls) 2.5 to 6.0% slope				
None	--	--	--	--
Slight	67	28	22	90
Moderate	62	26	20	85
Monona silt loam (Typic Hapludolls) 2.5 to 6.0% slope				
None	--	--	--	--
Slight	62	25	25	83
Moderate	56	23	23	76
Ida silt loam (Typic Udorthents) 6.0 to 9.9% slope				
None	--	--	--	--
Moderate	52	22	21	69
Severe	43	17	17	58

+ Fenton et al., 1971 (small grains-oats, forage-hay)

Productivity Abstract
Studies generally completed before 1979 are summarized in two tables. The main crops examined included corn, soybeans, small grains (oats), and forages. The majority of these productivity studies deal with corn. The types of research include topsoil removal or fill experiments and regression analysis of field data. The authors suggest that studies which use randomized plot designs may not accurately assess the effects of erosion on yields. Regression and topsoil removal/fill studies are not clearly distinguished from one another. Through various studies, it was shown that the technology needed to maintain yields on eroded soils differed depending on the soil properties and the extent of erosion.

Keywords: Erosion, review, corn, soybeans, small grains, Midwest, field studies, topsoil removal.

30. Larson, W. E., Fenton, T. E., Skidmore, E. L., and Benbrook, C. M. 1985. **Effects of soil erosion on soil properties as related to crop productivity and classification.** Pages 189-211 in R. F. Follett and B. A. Stewart, eds. Soil erosion and crop productivity. American Society of Agronomy, Madison, Wisconsin.

The effects of erosion on 8 benchmark soil series in the USA and the resulting problems for soil classification and mapping are reviewed. The effects of soil erosion on soil hydraulic properties such as available water capacity and runoff are considered, and the relation of soil properties to maize production potential for each of the 8 benchmark soils is given. A final section establishes a relationship between the productivity index and maize yields for several soil series.

Summary

Methods: Twelve soil profiles representing 8 soil series were selected from the USDA list of benchmark soils. These soils are commonly subjected to water erosion and row-cropping This article reviews the effects of erosion on soil properties and the relation of these properties to production potentials.
Degradation: Erosion (water)
Soils: Mollisols, Alfisols, Utilsols
Crop: Corn
Land Mgmt: High level management practices are assumed
Location: USA
Impact: Erosion degrades soil hydraulic conditions and decreases plant available water capacity. The generalized influence of water deficit on crop production is:

$$1 - \frac{Y_a}{Y_m} = Ky\left(1 - \frac{ET_a}{ET_m}\right) \quad where,$$

Ya = actual yield Ym = maximum yield
Ky = yield response factor ETa = actual evapotranspiration
ETm = maximum evapotranspiration

Results

Table 7.The influence of available water capacity (AWC) on relative yield decreases for specified conditions

Condition*	AWC	Initial available water	ETa/ETm	Relative yield decrease
	------cm-------			
1	6	6	0.40	0.60
	14	14	0.80	0.20
	20	20	0.94	0.06
2	6	6	0.40	0.60
	14	6	0.36	0.64
	20	6	0.32	0.68
3	6	6	0.92	0.08
	14	14	1.00	0.00
	20	20	1.00	0.00
4	6	6	0.77	0.23
	14	6	0.63	0.37
	20	6	0.53	0.47

*Calculations are for a 21 day period and are based on a soil depletion fraction (p) of 0.5. Conditions 1 and 2 received no additional water, whereas 3 and 4 had 3.0 cm of water added to available water after every seventh day. ETm was assumed to be 0.7 cm/day.

Table 9.Estimates of crop yields for selected phases of the Marshall and Seymour series.

Soil	Erosion phase	Corn	Soybeans
		-------Mg/ha--------	
Marshall	Slight	6.69	2.73
silty clay loam	Moderate	6.50	2.67
2-5% slopes	Severe	6.13	2.47
Seymour	Slight	5.50	2.20
silt loam	Moderate	5.19	2.13
2-5% slope	Severe	4.56	1.87

Productivity Abstract

The authors discuss the need for the development of more extensive guidelines for classifying eroded soils. Each soil series discussed is described in detail. Available water capacity is considered to be the main yield limiting factor. The Productivity Index Model was used as an indicator of soil productivity. The study examines the subsoil quality and how, as it is exposed by erosion, it can affect yields. The uneroded and eroded phases of a single soil series may create problems in soil classification as the two phases may no longer have similar characteristics (subsoil features are exposed).

Keywords: Water erosion, Productivity Index model, corn, available water capacity, Benchmark soils.

31. Mannering, J. V., Franzmeier, D. P., Schertz, D. L., Moldenhauer, W. C., and Norton, L. D. 1985. **Regional effects of soil erosion on crop productivity - Midwest.** Pages 271-284 in R. F. Follett and B. A. Stewart, eds. Soil erosion and crop productivity, American Society of Agronomy, Madison, Wisconsin.

The current estimates for crop yield reduction due to erosion in the Midwest of the USA and their development are reviewed. Research on quantitative field data relating soil erosion to productivity is reported and discussed in relation to future recommendations.

Summary

Methods: This paper had several objectives:

1. Review presently used estimates for crop yield reductions due to erosion in the Midwest;
2. Document how these estimates were developed;
3. Report new research efforts in the Midwest that are designed to provide quantitative field data relating soil erosion to productivity; and
4. Discuss the strengths and weaknesses of past and present research and develop recommendations for future research.

Degradation: Erosion
Soil: Fayette fine-silty loam, mixed, mesic Typic Hapludalf
Crop: Corn

Land Mgmt: Basic to high level management.
Location: Iowa, Indiana, Illinois, Ohio, Minnesota
Impact: The impact of erosion is dependent on slope, level of erosion and the native vegetation

Results

In Iowa:The Corn Suitability Rating represents the best method of estimating the effects of erosion on yield in this region (Midwest). The highest yielding soil, Muscatine, fine-silty, mixed, mesic Aquic Hapludoll was rated as 100 for purposes of comparison. For example, Fayette soil, fine-silty mixed, mesic, Typic Hapludalf rated 83 when moderately eroded.

Table 2.Some guidelines used in establishing CSR in Iowa for deep moderately fine textured soils

Soil Property	Adjustment Factor
Slope	
A. 0-2%	index soil
B. 2-5%	-5
C. 5-9%	-20
D. 9-14%	-30
Erosion	
1. none to slight	index soil
2. moderate	-2
3. severe	-5
Native vegetation	
prairie	index soil
prairie/forest	-5
forest	-10

Table 3.Comparison of estimated yield and CSR for some slope and erosion phases of Fayette silt loam soil.

Slope gradient	Erosion class								
	Slight			Moderate			Severe		
%	kg/ha	bu/ac	CSR	kg/ha	bu/ac	CSR	kg/ha	bu/ac	CSR
0-2	7212	115	90	--	--	88	--	--	--
2-5	7087	113	85	--	--	83	--	--	80
5-9	6773	108	70	6586	105	68	6271	100	65
9-14	6209	99	60	6021	96	58	5645	90	55

In Indiana:The CSR was adopted as the evaluation system with some modifications such the direct use of corn yields and 5 index soils rather the one.

In Illinois:Yields were estimated for each soil series, uneroded, 0-2% slope and adjusted downward as the slope and level of erosion increased.

In Minnesota:Yield potentials for uneroded soils were developed. No details were given as to how these potentials compared to the CSR.

A summary for each state in this region was found in Table 4.

Table 4.Estimated corn yields for various slope and erosion classes of deep, well drained soils with light coloured silt loam surface horizons

Slope gradient	Base yield*		Erosion class		
			slight	moderate	severe
%	kg/ha	bu/ac	-----% of base yield----		
Illinois (basic management)					
1(0-2)	4955	79	102	97	
4(2-6)			100	95	85
9(6-12)			96	91	81
15(12-18)			90	84	74
Indiana (average mgnt)					
0-2	6272	100	100	96	
2-6	6272	100	100	96	92
6-12	5770	92	92	88	84
12-18	5018	80	80	76	72
Iowa (high-level mgnt)					
0-2					
2-5	7087	113	100		
5-9			96	93	88
9-14			88	85	80
Minnesota (moderate level mgnt)					
0-2					
2-6	6586	105	100		
6-12			86		
12-18			71		
Ohio (average mgnt)					
0-2			104	100	
2-6	6899	110	100	96	88
6-12			96	92	84
12-18			88	84	77

*Base yields represent the Alford and Fayette series or a class of soils that include these series. Relative yields were calculated using the 2-6% slope, none to slight erosion phase. Sources of were derived from bulletins from respective state universities.

** Basic management includes the minimum input considered necessary for crop production to be feasible. High level management includes inputs that are near those required for maximum profit with current technology. Average management and moderate level management reflects what a majority of farmers are using.

Productivity Abstract

This review reports the results of ongoing or completed research in the mid-west U.S. The Corn Suitability Rating (CSR) is described and compared to estimated yields. This system of rating soils with different slopes, native vegetative cover, and erosion levels as compared to an index soil was used first in Iowa and then in Indiana, where there are one and 5 index soils, respectively. The authors advise that more field experiments need to be done on benchmark soils so that databases can be built in all the Midwestern states. These data bases are needed to validate the models being developed. Development of site specific models was also suggested.

Keywords: erosion, review, Midwest, field studies, models, Corn Suitability Rating.

32. Mielke, L. N. and Schepers, J. S. 1986. **Plant response to topsoil thickness on an eroded loess soil.** J. Soil Water Conserv. 41: 59-63.

Topsoil was added to an exposed C horizon of a loess soil in northeastern Nebraska in thicknesses of 0, 100, and 200 mm. The field was planted to dryland corn the first year, oats the second year, and corn the third and fourth years. Corn grain yield was significantly greater on the 100 mm and 200 mm topsoil treatments than with no topsoil; 200 mm was required to increase oat grain yield. Total dry matter production of oats generally was greater with the 100 mm and 200 mm treatments than with no topsoil on four sampling dates during the growing season. yield of corn and subsequent oat grain was not affected by adding 112 kg/ha of N over the base application of 34, 10, 10, and 7 kg/ha of N, P, K, and S, respectively, prior to the first corn crop. N concentrations in the oat plant and grain were not affected by topsoil thickness. Results indicate there are characteristics of topsoil beneficial to plant growth that, once gone, cannot be readily replaced simply by adding fertilizer.

Summary

Methods:	Topsoil added to exposed C horizon on ridgetops
Degradation:	Erosion (severe)
Crop:	Corn and oats
Soil:	Crofton-Nora complex: mesic Typic Ustorthent, mesic Udic Haplustolls
Land Mgmt:	Row and crop cover for several decades; some topsoil removed from the C horizon in 1978 and used as fill.
Location:	Near Stanton Nebraska
Impacts:	Corn yields were significantly higher in the 100 mm and 200 mm treatments than when no topsoil was added. Oat yields were significantly higher only when 200 mm of topsoil was added.

Results

Table 5.Corn yield and plant growth response to thickness of topsoil on an eroded Crofton-Nora soil, 1981

Topsoil Thickness (mm)	Corn Yield (t/ha)	Plant Population (plant/m2)	Ear Weight (g)	Ears per plant
0	7.8	2.7	264	1.08
100	8.7	2.9	288	1.04
200	8.6	3.1	284	1.00
LSD(0.05)	0.7	NS	NS	0.06

Table 6.Summary of the crop yield response relative to 200 mm topsoil thickness on an eroded Crofton Nora soil, 1981 to 1984.

Topsoil Thickness (mm)	1981 Corn grain	1982 Oats Grain	1982 Oats Residue	1983 Corn residue	1984 Corn grain
	% of 200 mm thickness				
0	91	71	78	80	78
100	101	82	80	101	95
200	100	100	100	100	100
200 mm yield	8.6	2.9	8.7	5.8	7.0
Topsoil Contrasts	Probability > F				
100 vs 0	0.00	0.26 NS	0.76 NS	0.02	0.00
200 vs 0	0.00	0.01	0.00	0.03	0.00

Productivity Abstract
The corn yield response to topsoil thickness is defined as:

Yield= $Y0 + aX^b$ where,
Y0=the yield before topsoil is added (determined by linear regression)
a and b= coefficients
X=topsoil thickness

This portrays the relationship as non-linear. The magnitude of this response was greater when there were less favourable growing conditions. The cause of the yield increases that occurred when topsoil was added was not examined in this study. An oat yield response curve was not defined.

Keywords: Simulated erosion, topsoil added, Nebraska, corn, oats, yield response curve, field study.

33. Olson, K. R. and Carmer, S. G. 1990. **Corn yield and plant population differences between eroded phases of Illinois soils.** J. Soil Water Conserv. 45: 562-566

A study was conducted to determine corn yield and plant population differences between eroded phases of an array of soil in Illinois. The initial study was conducted for 5 years at five different sites to document the effects of weather variability on corn yield and plant population differences. Paired moderately and severely eroded phases of Clarence (Aquic Argiudolls), Grantsburg (Typic Fragiudalfs), Hoyleton (Aquollic Hapludalfs), Rozetta (Typic Hapludalfs), and Tama (Typic Argiudolls) soil were included. Five year corn yield averages for plots on Rozetta and Tama soils with favourable subsoils for rooting showed nonsignificant differences between moderately and severely eroded plots. Over the 5 year period, corn yield averages for the plots on severely eroded Clarence, Grantsburg, and Hoyleton soils with root restricting subsoils declined 16% to 35% (P=0.05) from yields obtained on corresponding moderately eroded phases of these soils. Significant plant populations reductions (P=0.05) occurred only on plots of severely eroded phases of fine textured Clarence and Hoyleton soils. The study was expanded in the third year to include slightly eroded phases of Clarence, Grantsburg, and Hoyleton soils with root restricting subsoils. For 3 year corn yield and plant population averages over the three soils, severely eroded phase averages were significantly lower (P=0.05) than either the slightly or moderately eroded phase averages.

Summary

Methods:	This was a five year study conducted at five sites. All plots except those on the slightly eroded Clarence soils were located on the backslope of the slope profile. After 2 years the sites were divided into those with root restricting subsoils and those without. Analysis of variance was done to determine differences between erosion phases and soil series.
Degradation:	Erosion
Crop:	Corn
Soil:	Clarence - Aquic Arguidolls Grantsburg - Typic Fragiudalfs Hoyleton - Aquollic Hapludalfs Rozetta - Typic Hapludalfs Tama - Typic Arguidalfs
Land Mgmt:	High level of management
Location:	Urbana, Illinois
Impact:	The 5 year corn yield averages on plots of severely eroded Clarence, Grantsburg, and Hoyleton soils with restricting sub-soils were between 16 to 35% lower than average yields of moderately eroded plots.

Results

Table 3.Corn yield data for the 5 years at the paired moderately and severely eroded phases of Clarence, Grantsburg, Hoyleton, Rozetta, and Tama.

Soil series and Erosion phase	Corn Yield 1984	1985	1986	1987	1988	5-year Average	Change %
	--------------------kg/ha---------------						
Clarence							
Moderate	3300	4800	4600	5400	600	3700*	
Severe	2200	3200	3900	2900	0	2400	-35
Grantsburg							
Moderate	8500	9300	8800	7800	1900	7300*	
Severe	6200	9000	8000	5800	0	5800	-21
Hoyleton							
Moderate	5900	8100	5500	5100	6100	6100*	
Severe	5000	6300	4400	4300	5700	5100	-16
Rozetta							
Moderate	11200	10400	8500	9200	7700	9400**	
Severe	11000	9800	7100	7800	8200	8900	-5
Tama							
Moderate	10500	9500	10700	8700	1900	8300**	
Severe	10200	10000	9300	10000	4800	8900	+8
Average							
Moderate	7900*	8400**	7700*	7300*	3600**	7000*	
Severe	6900	7700	6600	6100	3900	6200	-11

*Moderate phase significantly different from severe phase (P=0.05)
**Moderate phase not significantly different from severe phase (P=0.05)

Table 6.Corn yield data for the 3 years at the slightly, moderately, and severely eroded Clarence, Grantsburg, and Hoyleton soils.

Soil series and Erosion Phase	Corn Yield 1986	1987	1988	3-year Average	Change %
	--------------kg/ha			---------------	
Clarence					
Slight	5300	6600	1700	4500*	
Moderate	4600	5400	600	3500**	-22
Severe	3900	2900	0	2300	-50
Grantsburg					
Slight	10000	9900	1600	7300 *	
Moderate	8800	7800	1900	6200**	-15
Severe	8000	5800	0	4600	-37
Hoyleton					
Slight	6800	5800	6500	6400*	
Moderate	5500	5100	6100	5600	-13
Severe	4400	4300	5800	4800	-25
LSD (0.05) between erosion phases within series	1900	1900	1900	1100	
Average					
Slight	7460*#	7400*#	3260*	6080*#	
Moderate	6330	6150**	2880	5080**	-16
Severe	5460	4330	1880	3890	-36
LSD (0.05) between erosion phases averaged over five series	1100	1100	1100	620	

*Denotes slight phase significantly different from severe phase.
**Denotes moderate phase significantly different from severe phase.
#Denotes slight phase significantly different from moderate phase.

Productivity Abstract

The initial results from this study were summarized in a 1988 paper by Olson and Nizeyimana (data from 1984 and 1985). These first results did not include the influence of climatic variability. This became possible when the study was expanded to 5 years. A slightly eroded phase was another addition to the study. All phases of erosion were naturally occurring. Both of these studies recognize the importance of considering the properties of the subsoil when examining the effects of erosion on crop yield. The Tama and Rozetta soil series did not have restrictive subsoils. The yields from the different erosion phases were not significantly different. The soils with the restrictive subsoils had significantly different yields from moderate and severe erosion phases. There were also significant differences in yields between the slightly and moderately eroded phases for the Clarence and Grantsburg soil series.

Keywords: Erosion, corn yield, field study, Illinois, natural erosion phases.

34. Olson, K. R. and Nizeyimana, E. 1988. **Effects of soil erosion on corn yields of seven Illinois soils.** J. Prod. Agric. 1: 13-19.

The primary objective of this study was to determine the impact of soil erosion on corn (Zea mays L.) yields for an array of soils in Illinois. Eight sites were located with slopes ranging from 3 to 14%. At each site, paired moderately and severely eroded phases of a soil series were located in the same field. The included soil series were Ava (Typic Fragiualfs), Clarence (Aquic Argiudolls), Grantsburg

(Typic Fragiudalfs), Hoyleton (Aquollic Hapludalfs), Parr (Typic Argiudolls), Rozetta (Typic Hapludalfs) (at two sites), and Tama (Typic Argiudolls). Based on soil boring observations, two to four 0.0025 acre plots were located within each of the moderately and severely eroded phases of a soil series. Corn was planted using a high level of management by either Illinois Agricultural Experimental Station personnel or by participating farmers. The corn was harvested by hand, shelled and moisture tested. A soil pit was dug within each eroded phase of all soil series and adjacent to each set of plots to sample and measure the chemical and physical characteristics of the soils. The soils chosen represent soils developed under prairie and forest vegetation, in deep loess, or in loess overlying fine and medium textured glacial till. Some of these soils have claypans (Hoyleton soils) or fragipans (Ava and Grantsburg soils). Soils formed in loess without root restricting subsoils showed slight yield reductions (5%) with increasing degree of erosion. Greater corn yield reductions (24%) occurred when either loess derived soils with root restricting subsoils (claypans or fragipans) or soils developed in glacial till were eroded.

Summary

Methods:	Seven soil series were examined with respect to two levels of erosion: moderate and severe. The erosion phase was determined according to criteria defined by the soil survey staff (Actual erosion levels were measured). The range of slope was from 3 to 14%. The past management practices were not known at all sites.
Degradation:	Erosion
Crop:	Corn
Soil:	Ava, Typic Fragiudalf Clarence, Aquic Argiudoll Grantsburg, Typic Fragiudalf Hoyleton, Aquollic Hapludalf Parr, Typic Argiudoll Rozetta, Typic Hapludalf (two sites) Tama, Typic Argiudoll
Land Mgmt:	There was some variation in tillage systems and levels of fertilizer. Moldboard plowing was done at the Ava, Parr, Tama, Clarence, and one of the Rozetta sites. The second Rozetta site was disked and the Hoyleton and Grantsburg sites had a no-till system. High levels of fertilizer were applied at all sites.
Location:	Various locations in Illinois
Impact:	Yields from the severe erosion phase with root restricting subsoils were 24 % less than the moderately eroded phases (on average over two years). Yields from the severe erosion phase without root restricting subsoils were 5% less than the yields from the moderately eroded phases.

Results

Table 1.The 1984 and 1985 corn yields for Illinois soils with root restricting subsoils.

Soil Series	Erosion phase	Depth and thickness of restrictive subsoil layer in.	Slope %	1984 mean	1985 mean	Average of 1984 & 1985 mean	Change %
				---------bu/ac----------			
Ava							
	Moderate	20-44	4	56+	130*	93*	
	Severe	17-38	5	37	87	63	-33
Clarence							
	Moderate	35-60	5	53+	76+	64*	
	Severe	29-60	6	35	51	43	-33
Grantsburg							
	Moderate	34-60	9	136*	148+	142*	
	Severe	20-49	10	99	143	121	-15
Hoyleton							
	Moderate	10-36	3	94+	129+	111*	
	Severe	6-16	4	79	100	89	-20
Parr							
	Moderate	46-60	6	111*	138+	125*	
	Severe	32-60	6	72	105	89	-29
LSD (0.05) between erosion phases within series				23	38	21	
Average							
	Moderate			90*	124*	107*	
	Severe			64	97	81	-24
LSD (0.05) between erosion phases averaged over 5 series				11	17	9	

* Significant at the 0.05 probability level.
\+ Not significant at the 0.05 probability level.

Table 2.The 1984 and 1985 corn yields for Illinois soils without root restricting subsoils.

Soil Series	Erosion phase	Restrictive subsoil layer	Slope %	1984 mean	1985 mean	Average of 1984 & 1985 mean	Change %
				---------bu/ac---------			
Rozetta 1							
	Moderate	None	3,8,14	173+	154+	163+	
	Severe	None	3,8,14	159	127	143	-13
Rozetta 2							
	Moderate	None	11	179+	165+	172+	
	Severe	None	12	175	155	165	-4
Tama							
	Moderate	None	9	167+	151+	159+	
	Severe	20-49	11	162	159	160	1
LSD (0.05) between erosion phases within series				24	38	21	
Average							
	Moderate			173+	157+	165+	
	Severe			165	146	156	-5
LSD (0.05) between erosion phases averaged over 5 series				11	17	9	

* Significant at the 0.05 probability level.
\+ Not significant at the 0.05 probability level.

Productivity Abstract
The effect of erosion on corn yields depended on the type of subsoil. The root restricting subsoils had lower initial water holding capacities. Reductions in yields were attributed to changes in certain soil properties, specifically, loss of organic C, increased clay content in topsoil, restricting rooting depth, and reduced plant available water storage. This study is one of the few studies that uses natural erosion conditions to determine moderate and severe erosion phases.

Keywords: Erosion, corn, Illinois, field study, natural erosion phases, root restricting subsoils, yields.

35. Onstad, C. A., Pierce, F. J., Dowdy, R. H., and Larson, W. E. 1985. **Erosion and productivity interrelations on a soil landscape.** Pages 193-200 in Erosion and soil productivity: Proceedings of the National Symposium on Erosion and Soil Productivity, December 10-11, 1984. New Orleans, Louisiana.

A soil landscape catena was selected in southeastern Minnesota comprising five soil mapping units. One hundred years of rainfall data were generated and used as input to estimate erosion and deposition at various points along the soil landscape. Productivity of the various soils and the catena itself was estimated after elapsed times of 10, 25, 50, 75, and 100 years using a productivity index. The productivity index of isolated soil mapping units decreased with erosion as expected. When the mapping unit was placed in its proper position in the soil landscape, its productivity index changed as a function of its position in addition to its soil physical characteristics related to erosion and sediment transport. For example, if a soil situated at the toe of a landscape unit receives sediment deposition, it is likely to increase or remain at the same productivity level. If a soil is located midslope, erosion is likely accelerated when compared to the soil considered alone, consequently, the productivity index is likely to decrease at an accelerated rate when compared to the soil considered separately. The analysis illustrates that changes in productivity indexes on soil mapping units can give misleading information unless they are considered in their proper positions on a soil landscape. The data also show that a soil landscape should be given more consideration as the basic unit for determining productivity changes over time as a result of soil erosion.

Summary

Methods: Erosion was simulated over a 100 year period. A soil landscape was divided into 9 sections (reaches) according to the slope along the landscape. The data collected for each reach included:available water, bulk density, clay content, and pH.
Degradation: Erosion (water)
Crop: Corn
Soil: Typic Hapludalfs
Land Mgmt: Continuous corn that was cultivated up and down hill
Location: Winona County, Minnesota.
Impact: Reaches 4 and 5 (steepest slopes) had significant decreases in PI whereas other reaches had slight decreases or increases in PI. Overall, the landscape unit retained its productivity throughout the first 25 years of erosion and decreased by about 4% during the next 75 years. There was considerable variability between the PI of the individual reaches.

Results

Table 3.Results of PI analyses for each reach of the natural transect for the years indicated.

	Productivity Index					
	Year					
Reach	0	10	25	50	75	100
1	0.47	0.48	0.50	0.52	0.54	0.56
	100a	102	106	111	115	118
2	0.47	0.50	0.53	0.57	0.58	0.58
	100	105	112	120	122	122
3	0.64	0.67	0.69	0.73	0.74	0.74
	100	104	108	115	116	116
4	0.54	0.50	0.43	0.27	0.18	0.18
	100	93	79	49	33	33
5	0.56	0.53	0.49	0.37	0.17	0
	100	95	89	67	31	0
6	0.20	0.18	0.12	0	0	0
	100	90	60	0	0	0
7	0.49	0.46	0.43	0.34	0.27	0.22
	100	94	87	69	55	44
8	0.54	0.53	0.52	0.49	0.46	0.43
	100	98	96	91	85	79
9	0.65	0.65	0.65	0.64	0.64	0.64
	100	100	100	99	99	99
Wt. ave	0.51	0.50	0.49	0.44	0.40	0.37
	100	98	96	86	79	73

a Lower numbers are percents with respect to year 0.

Table 4.Results of the PI analyses for each reach of natural transect without bedrock restrictions for the years indicated.

	Productivity Index					
	Year					
Reach	0	10	25	50	75	100
1	0.47	0.48	0.50	0.52	0.54	0.56
	100a	102	106	111	115	118
2	0.47	0.50	0.53	0.57	0.58	0.58
	100	105	112	120	122	122
3	0.64	0.67	0.69	0.79	0.78	0.80
	100	104	108	117	122	125
4	0.54	0.50	0.43	0.28	0.20	0.20
	100	93	79	51	37	37
5	0.72	0.73	0.77	0.81	0.81	0.81
	100	102	107	113	113	113
6	0.46	0.46	0.46	0.46	0.46	0.46
	100	100	100	100	100	100
7	0.63	0.61	0.59	0.53	0.47	0.41
	100	97	93	84	75	65
8	0.54	0.53	0.52	0.49	0.46	0.43
	100	98	96	91	85	79
9	0.68	0.68	0.68	0.68	0.68	0.68
	100	100	100	99	99	99
Wt. ave	0.58	0.58	0.58	0.58	0.57	0.56
	100	100	100	99	97	96

a Lower numbers are percents with respect to year 0.

Productivity Abstract
An actual landscape catena was used as the basis for studying differences in PI across a map unit. Both soil type and position on a slope were considered important elements in this study. The authors emphasize that the inclusion of landscape position in a productivity study will help avoid inaccurate, over-generalized estimates of yield loss. When bedrock restrictions are absent, the long term effects of erosion are less severe particularly on the steeper reaches of a landscape.

Keywords: Erosion, EPIC, CREAMS, PI, models, soil depth, deposition, corn, Minnesota.

36. Perrens, S. J., Foster, G. R., and Beasley, D. B. 1985. **Erosion's effect on productivity along nonuniform slopes.** Pages 201-215 in Erosion and soil productivity: Proceedings of the National Symposium on Erosion and Soil Productivity, December 10-11, 1984, New Orleans, Louisiana.

The validity of using uniform land profiles to represent nonuniform land profiles in analyses of the impact of erosion on crop productivity was investigated. For this purpose the EPIC model was used to compute a random sequence of rainfall and runoff values used as input to the CREAMS model to compute erosion and deposition along uniform, convex, concave, and complex land profiles for a typical Miami silt loam soil in northern Illinois. EPIC was also used to develop a function between loss of productivity and eroded depth for this Miami soil. Computed erosion rates along the profiles were combined with the productivity loss - soil loss function and integrated to compute net loss of productivity for the profiles over 200 years. Significant mathematical errors were discovered when uniform land profiles were used in this way. Computed erosion and deposition rates could be so large at some locations on nonuniform profiles that massive amounts of soil are computed to be relocated over long time periods like 200 years. This can cause major changes in landscape profiles. Future erosion/productivity inventories should therefore consider variation in erosion and deposition in space caused by both landscape profile shape and variation in soil properties. Furthermore, when large erosion and deposition rates are involved, landscape adjustment to erosion and deposition must be considered.

Summary

Methods: Two models were used to determine the productivity changes of a specific soil series depending on the landscape profile. Four profiles were considered: concave, convex, complex and uniform.
Degradation: Erosion (water)
Crop: Corn
Soil: Miami, silt, loam
Land Mgmt: The corn was continuously cropped and had a maximum rooting depth of 900mm. Tillage operations included: spring discing and field cultivation, May 10th planting, June 15th row cultivating, October 15th harvest, and November 15th moldboard plowing.
Location: Iroquois, Illinois
Impact: The convex landscape had the largest decrease in productivity over time because of an initial decrease in the first 20 years of the simulation and a continued (and slower) decline over the entire 200 years.

Results

Table 2.Relative productivity by profile shape and time when productivity increases with deposition.*

Profile Shape	Time (years) 10	20	50	100	200
Uniform	1.00	0.90	0.87	0.86	0.83
Convex	0.88	0.87	0.85	0.83	0.78
Concave	0.99	1.02	1.01	1.01	1.00
Complex	1.00	0.99	0.97	0.95	0.92

*Ratio of net productivity for the profile with erosion and deposition to the net productivity for the profile when no erosion or deposition occurs.

Table 3.Relative productivity by profile shape and time when some soil erodes before a loss of productivity occurs and when deposition does not increase productivity.

Profile Shape	Time (years) 10	20	50	100	200
Uniform	1.00	0.93	0.79	0.73	0.70
Convex	0.91	0.86	0.80	0.75	0.67
Concave	1.00	0.94	0.87	0.86	0.84
Complex	0.95	0.90	0.85	0.83	0.78

*Ratio of net productivity for the profile with erosion and deposition to the net productivity for the profile when no erosion or deposition occurs.

Productivity Abstract

An important distinction is made between whether deposition of soil adds to or does not add to productivity. When deposition does not add to productivity, the consequences of long term erosion are more severe. The convex landform had the lowest PI after 200 years in both cases. The mathematical models suggest that there is a non-linear relationship between erosion, loss of productivity and landscape. Because of this non-linear relationship, the average soil loss or sediment yield for a profile does not give an accurate estimate of productivity loss. Variations in soil properties along the land profile were not included in the analyses of this study.

Keywords: erosion, corn, models, productivity index, landform, deposition, long term erosion, Illinois.

37. Schertz D. L., Moldenhauer, W. C., Livingston, S. J., Weesies, G. A., and Hintz, E. A. 1989. **Effect of past soil erosion on crop productivity in Indiana.** J. Soil Water Conserv. 44: 604-608.

Quantitative analysis of the effects of past soil erosion on crop productivity are limited. the effect of past soil erosion on crop productivity was evaluated in three Indiana counties on three soils (Miami, a fine-loamy, mixed, mesic, Typic Hapludalf; Morley, a fine, illitic, mesic, Typic Hapludalf; and Corwin, a fine-loamy, mixed, mesic, Typic Argiudoll) from 1981 through 1986. Slight, moderate and severe erosion phases, using Soil Conservation Service criteria, were used to distinguish differing degrees of past erosion. Past erosion on the three soils evaluated reduced corn yields 15% and soybean yields 24% on severely eroded sites compared to slightly eroded sites over the 6 year period. These reductions were significant at the 5% level, using Duncan's multiple range test, and greater than values previously reported for severely eroded soil. This reduction points out the need for a national database, similar to this, of benchmark soils from which erosion-productivity models may be validated. A sampling procedure was developed in 1982 by sampling schemes within a row. Harvesting every fifth ear of corn resulted in an R squared of .978 over all erosion phases and all soils and provided a good estimate of the actual yield for that row. This finding is important where a large number of samples must be collected over a short period of time with limited personnel.

Summary

Methods: Three erosion phases were defined: slight, moderate, and severe (according to the U.S. Soil Conservation Service). Site selection was based on the following criteria:

- typical pedons of chosen soil series were known to occur and extensive erosion was evident on sloping landscapes;
- the influence of landscape or soil factors that do not effect erosion should be minimized. Care must be taken to ensure that properties such as soil depth are within the range of characteristics for that particular erosion phase for that soil;
- site locations should be on upper slope positions; and
- the slope gradient of the various erosion phases should be the same.

Analysis of variance was used to test the differences between yields, organic matter percentages, pH, phosphorous, potassium, and particle size ranges

Degradation: Erosion

Crop: Corn, soyabeans

Soil: fine-loamy, mixed, mesic Typic Argiudoll
Miami - fine-loamy, mixed, mesic Typic Hapludalf
Morley - fine, mixed, mesic Typic Hapludalf

Land Mgmt: Conventional tillage in use

Location: Benton, Montgomery, and Whitley counties, Indiana

Impact: Corn yields on slightly eroded sites were significantly greater than those on severely eroded sites in at least one year for each of the soils in the study. Severe erosion can reduce corn yields by 15% and soyabean yields by even greater percentages

Results

Table 4.Corn yield by erosion phase for Corwin, Miami, and Morley soils, by year.

Soil and Erosion phase	Yield (kg/ha) 1981	1982	1983	1984	1985	1986
Corwin						
Slight	8160a(15)	8967a(2)	3071a(8)	*	9604a(12)	*
Moderate	7729a(15)	10420a(2)	1758a(8)	*	8913ab(11)	*
Severe	7532a(15)	7532b(2)	1067a(8)	*	8474b(12)	*
Percent reduction	8	16	48		12	
Miami						
Slight	9102a(15)	10984a(12)	4268a(6)	10043a(6)	8160a(5)	11048a(6)
Moderate	8725a(15)	10420a(12)	4268a(6)	9102a(6)	8411a(5)	10797a(6)
Severe	7219b(15)	8474b(12)	4268a(6)	8788a(6)	7093a(4)	9541a(6)
Percent						

Soil and Erosion phase	1981	1982	1983	1984	1985	1986
Percent reduction	21	23	0	13	13	14
Morley						
Slight	7344a(15)	6528a(6)	*	6968a(7)	2825a(2)	5963a(6)
Moderate	7281a(15)	5398ab(6)	*	6277a(7)	2959a(2)	4770a(6)
Severe	6654a(15)	4331b(6)	*	6026a(8)	3766a(8)	4206a(6)
Percent reduction	10	34		14	33	29

a-bNumbers for a given yield for a specific soil and year not followed by the same letter are significantly different at the 5% level using Duncan's multiple range test.
Numbers in parenthesis represent number of sites in corn
* no sites in corn.
Average percent reduction or increase in corn yield between slight and severe phases of erosion

Table 6.Soybean yield by erosion phase for Corwin, Miami, and Morley soils, by year.

	Yield (kg/ha)					
Soil and Erosion phase	1981	1982	1983	1984	1985	1986
Corwin						
Slight	*	3632a(13)	*	7690a(11)	*	2287a(12)
Moderate	*	3228b(13)	*	2556a(12)	*	3018a(12)
Severe	*	3161b(13)	*	1950b(12)	*	1547b(12)
Percent reduction		13		28		32
Miami						
Slight	*	2892a(3)	2825a(6)	3026a(6)	3766a(3)	3026a(6)
Moderate	*	2954a(3)	2488a(6)	2892a(6)	3295a(3)	2959a(6)
Severe	*	3026a(3)	1816a(8)	2757a(6)	3228a(3)	2825a(6)
Percent reduction		4	36	8	14	6
Morley						
Slight	*	2892a(9)	1009a(12)	1614a(5)	1547ab(13)	2556a(6)
Moderate	*	2690a(9)	1076ab(12)	1412a(5)	1210a(13)	2421a(5)
Severe	*	2085b(10)	807a(12)	1210a(6)	1076b(15)	1210b(6)
Percent reduction		28	20	25	30	32

a-bNumbers for a given yield for a specific soil and year not followed by the same letter are significantly different at the 5% level using Duncan's multiple range test.
Numbers in parenthesis represent number of sites in soybeans
* no sites in soybeans.

Average percent reduction or increase in soybean yield between slight and severe phases of erosion

Productivity Abstract
This study shows that past soil erosion can reduce corn and soybean yields significantly but the amount of reduction varies by soil series and year. The yearly differences were attributed to the variability in climatic conditions, particularly, available water. Overall, corn yields were 15% less from the severely eroded plots than from the slightly eroded plots. Similarly, soybeans produced yields on the severely eroded soil which were 24% less than the slightly eroded soil.

Keywords: Erosion, Indiana, USA, field study, actual erosion levels, corn, soybeans, yield reduction.

38. Shaffer, M. J. 1985. **Simulation model for soil erosion -productivity relationships.** J. Envir. Qual. 14: 144-150.

A mathematical model is described that simulates the impact of soil erosion on the short and long-term productivity of soil. The model is known as the Nitrogen-Tillage-Residue Management (NTRM) model and has capabilities at the research level to simulate complex interactions of a growing crop such as corn (Zea mays L.) with climate inputs together with physical, chemical, and biological properties of the soil. Nitrogen-Tillage-Residue Management is intended to provide a means of evaluating existing and proposed soil management practices in the subject areas of erosion, soil fertility, tillage, crop residues, and irrigation. Illustration of model output, validation, and application is provided for three soils in the northern Corn Belt. These include a Fayette silt (Typic Hapludalf) (deep loess), a Dubuque sandy loam (Typic Hapludalf) (shallow to bedrock), and a Dakota fine sandy loam (Typic Argiudoll) (shallow to coarse material). Corn growth and yield are simulated under noneroded and two levels of eroded conditions for a period of 100 yr. Management techniques, which include supplemental N, conservation tillage, and irrigation, are simulated on the eroded profiles to evaluate relative benefits and demonstrate the types of results produced by model sensitivity analyses.

Summary

Methods:	This study describes the Nitrogen-Tillage- Residue-Management model (NTRM). There were three levels of erosion simulated: 0.0, 0.3, and 0.6 m of erosion. Three climate scenarios were simulated: dry, average, and wet. A third section of this study varied management practices such as fertilizer levels, tillage systems, and irrigation.
Degradation:	Erosion.
Crop:	Corn
Soil:	Fayette silt loam, Typic Hapludalf Dubuque silt loam, Typic Hapludalf Dakota fine sandy, Typic Argiudoll
Land Mgmt:	
Location:	Study area is the SE corner of Minnesota, NE corner of Iowa and the SW corner of Wisconsin
Impact:	

Results

Figures 4, 5, and 6 depict the topsoil thickness-yield relationship for each of the three test soils. The Dubuque and Dakota soils have greater reductions in yield than does the Fayette soil. The Fayette soil also experienced the greatest recovery when nitrogen was added (yields were still less than yields from uneroded soils). The Dubuque soil yields did not improve with conservation tillage and additional fertilizer until these practices were done in conjunction with irrigation. The Dakota soil yields improved with all test management practices. Irrigation provided the highest relative benefit.

Productivity Abstract

This paper gives an outline of the NTRM model and illustrates an application. The authors recognize the need for long term yield analysis to determine the effects of erosion. Yield simulations may be the best source of information for these long term studies. The results from short term tests may not reflect the climate variability. Management practices are also examined in this study. The NTRM model may be useful in determining the best combination of management practices for optimum productivity.

Keywords: Erosion, NTRM model, corn yield, management practices, Wisconsin, Minnesota, Iowa, long term simulations.

39. Spomer, R. G.and Piest, R. F. 1982. **Soil productivity and erosion of Iowa loess soils.** Trans. Am. Soc. Agric. Eng. 25: 1295-1299.

Soil and plant nutrients are being rapidly removed from inadequately protected rowcrop fields in Iowa, but increasing use of fertilizer and adoption of other technologies have masked the effect of erosion on crop yields. Prior to the adoption of hybrid seed corn in 1932 and increased use of commercial fertilizer beginning in the early 40's, Iowa average corn yields (1866-1932) remained nearly constant at 2.3 t/ha (37 bu/ac). Pottawattamie County corn yields averaged 2.9 t/ha (45.6 bu/ac), 1929 through 1953, with a small but steady annual increase of 0.037 t/ha (0.59 bu/ac). The most rapid increase in corn yields, highly correlated with fertilizer use, occurred during the decade of the 60's. Concurrently, we show that soil erosion rates from unprotected cornfields in the region greatly exceeded acceptable soil loss tolerances. Measured sediment yields from 33.6 ha (83 ac) research watershed since 1964 were 30.4 t/ha/yr (13.6 t/ha/yr), and the effective denudation of the watershed is occurring at a minimum rate of 40 cm (16 in) per century. Average annual nitrogen and phosphorous movement during a recent 5 year period of minimal runoff and erosion was 20 kg/ha (18lb/ac) and 3.0 kg/ha (2.7 lb/ac), respectively.

Summary

Methods:	Historical yield records and fertilizer records as well as research station data were examined to illustrate how, despite the high rates of erosion, yields have increased over time.
Degradation:	Erosion (water)
Crop:	Corn
Soil:	Typic Hapludolls Typic Haplorthents Cumulic Hapludolls
Land Mgmt:	Only fertilizer treatments were recorded
Location:	Pottawattamie County, Iowa Treynor, Iowa
Impact:	

Results

Table 1.State of Iowa Crop yields and average annual elemental fertilizer application.

Year	Corn yield t/ha	N kg/ha	P kg/ha
1940-44	3.30	<1	<1
1948	3.80	3.4	4.6
1949	2.95	2.7	4.5
1950	3.04	4.6	5.8
1951	2.73	6.2	5.9
1952	3.92	9.3	7.5
1953	3.33	15.2	8.0
1954	3.42	14.8	9.2
1955	3.04	9.1	7.3
1956	3.33	10.6	7.4
1957	3.89	14.3	8.7
1958	4.14	20.8	11.2
1959	4.08	18.4	8.8
1960	3.99	23.7	9.1
1961	4.74	35.6	12.9
1962	4.83	50.6	16.1
1963	5.02	55.3	17.7
1964	4.86	69.0	21.2
1965	5.15	85.2	25.8
1966	5.59	114.0	31.4
1967	5.56	116.5	28.6
1968	5.84	120.5	35.5
1969	6.21	141.5	37.9
1970	5.40	146.0	37.9
1971	6.40	145.4	31.7
1972	7.28	128.1	32.5
1973	6.72	140.4	31.9
1974	5.02	140.4	31.9
1975	5.65	125.3	30.6
1976	5.71	167.4	32.0
1977	5.40	141.3	29.8
1978	7.22	152.8	32.0
1979	7.97	168.9	33.6

Pottawattamie County
Yields increased at a rate of .037 t/ha/yr prior to 1953. This rate increased to .145 t/ha/yr for the period of 1957 to 1979. This increase corresponds with the increased use of fertilizers.

Table 2. Pottawattamie County corn yield and average elemental fertilizer applied.

Year	Corn yield t/ha	N kg/ha	P kg/ha	K kg/ha
1968	3.86	23.5	5.9	1.1
1969	5.45	102.0	22.1	7.9
1970	5.57	141.9	26.4	35.1
1971	6.15	127.9	23.7	31.0
1972	6.90	148.1	28.8	30.7
1973	6.74	166.7	28.9	37.3
1974	2.44	163.7	25.6	45.7
1975	4.36	117.8	20.3	31.2
1976	5.94	156.5	21.8	26.7
1977	5.42	151.4	24.8	40.7
1978	5.42	168.9	33.7	39.2
1979	7.47	213.9	39.5	65.6
1980	7.90	148.1	19.7	25.8

Table 3.Harvested corn yields, elemental fertilizer applied, and sediment yield, Watershed 2, Treynor, Iowa.

Year	Corn yield	N	P	K	Sediment yield from erosion
	t/ha	--------kg/ha--------			t/ha
1964	4.43	106.1	30.9	13.7	56.0
1965	5.10	139.3	17.4	16.5	81.6
1966	5.71	146.5	35.2	13.2	19.3
1967	6.71	163.0	38.1	13.7	168.6
1968	5.98	141.7	38.3	14.4	9.2
1969	7.61	184.7	43.3	31.5	2.2
1970	6.31	150.1	38.9	28.0	16.6
1971	7.60	180.8	39.8	29.3	29.8
1972	7.65	181.1	39.6	29.3	17.7
1973	7.10	175.7	38.9	29.1	1.1
1974	drought	158.1	39.1	28.3	0.7
1975	4.47	110.9	39.8	28.6	1.8
1976	5.16	180.1	41.9	30.9	<0.2
1977	5.56	234.5	41.2	28.2	18.2
1978	7.70	192.1	42.7	53.8	9.2
1979	8.07	185.2	40.1	28.7	4.3
1980		180.7	29.5	29.2	
Average for 1964-79					27.3

Productivity Abstract
Technological advances must be masking the effects of erosion because the erosion rates for this area are well above tolerance levels yet yields have not decreased. Historical fertilizer rates were used as technology indicators. Other technologies such as seed hybrids and improved implements still need to be considered.

Keywords: Erosion, corn yields, historical records, technology, Iowa, regression analysis.

40. Swan, J. B., Shaffer, M. J., Paulson, W. H., and Peterson, A. E. 1987. **Simulating the effects of soil depth and climatic factors on corn yield.** Soil Sci. Soc. Am. J. 51: 1025-1032.

Simulation models are needed to estimate crop yield responses to climate and soil water storage. Measured corn yields (Zea Mays L.) from a tillage-residue management study on the University of Wisconsin Lancaster Exp. Stn. were compared to simulated yields determined using the Nitrogen-Tillage-Residue-Management (NTRM) simulation model. Data collected at the site from 1982 to 1985 on crop, climate, soil, and management characteristics were utilized in this model. A significant interaction effect on corn yield was observed between climate and soil water holding capacity of individual plots. In 1983, 1984, and 1985 corn yields increased as soil depth to red clay residuum increased; in 1981 and 1982 corn yield had little relationship to soil depth to residuum. The observed differential effect of soil depth to residuum on corn yield under different years' climatic conditions necessitated the use of a simulation model to estimate corn yield accurately in a given year and to express the probability of obtaining a given yield. Frequency distributions for grain yield were determined for specific soil depths to residuum. Grain yield was determined as a function of soil depth for specific probability levels based on simulated site specific daily climatic values generated for a 100 year period.

Summary

Methods: Measured corn yields from a tillage-residue management study were compared to yields simulated using the NTRM model. The actual field depths of topsoil were used to determine the topsoil depth yield relationship. The time period for the yield simulations was 100 years.
Degradation: Erosion
Crop: Corn
Soil: Rosetta silty loam, Typic Hapludalf
Palsgrove silty loam, Typic Hapludalf
Land Mgmt:
Location: Lancaster Experimental Station, Wisconsin
Impact:

Results

Table 5.Measured corn grain yields and depth to clay residuum by replicate and monthly precipitation for 1981 to 1985.

Year	Corn grain yield in replication+				Monthly precipitation++			
	1	2	3	4	May	June	July	Aug
	Mg/ha				cm			
1981	9.21	9.20	8.91	9.23	2.2	20.9	7.4	28.8
1982	8.81	8.89	9.38	9.01	13.9	8.8	13.4	10.3
1983	4.57	5.35	6.05	6.97	13.2	8.3	8.5	9.7
1984	6.73	6.92	7.40	7.53	10.0	19.7	6.5	3.5
1985	7.27	7.60	8.26	8.43	12.6	3.4	5.4	8.5
Clay residuum average depth (m)	0.64	1.04	1.17	1.57				

+Corn grain yields were averaged over tillage treatments.
++Long periods of dependence on stored soil water: 1983-2.9 cm precipitation from 3 July to 25 Aug. (53 days); 1984-3.4 cm precipitation from 18 July to 31 Aug. (45 days); 1985-4.0 cm precipitation from 28 May to 25 July (57 days, largest event 0.9 cm)

Table 6.Yearly measured corn yield responses of individual plots to soil depth to residuum.

Year	n	Equation parameters+ r^2	a (Mg/ha)	b (Mg/ha/cm)
1981	48	0.00	9.30	-0.12×10^{-2}
1982	44	0.02	9.36	-0.31×10^{-2}
1983	48	0.78	2.42	2.98×10^{-2}
1984	56	0.20	6.17	0.91×10^{-2}
1985	51	0.47	5.10	1.65×10^{-2}

+Parameters in equation: Measured grain yield= a + bx where x is depth to residuum (cm).

Productivity Abstract
This paper mainly tested the performance of the NTRM model and illustrated the ability of the model to estimate long term yield responses to a variety of climatic conditions. A linear soil depth-yield relationship was established using the model. The variability of yearly responses to soil depth was attributed to the differences in the timing of precipitation throughout the growing season.

Keywords: Erosion, corn, simulated yield, NTRM model, topsoil depth, Wisconsin.

41. Timlin, D. J., Bryant, R. B., Snyder, V. A., and Wagenet, R. J. 1986. **Modelling corn grain yield in relation to soil erosion using a water budget approach.** Soil Sci. Soc. Am. J. 50: 718-723.

The effect of long-term soil loss on corn (Zea mays) grain yields in shallow soils of the Northeast is evaluated using a simple computer simulation model. Easily obtainable soil and meteorological data are used as input. The model relates the change in soil productivity to the reduction of available water holding capacity caused by long-term soil loss by erosion. Depth to an impermeable layer, which limits the total available water in the soil profile, is considered a nonrenewable soil property. Renewable soil properties such as surface soil structure and fertility, which can be maintained through optimum management, are not considered to limit yields. The model is based on the established relationship between relative yields and the relative transpiration ratio. A simple water budget estimates actual transpiration on a daily basis and calculates stress as a function of relative transpiration ratio. Yields are predicted from total seasonal stress and accumulated heat units. The model has been run using 16 yr of meteorological data to simulate varying climatic conditions, and correlations between actual and predicted yields on deep to moderately deep soils are good. Soil erosion is simulated by removing increments of soil depth. For each soil depth, the model predicts both mean yield and variance. Mean yield values are used to generate productivity curves that graphically depict the relationship between soil productivity and soil erosion. For medium textured soils in New York State, the model predicts that soil erosion will decrease mean yield and increase variability in annual yields when the depth to a root restricting horizon is <70 cm.

Summary

Methods: The Soil Erosion-Productivity model is described in this paper. It simulates the effects of sheet erosion on soil productivity under the conditions of limited soil depth. Corn grain yields are based on the relationship between relative yields and relative transpiration rates. Predicted yields are a function of available soil water and air temperature. Inputs for the model include weather, soil, and crop data.
Degradation: Erosion (sheet)
Crop: Corn (used to calibrate and validate model)
Soil: Niagara silt loam, Aeric Ochraqualfs, Matoon silt loam, Aeric Ochraqualfs
Land Mgmt:
Location: New York State
Impact: There is an immediate decline in corn yield in the Matoon soil series in response to erosion. The Niagara soil yields begin to decline when the soil depth is less than 70 cm. The relationship between topsoil thickness and yield is non-linear for both these soil series.

Results

The calibration and validation of the model were done by comparing 16 years of actual yields to the predicted yields. The calibration included years with average to high precipitation and the validation included the drier years. The predicted corn yields used to calibrate the model were highly correlated with the actual yields (R=0.86). The validating yields were not as highly correlated but still significant (R=0.71).

Product Abstract
Sharp declines and increased variability in yields are predicted when erosion occurs on soils with limiting layers at shallow depths. This model uses climate fluctuations, particularly precipitation and temperature to account for these effects. There are many other factors that could be included in this model such as organic matter content and how it relates to water holding capacity, rock content, lateral water movement, and runoff on sloping lands. This simple model has value in that it allows for relative comparisons between soil types by using readily available data.

Keywords: Erosion, water holding capacity, corn yields, New York, model, topsoil thickness, climate data.

No Crop Specified

42. Christensen, L. A. and McElyea, D. E. 1988. **Toward a general method of estimating productivity-soil depth response relationships.** J. Soil Water Conserv. 43: 199-202.

Four functional forms were investigated to determined their usefulness in estimating the relationship between soil erosion and crop yields. These functional forms were as follows: linear, polynomial, Cobb-Douglas, and Mitscherlich-Spillman. The Mitscherlich-Spillman method best met the theoretical requirements of making such estimates. A variable defined as the mechanical composition of the plant rooting zone was a superior prediction variable to topsoil depth. Soybean yield data for Cecil soils in Georgia were fitted to a Mitscherlich-Spillman function

Summary

Methods: This is a survey of the theoretical issues that should be considered in the development of models that define the soil depth-crop productivity relationship
Degradation: Erosion
Crop:
Soil :
Land Mgmt :
Location:
Impact:

Results

Productivity Abstract
This paper reviews the theoretical and practical issues that arise when choosing appropriate

explanatory variables in the topsoil depth-crop productivity relationship. The principles which should be included in the model were based on four characteristics of agronomic response:

1. the response of crop yield to additional topsoil should conform to the law of diminishing returns.
2. when topsoil depth is zero, positive yields should be possible.
3. the attainable yield should have a finite maximum.
4. top soil depth in excess of the maximum rooting zone should not decrease yield.

Four functional forms examined were (linear, polynomial, Cobb-Douglas, and Mitscherlich-Spillman forms). Only the Mitscherlich-Spillman form satisfied the four criteria.

Keywords: models, erosion, topsoil depth, yield response function.

43. Lal, R. 1988. **Monitoring soil erosion's impact on crop productivity.** Pages 187-200 in Lal, R. ed. Soil erosion research methods. Soil and Water Conservation Society, Ankeny, Iowa.

Quantifying the effects of soil erosion on crop yields is a complex task because it involves the assessment of a series of interactions among soil properties, crop characteristics, and the prevailing climate. The effects are also cumulative and often not observed until long after accelerated soil erosion begins. Furthermore, the magnitude of erosion's effects on crop yields depends upon soil profile characteristics and management systems. Crop yield, an integrated response to many interacting parameters, is difficult to relate under field conditions to any individual factor. It is, therefore, difficult to establish an one-to-one, cause and effect relationship between rates of soil erosion and erosion induced degradation on the one hand and crop yields on the other. (this is the opening paragraph of the chapter)

Summary

Methods: Several research methods are reviewed and summarized. These include:

1. Yield records from long term agronomic trials;
2. Using long term erosion plots for agronomic experiments with known soil loss;
3. New erosion plots under natural or simulated rainfall;
4. Desurfacing experiments;
5. Laboratory and greenhouse studies;
6. Assessment of soil properties through field surveys;
7. Geomorphological studies (soil loss tolerance); and
8. Crop productivity models.

Each method is described briefly, and typical results are listed for some of these methods.

Degradation: Erosion

Crop:

Soil:

Land Mgmt

Location:

Impact: Among the important soil physical constraints aggravated by erosion are reduced rooting depth, loss of soil water storage capacity, crusting and compaction, and hardening of the plinthite. Erosion results in the loss of clay and colloids which influences soil tilth and consistency. Soil chemical constraints and nutritional disorders related to erosion include low cation exchange capacity, deficiencies in N,P,and K, nutrient toxicity (Al, Mn), and high soil acidity.

Results

Productivity Abstract
All the direct methods of estimating the effects of erosion on crop production present some difficulties. Long term field experiments do not always have controlled management systems or totally lack management information. Also, changes in soil properties may not be included in the experimental design. Desurfacing experiments may overestimate the effect of erosion as natural erosion is a gradual process. Indirect methods such as field surveys to assess soil properties can give some indication of the effects of erosion. Details of plot history must be known to ensure that the soil property changes noted are in fact due to erosion. Only the Productivity Index model was discussed in any detail.

Keywords: Erosion, review, research methods, crop yields, model, Nigeria, soil properties, productivity.

44.Larson, W. E., Pierce, F. J., and Dowdy, R. H. 1985. **Loss in long-term productivity from soil erosion in the United States.** Pages 262-271 in S. A. El-Swaify, W. C. Moldenhauer, and A. Lo, eds. Soil erosion and conservation. Soil Conservation Society of America, Ankeny, Iowa.

In a survey of 75 important soils in the north central region judged to be eroding significantly, 50 percent of the soils exhibited a reduction in PI* of more than 0.1, 32 percent of the soils exhibited a reduction of more than 0.2, and 16 percent of the soils exhibited a reduction of more than 0.3 when 50 cm of soil were eroded. *PI denotes the Productivity Index defined by Kiniry et al (1983).

Summary

Methods: Soil was viewed as an environment for root growth and water depletion. High technology management and non-limiting cultural and fertilizer applications were assumed. The PI model was used to calculate losses in potential crop productivity (PI) due to erosion. This chapter was a review and summary of the work done using this model.
Degradation: Erosion
Crop :
Soil: Alfisols, Ultisol, Vertisol, Entisol, Mollisols
Land Mgmt : High levels of management are assumed.
Location:
Impacts:

Results

Table 1.Characteristics of selected US soils and changes in productivity index (PI) with simulated erosion.

Classification	Soil type	Erosion rate (t/ha/yr)	Initial PI	Change in PI with 50 cm soil removed
Alfisol				
Udollic Ochraqualf	Mexico	37	0.860	-.112
Typic Hapludalf	Fayette	31	0.860	-.017
Typic Hapludalf	Miama	30	0.765	-.0323
Typic Hapludalf	Dubuque	46	0.675	-.417
Mollisol				
Typic Hapludoll	Marshall	51	0.981	-.030
Typic Hapludoll	Kenyon	18	0.929	-.052
Typic Argiudoll	Pawnee	23	0.520	-.292
Ultisol				
Typic Hapludult	Cecil	34	0.506	-.057
Vertisol				
Udic Pellusterts	Houston Black	15	0.595	-.089
Entisol				
Typic Udorthent	Ida	105	0.945	0
Typic Udipsamment	Plainfield	6	0.360	-.088

Table 2.Average reduction in PI on 75 major soils in the north central states after removal of 25 and 50 cm of soil.

Reduction in PI	Percentage of soils* (cm eroded)	
	25#	50#
< 0++	7	7
0 - 0.1	60	43
0.1 - 0.2	21	19
0.2 - 0.3	11	16
0.3 - 0.4	1	12
> 0.4	0	4

*Soils include 39 Mollisols, 28 Alfisols, 6 Entisols, 2 Ultisols, and 1 Aridisol
#25 and 50 cm of soil represent about 3375 and 6750 t/ha.
++< 0 means an actual increase in PI.

Table 3.Range in PI on 75 major soils in the north central states after removal of 0, 25 and 50 cm of surface soil.

Initial PI	Distribution of soils Amount of erosion		
	Initially	25 cm	50 cm
	%		
0.9 - 1.0	32	21	16
0.8 - 0.9	25	23	24
0.7 - 0.8	17	13	16
0.6 - 0.7	3	13	3
0.5 - 0.6	12	7	7
0.4 - 0.5	7	5	13
0.3 - 0.4	4	9	4
0.2 - 0.3	0	1	11
0	0	1	7

Productivity Abstract
Of the 75 important soils in the north central U.S. examined in this study, 50% of them would experience at least a decrease in PI of 0.1 when 50 cm of topsoil was removed (long term erosion). Thirty-two percent of the soils had at least a 0.2 decrease in PI and 16% of the soil has at least a 0.3 decrease in PI. The Alfisol and Mollisol soil orders were used to illustrate intra-order variation with respect to the PI response to surface soil removed. The characteristics of the subsoil were the determining factors in the magnitude of PI reduction due to long term soil erosion.

Keywords: Erosion, subsoil properties, Productivity Index model, review, north central USA.

45. Nowak, P. J., Timmons, J., Carlson, J., and Miles, R. 1985. **Economic and social perspectives on T values relative to soil erosion and crop productivity.** Pages 119-132 in Follett, R. F. and Stewart, B. A. eds. Soil erosion and crop productivity, American Society of Agronomy, Madison, Wisconsin.

This paper examines the following social and economic perspectives on the relation of soil loss tolerance (T values) to soil erosion and crop production in the USA:(i) why soil erosion is of concern; (ii) why soil erosion will likely continue to be a problem; (iii) some of the limitations of using T values in the formulation of conservation policy; and (iv) how some of these limitations can be resolved through the development of multiple soil-loss tolerance values.

Summary

Methods: Current erosion-productivity research is reviewed and the use of soil loss tolerance values are evaluated. Multiple T values are briefly outlined.
Degradation: Erosion (wind and water)
Crop:
Soil:
Land Mgmt:
Location:
Impacts:

Results

Two T values were suggested:

T1 encompasses the concepts of dynamic changes in technologies and erosion rates; and
T2 includes the social and economic costs of erosion.

Productivity Abstract
Topsoil thickness, subsoil properties, and slope gradient are important elements in defining and refining soil loss tolerance. The traditional T value does not accommodate the variability in soil attributes within a soil series nor does it incorporate the social and economic tolerances of soil loss. The T1 and T2 values are only introduced in this study and the authors refer to more detailed discussions which outline the development of these tolerance values.

Keywords: Erosion, review, economic, social impacts, soil loss tolerance values.

46. Pierce, F. J. 1991. **Erosion productivity impact prediction.** Pages 35-52 in Lal, R. and Pierce, F. J. eds. Soil Management for Sustainability, Soil and Water Conservation Society, Ankeny, Iowa.

The erosion-productivity relationship for most soils is not known and its measurement is confounded by scales of space and time. Projections about the effect of erosion on soil productivity are difficult, if not impossible, to verify. The existing models are difficult to validate, and the available data bases needed for assessment are grossly inadequate. Erosion estimates are uncertain and uncertain and not available for many regions of the world. Spatial variation and landscape effects have not been adequately addressed in most erosion-productivity research. It is difficult to separate erosion from other degradation processes. We have yet to set critical limits for physical or economic degradation. Prediction is further complicated by the fact that future conditions, technologies, and resource demands are uncertain.

Summary

Methods: Current studies on soil erosion and its effect on crop production were reviewed and summarized. These studies are divided into 5 types:
1) EE -those dealing directly with erosion's effects
2) LL -land levelling
3) MR - mining reclamation
4) ER -erosion restoration
5) PE -greenhouse or pot experiments

Degradation: Erosion
Crop:
Soil:
Land Mgmt:
Location:
Impact:

Results

Nine general observations were summarized from the past 50 years of research:

1. Yield levels in these studies were low relative to present production levels. There has been no agreement as to which soil properties regulate productivity or how to measure these properties in standard units. There is also a lack of long term yield information, which makes it difficult to assess the effects of technology on the erosion-productivity relationship. Also, the contribution of soil in its natural state to crop production levels has declined.
2. The level to which fertilizers can restore the productivity of eroded soils depends on the nature of the subsoil (limiting factors include low pH, increased clay content, high aluminum saturation, reduced plant available water, and a reduced root zone due to bedrock).
3. Yields were often linearly related to topsoil depth. Many studies calculated yield loss per unit of soil loss. Topsoil thickness along a landscape was not included in these calculations.

4. There is a relationship between topsoil depth and crop yield. This relationship again depends on the characteristics of the subsoil.
5. There is no method of ascertaining that the losses of crop production due to erosion are permanent.
6. Uneroded sites are becoming harder to find. As a result, it will be difficult to estimate the history of erosion without an initial productivity level.
7. Not all effects of erosion on soil productivity have been investigated. The effects of gully and ephemeral erosion, land slides, and the associated loss of contiguous parcels of land have been ignored.
8. The effects of erosion on productivity occur so gradually that technology often masks these effects. It may take a considerable amount of time before yield decrease are detected.
9. The spatial relationships and variability of soils within the landscape have generally been ignored.

Productivity Abstract
Table 1 of this review is an excellent summary of 55 different studies organized by soil series. Corn and wheat were the dominant crops in this group of studies. The studies which describe the development and use of models are not included in the table. In the long term (100 years), the effects of erosion on crop yield are predicted to be manageable. These long term estimates are obtained from models such as EPIC. Unfortunately this type of prediction can only be made for a limited number soils. The author offers three important considerations when determining research priorities:

1. Agreement must be reached on a credible measuring device. Short term field trials do not provide enough information. Models which are capable of predicting spatial and temporal distributions of erosion processes and crop productivity are needed. Resource data bases must be developed and maintained as these data bases are the input for the models.
2. There should be some economic and social incentives for producers to participate in conservation practises on an international scale.
3. Considerable efforts must be made to restore land which is already degraded, particularly in developing countries.

Keywords: erosion, review, study types, USA, Canada, corn, wheat.

47. Pierce, F. J., Dowdy, R. H., Larson, W. E., and Graham, W.A.P. 1984. **Soil productivity in the Corn Belt: an assessment of erosion's long-term effects.** J. Soil Water Conserv. 39: 131-136.

Estimates of erosion's effects on soil productivity in the Corn Belt are projected over 25, 50, and 100 years. The weighted average loss in productivity is less than 8 percent for any major land resource area in the Corn Belt over the next 100 years. However, the productivity decline can be substantial on some soils in certain landscapes, especially where slopes exceed 6 percent. Deep, fertile soils and the preponderance of cropland on nearly level to gently rolling terrain buffers the Corn Belt against productivity reductions.

Summary

Methods: Estimated erosion and its effect on productivity is projected over 25, 50, and 100 years. Kiniry's Productivity Index model was used with a slight modification. Soil is indexed according to its suitability as an environment for root growth. The model is defined by these elements:

$PI = \sum(Ai*Ci*Di*WF)$ where i=1 to r
Ai = sufficiency of available water capacity
Ci = sufficiency of bulk density
Di = sufficiency of pH
WF= weighting factor representing the idealized rooting distribution
r = number of horizons in the rooting depth.

The PI ranges from 0 to 1. These estimates only consider the irreplaceable soil attributes not the nutrients which can be replaced by fertilization. The cost to maintain productivity is not considered either. The two main model inputs are from SOILS-5 and NRI databases.

Degradation: Erosion (water)
Crop: Corn, soybeans, small grains
Soil: Soils of the Northern Corn belt. Table 1 lists the soils that were included in the model
Land Mgmt: High levels of management assumed
Locatio: Corn belt: Minnesota, Wisconsin, Illinois, Iowa, Nebraska, S. Dakota, Kansas, Missouri
Impact: Over 100 years the corn belt will experience an 8% loss in productivity. Some areas that have steep slopes would have more severe losses in productivity

Results

The model performance was validated with reported corn yields and the Minnesota Crop Equivalent Rating.

Table 2.Hectares in cropland and weighted average erosion rates (NRI,1977), change in PI by slope class, and initial PI for each MLRA in the Corn Belt.

MLRA	Slope (%)	Hectares (1000s)	Estimated erosion (t/ha/yr)	PI	Change in PI (%) 25 yrs	50 yrs	100 yrs
102A	0-2	884	2		1	1	2
	2-6	1294	7		1	1	2
	6-12	158	18		1	2	5
	12-20	18	32		2	4	6
	total	2351	6	.82	0.7	1.0	1.7
102B	0-2	950	4		0	0	1
	2-6	1094	11		1	1	2
	6-12	550	45		2	3	5
	12-20	104	91		2	2	3
	20-45	4	184		2	3	7
	total	2702	19	.85	0.9	1.5	2.3
103	0-2	2787	3		0	0	1

	2-6	1932	11		1	2	4
	6-12	374	40		3	7	15
	12-20	45	82		7	13	19
	20-45	9	146		3	6	10
	total	5147	10	.86	0.8	1.6	3.1
104	0-2	646	5		0	1	1
	2-6	763	13		1	1	3
	6-12	130	37		2	4	8
	12-20	26	80		2	3	4
	20-45	6	130		4	2	0
	total	1571	13	.88	0.7	1.4	2.7
105	0-2	178	4		0	0	1
	2-6	524	12		1	1	3
	6-12	482	24		2	3	5
	12-20	217	59		6	13	20
	20-45	14	216		12	28	40
	total	1415	24	.83	1.9	3.8	6.4
106	0-2	402	6		1	1	1
	2-6	599	16		2	4	7
	6-12	460	34		4	6	9
	12-20	28	109		4	5	5
	total	1490	21	.83	2.5	3.9	5.9
107	0-2	853	5		1	1	1
	2-6	1157	18		1	1	2
	6-12	819	61		2	3	5
	12-20	376	114		2	3	4
	20-45	12	306		2	2	2
	total	3217	38	.92	1.0	1.8	2.7
108	0-2	2663	6		0	0	1
	2-6	2171	17		1	1	2
	6-12	985	42		2	4	6
	12-20	198	94		5	7	8
	20-45	9	214		6	6	5
	total	6024	19	.91	0.9	1.5	2.4
109	0-2	394	8		1	1	2
	2-6	432	23		1	1	5
	6-12	390	62		6	10	13
	12-20	56	168		7	8	9
	20-45	3	337		30	39	39
	total	1275	38	.80	3.0	4.9	7.1
110	0-2	1034	4		0	1	2
	2-6	512	17		2	4	9
	6-12	19	59		16	32	48
	20-45	6	298		39	48	48
	total	1571	10	.80	1.4	2.6	4.9
111	0-2	3289	4		1	1	3
	2-6	1703	12		2	4	8
	6-12	338	38		6	12	22
	12-20	47	75		14	26	36
	45+	3	928		61	61	61
	total	5380	10	.71	1.6	3.1	5.7
112	0-2	845	11		1	2	4
	2-6	806	21		3	6	11
	6-12	14	24		4	9	17

	12-20	3	131		51	79	100
	total	1668	16	.67	2.2	4.2	7.8
113	0-2	699	6		1	1	2
	2-6	384	27		2	3	6
	6-12	67	67		7	11	13
	12-20	9	149		8	20	38
	20-45	3	602		7	7	7
	45+	3	379		29	6	0
	total	1164	19	.73	1.6	2.7	4.4
114	0-2	829	6		1	1	2
	2-6	498	18		3	4	7
	6-12	120	46		6	12	21
	12-20	3	28		1	2	4
	total	1451	14	.75	1.7	3.0	5.5
115	0-2	1577	7		0	1	1
	2-6	1275	21		1	2	4
	6-12	459	59		4	7	10
	12-20	79	126		4	5	6
	20-45	6	207		2	3	2
	total	3369	22	.83	1.4	2.3	3.9

There was no clear general relationship between productivity losses and erosion rates. Certain soils are more vulnerable to productivity losses. Vulnerability of a soil (V) is the slope of the relationship of PI regressed against erosion rate. A series of potential reduction values were also calculated:
R =the PI reduction if 50 cm soil were removed uniformly from cropland
R'=an adjusted reduction potential which is calculated by combining V with a measure of potential for erosion, E, such as the RKLS product from the USLE equation
R'=-(E*V*t)/(PI*x) where,
V=vulnerability
t=time in years
PI=productivity index
x=t/cm/ha
R"=an adjusted reduction potential similar to R' with the addition of C(crop) and P(conservation practice) elements to the USLE.

Table 3.Weighted average values for RKLS, C, P, V, and PI and projected reductions in PI for each MLRA in the Corn Belt.

MLRA	RKLS (t/ha/yr)	C	P	V	PI	Potential Reduction R(%)	Adjusted Potential Reduction R'(%)	R"(%)	Change in PI (%)
102A	21	0.28	0.99	-0.25	0.82	15.2	5.0	1.4	1.7
102B	74	0.30	0.97	-0.15	0.85	8.6	9.8	2.8	2.3
103	28	0.36	0.99	-0.36	0.86	20.7	9.0	3.3	3.1
104	54	0.31	0.99	-0.32	0.88	18.2	15.1	4.6	2.7
105	176	0.20	0.85	-0.27	0.83	16.1	43.6	7.4	6.4
106	90	0.28	0.81	-0.15	0.83	8.9	12.3	2.7	5.9
107	134	0.33	0.88	-0.13	0.92	7.1	14.6	4.2	2.7
108	74	0.33	0.95	-0.16	0.91	7.0	10.3	3.2	2.4
109	129	0.33	0.95	-0.19	0.80	11.9	23.7	7.4	7.1
110	29	0.40	0.99	-0.39	0.80	24.2	10.7	4.2	4.9
111	39	0.29	0.99	-0.39	0.71	27.6	16.5	4.8	5.7
112	56	0.29	0.96	-0.23	0.67	17.0	14.6	4.1	7.8
113	67	0.31	0.99	-0.27	0.73	18.4	18.8	5.8	4.4
114	56	0.29	0.97	-0.30	0.75	20.2	17.2	4.8	5.5
115	80	0.33	0.96	-0.16	0.83	9.7	11.9	3.8	3.9

Productivity Abstract
The loss in non-replaceable soil productivity for the entire Corn Belt was projected to be less than 8 percent over the next 100 years. Certain landscapes will experience a much greater reduction in soil productivity due to slopes greater than 6% and unfavourable subsoils. These soils are more vulnerable to productivity losses. The Dubuque soil series in MLRA 105 (Wisconsin, Minnesota, Iowa) is an example of this vulnerability. The authors stress that when soil loss tolerances are being defined, both the vulnerability of soil to productivity losses and the vulnerability of a landscape to erode must be included in the calculation.

Keywords: Erosion, productivity index model, Corn Belt, USA, USLE, vulnerability, non-replaceable inputs.

48. Pierce, F. J., Larson, W. E., and Dowdy, R. H. 1984. **Soil loss tolerance: maintenance of long-term soil productivity.** J. Soil Water Conserv. 39: 136-138.

A method is presented to establish a quantitative basis for soil loss tolerance (T1) to maintain long-term soil productivity. T1 is a function of a soil's productivity, its vulnerability to productivity losses from erosion, an allowable reduction in productivity, and a planning horizon in years. Soils with little vulnerability to productivity losses from erosion will have a soil loss tolerance, T2, determined by other erosion concerns. The method has broad application. It requires only that the index of soil productivity used be normalized to a range of 0.0 to 1.0.

Summary

Methods: The concept of loss of soil productivity and erosion vulnerability is incorporated into the development of a soil loss tolerance value, T1 (t/ha/yr). T1 is calculated using the following equation:
$T1 = [\Delta * SP_0 * \chi]/(V*t)$ where,
Δ = % allowable reduction in productivity
SP_0 = soil productivity (PI)
χ = t/cm/ha
V = 100 * the slope of SP_0 vs cm soil removal curve at time 't'.

Degradation: Erosion

Crop:

Soil: Waukegan soil series, Typic Hapludoll
Ostrander soil series
Nicollet soil series
Rockton soil series
Dubuque soil series

Land Mgmt: High levels of management assumed.

Location: Minnesota

Impact: The deeper silty and loamy soils have a higher soil loss tolerance (T1 value). Soils developed from outwash plains and terraces, or soils that are shallow to bedrock, have low T1 values.

Results

Table 1.Ranges in T1 values for soil series of Dakota County Minnesota.

Group	Description	Survey area (%)	Range in T1	Dominant T1+
			---t/ha/yr---	
1	Nearly level, silty, loamy soils; on flood plains	3	13-ND++	13-93
2	level to very steep, silty, loamy soils; outwash plains	39 (36)	3-ND	3-9
	and terraces	(3)	9-40	11-15
3	nearly level silty and loamy soils; on outwash plains and terraces	7	6-ND	6-9
4	nearly level to steep, loamy	23 (8)	18-90	18-47
	and silty soils; on uplands	(6)	6-ND	22-36
		(6)	4-ND	4-36
		(3)	10-ND	ND
5	nearly level to sloping loamy soils that are underlain by bedrock; on uplands and terraces	9	4-38	4-13
6	gently sloping to very steep loamy and sandy soils; on uplands and pitted outwash plains	19	4-ND	4-47

+Dominant T1 refers to the range of T1 for the dominant soil in each group
++ND Not defined by equation 8 (T1 equation). Primarily alluvium, loess, and organic.

Productivity Abstract

The concept of soil loss tolerance was refined by including a vulnerability factor. It would be interesting to evaluate the soil loss tolerance of other soil series in other regions. Other on-site and off-site erosion effects still need to be included to complete the concept of soil loss tolerance.

Keywords: erosion effects, model, soil loss tolerance, Minnesota, vulnerability, on farm effects.

49. Putman, J., Williams, J., and Sawyer, D. 1988. **Using the erosion-productivity impact calculator (EPIC) model to estimate the impact of soil erosion for the 1985 RCA appraisal.** J. Soil Water Conserv. 43: 321-326.

The U.S. Department of Agriculture developed a sophisticated physical process model to simulate the soil-climate-plant- management processes in agricultural production and to estimate the impact of soil erosion on resource productivity and fertilizer requirements for the 1985 Resources Conservation Act appraisal. Estimates from this model, the erosion productivity impact calculator (EPIC), show that cropping patterns and the mix of management, tillage, and conservation practices inventoried in the 1982 National Resources Inventory are continued for 100 years, sheet and rill erosion and wind erosion will exceed the erosion tolerance (T) on 127 million acres and 64 million acres, respectively. This rate of soil loss will reduce productivity in the 100th year by an estimated 2.3 percent-the equivalent to taking 7.4 million acres of cropland out of production. Annual fertility requirements are estimated to increase by 798, 672, and 10,920 million pounds of nitrogen, phosphate, and lime, respectively. The present value of this 100 year national loss is about $22 million.

Summary

Methods: The EPIC model is used to estimate productivity losses at the end of 100 years of erosion. Additional fertilizer requirements are also estimated for the same time span. Wind erosion was estimated using the USLE.
Degradation: Erosion (wind and water)
Crop:
Soil:
Land Mgmt: Simulated by model
Location: Cropland USA, by region.
Impact:

Results

Table 3. Erosion-productivity coefficients.*

	Coefficients by Land Resource Group and crop type							
Item	Row crops	SmallRow graincrops	SmallRow graincrops		Small Row graincrops	Small grain		
	---------percent loss in productivity per ton of erosion---------							
Lake States	.0122	.0079	0086	.0056	.0034	. 0024	.0025	.0019
Corn Belt	.0068	.0027	0048	.0027	.0037	.0018	.0047	.0028
N. Plains	.0058	.0028	0044	.0013	.0051	.0019	.0074	.0090
Mountain	.0054	.0022	0011	.0071	.0033	.0029	.0068	

*Computed from EPIC simulations as the percent loss in productivity per ton of erosion.

Table 7. Potential productivity losses.*

	Productivity losses in the 100th year					
	Sheet and rill erosion			Wind erosion		
Region	Percent	Equivalent acre	Gross product	Percent	Equivalent acre	Gross product
Lake states	0.9	424	124	0.7	255	47
Corn Belt	3.5	3483	961	+	6	2
N. Plains	0.6	417	95	0.3	192	35
Mountain	0.4	443	15	1.4	442	74

*Productivity loss is computed from EPIC simulations. Equivalent acre loss is computed as the summation of percent loss of productivity in 100 years times total acres.
+Less than .05 percent.

Productivity Abstract

This paper reports the results of a 100 year EPIC simulation for the 1985 RCA appraisal. All cropland in the U.S. is included. There were several assumptions upon which this appraisal was based:

1. The 100 years of erosion occurred at the 1982 NRI rates
2. Cropping patterns do not change significantly over the 100 years
3. There is a mix of management practices, including conservation tillage.

Most of the cropland will not experience significant losses in productivity. However, there is a portion of cropland that will be greatly affected by further erosion and may suffer a 10% loss in productivity. Identifying these areas now may help keep these areas in production through the use of conservation practices. EPIC also estimates the costs of erosion which includes increased input costs and crop price fluctuations.

Keywords: Erosion, wind, water, EPIC model, long term simulation, loss of productivity, RCA appraisal, costs of erosion.

50. Renard, K. G. and Follett, R. F. 1985. **A research strategy for assessing the effect of erosion on future soil productivity in the United States.** Pages 691-702 in S. A. El-Swaify, W. C. Moldenhauer, and A. Lo, eds. Soil erosion and conservation, Soil Conservation Society of America, Ankeny, Iowa.

Demographic projections into the 21st century, for both the United States and planet earth, indicate the increasing needs for food and fibre production. Furthermore, if the United States continues to export greater amounts of grain, most available land will eventually be farmed. Maintenance of soil productivity must therefore be ensured. The research described to quantify soil erosion-soil productivity is formulated to provide a national perspective for the problem. Some facets of the new research are already underway; others are being planned or require the availability of new resources. The EPIC model, which is in its final phase of testing, will allow for significant improvement in projections for the 1985 RCA report over those in the 1980 report.

Summary

Methods: This paper reviews erosion-productivity research and outlines future research requirements. The EPIC model is described.
Degradation: Erosion
Crop:
Soil:
Land Mgmt:
Location:
Impact:

Results

Research techniques used to quantify the impact of erosion on crop yields included:
1. greenhouse experiments;
2. 2)soil removal or scalping;
3. 3)simulated rainfall and runoff; and,
4. 4)tracers

Productivity Abstract
After the research efforts are briefly described, the authors discuss the importance of encouraging farmers to participate in conservation programs to control soil erosion. The use of models,

particularly the EPIC model is a pillar in the development of a research strategy.

Keywords: Erosion, models, review, conservation tillage, file data, USA, research strategy.

51. Rijsberman, F. R. and Wolman, M. G. 1985. **Effect of erosion on soil productivity: an I nternational comparison.** J. Soil Water Conserv. 40: 349-354.

Drawing upon work done in the north central United State with the soil productivity index (PI), researchers from other countries are testing the applicability of the PI approach to quantifying the relationship between soil erosion and soil productivity on different soils and under different climatic conditions. Reported here is a comparison of research results from the United States, Hawaii, India, Nigeria, and Mexico. These results show that the PI approach is a promising tool, especially when factors in the model are modified to account for the specific soil characteristics that differ from those soils in the north central United States for which the model was originally designed.

Summary

Methods:	The Productivity Index (PI) model was used to examine the effects of erosion on crop productivity. The SOILS 5 and NRI databases were used as input for the model when the North Central U.S was studied. The PI model is based on irreplaceable aspects of soil. This index is usually correlated with corn yields.
Degradation:	Erosion
Crop:	Corn, soybean, barley, spring wheat, sunflower, oats
Soil:	Not specified for the Corn belt
Land Mgmt:	The model assumes optimal management, that is, the bulk density and pH in the top 0.2 m of the soil and the nutrient profile do not limit plant growth
Location:	North Central U.S. (Minnesota)
Impact:	As soil erodes, the PI decreases. The rate and severity of this decrease depended on subsoil characteristics.

Results

Figure 4 illustrates the relationship between crop yields and PI.

Productivity Abstract
The PI model is being tested in this study. First crops other than corn are considered and then the Index is applied to other countries. There are other references which go into greater detail about the development and uses of the PI model.

Keywords: Erosion, productivity, model, world, USA, crop yields, corn, wheat, oats, barley.

52. Williams, J. R., Allmaras, R. R., Renard, K. G., Lyles, L., Moldenhauer, W. C., Langdale, G. W., Meyer, L. D., Rawls, W. J., Darby, G., and Daniels, R. 1981. **Soil erosion effects on soil productivity: a research perspective.** J. Soil Water Conserv. 33: 82-90.

Accurate estimates of future soil productivity are essential to make agricultural policy decisions and to plan the use of the land from the field scale to the national level. Soil productivity is the capacity of a soil, in its normal environment, to produce a particular plant or sequence of plants under a specified management system. Because of this emphasis on a soil's capacity to produce crops, productivity should be expressed in terms of yield. Soil erosion depletes soil productivity but the relationship is not well defined.

Summary

Methods:	This 1981 review of the literature concerning soil erosion and crop productivity had three objectives: 1) To determine what is known about the problem by identifying it, identifying research accomplishments and identifying current research methods. 2)To determine what additional knowledge is needed. 3)To develop a research approach for solving the problem.
Degradation:	Erosion
Crop:	
Soil:	
Land Mgmt:	
Location:	
Impact:	

Results

Productivity Abstract
The gradual nature of productivity loss due to erosion over the long term is difficult to detect when studying the effects of erosion. Little soil erosion research has been since yields have not decreased to a point where producers are experiencing significant economic losses. Another deterrent to research in this area is the amount of time and energy needed to obtain yields to measure and compare erosion effects. The results from short term studies often are greatly influenced by climatic conditions and can only be applied to the local situation. It is suggested that more effort be invested in the development of models that simulate erosion and crop yields over the long term. The EPIC model was developed in response to the basic model requirements outlined by this review committee.

Keywords: review, erosion, models, research results, USA.

53. Williams, J. R., Putman, J. W., and Dyke, P. T. 1985. **Assessing the effect of soil erosion on productivity with EPIC.** Pages 215-226 in Erosion and soil productivity: Proceedings of the National Symposium on Erosion and Soil Productivity, December 10-11, 1984, New Orleans, Louisiana.

A method for use in determining and applying the E/P was developed. EPIC simulated crop yields and erosion rates are the variables involved in the E/P. Two long-term EPIC simulations are used to calculate EPI values (yields with erosion/yields with no erosion) for a given soil in a particular MLRA. A two parameter exponential function is used to relate average EPI to time. The function is differentiated and the independent variable is transformed from time to accumulated erosion to derive E/P.

Summary

Methods: This study outlines the parameters of the EPIC model which was used to develop and apply Erosion-Productivity relationships (E/P). Two simulation runs were needed:
1)represented perfect conservation by preventing erosion,
2)no conservation practices.
All other elements of the model were identical. An index EPI was defined:
EPI = YLDe/YLDu, where
YLDe = simulated yield with erosion.
YLDu = simulated yield without erosion.

Degradation: Erosion (wind and water)

Crop: Corn

Soil: Miami silt loam

Land Mgmt: Continuous corn is assumed, with fertilizer rates of 100 kg/ha N and 20 kg/ha P.

Location: Lafayette, Indiana

Impact: In the example, the EPI ratio decreases over time. The initial decrease is rapid and slows once the topsoil has been eroded. The assumed time span was 100 years

Results

Productivity Abstract
An advantage to this method of calculating E/P was the savings in computer time. This will allow for quick means of evaluating conservation practices and perhaps determining the costs of erosion in various areas of the U.S. Both water and wind erosion are included in these calculations.

Keywords: erosion, EPIC, model, corn, Indiana, productivity index.

54. Williams, J. R., Renard, K. G., and Dyke, P. T. 1983. **EPIC: A new method for assessing erosion's effect on soil productivity.** J. Soil Water Conserv. 35: 381-383.

The mathematical model EPIC (Erosion-Productivity Impact Calculator) was developed recently to determine the relationship between soil erosion and soil productivity in the United States. To accomplish this complex objective, four goals were set in the model development process. The model must be (a) physically based and capable of simulating the processes involved simultaneously and realistically using readily available inputs; (b) capable of simulating hundreds of years, if necessary, because erosion can be a relatively slow process; (c) applicable to a wide range of soils, climate, and crops encountered in the United States; and (d) efficient, convenient to use, and capable of assessing the effects of management changes on erosion and soil productivity.

Summary

Methods: This paper is one of several introductory articles which outline the functions and applications of the EPIC model. The model was in the test stage of development at the time of this writing.

Degradation: Erosion
Crop:
Soil:
Land Mgmt:
Location:
Impact: Generally, the analysis indicated a reduction in crop yield depending upon soil and climatic characteristics and fertilizer application rates. Yield reductions were estimated to be greater than 40% in some areas with high erosion rates.

Results

Table 2.Comparisons of simulated and recently measured crop yields

			Yield kg/ha		S.D. kg/ha	
State	Years	Crop	Measured	Simulated	Measured	Simulated
Iowa	5	Corn	6996	7653	1110	1035
Iowa	5	Oats	1755	2225	774	1000
Iowa	10	Corn	6162	7325	1908	1895
Iowa	7	Corn	7270	7235	1702	798
Iowa	7	Soybeans	1910	2065	284	531
Iowa	10	Corn	6593	7095	1296	1075
Iowa	5	Corn	6664	7580	815	790
Iowa	5	Corn	6575	7265	922	1215
Iowa	5	Corn	6077	7250	1279	1210
Iowa	4	Corn	7033	7205	1010	1175
Missouri	10	Corn	7833	7632	2077	1635
Ohio	3	Corn	8399	7460	2665	2020

Productivity Abstract

This paper is a progress report of the development of the EPIC model. The authors believe that the test results reported are reasonably similar to actual yields. More testing was to be done in crop growth simulation and nutrient use.

Keywords: erosion, development of EPIC model, USA, corn, oats.

Section 2: Compaction

Small Grain Cereals

55. Sheptukhov, V. N., Voronin, A. E., and Shipilov, M. A. 1982. **Bulk density of the soil and its productivity.** Sov. Soil Sci. 14: 97-107.

The results are reported of a study of the effect of excessive compaction of Sod-Podzolic and irrigated Chestnut soils and of Ordinary Chernozem under the effect of the moving parts of agricultural machines on the agrophysical properties and nutrient regime of soils and on spring barley yield. An increase in the bulk density of soils under the effect of human activity disturbed their water-air regime and gas exchange between soil and the atmosphere, impaired nitrification, and created conditions for denitrification. The nitrogen nutrition of spring barley deteriorated in excessively compacted soil and its yield dropped sharply.

Summary

Methods: This paper reports on a field study that dealt with the effect of increased bulk density on barley yields in the USSR. Compaction was induced by prescribed number of tractor passes. The bulk density at a depth of 10-20 cm was the compaction level measurement. This resulted in six levels of compaction ranging from 1.2 to 1.45 g/cm^3 (0.05 g/cm^3 increments). Two light tractors and two heavy tractor were used.
Degradation: Compaction
Crop: Barley
Soil: Sod-Podzolic soil, Ordinary Chernozem. Chestnut soil
Land Mgmt: Chestnut soil plots were irrigated
Location: USSR
Impact: Grain yields were significantly reduced when bulk density was greater than 1.40 g/cm^3 in the Sod-Podzolic soil. The ordinary Chernozem was much more sensitive to compaction in that yields were reduced when bulk density was only 1.11 g/cm^3. The irrigated Chestnut soil yields were significantly reduced when bulk density was 1.30 g/cm^3

Results

Table 7.Effect of bulk density of the soil on spring barley grain yield

Variants tractor passes type	no.	Bulk density g/cm^3 10-20 cm depth	Density of productive stems, stems per m^2	Number of grains in ear, grains	Yield cntr/ ha	Departure from the control cntr/ha
Sod-Podzolic soil (1976)						
Control		1.35	893	18.5	38.0	--
DT75	1	1.40	955	17.9	35.8	-2.2
	3	1.39	476	16.2	28.4	-9.6
MTZ52	1	1.40	709	15.6	37.4	-0.6
	3	1.43	736	15.8	31.1	-6.9
T150K	1	1.45	724	16.0	29.2	-8.8
K700	1	1.41	796	16.8	29.3	-8.7
	3	1.43	676	16.3	24.0	-14.0

LSD (0.05)		0.05	--	1.5	8.2	--
Ordinary Chernozem (1979)						
Control		0.87	694	15.1	37.5	--
DT75	1	1.08	648	13.8	34.0	-3.5
MTZ52	1	1.09	669	13.7	32.0	-5.3
T150K	1	1.13	527	13.7	31.1	-6.4
	3	1.21	328	13.4	15.7	-21.8
K700	1	1.11	630	13.6	30.6	-6.9
LSD (0.05)		0.05	--	1.3	6.0	--
Irrigated Chestnut soil (1979)						
	1	1.20	1080	12.0	53.6	-2.3
	2	1.25	865	14.8	55.9	--
	3	1.30	860	12.4	44.2	-11.7
	4	1.35	811	10.5	39.0	-16.9
	5	1.40	675	10.2	29.9	-26.0
	6	1.45	503	10.2	29.8	-26.1
LSD (0.05)		0.05	--	1.5	4.4	--

Productivity Abstract

This study illustrates that compaction can affect different soils to different degrees. The non-irrigated soils did not continue to exhibit yield decrease after the initial response to increased bulk density. The passes of the light tractor had no significant effects on yield. The irrigated Chestnut, however, continued to have significant decreases after each pass of the tractor. The barley plants showed signs of nitrogen starvation and this was attributed to the increased bulk density or level of compaction.

Keywords: Compaction, field study, barley, USSR, bulk density, nitrogen starvation.

56. Voorhees, W. B., Evans, S. D., and Warnes, D. D. 1985. **Effect of preplant wheel traffic on soil compaction, water use, and growth of spring wheat.** Soil Sci. Soc. Am. J. 49: 215-220.

The effects of wheel traffic on small grain emergence and early growth is commonly observed in production fields. However, the plant response is not consistent, but appears dependent on soil and climatic conditions. The objective of this study was to measure the effects of preplanting wheel traffic on soil compaction and 'Era' spring wheat (Triticum aestivum) growth in field plots in West Central Minnesota under a range of growing season conditions. The 1975 and 1977 growing season were slightly wetter than normal while the 1976 growing season was significantly drier. Treatment comparisons were wheat planted in soil compacted by wheel traffic during spring field operations and wheat planted in soil that had not been wheel trafficked. Normal field-sized equipment (tractor weight ranged from 4 000 to 7 000 kg) was used to perform spring fertilizer application, spring tillage, and seeding. The controlled wheel traffic soil was delayed by about 10 d because of poor seed-soil contact, and grain yield was 27% lower than in the nontracked soil. Shortly after planting in 1976, the nontracked soil lost excessive amounts of water by evaporation from the loose 0- to 0.15-m layer. As a result, wheat growth in the wheel-tracked soil was better than in the nontracked soil, and yield was increased by 53%. In both 1975 and 1976, there was slightly more water used from the wheel-tracked treatment than from the nontracked treatment, resulting in differences in water use efficiency. Effects of wheel traffic on wheat growth and yield were closely related to growing season precipitation and illustrate the need to consider probable climatic conditions when developing management systems for controlling field vehicular wheel traffic.

Summary

Methods: This field study had two compaction treatments, a control treatment (no wheel traffic) and compaction as a result of wheel traffic. Traffic lanes were established by performing all field operations in the same direction and by using the controlled wheel traffic concept. Precipitation, temperature, soil bulk density, and soil penetrometer resistance were recorded throughout the study. All plant and soil measurements were made in the centre of both wheel-tracked and nontracked areas.

Degradation: Compaction

Crop: Wheat

Soil: Forman clay loam, Udic Argiboroll

Land Mgmt: The sequence of field operations for wheat each year was:
1)Fall moldboard plowing to a depth of 25 cm.
2)Spring broadcast fertilizer of 107 kg/ha of 34-0-0.
3)Spring secondary tillage with a tandem disk to a depth of about 20 cm.
4)Seeding wheat with a 4.57 m wide drill at the rate of 134.5 kg/ha in rows .17 m apart.
5)There was an single application of herbicide to control broad leaf weeds using a bicycle sprayer.

Location: Morris, Minnesota.

Impact: The grain yield was 27% lower in the wheel tracked soil compared to the non wheel tracked soil in 1975. In drier conditions, the wheel tracked yields were increased by 53%. In 1977 the wheel tracked yields were only 8% less than the non-tracked yields.

Results

Table 5. Wheat grain and straw yield, and water use efficiency.

Treatment	Grain yield	Straw yield	Grain/straw ratio	Water use efficiency
	----Mg/ha----			kg grain/mm H_2O/ha
		1975		
No wheel traffic	3.70	4.50	0.82	11.6
Wheel traffic	2.69	4.44	0.61	8.1
LSD (0.05)	0.98	0.31		
		1976		
No wheel traffic	1.45	1.54	0.94	7.2
Wheel traffic	2.22	1.87	1.19	8.9
LSD (0.05)	0.39	0.37		
		1977		
No wheel traffic	2.73	--	--	--
Wheel traffic	2.52	--	--	--
LSD (0.05)	0.44	--		

Productivity Abstract

Compaction effects yields differently depending on the amount of precipitation during the growing season. In dry years, compaction affects yields positively, while in wet and average years yields are affected negatively. The amount of precipitation and effect of compaction on yield are linearly related (Fig. 5). It should also be noted that even though there is a positive effect from compaction in 1976, the wheel tracked yields were still below the noncompacted yields in 1975 and 1977. This is one of the few studies of the effect of compaction on wheat yields.

Keywords: Compaction, wheat, Minnesota, wheel tracks, precipitation levels, field study.

57. Wilhelm, W. W. and Mielke, L. N. 1988. **Winter wheat growth in artificially compacted soil.** Can. J. Soil Sci. 68: 527-535.

Dense soil tillage pans can develop from improper use of tillage tools. The influence of compacted layers or pans on plant growth and development, although much studied, is not clearly understood. This greenhouse experiment evaluated the influence of uniformly compacted soil and thin layers of compacted soil, placed at various depths, on early growth of winter wheat (Triticum aestivum L.). Artificially compacted soil [Alliance silt loam, Aridic Argiustoll in polyvinyl chloride tubes of 150-mm diameter by 350 mm long. Treatments were: (1) uniformly noncompacted (bulk density 1.3 Mg/m3) soil; (2) uniformly compacted (bulk density 1.8 Mg/m^3) soil; (3) a compacted (bulk density 1.8 Mg/m^3) soil layer at 100 to 200 mm depth with the remaining soil non-compacted (bulk density 1.3 Mg/m^3); or (4) a compacted (bulk density 1.8 Mg/m^3) soil layer at 180 to 200 mm depth with the remaining soil noncompacted. Generally, winter wheat grown in cores that were uniformly compacted or compacted in the upper layer responded similarly. Plant height at the end of the experiment (32 d after planting), for the uniformly compacted and the upper compacted layer treatments was 280 mm, compared to 323 mm for the control (uniformly noncompacted). Leaf area development was similar to the response indicated for plant height throughout the growth period. Root mass and length tended to be less in layered or compacted soil than in noncompacted soil. Roots accumulated within or immediately above the compacted soil layers. Higher bulk density or a shallow compacted layer produced winter wheat with reduced height, leaf area, and dry matter compared with soil of normal density or with a deeper compacted layer.

Summary

Methods: Green house compaction simulation was performed. A compacted soil had a bulk density of 1.8 Mg/m^3 and the noncompacted soil had a bulk density of 1.3 Mg/m^3.
There were four treatments:
1)uniformly non-compacted (control)
2)uniformly compacted
3)shallow layer compaction
4)deeper layer compaction
Compaction was achieved by 25 blows with a 2.5 kg falling weight. The measures of growth included height after 32 days, leaf area, and root mass and length.

Degradation: Compaction

Crop: Winter wheat

Soil: Alliance, fine-silty, mixed, mesic Aridic Argiustoll (similar to eluviated brown chernozem).

Land Mgmt:

Location: University of Nebraska Agriculture Research station near Sidney, Nebraska.

Impacts: High soil densities can significantly reduce above ground growth of wheat. Dense layers located near the soil surface may be more deleterious to growth than uniformly compacted profiles.

Results

Table 1.Growth characteristics of winter wheat grown in compacted and layered soils

Treatment	Plant height (mm)	Leaf area (mm2/plant)	Dry matter (mg/plant)	Rooting density Length (cm/m3)	Rooting density Mass (g/m3)
1	323	2635	167	3.41	21.7
2	287	2137	123	2.54	17.0
3	273	1873	125	3.09	17.9
	328	2505	163	3.38	24.3

Productivity Abstract
Because this study was not performed in field conditions and grain yields were not recorded, no clear relationship between wheat yield and compactions was evident. The only link to yield was that this study "strongly suggested" a reduction in residue production and that in dryland conditions the yield of grain is related to the amount of residue available from the previous crop.

Keywords: Compaction, wheat, rooting density, Nebraska, greenhouse study, tillage pan.

Corn and Soybeans

58. Anderson, F. N. and Peterson, G. A. 1985. **Sucrose yield of sugar beet as affected by chiselling and plowing compacted soils.** Soil Till. Res. 5: 259-271.

Sugar beet (beta vulgaris L.) growers in Nebraska, USA have been convinced by equipment manufacturers in the past 10 years that chisel tillage is needed on their soils to remove compaction zones. No data were available to assess the reality of their conviction that chiselling was an essential part of their tillage systems. The experiments discussed here were designed to test the impact and need for chiselling to depths up to 30 cm in systems where moldboard plowing depth of 20 cm is the most common primary tillage. Four degrees of soil compaction were created artificially in sugarbeet soils in Nebraska, USA, and combinations of mouldboard ploughing and chiselling were imposed on them. Compaction reduced sugar yields to extents that depended on the degree of compaction. In all but the severest compaction treatment, chiselling had the same effect as ploughing on yield restoration; in the most severely compacted soil chiselling was ineffective in one year and as effective as ploughing in another year. Combined ploughing and chiselling did not have an additive effect over that of ploughing or chiselling alone, and no treatment restored yields fully to those achieved on non-compacted soil. Penetrometer resistance measurements indicated that compacted soil below 30 cm depth was responsible for reduced sugar yields. On the soils used, each increase in resistance of 700kPa over the range 4000-8000kPa resulted in a 10% reduction of sucrose yield.

Summary

Methods: This field study was designed to examine to what extent chiselling could alleviate the effect of compaction on sugar beet growth. Certain plots were compacted by 20 passes of a road packer (3.2 T). After a 38 mm rainfall, 7 more passes were completed. This resulted in a level of compaction that was much higher than would normally exist on a typical farm. The chisel treatment was done on both compacted

	and non-compacted plots. In 1979 and 1980 several methods of compaction were used in addition to the road packer to represent different levels of compaction.
Degredation:	Compaction.
Crop:	Sugar beets, corn
Soil:	Tripp fine sandy loam, Typic Haplustoll
Land Mgmt:	Fertilizer was applied according to soil tests. All fields were irrigated as needed. Sugar beets were planted in rows 55 cm apart.
Location:	Western Nebraska
Impact:	Neither chiselling nor plowing totally restored yields to the non-compacted or lightly compacted yield levels.

Results

Table 2.The effects of type of compaction, plowing and chiselling on sucrose yield in 1979 and 1980.

Compaction	Plowing	Chiselling	Sucrose yield (Mg/ha)		
			1979	1980	Mean
None	No	No	8.53	-a	8.53
	No	Yes	7.67	--	7.67
	Yes	No	8.23	--	8.23
	Yes	Yes	8.34	--	8.34
V-blade	No	No	8.08	8.03	8.06
	No	Yes	7.87	7.36	7.62
	Yes	No	6.88	7.42	7.15
	Yes	Yes	7.36	7.40	7.38
Truck tracks	No	No	5.50	5.88	5.69
	No	Yes	5.89	8.25	7.07
	Yes	No	6.94	6.67	6.81
	Yes	Yes	6.70	7.21	6.95
Sheep's foot packer	No	No	1.76	2.98	2.37
	No	Yes	2.18	6.70	4.44
	Yes	No	5.19	6.98	6.08
	Yes	Yes	6.04	6.20	6.12
LSD (0.05)			1.06	1.06	1.06

a - In 1980 uncompacted plots were damaged and no data were collected

Table 4.Residual effects of compaction, plowing, and chiselling on corn yields in 1981 on plots compacted in 1980.

Compaction	Plowing	Chiselling	Yield (Mg/ha)
None	No	No	-a
	No	Yes	--
	Yes	No	--
	Yes	Yes	--
V-blade	No	No	5.50
	No	Yes	5.35
	Yes	No	5.80
	Yes	Yes	5.80
Truck tracks	No	No	3.20
	No	Yes	4.85
	Yes	No	5.50
	Yes	Yes	5.80
Sheep's foot packer	No	No	2.20
	No	Yes	3.50
	Yes	No	5.85

	Yes	Yes	6.20
LSD (0.05)			0.73

a -No data were collected because plots were damaged on 1980 before beets were planted.

Productivity Abstract
This study was redesigned in 1979. The initial results showed that there were no significant differences between yields in any of the treatments. The compaction effects were destroyed as moldboard plowing was used as the primary tillage operation over the entire study area. A plowing treatment was added to the study. The results of 1979 and 1980 indicated that the practices of chiselling and/or plowing may restore some portion of the yield loss due to compaction. The lower yields were attributed to low water infiltration rates. The sugar beet and corn yield results do give some indication of the effect of different levels of compactions on crop yields. When no plowing or chiselling operations were applied to plots, corn yields from heavily compacted plots were 62% lower than yields from the slightly compacted plots. The differences in yield were not significant when plowing and chiselling were applied.

Keywords: Compaction, Nebraska, sugar beets, corn, chiselling, plowing, field study.

59. Bauder, J. W., Randall, G. W., and Schuler, R. T. 1985. **Effects of tillage with controlled wheel traffic on soil properties and root growth of corn.** J. Soil Water Conserv. 40: 382-385.

An experiment was conducted to determine effects of tillage with controlled wheel traffic on corn (Zea mays) root growth and soil properties. Measurements were made following five years of four tillage treatments with controlled wheel traffic on a Nicollet- Webster soil in south central Minnesota. Only one side of each crop row was used for equipment wheel traffic. Tillage method had no significant effect on bulk density or gravimetric water content. However, it had a significant effect on cone index when measured during the sixth year of continuous tillage. Wheel tracks and traffic pattern, soil depth, and the two-factor interaction had significant effects on measured parameters, including mechanical resistance and root length density. Root length density was least and mechanical resistance was significantly greater in the trafficked positions. Tillage method had an over-shadowing impact on root length density and root distribution pattern. No-till and ridge till plant management on a fine-loamy soil resulted in relatively high mechanical resistance near the soil surface. This mechanical resistance, coupled with wheel traffic effects, caused maximum root accumulation in the 0- to 10-cm soil depth. The overall differences in soil physical properties, due to continuous tillage, caused a relatively wide range in total root length and root distribution patterns. Maximum root distribution occurred with the ridge till plant system.

Summary

Methods: The effects of the following four tillage systems on corn root growth were evaluated: no-till, ridge and flat till plant, fall chisel, and fall moldboard plowing tillage. Tillage treatments and traffic patterns were kept in the same positions for the duration of the study. P and K were broadcast in the fall before primary tillage, and N in the spring. Corn was planted in early to mid May.

Degradation:	Compaction
Crop:	Corn
Soil:	fine, loamy, Nicolett Webster soil
Land Mgmt:	Fall primary tillage was performed in November. All vehicular traffic was confined to the same rows (for all field operations) from 1975 to 1980. Individual treatment plot size was about 6.1 m by 38 m, with a 76.2 cm row spacing.
Location:	South central Minnesota
Impacts:	Maximum root length density occurred in the crop row where the seed was planted rather than the trafficked interrow. The no-till treatment had the greatest root length density in the 0 - 7.5 cm level which may explain the low drought resistance experienced by no-till corn. The tillage method had more effect on root distribution than did the amount of traffic.

Results

Figure 3 compares the root length densities of all tillage systems.

Productivity Abstract

Root length density is used to compare tillage systems with respect to the effect on root growth and soil properties. No actual or estimated corn yields are compared.

Keywords: Compaction, corn, Minnesota, root density, field study.

60. Chaplin, J., Lueders, M., and Rugg, D. 1986. **Sand soil after seven years of reduced tillage.** Trans. A. Soc. Agric. Eng. 29: 389-392.

A tillage study was conducted on a Hubbard loamy sand soil in central Minnesota. Tillage regimens included moldboard plowing followed by a furrow press type packer, chisel ploughing, no-till or direct drilling and ridge sowing. All operations were conducted in the spring for corn and soyabeans grown in rotation on irrigated 47 m by 15 m plots. A compacted layer, mean cone index 2200 kPa, exists at a depth of 24 cm for the mouldboard plough, no-till and ridge regimens, possibly as a result of the previous years' mouldboard ploughing. Yield differences were not attributed to the compacted layer measured in the wheel track spaces between rows.

Summary

Methods:	Tillage treatments included moldboard plowing, chisel plowing, ridging, and no-till planting. Prior to the start of the study tillage was mainly moldboard plowing. Six compaction profiles were recorded for each plot. Yield was the dependent variable in the analysis of variance and year, tillage system, and plot position were the independent variables.
Degradation:	Compaction
Crop:	Corn, soybeans
Soil:	Hubbard, loamy sand
Land Mgmt:	Corn stalks were left undisturbed over the winter. Tillage operations were conducted in the spring. All plots had an application of 340 kg/ha super phosphate prior to

tillage. The corn seeding rate was 74,000 seeds/ha (treated with 170 kg/ha of 8N:10P:30K and 7.9 kg/ha of insecticide). The soybean seeding rate was 420,000 seeds/ha (without fertilizer or insecticide). All plots were irrigated.

Location: Becker research station, Central Minnesota

Impact: Yield differences were not attributed to the compacted layer measured in the wheel track spaces between rows. Field position had a significant effect on yield.

Results

Table 1. Crop yield (t/ha) Analysis of Variance

Soybeans — Number of observations=24; Yield mean=3.27 t/ha; Squared multiple correlation=0.808

Source	of squares	DF	Mean-square	F-ratio	P
Year	8.53	2	4.27	5.30	0.016*
Tillage	2.50	3	0.83	1.04	0.402
Square	4.27	1	4.27	5.31	0.034*
Error	13.68	17	0.80		

*=significant (P<0.05)

Corn — Number of observations=23+; Yield mean=8.94 t/ha; Squared multiple correlation=0.768

Source	of squares	DF	Mean-square	F-ratio	P
Year	185.53	2	92.67	21.85	0.000*
Tillage	15.22	3	5.07	1.20	0.343
Square	20.31	1	20.31	4.79	0.044*
Error	13.68	17	0.80		

*=significant (P<0.05)
+(case of yield = 4.40 t/ha deleted)

Table 2. 95% confidence interval expressed on the average yield for each tillage system.

Tillage	Corn @ 15.5% MCWB			Soybeans @ 13.0% MCWB		
System	Average	Lower	Upper	Average	Lower	Upper
	t/ha					
Moldboard plow	9.13	8.68	9.57	3.39	3.19	3.59
No-till	8.88	8.38	9.37	3.25	3.05	3.46
Chisel	9.11	8.67	9.56	3.28	3.08	3.48
Ridge	8.64	8.20	9.09	3.15	2.95	3.35

Productivity Abstract

The objectives of this study were to examine the compaction profiles that resulted from the use of four different tillage systems and to determine if these profiles had an effect on crop yields. The authors suggest that a plow sole may have been present throughout the seven year study as a compacted layer was located at 24 cm in the moldboard plow, ridge, and no-till plots. Only the chisel plow had a lower cone index. However, the yield from the chisel plow treatment was not significantly different from the other treatments. Non irrigated plots may react differently.

Keywords: compaction, corn, soybeans, tillage systems, field study, irrigated, penetrometer, Minnesota.

61. Dickey, E. C., Peterson, T. R., Gilley, J. R., and Mielke, L.N. 1983. **Yield comparisons between between continuous no-till and tillage rotations.** Trans. Am. Soc. Agric. Eng. 26: 1682-1686.

Continuous use of zero tillage planting systems may result in reduced yields, especially on finer textured soils that tend to be poorly drained. Soil compaction and poor soil aeration have been identified as possible factors contributing to the lower yields. Research conducted to evaluate tillage rotations on these soils shows that periodic use of the mouldboard plough can result in statistically higher yields as compared with continuous zero tillage. However, use of chisel plough and disk tillage systems following 3 years of continuous zero tillage did not result in yield increases. A relationship between cone penetrometer index and yield indicates a trend towards lower yield and higher index values, with continuous zero tillage having the highest index.

Summary

Methods: There were 4 tillage systems in this 4 year field study. Yield responses and cone indices were measured for each tillage treatment within four irrigation treatments. The tillage systems were:

1) No-till
2) Disk
3) Chisel
4) Moldboard plow

There was a non-irrigated treatment and three levels of irrigated plots:

1) adequate water to fully supply a plant's evapotranspiration requirements (1.0 ET)
2) 0.75 ET
3) 0.50 ET

Over the 4 years the following tillage treatments were used to evaluate the effect of changing from continuous no-till to other tillage systems:

1) Continuous no-till
2) Two years no-till followed by:
   - plow system
   - chisel system
   - disk system
3) Three years no-till followed by:
   - plow system
   - chisel system
   - disk system

A continuous disk treatment was also performed to compare to the no-till treatments as disking is common in Nebraska.

Degradation:	Compaction
Crop:	Corn
Soil:	Sharpsburg-Fillmore association
Land Mgmt:	Field operations for each tillage system: 1)No-till - shred stalks, plant, apply herbicide, fertilize, cultivate twice. 2)Disk - shred stalks, disk twice, plant, apply herbicide, fertilize, cultivate twice. 3)Chisel - shred stalks, chisel, disk, plant, apply herbicide, fertilize, cultivate twice. 4) Moldboard - shred stalks, plow, disk twice, plant, apply herbicide, fertilize, cultivate twice. Fertilizer was applied to all plots according to soil test results.
Location:	Mead Nebraska
Impact:	Periodic use of the moldboard plow can result in statistically higher yields as compared to continuous no-till. A relationship between cone penetrometer index and yield indicates a trend toward lower yield with higher index values with continuous no-till having the highest index.

Results

Table 2.Grain yield from the tillage and water treatment combinations for the four year study.

		Yield			
		Water treatment			
Year	Tillage treatment*	Non-irrigated	0.50 ET	0.75 ET	1.0 ET
		------------------	kg/ha	----------------------	
1978	N	9270	10700a#	9450a	11000a
	D	8360	9740b	10400a	10200a
1979	NN	4810a	7910a	8750a	9070a
	DD	4890a	7770a	9420a	8780a
1980	NNN	327b	5840ab	6910b	8260a
	DDD	505b	5300b	7460b	8360a
	NND	704b	5370ab	7080b	8170a
	NNC	1290b	6140ab	7370b	8760a
	NNP	2900a	6640a	8550a	8770a
1981	NNNN	7350b	8980bc	8710ab	9030ab
	DDDD	8310ab	8360c	8040b	8350b
	NNND	--	9160abc	8510ab	8710ab
	NNNC	--	9170abc	8720ab	8750ab
	NNNP	8650a	9700a	8950ab	8990ab
	NNPN		9230ab	9440a	9890a

*N is no-till system, D is disk system, C is chisel system, and P is moldboard plow system.
#Numbers with the same superscript are not significantly different (Duncan's multiple range, 5% level) within each water treatment and each year.

Table 3.Cone index values by tillage and water treatment for different depths.

Water Treatment	Tillage Treatment*	Cone index Soil depth (cm) 0-5	5-10	10-15	15-20
		------------kg/cm**2----------			
Non-irrigated	P	3.28a#	3.52a	4.62a	5.66a
	C	4.21a	4.61a	5.05a	5.88ab
	D	5.84b	6.08b	6.75b	6.82ab
	N	8.02c	8.20c	7.53b	7.59b
0.50 ET	P	2.10a	3.75a	3.94a	4.78a
	C	2.88ab	4.45ab	4.83ab	5.39a
	D	4.24bc	5.60b	5.31bc	6.91b
	N	5.92c	5.73b	6.29c	7.12b
0.75 ET	P	2.13a	2.03a	2.81a	4.56a
	C	2.68a	3.88b	5.17b	6.55b
	D	3.68a	4.82b	5.73b	6.83b
	N	5.48b	6.06c	6.20b	6.38b
1.0 ET	P	3.74b	2.99a	2.69a	3.63a
	C	1.36a	2.83a	4.08b	4.69b
	D	2.33a	3.57a	4.17b	4.75b
	N	4.88c	5.10b	4.56b	5.13b

*P is moldboard plow system, C is chisel system, D is disk system, and N is no-till system.
#Numbers with the same superscript are not significantly different (Duncan's multiple range, 5% level) within each depth and water treatment.

Productivity Abstract
The inclusion of various water treatments illustrates that soil compaction that exists during a continuous a no-till tillage system is intensified under dry conditions. The driest year, 1980, had significantly low yields in both the non-irrigated treatments and the 0.50 ET water treatment. Moldboard plowing after two or three years of no-till produced significantly higher yields in only the low water treatments. A linear relationship between cone index and yield was developed using the results from the 0.50 and 0.75 ET water treatments at a soil depth of 5-10 cm. The yield reductions experienced in the continuous no-till system were attributed to the significantly higher cone index at that soil depth. The authors note that yield reductions in other studies occurred at much higher cone indices (Threadgill, 1982, cone index values of 21.1 kg/cm^2 would reduce crop yields). In this experiment the no-till cone index for the no-till system at the 5-10 cm depth ranged from 5.1 to 8.2 kg/cm^2.

Keywords: Compaction, corn, Nebraska, field study, tillage systems, cone index values, moldboard plowing.

62. Dolesh, B. J., Jasa, P. J., and Dickey, E. C. 1987. **Spring subsoiling effects on soil compaction and yield.** Am. Soc. Agric. Eng. paper no. 87-1004: 12pp.

The effects of layby subsoiling on soil compaction, induced with a 20 tonne axle load, and maize yield were evaluated. Compacted subsoiled plots had 61% lower yields than the non-compacted plots. Subsoiling reduced the penetration resistance, but yields did not increase significantly in that growing season. However, in the following season, there was a yield response to subsoiling.

Summary

Methods: This field study had three treatments:

1) The no treatment plot. This plot was representative of a typical field where any existing soil compaction would be due to using the same tillage system for several years.
2) Compacted treatment. Both rows and row middles were compacted by a tractor pulling a single axle grain cart that had a total weight of 20 Mg. This was done in late March and in early May of 1985.
3) Subsoiling treatment. Subsoiling was to a depth of 40 cm in the row middles when the corn was approximately 30 cm high.

Degradation: Compaction

Crop: Corn

Soil: Filmore silty clay loam, Typic Argialbolls

Land Mgmt: Nitrogen was applied to all plots at the rate of 132 kg of N per ha. The field was tandem disked twice to a depth of 10 cm. Corn was planted at a rate of 41500 seeds/ha in rows spaced 91 cm apart. A single crop cultivation was performed on the entire field before the subsoiling treatment was applied to the appropriate plots.

Location: Mead, Nebraska.

Impact: *1985*

- Compaction treatment plots had 61% less yield than the field condition plots.
- Subsoiling did not significantly effect yields.

1986

- There was no significant difference between the compaction treatment yields and the field condition yields.
- The 1985 subsoiling treatment had an effect on the 1986 yields. Yields from the subsoiled plots were 12% greater than the yields from the non-subsoiled plots.

- When all initial treatments were subsoiled in 1986, results were similar to 1985.

Results

Table 2. Mean yield of treatments

Treatment	1985 yield t/ha	1986 yield t/ha
Compacted 1985	3.47*	7.82
Filed conditions	8.80*	7.94
Subsoiled 1985	5.99	8.32*
Non subsoiled	6.28	7.44*
Compacted 1985 Subsoiled 1986		4.77*
Field conditions subsoiled 1986		6.40*
Subsoiled 1985, 1986		5.71
Non-subsoiled 1985, Subsoiled 1986		5.46

*Yields are significantly different using ANOVA at the 10 percent significance level.

Productivity Abstract
The authors made the following conclusions from their results:

1) Corn yield was significantly reduced in both years when compaction was induced by a 20 Mg load.
2) Layby subsoiling did not produce an immediate yield response as a yield increase on the 1985 subsoiled plot was experienced in 1986.
3) Hot dry weather that immediately followed subsoiling in 1986, may have been responsible for the lower yields (29% less than the non-subsoiled plots) in the subsoiled plots.

This short term study illustrates how climatic variability can effect the results from year to year. The amount of precipitation was greater in 1986 than in 1985 (824 mm vs 508 mm). However, the was an eight day dry spell immediately following subsoiling in 1986. These two years are difficult to compare as a result of this weather difference.

Keywords: Compaction, corn yield, subsoiling, field study, Nebraska, moisture stress.

63. Erbach, D. C., Melvin, S. W., Cruse, R. M., and Janzen, D. C. 1986. **Effects of tractor tracks during secondary tillage on corn production.** Am. Soc. Agric. Eng. paper no. 86-1533: 13pp.

Compaction caused by tractor traffic during secondary tillage was studied in a field experiment. Twelve track and wheel type tractors were evaluated. Corn emergence, growth and yield were significantly reduced by the tractor traffic. Soil bulk density, water content, and penetration resistance were greater in the tractor tracks. Track-type tractors tended to have less affect on soil conditions and corn growth than did wheel type tractors.

Summary

Methods: There were 15 tractor treatments assigned to 12 plots. Tillage was done to a 10 cm depth with a 9.8 m wide field cultivator. Plots were planted perpendicular to tillage direction. Corn plant response was measured by: rate of stand establishment, plant population, plant height, barren plants, yield, and grain moisture content at harvest.
Degradation: Compaction
Crop: Corn
Soil: Chequest silty clay loam Typic Haplaquolls
Land Mgmt: Corn was planted at a rate of 69,200 seeds/ha. Herbicides were sprayed on with liquid nitrogen (200 kg/ha N). Atrazine, cyanazine, and alachlor were also applied. The plots were not cultivated.
Location: Southeast Iowa
Impacts: The wheel tracks for secondary tillage caused an average yield reduction 11%.

Results

Table 4. Effect of tractor track on corn growth.

Year Location	ERI	Plant population Emerged	Harvest	Plant height	Yield	Grain moisture
	%/d	---plants/ha---		cm	t/ha	% wb
1984						
Tractor track	6.7	57700	59600	178	9.5	22.9
Non-track	7.8	61100	62700	194	11.5	21.8
LSD (P=0.05)	0.30	940	NS	3.9	0.57	0.46
1985						
Tractor track	11.6	58000	60400	---	10.8	18.1
Non-track	13.3	60100	58700	---	12.2	17.5
LSD (P=0.05)	0.30	1260	1480		0.27	0.17
1986						
Tractor track	12.4	52900	53400	227	10.2	17.2
Non-track	12.7	54100	52800	233	10.8	16.8
LSD (P=0.05)	0.24	1100	NS	2.1	0.25	0.22
Average						
Tractor track	10.2	56200	57800	202	10.2	19.4
Non-track	11.3	58400	58100	214	11.5	18.7
Response in tractor track as % of non tractor value	90	96	99	94	89	104

Table 6. Corn growth as affected by type of tractive device.

Year Device	ERI	Plant population Emerged	Harvest	Plant height	Yield	Grain moisture
	%/d	---plants/ha---		cm	t/ha	% wb
1984						
Track	7.1(93)	54900(97)	59500(98)	185(96)	9.8(87)	22.9(106)
Wheel	7.8(79)	54100(92)	59600(92)	172(88)	9.2(79)	22.9(104)
1985						
Track	11.9(90)	57900(96)	60400(104)	---	11.7(91)	18.0(103)
Wheel	11.3(84)	58000(96)	60400(101)	---	10.7(84)	18.2(104)
1986						
Track	12.4(98)	52700(98)	52900(101)	229(99)	10.2(97)	17.0(100)
Wheel	12.5(97)	53200(97)	53900(101)	223(95)	10.0(91)	17.4(104)
Average						
Track	10.4(94)	55200(97)	57600(101)	207(98)	10.5(92)	19.3(103)
Wheel	10.0(87)	55100(95)	58000(98)	198(92)	10.0(85)	19.5(104)
Response for track as percentage of that for wheel	104	100	99	105	105	99

Numbers in parenthesis are the percentage that the value measured in the trafficked area is of that measured in the untrafficked areas of the corresponding plots.

Productivity Abstract

This article was presented as a progress report and as such does not make any definite conclusions. There were two objectives:

1) to evaluate the compaction caused by tractor-type and wheel type tractor during the secondary tillage in the spring; and
2) to determine the effect of compaction on corn growth and yield.

There were some significant yield decreases in the wheel trafficked plots (a 3 year average of 11%).

There was to be at least one more year in this study. Soil water content was measured each year at the time of secondary tillage. Of the three years, 1986 had the highest soil moisture. The effects of soil moisture were not examined in this report.

Keywords: Compaction, wheel induced, corn, Iowa, field study.

64. Fausey, N. R. and Dylla, A. S. 1984. **Effects of wheel traffic along one side of corn and soybean rows.** Soil Till. Res. 4: 147-154.

There is a continuing need for information illustrating the seriousness of the soil compaction problem over a range of soils, climatic, and agronomic conditions and encouraging the adoption of controlled traffic. Compaction from wheel traffic adjacent to crop rows had significant effects on the soil physical conditions in Kokomo silty clay loam (Typic Argiaquoll) and on the corn (Zea mays L.) and soybean (Glycine max L.) yields. Traffic patterns were established to compare rows that had traffic on one side of the row with those that had traffic on neither side. These traffic patterns were followed for planting and spraying operations for a total of five passes. Corn had either no nitrogen fertilizer or adequate fertilizer and soybean had no fertility variable. Bulk density and cone penetration resistance were significantly higher in the wheel tracks than in the untracked areas at the 0-15 and 15-30 cm depths. With adequate fertilizer, yields of corn and soybeans from rows along wheel tracks were equal to those from untracked areas. With no nitrogen fertilizer, corn yields were significantly lower from rows along wheel tracks.

Summary

Methods: The corn was planted in rows spaced 76 cm apart at a rate of 65000 plants/ha. The same row spacing was used for soybeans with a planting rate was 344000 plants/ha. Corn had four treatment comparisons: high and low fertility levels and 2 traffic levels (none or one side). Soybeans had only 2 treatment comparisons for wheel traffic (rows adjacent or not adjacent to traffic). Soil properties such as soil water potential, soil strength or resistance, and bulk density were measured in addition to yield. Corn yields were corrected to 15.5% moisture content and soybeans yields were corrected to 13.0% moisture content. After harvest, the hydraulic conductivity of the wheel compacted and non-compacted areas were measured.

Degradation: Compaction

Crop: Corn, soybeans

Soil: Kokomo silty clay loam, Typic Argiaquoll

Land Mgmt: Before the field trial began the plots were plowed 25-30 cm deep in the fall. Phosphate and potash were applied at a rate of 112 kg/ha. No fertilizer was applied to the corn at planting. Pre-emergence herbicide was applied to both the corn and soybean plots. The tractor used was 3.5 Mg or 1.75 Mg per rear tire.

Location: Ohio

Impact: Significant yield differences were obtained where the supplemental fertilizer was not applied. There was an 11% difference between the yields of the tracked and non-tracked plots.

Results

Table 3.Corn and soybean yields from 76 cm spaced rows, with and without a compacted wheel track along one side of row, and for two fertility levels on the corn plot.

Crop	Statistical Parameter	Yield Mg/ha Track	No track
Corn (adequate fertility)	Mean	11.83	11.61
	Std.error	0.47	0.66
Corn (low nitrogen)	Mean	3.56a	4.01
	Std.error	0.66	1.10
Soybeans	Mean	3.01	2.97
	Std.error	0.16	0.13

a - Different from no track at 5% level.

Productivity Abstract
The corn plots and soybean plots reacted similarly to the presence of wheel traffic. The compaction from wheel traffic only affected corn when there are low fertility levels (11% yield reduction in rows with wheel traffic beside them). The authors suggest that the detrimental effects of compaction can be minimized if wheel traffic is confined to the crop inter-row area and on one side only. High fertility seems to be necessary to maintain corn yields if wheel traffic compaction is present. The cost of maintaining this yield is not discussed.

Keywords: Compaction, corn, soybean, wheel traffic, Ohio.

65. Giles, J. F. 1983. **Soil compaction and crop growth.** N. Dakota Farm Res. 41: 34-35.

Factors involved in soil compaction are discussed. Yields of soyabeans taken from tractor wheel tracks on a Bearden silty clay loam were 50% lower compared with those adjacent to the wheel tracks.

Summary

Methods: The causes compaction are briefly discussed and then the results of a current field study are presented. Track and non-track yields were compared.
Degradation: Compaction
Crop: Soybeans
Soil: Bearden silty clay loam
Land Mgmt:
Location: North Dakota
Impact: Yields from the wheel track were 50 % less than yields from the non-track area of the field. Since the wheel tracks only cover 11% of the field, the whole plot yield would be 5% less than a field without wheel tracks

Results

Table 3.Plant population and yield of soybeans in and out of tractor wheel tracks on Bearden silty clay loam.

Parameter	Non-track	Track
Population (plant/ 10 ft row)	37	29
Yield (bu/ac)	32.0	16.1
Yield (2 track rows/19 rows)	30.3	

Productivity Abstract
This is a very brief discussion on compaction. Increased soil density inhibits root growth which is particularly harmful to tubers such as sugar beets and potatoes. Some consideration of soil moisture levels is necessary to prevent compaction from wheel traffic.

Keywords: Compaction, North Dakota, soybeans, wheel track, review.

66. Gray, L. E. and Pope, R. A. 1986. **Influence of soil compaction on soybean stand yield, and Phytophthora root rot incidence.** Agron. J. 78: 189-191.

In field tests over 2 yr on a Drummer silty clay loam soil, when plots were compacted once in the spring of each year after the first discing by driving a tractor over the plots, soil bulk density was significantly increased. In both years initial and final stands of cv. Corsoy soyabeans (susceptible to P. megasperma f.sp. glycinea) were reduced in the compacted soils. In 1983 there was no effect of soil compaction on stands of Corsoy 79 (resistant to races 1, 2, 3, 6, 7, 8 and 9) but in 1984 the final stands were lower on compacted plots. The number of Corsoy plants killed by the fungus was increased by soil compaction in both years. In 1983 there was no difference in seed yield of Corsoy 79 in compacted and noncompacted field plots. In both years the yield of Corsoy was lower in the compacted plots. There was also a significant difference in yield between Corsoy and Corsoy 79 in both years in the compacted plots.

Summary

Methods: The plot area for this field experiment had been in continuous soybean production for 6 years prior to the study. There were two compaction treatments, compacted and non-compacted. Compaction was achieved by driving a 5363 kg tractor with 47.5 cm rear tires over the plot. The wheel track was offset by one tire width on each pass in order to cover the entire plot
Degradation: Compaction
Crop: Soybeans
Soil: Drummer silty clay loam, Typic Haplaquoll
Land Mgmt: The following field operations took place in all plots:
1) Fall moldboard plowing to a depth of 25 cm.
2) Spring discing
3) Herbicides were applied (metolachlor, chloramben) at recommended rates.
4) The plots were disked twice with a light tandem disk harrow to a depth of 6.5 cm to form a seedbed.

Location : Urbana, Illinois.

Impact : The Corsoy variety soybean had a significant reduction in yield due to compaction, while the Corsoy-79 variety only had a significant reduction in yield in 1984.

Results

Table 2.Mean yields of Corsoy and Corsoy-79 soybeans in a compacted and non-compacted Drummer soil in 1983 and 1984.

	Yield	
	Cultivar	
Soil treatment	Corsoy	Corsoy-79
	--------kg/ha--------	
1983		
Compacted	2054	3650
Non-compacted	2830	3500
CV (%)	6.0	
1984		
Compacted	1303	2166
Non-compacted	2550	2881
CV (%)	12.8	
	Analysis of variance	
1983		
Effect		
Compaction	**	
Variety	**	
Compaction x Variety	**	
1984		
Effect		
Compaction	**	
Variety	**	
Compaction x Variety	NS	

Productivity Abstract

The main focus of this study was to determine if compaction influenced soybean stand establishment and root rot incidence. The yield comparisons were not central to this study. The incidence of root rot was increased by compaction and the authors relate this directly to the yield reductions measured in compacted soils. Unlike many other compaction studies, there is no mention of the role of precipitation in the effect of compaction on yield. Soil moisture contents at the time of compaction were recorded.

Keywords: Compaction, soybean yields, Phytophthora root rot, Illinois, field study.

67. Lindemann, W. C., Ham, G. E., and Randall, G. W. 1982. **Soil compaction effects on soybean nodulation, $N_2(C_2H_4)$ acetylene fixation and seed yield.** Agron. J. 74; 307-311.

Often soil compaction is considered undesirable for plant growth and may limit soybean yield. The objective of this study was to determine the effect of soil compaction on soybean plant growth, yield, nodulation, and N fixation. Field experiments were conducted for two years (1976 and 1977) on a Webster clay loam soil (fine-loamy, mixed, mesic Typic Haplaquolls). Plots were compacted by 0, 1, 2, and 3 tractor passes over the same area approximately two weeks before planting. Soybean biomass and plant height were measured in 1977, but soil bulk density and soybean yield were measured in both years. Nodulation and acetylene reduction activity were measured four times during the season for taproots and two times for lateral roots in both years. Bulk density was increased significantly both years by tractor compaction. In 1976, when extremely dry condition existed throughout the growing season mean seed yield values were greater on the tractor compacted plots (2161, 2106, and 2283 kg/ha for the 1, 2, and 3 tractor pass treatments respectively) than on the non-compacted plots (1977 kg/ha), but the yields were not statistically significant. Taproot nodulation and acetylene reduction were also significantly greater on the 2 tractor pass treatment than on the non-compacted plots, but little difference in lateral root nodulation and acetylene reduction was noted. In 1977, when greater than normal precipitation occurred, compaction decreased significantly plant growth and taproot nodulation and tended to decrease lateral root nodulation. Acetylene reduction was not affected by compaction. The mean seed yield value was greatest in the non-compacted plot (4117 kg/ha) and the mean values declined with increasing tractor compaction (4105, 3955, and 3854 kg/ha for the 1, 2, and 3 tractor pass treatments, respectively), although the yields were not statistically different. The effect of soil compaction in the spring prior to planting appeared to be dependent on the amount of precipitation in the growing season.

Summary

Methods:	There were four compaction treatments in this study: 1) zero tractor passes (control). 2) 1 tractor pass (3583 kg). 3) 2 tractor passes. 4) 3 tractor passes. Bulk density and soil moisture samples were taken at two depths. Soybean dry matter, nodulation, and acetylene reduction activity were also recorded. Different locations were used for each year and both plots were previously cropped in corn and fall plowed.
Degradation:	Compaction
Crop:	Soybeans
Soil:	Webster clay loam, Typic Haplaquolls
Land Mgmt:	Prior to planting the entire plot was tilled to a depth of 5 cm to prepare the seedbed.
Location:	Waseca, Minnesota.
Impact:	The greatest mean yield was obtained in the non-compacted soil (4117 kg/ha). Yields decreased as compaction increased in wet years. In dry years, yields increased with increased levels of compaction.

Results

Table 1. Effect of compaction treatments on soil bulk density.

	Bulk density			
	1976		1977	
Compaction	Soil depth (cm)			
treatment	5-15	15-25	5-15	15-25
	------------g/cm**3----------			
0	1.16a	1.24a	1.25a	1.46a
1 tractor pass	1.26b	1.37b	1.46b	1.49b
2 tractor passes	1.25b	1.39b	1.55c	1.53c
3 tractor passes	1.28b	1.33b	1.54c	1.56d

a-dMeans followed by the same letter within each column are not significantly different at the 5% probability level as determined by Duncan's multiple range test.

Table 3. Effect of soil compaction on soybean seed yield.

Compaction treatment	Soybean seed yields 1976	1977
	------kg/ha-----	
0	1977	4117
1 tractor pass	2161	4105
2 tractor passes	2106	3955
3 tractor passes	2283	3854
C.V. %	8	7

There were no significant differences between seed yields.

Productivity Abstract

This study illustrates that in the short term, the effect of compaction on soybean yields is directly related to the amount of precipitation during the growing season. Since there are only two years in this study, it is difficult to determine a yield response to increasing levels of compaction. Only general trends in yields may be described. The trends identified in this study were:

1) yields increased as compaction increased in dry years; and
2) yields decreased as compaction increased in wet and normal years.

The authors state that the results of this study should not be extrapolated to different soils and climates.

Keywords: Compaction, soybeans, seed yield, field study, Minnesota, bulk density.

68. Schuler, R. T. and Lowery, B. 1986. **Long term compaction effect on soil and plant growth.** American Society of Agricultural Engineers paper no. 86-1048: 20pp.

Three levels of soil compaction were applied on Rozetta and Kewaunee silt loam soils using an 8 t tractor, 12.5 t combine harvester or liquid manure spreader and, as a control, no compaction other than field operations with loads less than 4.5 t per axle. After 3 years growing maize some residual effects of compaction remained. Cone resistance in the subsoil increased at higher compaction levels, and plant heights were less in compacted soils. Grain yield and moisture, plant emergence and soil moisture data indicated no residual compaction effects.

Summary

Methods: This field experiment had three levels of compaction:

1) Control level, normal field operations.
2) Compaction from an 8 T tractor (both soils series)
3) Compaction from a 12.5 T combine (Rozetta soil) and 12.5 T liquid manure spreader (Kewaunee soil).

Each of the compacted plots were completely covered with wheel traffic four times. These compaction treatments were applied only in the spring of 1983. Soil moisture content was measured at the time of compaction.

Degradation: Compaction
Crop: Corn
Soil: Rozetta silt loam, Typic Hapludalf Kewaunee silt loam, Typic Hapludalf
Land Mgmt: Plots were managed for maximum yield production with respect to nutrient application. Field operations included:

1) Fall tilled annually with a chisel plow (Rozetta soil) or moldboard plow (Kewaunee soil) to a depth of 23 and 20 cm, respectively
2) Secondary tillage was disking on Rozetta soil and field cultivation on Kewaunee soil

Location: Valders, Wisconsin
Impact: Yields from the Rozetta soil were decreased in 1983 and 1984 but not in 1985. The Kewaunee soil yields were only adversely affected by compaction in 1983.

Results

All results are illustrated in a series of figures. The yield data for the Rozetta soil and Kewaunee soil are depicted in Figure 10 and Figure 11, respectively. The following table summarizes these results.

The effect of compaction on corn grain yields for Rozetta and Kewaunee soils, 1983 to 1985.

		Yield (Mg/ha)		
Soil series	Treatment (T)	1983	1984	1985
Rozetta	4.5	6.6	10.2	7.5
	8.0	6.4	9.6	8.0
	12.5	5.7	9.3	7.4
Kewaunee	4.5	7.5	10.8	5.3
	8.0	6.5	10.7	4.7
	12.5	4.3	11.0	5.1

Productivity Abstract

The single compaction event in the spring of 1983 did not effect the yields to any significant level after two years and in the case of the Kewaunee soil, after one year. Plant height continued to be affected by compaction. Seasonal freezing and thawing did not completely ameliorate subsoil compaction. No information was available concerning climate variability from year to year. The lack of tables made it difficult to evaluate the results.

Keywords: Compaction, corn yield, Wisconsin, field study, soil moisture.

69. Sial, J. K., Marley, S. J., and Erbach, D. C. 1986. **Effects of controlled traffic in corn plots.** American Society of Agricultural Engineers Paper no. 86-1049: 23pp.

Effects of several tractor passes on both sides, one side, neither side, or on top of maize rows on chiselled and no-till plots were studied over two crop seasons. No-till plots were superior to chiselled plots particularly during the first year due to early emergence in no-till plots. Traffic on both sides of rows had a slight undesirable effect on early plant growth compared to the traffic on neither side of rows. Rows adjacent to untilled inter-rows performed better than rows with tilled inter-rows. Residual effects of compaction through the growing season and following winter were shown by higher soil strength in compacted areas.

Summary

Methods: There were 3 levels of traffic: traffic on both sides, on side, and neither side of the crop row. Inter-row tracks were tilled and not tilled. These treatments were applied to chiselled and no-till soil conditions. Each treatment was replicated 4 times. Designated inter-rows were compacted before planting. This was considered to be Experiment 1 (1984 and 1985). In 1985, a second experiment was added: traffic over top of corn rows before chiselling for planting with no idle passes made to amplify compaction.
Degradation: Compaction
Crop: Corn
Soil: Not specified
Land Mgmt:
Location: Ames, Iowa
Impact: In 1984 the no-till plots had a higher average yield than the chiselled plots. There were no differences in yield in 1985.

Results

Table 5.The effects of tillage and machinery traffic on corn yield and grain moisture percentages.

	Tillage		Traffic				Track	
Experiment	NT	C	BS	OS	NS	TOP	NotT	T
t 1 (1984)								
yield (t/ha)	5.67	4.81	5.41	4.67	5.54	--	5.40	5.04
moisture (%)	16.7	17.3	16.9	16.8	17.3	--	17.0	17.0
tt 1 (1985)								
yield (t/ha)	5.66	5.23	5.43	5.63	5.40	--	5.27	7.73
moisture (%)	36.4	37.6	37.1	37.1	36.3	--	35.8	38.3
t 2 (1985)								
yield (t/ha)	6.55	6.50	6.30	6.54	6.51	6.72	6.66	6.38
moisture (%)	40.6	42.1	41.5	41.8	41.7	40.3	41.0	41.7

t - one year interrow traffic
tt - two year interrow traffic
tillage treatments:NT=no-till, C=chiselled
traffic treatments:BS=both side of row, OS=one side of row, NS=neither side of row, and TOP=top of row.
track treatments:NotT=track not tilled, T=track tilled

Productivity Abstract

Lower yields were attributed to the delay in emergence in the chiselled plots. The effect of compaction on crop yield is not specifically addressed. The penetration resistance data suggest that compaction is still present in the no-till plots, yet the yields do not seem to be affected. The weather was also quite different between 1984 and 1985. The authors suggest that more complete results would be available over longer study periods.

Keywords: Soil compaction, corn, tillage response, Iowa, field study, controlled traffic.

70. Stucky, D. J. and Lindsey, T. C. 1982. **Effect of soil compaction on growth and yield of soybeans grown in a greenhouse on several reconstructed soil profiles from prime**

farmland in southern Illinois. Reclam. Reveg. Res. 1:297-309.

Soil materials were collected from 4 naturally-occurring horizons (A, B, C_1 and C_2) from 2 potential surface-mine sites in Perry and Jackson Counties in southern Illinois. Soil from each horizon plus 1:3 ratio mixtures of B:C_1 and B:C_2 horizons were fertilized and compacted into pots to 3 different bulk densities. The 3 densities were - not compacted; moderately compacted; severely compacted (approximately 1.2, 1.4 or 1.6 g cm^{-3}). Soybean seeds (Glycine max (L.) Merr., cultivar Williams) were planted and inoculated with strain 110 of Rhizobium japonicum nitrogen-fixing bacteria. The objectives of this study were to determine (1) the effect of compaction on the ontogeny and yield of soybeans grown on rooting media which was constructed from naturally- occurring, and mixtures of naturally-occurring, soil horizons from prime farmland soils, and (2) how information derived from a Proctor test may be utilized to help maximize the yield potential of soils from prime farmlands which will be reconstructed after being surface mined. Generally, yields decreased with increased compaction. In all instances, yields of plants grown in soil compacted to 1.4 g cm^{-3} out-yielded plants grown in soils compacted to approximately 1.6 g cm^{-3}. This is significant because in southern Illinois the bulk density of many disturbed soils below 15 cm is above 1.6. A correlation analysis indicated that yield was positively correlated with root weight and plant development. The statistically significant correlation with plant height was recorded during the third week of growth and it remained significant throughout the experiment. Blending B- and C-horizon material in a ratio 1:3 resulted in significantly higher plant yields as compared to plants grown in B-horizon soils. Yields of plants grown in C-horizon soils were statistically equal to yields of plants grown from soils in the A-horizon. The authors concluded that the most potentially useful information derived from a standard Proctor test was that which permitted the determination of the soil moisture percent at which soils are least susceptible to compaction. In addition, the Proctor test can determine the effect of blending horizons or adding organic matter on the compactability of a potential new soil composition.

Summary

Methods: There were six soil horizons treatments and three compaction treatments for each horizon:
1) 1.2 g/cm^3 - no compaction;
2) 1.4 g/cm^3 - moderate compaction; and
3) 1.6 g/cm^3 - severe compaction.
Sample pots contained 9 litres of soil from a horizon in pots 40 cm deep. The top 3.25 cm of each pot were not compacted. This was done for both soil types (two sites).

Degradation: Compaction

Crop: Soybeans

Soil: Aquollic Hapludalf (Hoyleton)
Typic Hapludalf (St. Charles)

Land Mgmt: Each sample pot was fertilized according to soil test results such that nutrient deficiencies were minimized. Five sterilized soybean seeds were planted in each pot.

Location: Jackson County, Illinois

Impact: In all instances, yields of plants grown in soil compacted to 1.4 g/cm^3 out-yielded plants grown in soils compacted to approximately 1.6 g/cm^3.

Results

Table 3.Combined mean treatment yields of different soil horizons

Soil horizon	Site 1 mean g/pot	Site 2 mean g/pot
A	17.29ab*	17.74ab
B	13.58c	9.99d
C1	18.78ab	16.34b
C2	17.51ab	17.35ab
B:C1	16.21b	13.83c
B:C2	18.99a	13.43c

*Means followed by the same letter are not significantly different at the 5% level according to Duncan's multiple range test.

Table 4.Combined mean treatments yields for different compaction levels

Compaction level	Mean g/pot
None	19.17a*
Moderate	16.53b
Severe	12.06c

*Means followed by the same letter are not significantly different at the 5% level according to Duncan's multiple range test.

Table 5.Mean yields and weight of roots (g/pot) for all treatments

		Hoyleton		St. Charles	
Compaction Level	Horizon Zone	Yield	Root weight	Yield	Root weight
None	A	20.29abc*	6.91	22.20ab	4.15
Moderate	A	18.85bcdef	6.03	17.39cdefg	3.51
Severe	A	12.06hijkl	2.85	13.63ghij	3.05
None	B	18.54bcdef	4.02	8.27l	2.44
Moderate	B	12.28hijkl	2.13	13.19ghij	1.06
Severe	B	9.92jkl	1.61	8.53kl	1.29
None	C1	24.17a	4.71	19.67acde	3.57
Moderate	C1	19.13bcdef	3.21	15.95defgh	1.42
Severe	C1	13.06ghijk	1.87	13.41ghij	1.56
None	C2	20.29abcd	5.61	24.44a	5.11
Moderate	C2	19.65bcde	6.10	14.98fghi	2.83
Severe	C2	12.58hijkl	2.11	12.64hijkl	0.79
None	B:C1	21.29abc	5.21	12.62hijkl	1.98
Moderate	B:C1	15.15efghi	1.83	17.68bcdefg	2.37
Severe	B:C1	11.93hijkl	1.41	11.19ijkl	1.58
None	B:C2	24.04a	6.26	13.61ghij	1.91
Moderate	B:C2	18.31bcdef	1.91	15.56efghi	2.95
Severe	B:C2	14.64fghi	1.43	11.11ijkl	0.71

*Means followed by the same letter are not significantly different at the 5% level according to Duncan's multiple range test.

Productivity Abstract

The objectives of this study were to determine:

1) the effect of soil compaction on the ontogeny and yield of soybeans grown on reconstructed prime farmland soil horizons in a greenhouse study
2) how information derived from a Proctor test may be utilized to help maximize the yield potential of prime farmland soil.

The yields from the different soil horizon were meant to describe the fertility profiles of each soil series. The Hoyleton soil series was the most productive of the two soils in this study over all treatments (17.07 g/pot). Both soils series had significantly lower yields from the B horizon pots.

Keywords: Compaction, soybeans, greenhouse experiment, bulk density, Illinois.

71. Voorhees, W. B., Johnson, J. F., Randall, G. W., and Nelson, W. W. 1989. **Corn growth and yield as affected by surface and subsoil compaction.** Agron. J. 81: 294-303.

In field trials at Lamberton (Ves clay loam) and Waseca (Webster clay loam) Minnesota in 1982-86, maize was subjected to no compaction or subsoil compaction by 9 or 18 t/axle loads, with or without annually applied between row surface compaction of <4.54 t/axle. Grain yield decreased by 9 and 30% with 9 and 18 t/axle, resp., in the 1st year at Waseca. In the 2nd year grain yield decreased by 12% with the 18 t/axle load. Soil water loss data indicated a more shallow rooting depth and/or reduced root activity with the 18 t load. High axle loads on dry soil at Lamberton caused little soil compaction; grain yield decreased by only 6% in the 1st year. High axle loads on a wet soil at Lamberton compacted the soil to 60 cm depth but compaction and yield reductions were not apparent the following year due to dry weather. Surface layer compaction from annual interrow traffic did not cause a yield response consistently at any site.

Summary

Methods: There were six compaction treatments in this field study. The two subsoil treatment were applied once at the beginning of the study (9.0 Mg and 18.0 Mg). The surface layer compaction consisted of controlled traffic wheel compaction (each axle < 4.5 Mg). The two Ves sites were divided into wet and dry plots according to differences in field moisture content when compaction treatments were about to be applied (wet plot - 90% of capacity and dry plot - 60% of capacity).

Degradation: Compaction

Crop: Corn

Soil: Webster clay loam, Typic Haplaquolls
Ves clay loam, Udic Haplustolls

Land Mgmt: Each year the plots were planted half in corn and half in soybeans, alternating positions each year. The Ves sites had 143 kg/ha of anhydrous ammonia injected into the interrows each fall in preparation for the next years corn crop. The Webster plots had 168 kg/ha of urea anhydrous nitrate applied on corn plots each spring. Corn was planted at a rate of 61000 to 64000 plants/ha on the Webster sites and 58000 to 60000 plants/ha on the Ves sites.

Location: Lamberton and Waseca, Minnesota.

Impact: Webster soils had a 30% reduction in yield the first year after subsoil compaction and then gradually the yields were restored to the non-compacted levels. The yields from both of the Ves sites had some reduction in yields but these were neither significant nor uniform. Annual surface compaction did not have a significant negative effect on yields from either soils.

Results

Table 1.Corn yield as affected by subsoil and surface compaction on Webster and Ves clay loam. 1982-1986.

Subsoil compaction Mg/axle	1982	1983	1984	1985	1986
	Corn grain yield, kg/ha				
			Webster		
< 4.5	10690a*	9531a	8700a	10328a	7749a
9.0	9722a	9201a	8821a	10491a	8381a
18.0	7467b	8376b	8082a	10000a	8067a
CV**	16.3	6.8	18.2	4.5	15.7
			Ves - dry		
< 4.5	9742a	6474a	9746a	9865a	10950a
9.0	9858a	6750a	8846b	9986a	10994a
18.0	9146b	6306a	9582a	9778a	11054a
CV	3.9	4.5	6.2	3.0	2.0
			Ves - wet		
< 4.5	--	5642a	10058a	9766a	10985a
9.0	--	5740a	10047a	9924a	11198a
18.0	--	5707a	10147a	9703a	11142a
CV		10.3	4.4	4.1	5.2
Surface compaction	1982	1983	1984	1985	1986
			Webster		
NWT#	9562a	9161a	8945a	10354a	8209a
WT##	9241a	8911a	8124b	10193a	7922a
CV	11.5	3.9	6.3	5.1	6.7
			Ves - dry		
NWT	9545a	6671a	9267a	9483a	10507a
WT	9619a	6349a	9515a	10271b	11491b
CV	4.1	9.0	7.6	1.1	6.3
			Ves - wet		
NWT	--	6060a	10989a	9801a	11068a
WT	--	5333a	9179b	9794a	11149a
CV		16.1	3.9	2.1	5.9

*Yields within a year and site followed by a different letter are significantly different at P = 0.05 as indicated by honestly significant difference (HSD)
**CV = coefficient of variation
#NWT = no wheel traffic
##WT = wheel traffic.

Productivity Abstract

This study is unique in that it examines both a single subsoil and annual surface compaction. Although corn yield does not suffer any lasting damage from either type of compaction, the first year reduction in yield was quite severe on the Webster soil. The typical farm operation may, in fact, experience subsoil compaction on a regular basis, thus not allowing for the recovery time. There is still a need to include climatic factors in the study of compaction and its effect on crop yields. The wet and dry Ves sites for example, indicate that there is a significant relationship between available water and the effect of compaction.

Keywords: Subsoil compaction, surface compaction, corn yield, Minnesota, field study, long term effects.

72. Wilkens, P. W. and Whigham, D. K. 1986. **Soybean response to postemergent wheel traffic.** Crop Sci. 26: 599-602.

Considerable research has demonstrated the yield advantage of soybean [Glycine max. (L.) Merrill] grown in narrow row spacings, but little information is available concerning post emergence wheel traffic for conventional intrarow cultivation or spray application. The objective of this study was to determine yield and plant characteristics of soybeans subjected to postemergence wheel traffic. Three indeterminant soybeans cultivars, Asgrow 3127, Corsoy and Northrup King 1492, were planted in a 35-cm row spacing in 1980 and 1981 on Aquic Hapludolls and Typic Hapludolls, respectively. Treatments were applied by driving a tractor through the plots at one of 6 growth stages from VE (emergence) to R4 (full pod). A skip-row treatment where wheel track rows were not planted, was also included. Individual rows were harvested within each plot and grouped together as wheel-track rows (rows driven over), border rows (rows adjacent to the wheel-track rows) and non-border rows (rows not bordering on wheel track rows). The whole-plot seed yield of Asgrow 3127 and Northrup King 1492 were not reduced by wheel traffic up to full flowering, while yield of Corsoy was reduced (9-19%) by wheel traffic at vegetative stage V5 and reproductive stages of full flower and full pod. Yield losses in wheel-track rows ranged from 26% for wheel traffic at emergence to 92% at the full-pod stage. Yield increases in border rows ranged from of 5% for wheel traffic at emergence to 20% at the full-flower stage in a compensatory response to yield losses in wheel track rows. Seed weight was increased in border rows after treatment at full-pod stage, and in general, border row plants set pods lower on the stem and had more branches, nodes and pods/plant. Although cultivars responded differently, the yield advantage of narrow row spacing was not seriously reduced by postemergence wheel traffic.

Summary

Methods:	Field trials began in 1980. There were three soybean cultivars and 8 wheel traffic treatments. These treatments consisted of driving over rows 3 and 7 of each plot at 6 developmental stages plus a skip row treatment where rows 3 and 7 were not planted. Plots that were solid planted and had no wheel traffic were considered the control treatment. A 3200 kg tractor was driven through the plots when 50 % of the plants had reached the given developmental stage. An analysis of variance was done to determine if there were yield differences. The 6 developmental stages are described in Table 1.
Degradation:	Compaction.
Crop:	Soybean
Soil:	Aquic Hapludolls, Typic Haplaquolls
Land Mgmt:	The seeding rate was 370000 plants/ha with a row spacing of 35 cm. All plots received alachlor at 3.06 a.i. kg/ha and chlorpropham at 1.68 a.i. kg/ha. The plots were also hand weeded when necessary to reduce weed growth competition and avoid cultivation damage.
Location:	Ames, Iowa
Impact:	There were significant reductions in whole plot yields due to tractor traffic in both 1980 and 1981 for 2 of the 3 cultivars compared to the control plot. The third cultivar had a significant reduction in yield only for the traffic treatment that occurred in the last stage of development averaged over the two years.

Results

Table 2.Seed yields of three soybean cultivars as affected by skip-row planting and tractor wheel traffic at six developmental stages.

Cultivar and stage	Seed Yield, Year 1980 kg/ha	1980 % change	1981 kg/ha	1981 % change	Mean kg/ha	Mean % change
Asgrow 3137						
control	4462		4062		4262	
VE	4395	-2	3979	-2	4187	-2
V1	4325	-3	4001	-1	4164	-2
V3	4338	-3	3924	-3	4131	-3
V5	4357	-2	4127	+2	4242	0
R2	4230	-5	3978	-2	4104	-4
R4	4085	-8	3734	-8	3909	-8
Skip row	4274	-4	3825	-6	4049	-5
Mean	4308		3054		4131	
SE	108		102		74	
Corsoy						
Control	4329		3816		4073	
VE	4121	-5	3693	-3	3907	-3
V1	4026	-7	3734	-2	3880	-5
V3	3955	-9	3680	-4	3817	-6
V5	4031	-7	3167	-17	3599	-12
R2	3833	-11	3389	-11	3611	-11
R4	3531	-18	3063	-20	3297	-19
Skip row	3963	-8	3446	-10	3704	-9
Mean	3974		3499		3736	
SE	141		101		87	
NK 1492						
Control	4342		3739		4041	
VE	4026	-7	3783	+1	3905	-3
V1	4215	-3	3751	0	3983	-1
V3	3867	-11	3763	+1	3815	-6
V5	4180	-4	3625	-3	3902	-3
R2	3986	-8	3631	-3	3809	-6
R4	3615	-17	3559	-5	3587	-11
Skip row	4112	-5	3643	-3	3877	-4
Mean	4043		3687		3865	
SE	104		139		87	

Table 3.Seed yield (averaged across cultivars and years) of border, non border, and wheel track soybean rows within whole plots.

Treatment stage	Seed yield, Non border kg/ha	Non border % change	Border kg/ha	Border % change	Wheel track kg/ha	Wheel track % change
Control	4153		4128		4079	
VE	4138	0	4304	+4	3009	-26
V1	4328	+4	4662	+13	2228	-45
V3	4257	+3	4791	+16	1676	-59
V5	4249	+2	4697	+14	1849	-54
R2	4459	+7	4938	+20	722	-82
R4	4202	+1	4784	+16	320	-92
Skip row	4336	+4	5514	+34		
SE	88		91		89	

Productivity Abstract
The authors used this study to determine the least harmful time to apply herbicides. The tractor traffic is not really a measure of surface compaction. Changes in soil characteristics are not discussed.

Keywords: Wheel traffic compaction, soybeans, field study, Iowa, growth stage.

Crop Not Specified

73. Matsepuro, V. M. 1982. **Characterizing the effect of soil compaction on the yield of agricultural crops Gaussian mathematical curves.** Sov. Agric. Sci. 3: 52-53.

The dependence of the agricultural crop harvest on the soil compaction is in the form of a bell-shaped curve, known in the probability theory as a Gaussian curve. In accordance with this the effect of soil compaction on the yield of agricultural crops is determined by the following parameters: the optimal compaction; the maximum crop yield corresponding to the optimal compaction; and a value which characterizes the crop "sensitivity" to compaction. This model can be used to determine such important agrotechnical indices as the characteristics of optimal compaction and the corresponding maximum (for a given moisture content and amount if nutrient substances) crop harvest, from experiments in which the soil compaction is suboptimal. It is then possible to predict the harvest losses and to decide on the extent to which the possibilities for improving soil treatment technology are utilized during crop cultivation.

Summary

Methods: This is a short exercise in mathematical modelling which attempts to characterize the effect of compaction on crop yields.
Degradation : Compaction
Crop:
Soil:
Land Mgmt :
Location:
Impact: A bell shaped, Gaussian curve is proposed to represent the yields response to different levels of compaction.

Results

The specific equation for this relationship is:
$Q = Q_0 * e - [(p-p_0)^2/2k^2]$ where,
Q = agricultural crop harvest
Q_0=maximum harvest, corresponding to optimal compaction
p = value which characterizes compaction
p_0= value which characterizes optimal compaction
k =a parameter which characterizes the crop sensitivity to compaction.

Productivity Abstract
This compaction model recognizes that compaction has different effects on plant growth depending on soil moisture content. Maximum yields can only be achieved when there is an optimal amount of compaction. When the existing level of compaction is known, along with an estimate for maximum yield, the optimal level of compaction can be determined from the equation presented.

Keywords: Compaction, model, optimal compaction, maximum yield, moisture, soil structure, Gaussian curve.

Section 3: Salinization

Small Grain Cereals

74. Bole, J. B. and Wells, S. A. 1979. **Dryland soil salinity: effect on the yield and yield components of 6-row barley, 2-row barley, wheat, and oats.** Can. J. Soil Sci. 59: 11-17.

Six-row barley outyielded 2-row barley which outyielded wheat and oats in field plots on non-irrigated saline soil in southern Alberta. Salinity reduced the number of 6-row barley spikes less than it did the number on other cereals compared to spike production on adjacent non-saline soils. More kernels per spike were maintained on 6-row barley than on other cereals under salinity stress but average kernel weight was not differentially affected. Although salinity reduced the germination of wheat to a greater extent than it did other cereals, adequate stands of all cereals were established and germination was not a major factor except on a plot where salinity stress was combined with spring drought. Six-row barley did not maintain its salt-stressed yield advantage over the cereals under drought conditions on a non-saline soil. The tolerance of cereals of osmotic stress thus differed from the tolerance to drought stress under dryland field conditions.

Summary

Methods: Two row and six row barley cultivars were established on 6.1 x 6.3 m dryland plots on a saline soil for three years. Identical non-saline plots were also established. The effect of salinity on different yield components was also measured (spike production, kernels per spike, and kernel weight).
Degradation: Salinization
Crop: Two row and six row barley, spring wheat, and oats.
Soil: Dark Brown Carmangay sandy loam, Brown Chin loam
Land Mgmt: Adequate fertilizer was incorporated before seeding at a rate of 20-50 kg/ha and weeds were controlled with 890 ml/ha of bromoxynil-MCPA
Location: Champion, Alberta and Milk River, Alberta
Impacts: Six row barley was the least effected by the increased salinity of the soil. The yield from the saline soil was 62% of the yield from the non-saline soil. The mean yield of 2-row barley was only 40% of the yield obtained from non-saline soils. Wheat grown on saline soil had yields that were 41% of the same wheat grown on non-saline soils. Oat yields on saline soils were only 25% of the oat yields from non-saline soils.

Results

Table 1 lists the salinity levels at different soil depths for both the saline and non-saline soils.

Table 2. Yield (kg/ha) of cereals on saline field plots at Champion, Alberta, 1975

	Wheat	2-row barley	6-row barley
Mean	1069c	1438b	2199a
S.D.	81	74	96

a-cAny two means followed by the same letter do not differ significantly (P<0.05)

Table 3. Mean yield (kg/ha) of barley cultivars at Champion, Alberta, (1976 and 1977) and Milk River, Alberta (1976)

	2-row barley		6-row barley	
	Saline	Non-saline	Saline	Non-saline
Mean	671d	1986a	1094c	1800b
S.D.	105	89	110	85

a-dAny two means followed by the same letter do not differ significantly (P<0.05)

Table 4. Yield (kg/ha) of cereals produced on saline field plots and the percent of that on adjacent non-saline plots

	Oats	Wheat	2-row barley	4-row barley
Mean	425	548	863	1370
Percent	25	41	40	62

Productivity Abstract
Three types of cereals are compared on saline and non-saline soils. Barley had a higher yield potential than other cereals on a saline soil. This study does not attempt to determine salt tolerance levels or predict how a further increase in salinity may effect cereal yields. It does illustrate that cereals have higher yields when grown on non-saline soils.

Keywords: salinity, barley, oats, wheat, Alberta, drought stress.

75. Chang, C., Sommerfeldt, T. G., Schaalje, G. B., and Palmer, C. J. 1986. **Effect of subsoiling on wheat yield and salt distribution of a Solonetzic soil.** Can. J. Soil Sci. 66: 437-443.

The effect of subsoiling, deep ripping to 52 cm depth, in the amelioration of a Solonetzic soil under irrigated and non-irrigated conditions were examined at the Vauxhall Research Substation in Alberta. All plots were fertilized by broadcasting N and P_2O_5 at rates of 80 and 42 kg/ha respectively. Hard spring wheat (Triticum aestivum L. 'Neepawa') was grown annually from 1980 to 1984. The plot area had a high degree of spatial variability in both physical and chemical properties of the soil. Subsoiling in the fall of 1979 and 1980 had no significant effect on soil salinity and sodicity or on wheat yields under non-irrigated conditions. However, under irrigated conditions, subsoiling enhanced the downward movement of salts and had a significant overall profile effect on soil salinity and sodicity, but it had no significant effect among depths within the profile. Subsoiling also has no significant effect on wheat yield under irrigated conditions. Irrigation alone improved the soil salinity and sodicity conditions, increased wheat yields, and reduced yield variability.

Summary

Methods: Two adjacent fields, one irrigated and one non-irrigated, were chosen. Each field had 3 subsoiling treatments. Treatments 1 and 3 were subsoiled to a depth of 52 cm and the yields were compared to control plots that were not subsoiled. Wheat yield data from irrigated and non-irrigated experiments were analyzed separately. Electrical conductivity of the saturation paste was used to measure the level of salinity.

Degradation: Salinization

Crop: Spring wheat (Neepawa)

Soil: Brown Soloneztic

Land Mgmt: Irrigation treatments varied from year to year. The following amounts of water were added to the irrigated plots:
1)32 cm in 1980;
2)19 cm in 1981;
3)18 cm in 1982;
4)22 cm in 1983; and
5)25 cm in 1984.

Location: Vauxhall Subresearch Station, Alberta

Impacts: Irrigated plots had higher, less variable yields than similar non-irrigated plots.

Results

Table 2. Electrical conductivity of soil saturation extracts.

Depth (cm)	Treatment 1	sd	Treatment 2	sd	Treatment 3	sd
	dS/m					
Irrigated						
0-15	0.89	0.15	1.00	0.24	1.20	0.80
15-30	1.35	1.83	1.66	1.90	1.15	1.23
30-45	2.14	3.06	4.11	4.35	2.63	3.49
45-60	2.36	2.83	5.75	5.48	3.55	4.69
60-90	3.94	4.36	7.06	6.85	4.77	4.78
Non-irrigated						
0-15	1.32	0.85	1.49	0.90	1.48	1.03
15-30	3.25	2.97	4.48	5.38	3.29	4.07
30-45	8.84	6.49	10.58	8.83	8.98	7.90
45-60	11.46	6.61	12.96	7.86	11.32	8.16
60-90	12.64	6.28	12.99	5.97	11.85	7.38

Soil samples were taken in the fall of 1983.
Treatment 1 subsoiled in 1979 and treatment 3 subsoiled in 1980

Table 4. Wheat yield from 1980 to 1984.

Year	Treatment 1 Yield	sd	Treatment 2 Yield	sd	Treatment 3 Yield	sd	Mean Yield
	kg/m2						
Irrigated							

1980	0.285	0.089	0.298	0.087	0.297	0.097	0.293
1981	0.401	0.085	0.379	0.071	0.390	0.092	0.390
1982	0.350	0.119	0.361	0.096	0.355	0.080	0.355
1983	0.278	0.089	0.306	0.098	0.291	0.087	0.292
1984	0.153	0.048	0.148	0.048	0.156	0.084	0.152
Mean	0.293		0.298		0.298		
			Non-irrigated				
1980	0.126	0.098	0.145	0.055	0.128	0.055	0.133
1981	0.096	0.075	0.092	0.073	0.055	0.053	0.091
1982	0.057	0.072	0.071	0.067	0.055	0.053	0.061
1983	0.167	0.059	0.169	0.072	0.167	0.071	0.168
1984	0.018	0.019	0.016	0.014	0.017	0.010	0.017
Mean	0.093		0.098		0.090		

Treatment 1 subsoiled in 1979 and treatment 3 subsoiled in 1980.
sd is the standard deviation between plots.

Productivity Abstract

This study attempted to determine if the practice of subsoiling improved wheat yields on saline soil. There was no significant differences between yields obtained from the 3 treatments. Irrigated and nonirrigated yield were not statistically compared. However, the yields from the irrigated fields were generally higher and less variable. The levels of salinity were lower in the irrigated fields.

Keywords: Wheat, subsoiling, salinization, Alberta, field study, irrigation.

76. Francois, L. E., Donovan, T. J., Lorenz, K., and Maas, E. V. 1989. **Salinity effects on rye grain yield, quality, vegetative growth, and emergence.** Agron. J. 81: 707-712.

Although current rye (Secale cereale L.) grain production is concentrated mainly in the northern half of the USA and Canada, some rye grain is grown in the arid southwest. Soils in this area are, or have the potential to become, highly saline from the application of saline irrigation water. Since there is nearly a complete lack of information about the response of rye grown under saline conditions, a 2-yr field plot study was conducted. Six salinity treatments were imposed on a Holtville silty clay (clayey over loamy, montmorillonitic water artificially salinized with NaCl and $CaCl_2$ (1 to 1 by weight). Electrical conductivities of the irrigation waters were 1.1, 4.0, 8.0, 12.1, 16.0, and 20.1 dS m^{-1} the first year, and 1.1, 3.9, 7.5, 11.6, 15.6, and 19.8 dS m^{-1} the second year. Grain yield and vegetative growth were measured. Relative grain yield of two cultivars, Maton and Bonel, was unaffected up to a soil salinity of 11.4 dS m^{-1} (electrical conductivity of the saturation extract;K_e). Each unit increase in salinity above 11.4 dS m^{-1} reduced yield by 10.8%. These results place rye in the salt-tolerant category. Yield reduction was attributed primarily to reduced spike weight and individual seed weight rather than spike number. Bread quality decreased slightly with increasing levels of salinity. Straw yield was more sensitive to salinity than was grain yield. Plant emergence was determined in greenhouse sand cultures. Both cultivars were slightly less salt tolerant during plant emergence than during subsequent stages of growth.

Summary

Methods: The plots in this field study were isolated by fibreglass dividers. There were 6 salinity treatments and two cultivars.
Degradation: Salinization
Crop: Rye grain
Soil: Holtville silty clay soil
Land Mgmt: Nitrogen was added to each plot at a rate of 74.3 kg/ha in 1985 and 70.7 kg/ha in 1986 when the plots were irrigated.
Location: Brawley, California
Impact: Grain yields were relatively unaffected by soil salinity up to the 11.4 dS/m level. Above that level, yields decreased by 10.8% for each unit increase of salinity.

Results

Table 2.Grain yield for Maton (M) and Bonel (B) rye grown at six levels of salinity during two growing seasons.

Soil salinity dS/m	Grain yield M	Grain yield B
	-----g/m^2------	
1985-1986		
5.8	255	292
8.5	265	296
10.9	234	244
13.5	220	194
14.6	133	127
15.9	96	81
1986-1987		
5.8	238	208
8.8	223	231
13.4	242	204
14.5	221	188
15.0	172	161
16.7	157	142

Analysis of variance

Source	df	Mean squares Grain yield M	Mean squares Grain yield B
1985-1986			
Salinity	5	14.47*	23.38*
Linear	1	53.35*	102.84*
Quadratic	1	14.33*	12.67*
Cubic	1	0.62	0.00
Error	10	1.02	0.88
1986-1987			
Salinity	5	3.80*	3.21*
Linear	1	8.66*	10.06*
Quadratic	1	4.35**	5.27*
Cubic	1	2.05***	0.09
Error	10	0.37	0.38

*,**,***significant at the 0.005, 0.01, and 0.05 levels of probability

respectively.

Productivity Abstract

A salt tolerance threshold was determined for each of the two cultivars (ie. the maximum allowable K_e without a yield decline. Notet that once the threshold was reached, the yields reacted differently in each of the two years. The reductions in yields per unit of salinity increase in 1986 were larger for both cultivars (20.8 and 11.1%) compared to the 1987 reductions (6.2 and 5.3%). This difference may be attributed to a difference in mean temperature. The daily mean temperature in the first year was 24.5 ^{0}C and 21.4 ^{0}C in the second year. Wheat has been known to have a higher salinity tolerance in cooler climatic conditions. This may apply to rye grain as well.

Keywords: Rye, salinity, controlled field study, silty clay,.

74. Janzen, H. H. 1988. **Comparison of barley growth in naturally and artificially salinized soils.** Can. J. Soil Sci. 68: 795-798.

An experiment was conducted under controlled conditions to compare growth of barley in naturally and artificially salinized soils. In two Chernozem soils, a Whitney clay loam and a Cavendish sandy loam, the decline in barley yield per unit increase in salinity was the same in naturally and artificially salinized treatments. These findings suggest that artificially salinized soils accurately simulate the effects of naturally saline soils in their effect on barley growth. The results further substantiate previous findings that growth response to salinity appears to be related to the availability of calcium in the soil.

Summary

Methods:	Barley yield responses to naturally and artificially salinized soils were compared. Each set of soil had a salinity gradient ranging from non saline to severely saline. Four levels of salinity were defined. The plants were harvested after 38 days.
Degradation:	Salinization
Crop:	Barley
Soil:	Cavendish, Orthic Brown Chernozem - sandy loam. Whitney, Orthic Dark Brown Chernozem - clay loam.
Land Mgmt:	Soil moisture content was maintained at a level of at least 60% of field capacity. N, P, K, and S were applied at the rates of 111, 63, 47, and 19 mg/kg.
Location:	Lethbridge, Alberta
Impacts:	Barley yields decrease as salinity increases

Results

Linear regression lines were developed for all treatments which defined the effect of electrical conductivity (saline level) on yield. Table 1 summarizes the comparisons of these regression lines for all treatments.

Table 1. Tests for significance of difference among regression lines for relationship between yield and electrical conductivity

	Hypothesis	
Treatments	Same line	Same slope

Cnat,Csim1,Csim2, Wnat,Wsim1,Wsim2,	No	No
Cnat,Csim1,Csim2	No	Yes
Csim1,Csim2	Yes	Yes
Wnat,Wsim1,Wsim2	Yes	Yes
Cnat,Wnat	Yes	Yes
Csim1,Csim2,Wsim1,Wsim2	No	Yes

Productivity Abstract
The knowledge that naturally and artificially salinized soils elicit similar yield responses in barley will help advance the understanding of the effects of increased salinization on yield. Laboratory yield simulations allow for greater control of the growing environment. There was no discussion on the exact nature of the yield response to increases in salinity.

Keywords: salinization, natural, artificial, barley, Alberta.

78. Janzen, H. H. and Chang, C. 1987. **Cation nutrition of barley as influenced by soil solution composition in a saline soil.** Can. J. Soil Sci. 67: 619-629.

An investigation was conducted under controlled environment conditions to identify possible cation deficiencies in barley cv. Galt grown under sulphate-dominated salinity stress. Soil was artificially salinized to produce a factorial of five salinity levels (ranging from approximately 6.5 to 17.5 $dS\ m^{-1}$) and five salt types containing various ratios of Na:Mg:Ca. A control treatment (3.1 dS/m) was also included. Barley was grown for 75 days and harvested for analysis of dry matter yield and tissue composition. Yield response to salinity stress was not differentially affected by the type of salt used in salinization. Concentrations of sodium and magnesium in the plant tissue were generally increased by salinity stress, but these accumulations did not restrict yield since no consistent relationship was found between the concentration of these cations and barley yield. Potassium concentration in the plant was inversely related to the level of soil salinity, apparently because of an antagonistic effect of sodium, but was not consistently related to barley dry matter yield. Calcium uptake was also suppressed by soil salinity. In contrast to the results observed for other cations, a very strong relationship indicative of a yield response curve was observed between yield and calcium concentration in the plant tissue, particularly when the latter was expressed as a ratio of total cation concentration (R^2=0.94). Furthermore, calcium concentration in the plant tissue and estimated calcium activity in the soil solution in highly salinized treatments were well below those considered adequate. These results suggest that calcium deficiency may have played a role in restricting yield under salinity stress. The apparent calcium deficiency induced by salinity stress was attributed to reduced activity of calcium in the soil solution because of precipitation with sulfate and high ionic strength.

Summary

Methods: There were 6 levels of salinity for each of 5 different types of salt. Twenty barley seeds were placed in a pot and thinned to 10 plants after emergence.
Degradation: Salinization.
Crop: Barley
Soil: Solonetzic soil
Land Mgmt: All plants received supplemental N and P.

Location: Lethbridge, Alberta
Impact: A very strong relationship indicative of a yield response curve was observed between yield and calcium concentration in the plant tissue. Calcium activity in the soil was reduced as salinity was increased.

Results

Table 2.Calculated values of maximum yield (Y_m), electrical conductivity at 50% of maximum yield (EC_{50}), and P for barley growing in soil salinized with 5 different salt treatments

Salt type	Y_m	EC_{50}	P	R^2
1	3.3	11.2	4.6	0.95
2	3.2	11.3	4.5	0.97
3	3.2	12.0	4.2	0.93
4	3.2	12.4	5.3	0.96
5	3.4	11.8	5.2	0.95

Ym=g/plant
R^2value for the relationship between measured yields and yield predicted by the fitted equation.

The equation used: $Y=Y_m/[1+ (EC/EC_{50})^P]$
where Y_m=yield maximum
EC=electrical conductivity
EC_{50}=electrical conductivity corresponding to $Y=0.5(Y_m)$
P=a constant

This relationship is illustrated in Figure 1.

The specific equation was: $Y=3.44/[1+(EC/11.4)^{4.37}]$

Productivity Abstract

The type of salt used did not significantly effect the response of barley to increased levels of salt. Yields declined significantly when the electrical conductivity of the soil exceeded 6 dS/m. The measured yield values were not tabulated. Yield is actually dry matter yield rather than grain yield. Calcium uptake was depressed as salinity levels were increased. Dry matter yield was strongly related to the calcium concentration in the plant tissue as yield was significantly reduced when the calcium concentration fell below 85 mmol/kg.

Keywords: barley, salinity, Alberta, cation uptake, greenhouse study.

79. Maas, E. V. and Poss, J. A. 1989. **Salt sensitivity of wheat at various growth stages.** Irrig. Sci. 10: 29-40.

The relative salt tolerance of two wheat species (Triticum aestivum L. and Triticum turgidum L.) at different stages of growth was determined in a greenhouse experiment. Plants were grown in sand cultures that were irrigated four times daily with modified Hoagland's solution. Salinization with NaCl and $CaCl_2$ (2:1 molar ratio) provided seven treatment solutions with osmotic potentials (Ψ_s) ranging from -0.05 to -1.25 MPa (electrical conductivities 1.4 to 28 dS/m). Salt stress was imposed for 45 days beginning at either 10, 56, or 101 days after planting. The three 45-day stages are referred to here as the vegetative, reproductive, and maturation stages although the first stage included spikelet differentiation. In a separate experiment, seedling growth was measured after 21 days of salt stress (Ψ_s=-0.05 to -0.85 MPa) initiated at 0, 7, 11, and 16 days after planting. Salt stress (Ψ_s=-0.65 MPa) delayed germination by 4 days for both wheats but full emergence occurred. Relative growth response curves of seedlings were alike regardless of whether salt stress was imposed at planting or at the 1st, 2nd, or 3rd leaf stage of growth. Salt stress also retarded development and tillering but hastened plant maturity. Grain yields from plants stressed during either the vegetative, reproductive, or maturation stages indicated that both species became less sensitive to salinity the later the plants were stressed. Grain yield was reduced 50% at Ψ_s=-0.76, -1.53, and -1.58 MPa for Probred and -0.65, -1.08, and -1.34 MPa for Aldura when salinized during stages 1, 2, and 3, respectively. Salinity reduced grain yield by reducing seed number more than seed weight indicating that salt stress during stage 1 affected spikelet differentiation. Straw yield was significantly reduced by salt stress only during stage 1. Leaf mineral analysis revealed that Aldura readily accumulated Na whereas Probred did not. Both species accumulated Cl but concentrations were much higher in Aldura. K uptake was severely inhibited by salt stress imposed during the first stage but not wen imposed in the second stage.

Summary

Methods:	This was a greenhouse experiment and was divided into two parts: a seedling experiment and a growth stage experiment. The plants were irrigated four times a day with a nutrient solution. This solution was salinized by adding NaCl and $CaCl_2$ at a 2:1 molar ratio. The seedling experiment had 4 salinity treatments applied at four times (preplant, 1st leaf, 2nd leaf, 3rd leaf). The growth stage experiment had six salinity treatments applied at three stages of growth (vegetative, reproductive, maturation).
Degradation:	Salinization
Crop:	Wheat
Soil:	Sand cultures
Land Mgmt:	
Location:	
Impact:	Grain yields were decreased the most when salinity was increased during the vegetative stage of growth.

Results

Table 4.Grain yields of wheat cultivars Probred and Aldura as influenced by salinity at the vegetative (V), reproductive (R), and maturation (M) stages of growth.

Salinity treatment (MPa)	Probred (g/plant)			Aldura (g/plant)		
	V	R	M	V	R	M
-0.05	3.68	3.68	3.68	2.56	2.56	2.56
-0.25	4.32	4.75	3.92	3.15	2.52	2.62
-0.45	4.02	3.69	4.27	1.72	2.44	2.20
-0.65	2.55	4.16	3.59	1.61	1.96	2.89
-0.85	1.28	3.70	3.35	0.72	1.48	3.06
-1.05	1.31	2.93	3.65	0.65	1.48	2.37
-1.25	0.63	2.86	2.73	0.77	1.09	1.83

Source	df	Analysis of variance

		Probred F value	$P>F^a$	Aldura F value	$P>F^a$
Rep	2	3.21	0.076	0.63	0.055
Salinity	6	14.01	0.000	13.25	0.000
Growth stage	2	22.27	0.000	24.03	0.000
S x GS	12	3.68	0.002	4.53	0.000

[a]Probability that a significant F value would occur by chance.

Figure 2 illustrates relative wheat yields as a function of osmotic potential of the soil solution imposed during the three growth stages.

Productivity Abstract

The results of the growth experiment indicate that the vegetative stage is the most sensitive to salinity stress. The relationship between yield and increased levels of salinity is not linear (Figure 2). The two cultivars seem to have different tolerance levels. Aldura yields were reduced at the Ψ=-0.45 MPA salinity level and Probred yields began to decline at the 4th level of salinity (Ψ=-0.65 MPa). The Probred yields were higher at low levels of salinity (for the vegetative stage). However, this was not the case at the very highest levels of salinity where the yields were very similar (Probred, 0.63 g/plant; Aldura, 0.77 g/plant).

Keywords: salinity, growth stages, wheat yield, greenhouse experiment.

80. McKenzie, R. J., Sprout, C. H., and Clark, N. F. 1983. **The relationship of the yield of irrigated barley to soil salinity as measured by several methods.** Can. J. Soil Sci. 63: 519-528.

A field study was conducted to measure the effect of soil salinity on barley grown under irrigated conditions in Alberta. Salinity was measured by the saturated paste extract, 1:2 soil-to-water extract, vertical probe and horizontal surface array methods. Correlation coefficients were determined between salinity measurements and the yield of barley to establish the suitability of these methods for predicting the growth of barley. Nineteen fields over 2 yr were monitored and soil salinity and the yield of barley were determined at a number of sites in each field. All methods of measuring salinity were significantly correlated (P = 0.01) with the yield of barley. At a EC of 7.8, yields of barley were reduced by 50%. Sodium concentration and sodium absorption ratio were closely correlated with the yield of barley and with the saturated-paste-extract salinity. Soil moisture and pH were not as effective as salinity and sodium measurements in predicting the yield of barley. The saturated-paste-extract salinity was more closely correlated with the 1:2 soil-to-water extract than with the vertical probe or horizontal surface array. The latter three methods were effective for rapid determination of the yield reductions which would occur on saline soils. No difference in tolerance to salinity was found between Klages (two-row) and Galt (six-row) cultivars of barley.

Summary

Methods: This 2 year field study measured natural levels of salinity that ranged from low to high. Soil samples were taken in July to measure the soil moisture content, the 1:2 soil to water extract salinity, and saturated paste extract salinity. These reading were taken at depths of 0-15, 15-30, 30-60, 60-90, and 90-120 cm. Two other types of salinity measurements were also used and all methods were examined through regression analysis to determine the best yield predictor (Vertical probe readings and Horizontal surface array).

Degradation: Salinization

Crop: Barley

Soil: Lacustrine, clay, clay loam

Land Mgmt: All plots were irrigated either by flood-irrigation or centre pivot irrigation.

Location: Alberta

Impact: There was an 8.8% decrease in yield per unit increase of saline paste. The flood irrigated barley yields were affected more by increased levels of soil salinity than were the yields from the centre pivot irrigation.

Results

Table 2.Coefficients of determination (r^2) from 3rd degree curves of relative yield of barley grain vs soil salinity for various methods and depths of sampling.

Depth of salinity sample	Saturated EC		1:2 Soil-to-water EC		Vertical Probe EC		Horizontal surface array EC
	1979	1980	1979	1980	1979	1980	1980
0-15 cm	0.60+	0.75	0.54	0.59	0.60	0.72	
0-30 cm	0.58	0.74	0.54	0.52	0.52	0.66	0.56
0-120 cm	0.48	0.49	0.44	0.45	0.40	0.41	0.62

\+ all r^2 values are significant at the 1% level of significance
n = 65 for 1979, n = 60 for 1980.

Productivity Abstract

This article concentrates on the comparison of salinity measures rather than the salinity-yield response for barley. The regression curves depicted in the various figures show that this relationship is not linear but a third degree regression equation. The saturated paste extract method of measuring salinity gave the most accurate prediction of grain yield but is more difficult to obtain than the other methods.

Keywords: Salinization, barley, Alberta, methods of salinity measurement, field data, regression analysis.

81. Peters, J. R. 1983. **The effects of phosphorus and nitrogen fertilizer on the relationship between soil salinity levels and the grain yield and protein content of barley grown on stubble land.** Can. J. Soil Sci. 63: 705-718.

The effect of fertilizer P, N and N-P combined on barley grain yield and protein content when grown on stubble land ranging widely in surface salinity (0-60 cm depth) was tested. Critical salinity levels were calculated from linear regression equations derived from sampling sites with surface salinity level >= 6mS/cm. Added P did not appear to affect the salt tolerance of barley. Yield increases due to fertilizer N were reduced rapidly as soil salinity levels increased and in one trial appeared to reduce the tolerance of barley to salinity. Calculated salinity levels at 50% and zero yield of N-fertilized barley were lower than for barley not fertilized with N. Calculated salinity levels at zero yield for the control and P treatments were 18.5 and 15.1 mS/cm respectively. These levels compared favourably with values reported in the literature for barley grown on saline fallowed land. Protein content of barley grain increased with an addition of N and with salinity. The latter fact could be largely explained by a strong positive correlation between soil salinity and NO_3 N levels and to a lesser degree by a reduction in yield with increasing salinity.

Summary

Methods:	This field study measured electrical conductivity (salinity) at three sampling depths. The soil pH was also recorded. There were four fertilizer treatments with varying levels of N and P.
Degradation:	Salinization.
Crop:	Barley
Soil:	Dark Brown and Black soil zones
Land Mgmt:	
Location:	Marriott, Landis, and Rosthern, Saskatchewan.
Impacts:	Yield increases due to N fertilizer were reduced rapidly as soil salinity levels increased.

Results

Table 3.Negative correlation coefficients between barley grain yields and soil salinity levels.

	Fertilizer treatments			
Soil depth	Control	P	N	N-P
	(a) Marriot 1978			
0-15	+0.019	0.314	0.180	0.331
0-30	0.177	0.505*	0.416	0.468*
0-60	0.168	0.531*	0.496*	0.626**
0-60++	0.525*	0.607**	0.432*	0.766**
	(b) Marriot 1979			
0-15	0.359	0.096	0.344	0.030
0-30	0.596**	0.319	0.618**	0.419
0-60	0.661**	0.435*	0.669**	0.578**
0-60++	0.571**	0.454*	0.616**	0.323(0.10)
	(c) Landis 1978			
0-15	0.129	0.269	0.207	0.245
0-30	0.211	0.222	0.281	0.217
0-60	0.226	0.251	0.349	0.220
0-60++	+0.254	0.065	0.265	0.250
	(d) Landis 1979			
0-15	0.035	0.196	0.163	0.548**
0-30	0.051	0.246	0.309	0.615**
0-60	0.040	0.142	0.257	0.639**
0-60++	0.105	0.594*	0.016	0.509*
	(e) Rosthern 1979			

0-15	0.681*	0.658*	0.838**	0.928**
0-30	0.644*	0.624*	0.849**	0.929**
0-60	0.614*	0.550(0.08)	0.863**	0.896**
0-60++	0.652(0.08)	0.886**	0.951**	0.960**

++Mean salinity level of the 0-15, 15-30, and 30-60 cm depths taken at seeding and harvest time using, for correlation purposes, only those sites with a mean salinity level thus calculated >= 6.0 mS/cm.

*,**Correlation coefficients significant at P<= 0.05 and P<=0.01, respectively, or at the level indicated in parenthesis.

Table 5.Pertinent soil characteristics and mean yields of barley grown on soil with specific salinity ranges.

Salinity range	Mean salinity	Grain yield control	Grain yield fertilized		
		----------kg/ha------------			
		(a) Marriot 1978			
mS/cm	mS/cm		P	N	N-P
0-3	1.9	844	1251	1600	2434
3-6	4.4	976	1221	1514	981
6-9	7.5	1135	1297	1258	1711
9-12	11.0	801	1008	1063	1250
12-15	12.6	903	888	922	828
		(b) Marriot 1979			
0-3	2.2	948	893	1440	1605
3-6	5.0	1156	732	2369	1606
6-9	7.9	687	740	900	944
9-12	10.8	427	485	413	464
		(c) Landis 1978			
0-3	2.4	799	818	822	813
3-6	4.5	753	838	813	793
6-9	7.3	574	735	709	751
9-12	10.4	641	829	713	822
12-15	12.9	753	625	745	638
		(d) Landis 1979			
0-3	2.1	1048	1324	1312	1735
3-6	5.1	1376	1422	1190	1516
6-9	7.4	1314	1551	1189	1442
9-12	10.0	1036	1147	1050	1197
		(e) Rosthern 1979			
0-3	1.0	1374	2082	2200	3012
3-6					
6-9	7.6	1293	2195	1258	2140
9-12	10.5	944	1339	679	842

Table 6.Calculated salinity levels* at maximum, 50% and zero barley grain yields and yield reductions per unit increase in soil salinity.

	Rosthern 1979 stubble				Rosthern 1978 fallow	
	Control	P	N	N-P	Control	P
A) Actual max. yields (kg/ha)						
Mean of 0-3 mS/cm	1374	2082	2200	3012	--	--

Mean of 3-6 mS/cm	--	--	--	--	2915	3305
B) Correlation coefficients yield vs salinity#	-0.65 (0.08)	-0.89 **	-0.95 **	-0.96 **	-0.71 **	-0.78 **
C) Predicted yield at zero salinity kg/ha	2185	4393	2756	5439	3972	4508
D) Predicted yield reduction per unit increase in salinity kg/ha.	118.0	290.4	197.7	436.6	242.3	296.8
E) Calculated yield reduction per unit increase in salinity %@	8.6	13.9	9.0	14.5	8.3	9.0
F) Calculated salinity level at max. yield in mS/cm@@	6.9	8.0	2.8	5.6	4.4	4.1
G) Calculated salinity level at zero yield in mS/cm&	18.5	15.1	13.9	12.5	16.4	15.2
H) Calculated salinity level at 50% yield in mS/cm&&	12.7	11.5	8.4	9.0	10.4	9.6

*Salinity levels are the mean of samples (spring and fall) at depths of 0-15, 15-30, 30-60 cm.
#Yield vs salinity, when mS/cm >= 6
@D divided by A
@@C minus A divided by D
&C divided by D
&&F plus G divided by 2
**Statistically significant at P<0.01 or at level indicated in parentheses.

Productivity Abstract
All the cultivars that were examined in this study had a similar reaction to salinity levels. Initial yield reductions occurred at the 6mS/cm salinity level and as a result this level was deemed the salinity threshold for barley. The cultivar which had the highest correlation coefficients with the regression equations was the Rosthern barley. This cultivar was then used to calculate salinity level at:

1) Maximum yield;
2) Zero yield; and,
3) Yield reduced to 50% of maximum.

The benefits of fertilization are greatly reduced or even eliminated when salinity levels are above thresholds.

Keywords: Salinization, barley cultivars, fertilizer, Saskatchewan, linear regression, field study.

82. Rabie, R. K., Matter, M. K., El-Maksoud, A., Khamis, A., and Mostafa, M. M. 1985. **Effect of salinity and moisture content of soil on growth, nutrient uptake and yield of wheat plant.** Soil Sci. Plant Nutr. 31: 537-545.

A pot experiment was conducted to investigate the effect of salinity and moisture content of soil on growth, nutrient uptake, sodium-potassium relationship, and yield of wheat plant. Levels of soil salinity were adjusted to 0.18 (control), 0.3, 0.6, and 0.9% of oven dry soil. Levels of soil moisture were 40, 60, and 80% of capillary capacity. The following results were obtained:

1) Dry matter yield, uptake of N, P, and K as well as protein content in grains all increased at

the salinity level of 0.3% and then decreased with increasing soil salinity up to the 0.9% level which was severely depressive. However, the number of grains per spike. the weight of 1000 grains and the efficiency of grain yield production percent all were generally decreased with each increase in soil salinity.

2) Dry matter yield as well as the uptake of N, P, K, and Na were increased when the soil moisture was 60% of the capillary capacity at the tillering stage and 60 to 80% at the booting and maturity stages.

3) Upon maturation, the highest values for the number of grains per spike were obtained when the soil moisture content was 80% of capillary capacity. However, the highest values for the weight of 1000 grains and protein content in grains per plant were recorded when the moisture content was 60%. Nevertheless, the higher the soil moisture content the lower the efficiency of grain yield production percent.

4) A negative relationship was observed between sodium and potassium concentrations in plant tissues other than grains, regardless of the levels of soil moisture.

Summary

Methods: There were 4 levels of salinity (control: 0.18, 0.3, 0.6, and 0.9% of oven dry soil) and 3 levels of moisture content (40, 60, and 80% of capillary capacity) in this pot experiment. Ten seeds were planted in each pot and then thinned to five plants after emergence.
Degradation: Salinization
Crop: Wheat
Soil:
Land Mgmt: N and P were applied at a rate of 0.84 and 0.4 g/pot, respectively.
Location: Egypt
Impact: There was an initial increase in dry matter yield at the first level of salinity and a decline in yields at all the higher salinity levels. This was the case for all moisture contents.

Results

Table 2.Dry matter yield (mg/plant) in a wheat plant at different growth stages, as affected by salinity and moisture content of soil.

Treatment	Tillering stage	Booting stage	Maturity stage Straw	Maturity stage Grain
M1 Cont.	0.19	0.96	0.98	1.52
S1	0.23	1.20	1.26	1.80
S2	0.12	0.91	0.92	1.20
S3	0.04	0.18	0.20	0.81
Means	0.15	0.81	0.84	1.18
M2 Cont.	0.21	1.74	2.06	3.18
S1	0.32	2.25	2.96	4.26
S2	0.20	1.18	1.88	2.36
S3	0.07	0.22	0.52	0.42
Means	0.20	1.35	1.86	2.56
M3 Cont.	0.20	1.72	2.80	3.26
S1	0.26	2.10	3.53	4.24

S2	0.20	1.39	2.56	2.92
S3	0.07	0.28	2.38	2.73

Cont., S1, S2, S3,indicate soil salinity levels of 0.18, 0.3, 0.6, and 0.9% of oven dry soil respectively.
M1, M2, M3,indicate soil moisture contents at 40, 60, 80% of capillary capacity, respectively.

Productivity Abstract
The moisture content did not change the effect of increased soil salinity as all yields reacted similarly to an increase in soil salinity regardless of moisture content. There was an initial dry matter yield increase when the salinity level was 0.3% and a steady decline in yield as salinity increased. This laboratory study may define a salinity threshold for wheat. A disadvantage to this study is that no particular soil series or set of management practices are considered. Soil structure and management practice may greatly reduce the effects of salinity. The quality of grain was also monitored as salinity levels increased.

Keywords: salinity, laboratory study, moisture level, wheat.

Oilseeds

83. Fowler, D. B. and Hamm, J. W. 1980. **Crop response to saline soil conditions in the Parkland area of Saskatchewan.** Can. J. Soil Sci. 60: 439-449.

The salinity tolerance of six annual crop species, wheat, oats, barley, rye, flax and rapeseed, were determined on saline soils that occur north of the Quill Lakes in the northeastern corner of the agricultural area of Saskatchewan. The relative merits of a salt tolerant grass legume mixture were also given consideration. The effects of salt stress on spring sown cultivars became apparent following exposure to hot, dry summer weather. In contrast, maximum salt tolerance for both winter wheat and winter rye was a function of winterkill. Winter hardiness of both winter annuals was reduced by saline conditions, but rye was more adversely affected than winter wheat. Large decreases in seed yield, plant dry weight and height occurred before the effects of increased soil conductivity were expressed by hectoliter weight, 1000 kernel weight, date of maturity, protein content and oil content. Among the spring and winter annual cultivars considered, Bonanza barley and Garry oats demonstrated the greatest salt tolerance. However, where severely saline conditions occurred, mixtures of salt tolerant perennial grasses and alfalfa proved to be more productive than either barley or oats. The salinity tolerance of all cultivars was greater for years with more favourable growing conditions. It was apparent that stress factors, such as soil salinity, cold, heat, drought, etc., have a cumulative effect in reducing crop performance. This observation emphasizes the importance of minimizing all stress factors when attempting to crop saline soils. Detailed soil analyses indicated that where salts were a problem, the level of salinity was extremely variable, often changing dramatically over short distances. This extreme variability made it difficult to assess the magnitude of the salinity problem. In this regard, crop performance, especially plant height, provided a good indicator for identifying saline areas for purposes of soil testing.

Summary

Methods: Field trials were conducted on soils which had a five level saline gradient (non-saline, slightly saline, moderately saline, severely saline, and very severely saline). Crop performance indicators included seed yield, plant dry weight, height, 1000 kernel weight, and percent protein and oil content. Soil conductivity readings were determined using the saturated paste method.

Degradation: Salinization

Crop: Red spring wheat (Neepawa), Winter wheat (Sundance), Winter rye (Cougar), Spring rye (Gazelle), Barley (Bonanza), Oats (Garry), Rapeseed (Torch), Flax (Noralta)

Soil: Black and Dark Gray Chernozemic, Yorkton and Whitewood soil associations

Land Mgmt: All crops were seeded into summer fallow and 67 kg/ha of 11:55:0 N:P:K was applied during planting.

Location: Quill Lakes region, North Eastern Saskatchewan

Impact: Barley and oats had the lowest yield decreases per unit increase of salt (6.7 and 7.9%, respectively). Winter wheat, spring rye, rapeseed, and flax had yields decreases of approximately 11.5% per unit increase of salt.

Results

Table 4.Crop performance (Pn) on non-saline soils. Mean for 1975 and 1977.

Cultivar	Seed Yield (t/ha)	Plant dry wt (t/ha)	Height (cm)	1000 kernel wt (g)	Protein* (%)	Oil (%)
Sundance	2.75b	10.94a	102bc	36.5a	10.1ef	
Cougar	2.94b	10.82a	121a	25.5c	8.6f	
Neepawa	2.48c	9.56a	82e	32.5b	15.3c	
Bonanza	3.18a	10.57a	85de	39.0a	12.8d	
Garry	2.78b	10.34a	98cd	32.0b	12.9d	
Gazelle	2.47c	10.04a	111ab	27.0c	11.8de	
Torch	1.49d	7.65bc	85de	2.3e	35.0a	42.8a
Noralta	1.09e	6.92c	59f	5.4d	34.1b	44.0a

*Protein and oil contents reported on moisture-free basis. Protein contents were determined by multiplying Kjeldahl nitrogen by the protein conversion factors reported by Tkachuk (1969). Protein contents for Torch and Noralta are for oil free meal.

a-fWithin column means followed by the same letter are not significantly different at the 0.05 level as tested by a Duncan's new multiple range test.

Table 5. Comparison of crop performance in 1975 and 1977

	1975	1977
1. Performance on non-saline soils (Pn)		
Seed yield (t/ha)	2.03b	2.77a
Plant dry weight (t/ha)	6.41b	12.80a
Height (cm)	92 a	93 a
1000 kernel weight (g)	25 b	25 a
2. Point (C1) of initial response (mS/cm)		
Seed yield	2.8b	4.5a
Plant dry weight	2.8b	4.7a
Height	3.5b	4.8a
3. Percent decrease in crop performance per unit increase in soil conductivity (Cp)		
Seed yield	10.4a	9.9a

Plant dry weight	9.9a	9.6a
Height	8.7a	9.0a
4. Maximum conductivity (Cm) tolerated (mS/cm)	11.0b	13.8a

a-bWithin rows means followed by the same letter are not significantly different at the 0.05 level as tested by a Duncan's new multiple range test.

Table 6.Conductivity (C1) at which a reduction in crop performance occurred

Cultivar	Seed Yield	Plant dry wt	Height	1000 kernel wt 1975	1000 kernel wt 1977	Seed protein* content 1975	Seed protein* content 1977	Seed oil content 1975	Seed oil content 1977
Sundance	3.4bc	3.4 ab	3.8ab	8.0	NS**	7.0	NS		
Cougar	2.3d	2.6b	3.2b	6.5	7.0	NS	NS		
Neepawa	4.1ab	4.2a	4.1ab	NS	NS	NS	NS		
Bonanza	2.8cd	3.9a	4.1ab	8.0	6.0	12.0	10.5		
Garry	4.4a	4.2a	5.0a	NS	9.5	NS	NS		
Gazelle	3.9ab	4.2a	4.3ab	8.0	9.0	NS	NS		
Torch	3.6abc	3.6ab	4.3ab	6.5	NS	NS	NS	8.0	9.0
Noralta	4.4a	3.9a	4.2ab	NS	NS	NS	NS	8.0	NS

*Conductivity at which there was an increase in seed protein content.

**NS No significant change in performance for the range of conductivity encountered.
a-dMean values for 1975 and 1977 trials. Within column means followed the same letter are not significantly different at the 0.05 level as tested by a Duncan's new multiple range test.

Table 7.Percent decrease in crop performance per unit increase in soil conductivity beyond the point (C1) of initial response. Mean for 1975 and 1977.

Cultivar	Seed yield	Plant dry wt	Height
Sundance	11.5a	11.0a	9.9ab
Cougar	9.6bc	9.2ab	8.1abc
Neepawa	10.7ab	11.0a	10.3ab
Bonanza	6.7d	5.9c	6.1c
Garry	7.9cd	7.7bc	7.1bc
Gazelle	11.7a	11.4a	8.9abc
Torch	11.6a	11.0a	10.6a
Noralta	11.6a	10.6a	10.0ab
Mean	10.2	9.7	8.9

a-dWithin column means followed by the same letter are not significantly different at the 0.05 level as tested by a Duncan's new multiple range test.

Table 8.Soil conductivity (mS/cm) at which plant survival ceased (Cm). Mean for 1975 and 1977

Cultivar	Cm
Sundance	10.8b
Cougar	10.8b
Neepawa	11.5b
Bonanza	15.6a
Garry	15.6a
Gazelle	11.4b
Torch	11.5b
Noralta	11.9b

a-bMeans followed by the same letter are not significantly different at the 0.05 level as tested by a Duncan's new multiple range test

Productivity Abstract

Crops planted in years that have favourable growing conditions have higher salt tolerances. There was no advantage to planting in the fall over planting in the spring on saline soils. Spring sown barley and oats had the highest salt tolerances. Significant yield losses would still occur on very severely saline soils even under the most favourable growing conditions.

Keywords: Salinization, wheat, rye, barley, oats, rapeseed, flax, field study, Saskatchewan, salt tolerance, stress factors.

Section 4: Acidification

Small Grain Cereals

84. Foy, C. D. 1987. **Acid soil tolerance of two wheat cultivars related to soil pH, KCl extractable aluminum and degree of aluminum saturation.** J. Plant Nutr. 10: 609-623.

Aluminum toxicity, associated with soil acidity, is a major growth limiting factor for plants in many parts of the world. More precise criteria are needed for identification of potential Al toxicity in acid soils. The objective of the current study was to relate the acid tolerances of two wheat cultivars to three characteristics of an acid Tatum subsoil (clayey, mixed, thermic, Typic Hapludult): pH in a 1:1 soil water suspension; KCl extractable Al; and degree of Al saturation. Aluminum tolerant 'BH 1146' (Brazil) and Al sensitive 'Sonora 63' (Mexico) wheat cultivars were grown in green house plots of soil treated with $CaCO_3$ to establish final soil pH levels of 4.1, 4.6, 4.7, 4.9, 5.2, and 7.3. Soil Al, Ca, and Mg were extracted with 1N KCl and K saturation was calculated as KCl-Al/KCl Al + Ca + Mg%. With the soil pH range of 4.1 to 4.9, BH 1146 tops and roots produced significantly more dry matter than did those of Sonora 63; however, at pH 5.2 and 7.3, the top and root yields of the two cultivars were not significantly different. Significant cultivar differences in yield occurred over a range of 36 to 82% saturation of the Tatum soil. Graphs of relative top or root yields against soil pH, KCl extractable Al and Al saturation indicated that the two cultivars could be separated for tolerance to Tatum sol under the following conditions: pH less than 5.2 (1:1 soil-water); KCl-Al levels greater than 2 c mole/kg and Al saturations greater than 20%. Results demonstrated that any soil test used to predict Al toxicity in acid soils must take into account the Al tolerances of the plant cultivars involved.

Summary

Methods: The experiment was conducted in a greenhouse. There were six levels of soil pH (4.1, 4.6, 4.7, 4.9, 5.2, and 7.3). Measures of productivity included plant top dry matter and root dry matter.
Degradation: Acidification
Crop: Two wheat cultivars.
Soil: Tatum subsoil, clayey, mixed, thermic, Typic Hapludult
Land Mgmt: The soil was taken from a wooded area in Virginia. Before planting the soil was fertilized with 100, 109, and 137 g/kg of N, P, and K respectively. Fifteen seeds were planted per pot and then was thinned later to 8 seedlings per container.
Location: Orange, Virginia
Impact: As the pH was increased, the top dry weight of both cultivars also increased.

Results

Table 2.Top and root dry weights of two wheat genotypes grown on Tatum subsoil treated with six lime levels.

$CaCO_3$ added g/kg	Final soil pH	Top dry weight BH 1146	Top dry weight Sonora 63	Root dry weight BH 1146	Root dry weight Sonora 63
		g/pot			
0	4.1	0.66a	0.06b	0.40a**	0.02b**
375	4.6	1.66a**	0.19b**	0.85a	0.04b
750	4.7	2.11a**	0.26b**	0.97a	0.08b
1500	4.9	2.60a**	0.77b**	1.13a**	0.23b**
3000	5.2	3.22a	3.13a	1.22a	0.83a
6000	7.3	3.41b	3.67a	1.16a	0.82a

Within a $CaCO_3$ level, any two genotypic means having a letter in common are not significantly different at the 5% level by the Duncan Multiple Range test.

** significant at the 1% level.

Product Abstract

Top and root dry weights were used to determine the aluminum toxicity characteristics of two wheat cultivars. No relationship was established between grain yield and increased levels of acidity.

Keywords: acidification, wheat dry matter, greenhouse experiment, aluminum toxicity.

85. Johnson, J. W. and Ohki, K. 1984. **The influence of soil PH on leaf area and yield of wheat [Triticum aestivum].** Crop Sci. 24: 377-378.

Seven soft red winter wheat (Triticum aestivum L. em. Thell.) cultivars were grown to study the influence of soil pH on morphological traits and to determine the specific leaf weight of flag leaves. Cultivars were grown in the field at two surface soil pH levels (5.2 and 6.1). Measurements of flag leaves from the primary stems were recorded at the milk and dough stages. Low soil pH significantly reduced dry weight, flag leaf area and grain yield. Linear regression equations of leaf area vs leaf weight accounted for approximately 94 and 92% of variation at pH 6.1 and 5.2 respectively. Dry weight of flag leaves could be used to rank cultivars for flag leaf area. Leak area was correlated with dry weight (r=0.98, significant at the 0.01 level). Grain growth was related to soil pH but was not related to flag leaf area. The stage of growth did not affect leaf weight:area relationships.

Summary

Methods: Seven wheat cultivars were examined in this field study. Two pH levels were used: 5.2 and 6.1 (in the plow layer).
Degradation: Acidification.
Crop: Wheat (spring).
Soil: Cecil sandy loam, Typic Hapludult
Land Mgmt: The soil ranged from very strongly acidic to strongly acidic naturally. Liming was done 2 years before the start of the study to raise the soil pH.
Location: Georgia

Impact: Low pH significantly reduces grain yield. At the high pH, yields were 44% higher than the yields from the low pH soils.

Results

Table 1.Mean values for flag leaf and agronomic characteristics of soft red wheat cultivars.

Variable	Dry weight mg/leaf	Flag leaf area cm^2/leaf	Grain yield kg/ha
Soil pH			
6.1	75a	17.7a	4584a
5.2	69b	16.0b	3180b

Productivity Abstract

This is one of the only studies that examines wheat yield responses to increased soil acidity. The two levels of pH do not give a particularly detailed description of this relationship, but there is a significant decrease in yield at the lower pH.

Keywords: red spring wheat, field study, soil acidity, Georgia.

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