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Benefits of crop rotation
for sustainable agriculture in dryland farming

Canada

Benefits of crop rotation for sustainable agriculture in dryland farming

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CONTENTS

INTRODUCTION

Since the early 1900s, Agriculture Canada research stations, situated strategically throughout the soil zones in the Prairie Provinces (Fig. 1) have conducted more than 68 long-term crop rotation studies. Twenty of these studies still continue. This publication, which focuses on the period since the 1950s, summarizes the effects of rotation length, crop sequence, substitute crops for summer fallow, and fertilization using N and P on the following:

- crop production and quality
- pests
- soil moisture
- N and P uptake
- soil quality
- profitability
- energy efficiency.

Highlights from these studies are discussed under each of the topics listed above. Recommendations follow on how to run an efficient, economical, and environmentally responsible farming operation on the Canadian prairies.

Our aim here is to provide a handy booklet of current information and advice for a wide audience on the benefits of crop rotation in dryland farming.

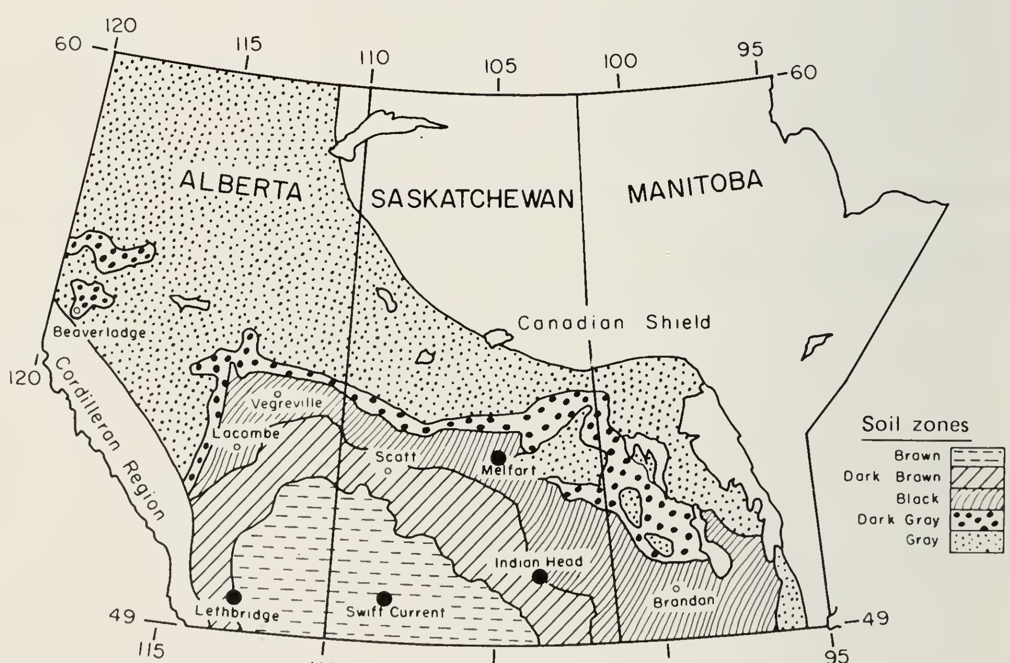

Fig. 1 Location of research stations and major soil zones of the prairie region.

The complete report of Agriculture Canada's recent rotation studies is presented in *Crop rotation studies on the Canadian prairies*. This detailed book is targeted primarily toward the scientific community but is also a useful reference for extension personnel. It will be sold in Canada in 1990 by authorized bookstore agents or can be purchased by mail from:
Canadian Government Publishing Centre
Supply and Services Canada
Hull, Quebec K1A 0S9

CROP YIELDS AND QUALITY

Water and its efficient use is the key to successful crop production in the Brown and Dark Brown soils of western Canada. Allowing some fields to lie idle in summer fallow for a season increases subsequent grain yields per unit of seeded land, but it seldom increases the total annual production of grain from the farm (Fig. 2). In fact, total annual grain production is generally highest for rotations in which land is cropped continuously.

Higher grain yields per seeded area for crops grown after summer fallow than for those seeded on stubble occur because more moisture is available to the former (Fig. 2, *bottom left and right*). For example, in the dry Brown soils, when recommended management practices of stubble mulch tilling and fertilizing are used, yields of wheat seeded on stubble average 71–74% of yields from wheat seeded on fallow. In the moister Dark Brown soils comparable yields average up to 81% and in the wet Black soils up to 88% of yields of fallow-seeded wheat.

Soil testing is important in determining which and what rates of fertilizers to apply. For fallow-seeded crops N fertilizer is rarely required but P fertilizer is; on stubble-seeded crops both N and P fertilizers are generally required.

Grain yields do not seem to decline with time, and in some cases they appear to increase. However, improved crop varieties and production technologies may have masked any decline in yields resulting from losses in soil productivity.

Cropping sequence influences yields, particularly in the Black and Gray soils. Yields of cereal grains are commonly higher when crops are grown on stubble of oilseed crops than on stubble of another cereal. Including flax (Fig. 3) in the rotation sometimes reduced subsequent wheat yields, because flax does not compete well with weeds. However, often its effect on subsequent crops was not clear cut. Rotations that include grass–legume forage or legumes grown as green manure may be practical in the Black and Gray soils. However, their effects on subsequent cereal yields are neither consistent nor always beneficial. In drier regions problems with establishing legumes and the competition they provide for scarce moisture limit their suitability for rotating with cereals.

Fig. 2 (*top*) **Little difference between wheat on fallow in fallow–wheat–wheat and continuous wheat in a wet year (1986) at Swift Current, Sask., but wheat on fallow (*bottom left*) and wheat on stubble (*bottom right*) in a dry year (1984) show why farmers in the drier areas choose fallow.**

Fig. 3 A uniform stand of flax grown in Dark Brown soil at Scott, Sask.

Fig. 4 Grassy weeds are a major deterrent to the use of extended rotations. For example, note millet infestations in continuous spring wheat in a dry year (1988) at Swift Current, Sask.

Grain quality, which is measured by protein content and kernel density, is good under all treatments but generally decreases from the Brown to Dark Brown to Black and Gray soils.

PESTS

Weed problems are least in rotations that include summer fallow or intertilled crops. Both flax and sweetclover are highly susceptible to weed infestation. Cereals grown continuously often succumb to grassy weeds after 5–6 years of cropping (Fig. 4). However, mixed rotations of cereal and forage can help to suppress weeds in the Black and Gray soils.

Plant diseases, such as common root rot in wheat and blackleg and stem rot in canola, are more common in the wet soil regions. To ensure low infestations on the next host crop, the rotation should include at least a 3-year break from susceptible crops. Stem rot, which attacks flax, pulse, clover, and alfalfa, does not attack cereals and grasses, which can thus be used as break crops. Diseases pose fewer problems in the drier conditions of the Brown and Dark Brown soils.

SOIL MOISTURE

The amount of moisture conserved in the soil under the various crop rotations appears not to have changed during the past 30–40 years. However, research into alternative ways of managing crop residues to increase water conservation (e.g., conservation tillage, snow trapping, and deep ripping to aid snowmelt infiltration) promise significant improvement in this regard for the Brown and Dark Brown soils (Fig. 5). Stored moisture directly influences yields in the drier areas but is of less significance in wetter areas. In the Brown and Dark Brown soils, about 33% of the precipitation received in the 9 months between harvest and seeding of cereal crops or crops grown on stubble is stored in the soil. In comparison, only 18–20% of the moisture received in 21 months of fallow is stored in the soil. In the Black and Gray soils, usually less than 10% of moisture commonly received is stored.

Storage of soil moisture in the root zone is important because growing season precipitation is so unpredictable in amounts and distribution. Tillage increases moisture loss from soil, which reduces germination and subsequent vigor of crops. At seeding in the Brown and Dark Brown soils, land lying fallow has, on average, about 40 mm more moisture in the root zone than stubble-covered land. By the time the crop reaches the shot-blade stage of growth, this difference in available moisture disappears. By harvest, no available soil moisture remains stored in either system.

Fig. 5 **(*top*) Chemical fallow or conservation tillage will enhance water stored in soil and reduce erosion; (*bottom*) cereal trap strips, constructed at little cost during harvesting, can increase water capture from snow.**

Amount of rainfall and when it falls during the growing season determine grain yields in drier areas. The best yields in all systems result from rainfall received during the grain-filling period. However, for stubble-seeded crops, rainfall at seeding time is also essential for the establishment of seedlings.

Underfertilization reduces both crop yields and residues; thus, less snow is captured and less moisture stored. In drier regions, fertilization must be conservative because of the frequency and unpredictability of drought occurring. Often the well-fertilized crops are the ones that suffer the most during droughts (Fig. 6).

Available soil moisture in a rotation is also much affected by the sequence of crops grown. In the Dark Brown soils, canola and oat hay use less water than does spring wheat. However, combinations of legumes and grass hay use much more water than wheat. Thus with less moisture available, subsequent yields of wheat in forage–wheat rotations generally fall. Use of perennial hay in cereal rotations in drier regions depletes soil moisture much more than does use of annual crops, thus subsequent grain yields can be substantially reduced for several years. In the wetter Black and Gray soils, perennial hay rarely affects subsequent yields of grain crops because soil moisture is usually adequate.

The efficiency of moisture use for well-fertilized wheat grown either on fallow or stubble on the Brown soils has increased over the past 40 years. This change reflects improvements in crop management and in varieties of wheat. In the Dark Brown soils, the efficiency of moisture use for spring wheat is similar to that measured on Brown soils. Values are much greater on the Black and Dark Gray soils.

USE OF FERTILIZERS

Considerable leaching of nitrates below the rooting depth of spring wheat is a problem that occurs periodically even in the normally dry Brown soils. Leaching is greatest under fallow and in wet years. Loss of available N is reduced in three ways:

- by managing fertilizers properly
- by using continuous cropping
- by growing fall-seeded crops such as fall rye.

Available P in surface soil is enriched by frequent application of fertilizer, especially when a crop is present and where heavy-textured soils exist. Changes in available P are related to temperature and moisture.

Uptake of N and P by plants is related directly to the amount of dry matter produced. In the Black and Gray soils, incorporating legumes and grasses in soil enriches the amount of N available to the subsequent crop. In some cases both yield and protein content of grain show increase; in others only the protein increases.

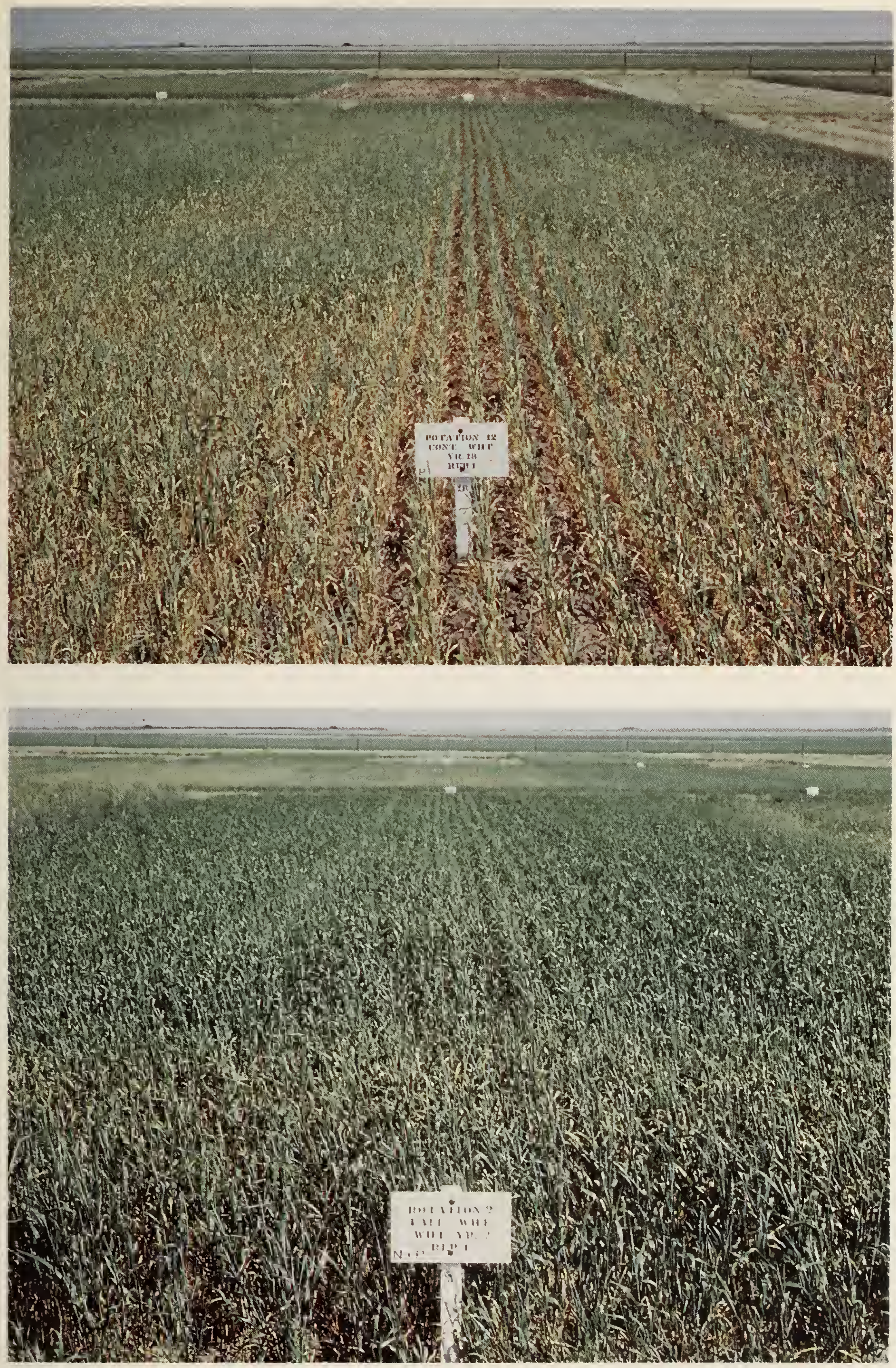

Fig. 6 (*top*) **Well-fertilized crop uses water too rapidly at first and runs out of water early in dry years;** (*bottom*) **less well fertilized crop uses water more slowly and water availability persists later into a dry year (Swift Current July 1984).**

SOIL QUALITY

Frequent fallowing and excessive tillage undeniably degrade soil quality in the long term. Poorer soil quality is evident from the following characteristics:

- loss of organic matter
- poorer quality of organic matter
- reduced microbial activity
- greater incidence of soil crusting
- greater susceptibility to erosion.

Fertilizing according to soil test recommendations and extending the rotation length may increase the soil organic matter and improve soil quality, particularly for soils of low organic matter or those that were previously degraded.

Although the application of N fertilizer lowers the soil's pH, the effect is insufficient to warrant concern in the short term.

In Black and Gray soils, the amount and quality of soil organic matter can be maintained by including legumes in the rotation, either for green manure or as forage (Fig. 7, *top*). However, the quality of soils under mixed rotations is usually no better than that under adequately fertilized continuous wheat. In the Brown and Dark Brown soils, moisture limitations restrict the use of biennial or perennial legumes with cereals, but research to find appropriate, annual, legume green manure crops is in progress (Fig. 7, *bottom*).

ECONOMICS

Despite the long-term benefits obtained from continuous cropping, producers often choose rotations that include fallow for reasons of short-term economic survival. For example, in the Brown and Dark Brown soils, net returns are often much higher for rotations that include fallow. Deterrents to the use of extended crop rotations in these soils include the following:

- higher cash outlay for more fertilizers, herbicides, and capital items
- greater risk of financial loss because of highly variable weather during the growing season.

In the Brown soils, despite some extra cost and risk, producers would benefit financially by adopting a 3-year rotation of fallow–wheat–wheat rather than the traditional 2-year rotation of fallow–wheat. In the Brown and Dark Brown soils, it is unknown whether extending rotations beyond 3 years would be more, or less, profitable. A method for determining reserves of soil moisture in spring could help producers to estimate whether stubble cropping carries an acceptable financial risk.

Fig. 7 (*top*) **Forage crops play a significant role in maintaining soil quality in crop rotations in wetter areas;** (*bottom*) **in drier areas the search for appropriate annual legume green manure crops is promising. (The photo shows discing-in field peas for green manure at Swift Current).**

In the Black soils, producers have the widest choice of cropping systems. The following rotations are all economically attractive depending on costs and prices:

- cereals only (Fig. 8, *top*)
- cereals and oilseeds (Fig. 8, *bottom*)
- cereals and forages
- cereals, legumes for green manure, and summer fallow.

Monoculture of wheat sometimes carries greater input costs and financial risk because of increased problems with weeds, diseases, and insects.

ENERGY

Only since the energy crisis of the early 1970s have producers considered the efficient use of nonrenewable energy in determining crop rotations. Two types of energy are directly related to cropping intensity:

- nonrenewable energy used in farming
- metabolizable energy returned in grain for human consumption.

For example, continuously cropped wheat uses nearly twice as much energy as a 2-year rotation of fallow–wheat. However, continuously cropped wheat produces 55% more metabolizable energy annually.

In contrast, energy use efficiency, both in terms of the ratio of energy output to input and amount of grain produced per unit of energy used, are lowest for continuous rotations and highest for rotations that include fallow. Legumes included in the rotation considerably reduce the need for additional N fertilizer and thus improve energy efficiency.

RECOMMENDATIONS

Summer fallow

Summer fallow remains a legitimate option in the cropping systems of western Canada. Its role and recommended use depend on the interaction of soil, climate, and economic variables. In the Brown and Dark Brown soils where moisture stress is the main factor limiting yields, use summer fallow and snow management techniques to replenish soil moisture and thus reduce economic risks. In the Black and Gray soils where moisture is usually sufficient, use summer fallow only to control otherwise unmanageable pests or when drought threatens.

Fig. 8 (*top*) **On the prairies spring wheat is "king";** (*bottom*) **but oilseed crops such as canola are adapted to the cool wetter areas and can be quite profitable.**

To minimize the soil degradation associated with fallow:

- reduce the frequency of fallow in the rotation to once every 3 or 4 years in the Brown and Dark Brown soils
- use partial fallows (e.g., green manure or cereal hay crops) in the Black and Gray soils
- adopt soil management techniques that conserve crop residues (e.g., stubble mulching).

For best weed control on summer fallow apply herbicides such as 2,4-D in late fall or early spring, which will allow delay of the first tillage until early summer.

Perennial forages

In the Black, Dark Gray, and Gray soils, perennial forages included in crop rotations improve soil quality, crop nutrition, and crop yields. Extended rotations of spring wheat with several years of forage for hay generate favorable net economic returns.

In the Brown and Dark Brown soils, deep-rooted perennial forages remove too much soil moisture, so they are not recommended for use in cereal-based rotations.

Subsequent crops

The influence of each crop on the subsequent crop in the rotation depends on:

- use of soil moisture by the first crop
- effects on residual fertility
- effects of pest populations
- unidentified effects of one crop on the other.

For example, oilseed crops such as flax and canola generally deplete soil moisture less than do cereal crops. Thus oilseed crops may increase potential yields of subsequent crops in drier soils. The same crops, particularly flax, do not compete well with weeds. Proliferation of weeds may suppress the yield of subsequent crops. Legumes are suspected of providing other crops in rotation with benefits other than those produced by nitrogen fixation.

Regardless of the cropping system used, rotating crops periodically helps to control certain weeds, diseases, and insects.

Fertilizers

Intensive cropping systems lead to declining fertility in indigenous soils, so fertilizers become progressively important in rotation farming. Fertilizers used appropriately, generally increase expected net returns by increasing yields. Fertilizers also

- increase efficiency of moisture use by stimulating root growth
- improve snow-trapping and moisture conservation by increasing crop residues on the soil surface

- enhance long-term productivity of soil by increasing the content and quality of organic matter.

Their use may *not* be appropriate in rotations with high frequency of fallow or legumes, or when costs of fertilizers are high.

Although ammonium-based fertilizers may lower the pH value of the soil, in most soils acidification may only become a significant problem after many years.

Agronomic practices

Agronomic practices greatly affect soil quality in long-term crop rotations. In fact, by adopting economically viable, conservation-oriented management practices, soil productivity can be maintained at acceptable levels. After initial cultivation, the concentration of organic matter in most soils declines. The appropriate use of crop sequences, tillage practices, and fertilizers can halt or even reverse such declines. Yields of crops grown on arable land have generally increased over the years. It is not clear how much the increase results from varietal and technological advances and how much from the dynamics of soil quality. A decline in soil productivity is not necessarily inevitable for all producers, despite predictions.

Fall tillage is discouraged in the Dark Brown and Brown soils but may offer some advantage in more humid regions where crop residues are excessive.

Farmyard manures are very effective sources of readily available nutrients that will improve soil quality and increase yields. Where available to producers, their use is definitely encouraged.

Crop selection

The ideal cropping system in most conditions must remain flexible, with crops selected in response to:

- soil moisture reserves
- economic variables
- infestations of weeds or pests.

Crop sequences can now be sufficiently flexible to exploit changes in economic and agronomic conditions. Although most producers have long-term cropping strategies, short-term revisions in response to economic and climatic factors are encouraged.

Environmental quality

In decisions regarding cropping strategies, consider not only short-term benefits but also their long-term effects on the quality of the soil and environment. Agronomic practices strongly influence

- concentrations of organic matter
- soil erodibility
- soil pH

- soil biota activity
- soil structure and tilth
- other indices of soil quality.

Less well known, but equally important to consider, are the effects of various cropping practices on the environment by the following mechanisms:

- nitrate leaching
- evolution of carbon dioxide and oxides of nitrogen
- contamination of groundwater with pesticides
- accumulation of pesticides in soil and farm produce.

All these ramifications must be considered in the design of optimum cropping systems.

LIMITATIONS

These recommendations are based on the results of rotation experiments that have certain inherent limitations. Rotation studies are limited to a few sites. For example, Swift Current, the only site in the Brown soils is usually much wetter than most soils in this zone. Most results are from relatively productive soils of uniform topography and medium texture. Results are also affected by

- limited number of crops examined
- lack of replication in some long-term studies
- possible confounding effects of gradual changes in cultivars and management practices over time.

Because agronomic practices change, those management systems currently recommended generally may not have been studied over the long term.

FUTURE RESEARCH

Several agronomic facets deserve more detailed examination or can be improved upon in future studies of crop rotations. Little information is yet available on the influence of cropping practices on infestations by weeds, diseases, and insects.

Study of soil parameters is limited to few experiments. Cropping practices or components that deserve particular emphasis in the future include:

- organic, or sustainable, production systems
- flexible cropping systems that reduce economic risk without resorting to frequent fallowing
- partial fallow systems such as legume green manuring, especially annuals for the drier regions
- more effective management of snow in drier regions

- more diverse cropping systems using a greater variety of crop species
- the effect of flax on subsequent crops in rotation
- conservation tillage and its consequences for maintenance of soil and environmental quality.

There is a real need for a comprehensive, team-oriented approach to research in crop rotations for sustainable agriculture.