THE LONG-TERM AGRONOMIC AND ECONOMIC EFFECTS OF CROP ROTATIONS IN WESTERN CANADA

R.P. Zentner, C.A. Campbell, K.E. Bowren, H.H. Janzen, R.D. Tinline
H.W. Cutforth, S.A. Brandt, G.P. Lafond and L. Townley-Smith

ABSTRACT

Agriculture Canada Research Stations in western Canada have conducted more than 68 long-term crop rotation experiments since the early 1900's; twenty of these are still ongoing. A committee of scientists, representing all Research Stations on the Prairies has just completed an in-depth review and summary of the major findings from these studies. Based on their findings, they also developed recommendations that can be used by managers in decision making and rationalization of resource use for current and future studies of this kind. The resulting two publications which will be released in early 1990 include: i) a bulletin entitled 'Benefits of Crop Rotation for Sustainable Agriculture in Dryland Farming', which presents producer recommendations on how to run an efficient, economical, and environmentally responsible cropping operation, and ii) a detailed technical book entitled 'Crop Rotation Studies on the Canadian Prairies', which is directed at the scientific community but is also useful for extension personnel and producers. This paper highlights some of the main aspects reported in these publications and attempts to give a coherent and broader interpretation of the underlying principles and processes of crop production. The discussion focuses on the effects of rotation length, crop sequence, substitutes for summerfallow, and N and P fertilizer, on crop production, grain and forage quality, soil moisture conservation and moisture use efficiency, N and P uptake by the plants, nutrient losses, soil quality, profitability, nonrenewable energy efficiency, and crop pests.

INTRODUCTION

A crop rotation is a planned sequence of crops grown in recurring succession on the same area of land. The selection of a crop rotation is influenced by three sets of factors or criteria. The first set consists of physical considerations and includes soil characteristics, weather constraints, intercrop dependences, soil and environmental impacts, and incidence of pests. These factors determine crops that can be grown, substitution possibilities, and expected yields.

The second set of factors consists of economic considerations such as amount and seasonality of resources, expected prices for products, costs of inputs and credit, marketing opportunities, agricultural policies and programs, tax considerations, financial position of the farm, availability of equipment and labor, and ability of the farm to withstand major fluctuations in income. These factors provide the criteria on which to base rational decisions by weighing the relative advantage of each crop, agronomic consideration, and resource service in relation to financial goals of the farm.

The third set of factors consists of the decision-making and organizational abilities of farm managers. These include knowledge, skills, management ability, and attitudes towards risk. These factors determine or govern the degree of success of farm managers in processing information and in choosing and directing the optimal cropping program for their particular farm.

Crop rotations have been studied in western Canada since the 1890's. Most studies were carried out by Agriculture Canada, but a limited number have been conducted by universities (Poyser et al. 1957, Robertson 1979, Robertson and McGill 1983). Hopkins and Barnes (1928) and Hopkins and Leahey (1944) first attempted to summarize the results of experiments conducted by Agriculture Canada. Later, Ripley (1969) presented a comprehensive summary up to 1965, including a through review of the pertinent literature. This paper presents some of the main findings and conclusions reported in the recently written book by Campbell et al. (1990) and bulletin by Zentner et al. (1990) which summarize Agriculture Canada's long-term crop rotation studies up to 1988.

MATERIALS AND METHODS

More than 68 long-term crop rotation experiments have been conducted at Agriculture Canada Research Stations located throughout the major soil zones of the Prairie Provinces (Figure 1). Of these studies, 20 still continue. The focus was on the effects of rotation length, crop sequence, summerfallow substitute crops, and N and P fertilization on crop production, grain and forage quality, uptake of N and P by plants, crop pests, conservation of soil moisture and its efficient use, economic returns and non-renewable energy efficiency, and on changes in physical, chemical, and biological properties of the soil.

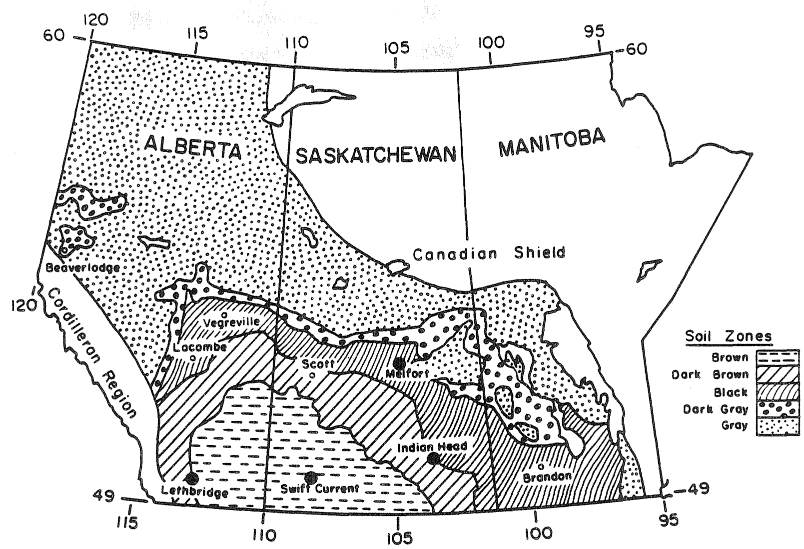

Figure 1. Location of Research Stations conducting long-term Crop Rotation Studies.

SUMMARY OF RESULTS

Crop Production and Quality

* Grain yields of crops grown on summerfallow were seldom twice those obtained from previously cropped land; thus, total output was generally highest for rotations in which the land was continuously cropped and lowest for rotations with high proportions of fallow.

* Year-to-year variability in grain yields was considerably lower for fallow-than for stubble-seeded crops, reflecting the greater amount of moisture available to the former.

* In the dry Brown soil zone, with recommended management practices, stubble-seeded wheat yields average 71-74% of those for fallow-seeded wheat; in the more moist Dark Brown soil zone they average up to 81% and, in the wet Black soils, up to 88% of fallow-seeded wheat yields.

* The benefits of soil testing to determine appropriate rates of P fertilizer for fallow-seeded crops, and both N and P fertilizer for stubble-seeded crops were demonstrated.

* Grain yields did not decline with time; in several studies they generally increased. However, the use of improved production technologies may have masked any decline resulting from reduced soil productivity.

* Cropping sequence influenced yields, particularly in the Black and Gray soil zones, where cereal grain yields were often higher when grown on stubble of oilseed crops than on stubble of another cereal.

* The inclusion of flax in the rotation often reduced subsequent wheat yields because greater weed infestations often developed in flax.

* Rotations that included grass-legume forage crops or legume green manure crops may be practical in the Black and Gray soil zones, but their effects on subsequent cereal yields were neither always consistent nor beneficial; problems with plant establishment and competition for scarce moisture limit their suitability in the drier regions.

* Grain quality (protein and density) was good under all treatments but generally decreased from the Brown to Dark Brown to Black and Gray soil zones.

<u>Crop Pests</u>

* The limited results on agricultural pests showed that summerfallow and intertilled cropping systems had the least problems with weeds.

* Flax and sweetclover were highly susceptible to the herbicides used to control weeds, whereas continuous cereals often succumbed to grassy weeds after 5-6 years of cropping.

* Use of mixed cereal-forage rotations helped to suppress weeds in the Black and Gray soil zones.

* Plant diseases found in the wet soil regions, such as common root rot in wheat and blackleg and stem rot in canola, require at least a 3-year break from susceptible crops to ensure low infestations on the subsequent host crop.

* The dry conditions common to the Brown and Dark Brown soil zones and the inherent resistance of hard red spring wheat to disease combined to minimize crop pest problems in these regions.

<u>Soil Moisture</u>

* The quantity of moisture conserved in fallow and stubble soils has not changed compared to 30-40 years ago.

* In the Brown and Dark Brown soil zones about 33% of the precipitation received in the 9 months between harvest and seeding of stubble crops, and between 18 and 20% of that received during the 21-month fallow period, were stored in the soil.

* In the Black and Gray soil zones moisture conserved was often less than 10% of that received. Consequently, stored soil moisture commonly influenced yields in the drier areas, but rarely in the more humid areas.

* In the Brown and Dark Brown soil zones, fallow systems had about 44 mm more moisture in the root zone than stubble systems at seeding. By the shot-blade stage of plant development this advantage had disappeared and by harvest both systems generally had no remaining available soil moisture.

* Amount and distribution of rainfall received over the growing season

was very important in determining final grain yields in the drier areas.

* In all cropping systems, moisture availability during the grain filling period was most critical for final grain yields, but for stubble-seeded crops, having adequate moisture at seeding time was also important to ensure good seedling establishment.

* Relationships between spring wheat yields and total moisture use showed that the average initial yield point (moisture required to produce the first kilogram of grain) occurred at about 70 mm available moisture and each additional mm of moisture produced 9.2 kg grain per ha.

* Use of perennial hay crops in cereal rotations in the drier regions depleted soil moisture reserves much more than annual crops; thus, subsequent grain yields were often reduced for several years.

* In the Black and Gray soil zones, even though forage crops may cause significant reductions in soil moisture, they had little effect on yields of subsequent grain crops.

Nitrogen and Phosphorus Dynamics

* Considerable amounts of NO_3-N can be leached below the rooting depth of spring wheat even in the normally dry Brown soil zone. Nitrate leaching was greatest under fallow systems. Losses were reduced by proper management of fertilizer, by use of continuous cropping rotations, and by growing fall-seeded crops such as fall rye.

* Frequent applications of P fertilizer enriched available P in surface soil, especially when a crop was present and particularly in heavy-textured soils.

* Changes in available P were related to temperature and moisture; available P also increased over-winter.

* Plant uptake of N and P was related directly to the production of dry matter.

* In the Black and Gray soil zones, plow-down of legumes and grasses increased the soil-available N. This extra N increased N uptake by the subsequent cereal crops; sometimes both yield and grain protein were enhanced, but in other cases only the latter was increased.

Soil Quality

* The results confirmed the degradative effects of frequent fallowing on soil quality, evidenced by organic matter loss, depreciated organic matter quality, reduced microbial activity, and enhanced susceptibility to erosion.

* Applications of N fertilizer lowered soil pH, but the effect was insufficient to warrant concern in the short term.

* Inclusion of legume green manure and grass-legume forage crops in the

rotation with cereals benefited soil productivity on soils with low initial organic matter, but soils with inherently high organic matter, the use of legume crops contributed little to soil productivity. Soil quality maintained by the legume-type rotations usually did not exceed that under adequately fertilized continuous wheat, perhaps because of the inclusion of fallow in the cereals-forage rotations.

Economic Performance

* The realities of short-term economic survival will likely prevent producers from adopting rotations requiring annual cropping despite their long-term benefit to soil productivity. This situation is especially so in the Brown and Dark Brown soil zones where net returns were often much higher for rotations that included fallow.

* The major deterrents to adoption of extended crop rotations in these regions were the higher cash outlay required to purchase the additional inputs (e.g., fertilizers, herbicides, and capital items) and the high risk of financial loss resulting from highly variable weather during the growing season.

* In the Brown soil zone, producers could beneficially move from the traditional 2-year fallow-wheat rotation to a 3-year fallow-wheat-wheat rotation even though there is some additional cost and risk.

* In the Dark Brown soil zone, although no evidence was found that producers could profitably extend rotation lengths beyond the 3-year fallow-wheat-wheat or fallow-canola-wheat, none of the studies in this, or in the Brown soil zone included intermediate length rotations (e.g., 4- or 5-year), thus it is unknown whether extending rotations beyond 3 years would be more, or less profitable.

* In the Black soils, producers have the widest choice of cropping systems. Rotations that include only cereals, cereals and oilseeds, cereals and forages, and cereals and legume green manure crops combined with periodic use of summerfallow were all economically attractive under some cost-price situations. Only wheat in continuous monoculture was sometimes questionable because of problems with diseases and, more recently, insects.

Energy Considerations

* The limited results on energy considerations showed that in the Brown soil zone non-renewable energy inputs and metabolizable energy for human consumption were directly related to cropping intensity.

* Continuously cropped wheat required a near-doubling of total energy inputs compared to the 2-year fallow-wheat rotation; but, in so doing, metabolizable energy output was increased by about 35%.

* In contrast, the energy output-to-input ratios and the quantity of grain produced per unit of energy used were lowest for the continuous-type rotations and highest for the fallow-type rotations.

* Inclusion of legumes in the rotation with cereals where moisture was

less limiting, considerably reduced the requirements for non-renewable energy inputs, especially for N fertilizer, and thus improved energy efficiency.

CONCLUSIONS

Summerfallow remains a legitimate option in the cropping systems of western Canada, though its role and recommended use vary depending on edaphic and climatic conditions. In the Black and Gray soil zones, where moisture deficits are relatively small, summerfallowing can be justified only for control of otherwise unmanageable pests or in the event of potential drought. In the Brown and Dark Brown soils, however, where moisture stress is the primary yield-limiting factor, the replenishment of soil moisture during fallow reduces economic risks and warrants the inclusion of some summerfallow in the crop rotation. Although frequent inclusion of fallow enhances soil degradation, this effect can be minimized by using techniques for conservation tillage, by use of partial fallows (e.g., green manure or cereal hay crops), or by reducing the frequency of fallow in the rotation. Economic analyses indicate that the optimum frequency for using fallow in the Brown and Dark Brown soil zones is about once in 3 years, though that value varies depending on soil and economic variables.

Inclusion of perennial forages in crop rotations represents an important means of improving soil quality, crop nutrition, and crop yields in the Black, Dark Gray, and Gray soil zones. Economic analyses indicate that extended rotations of spring wheat, with several years of forage grown for hay, generate favorable net economic returns. In the Brown and Dark Brown soil zones, the inclusion of perennial forages is not recommended because of excessive depletion of soil moisture by these deep-rooted crops.

The influence of one crop on the yield of a subsequent crop in the rotation is largely contingent on use of soil moisture by the first crop, residual fertility effects, and effect on pest populations. Oilseed crops (flax and canola) generally deplete soil moisture to a lesser extent than cereal crops and thereby increase the potential yields of subsequent crops in drier soils. These same crops, however, particularly flax, do not compete well with weeds and may therefore suppress the yield of subsequent crops by allowing weeds to proliferate. Regardless of cropping system, periodic rotating of crops is recommended for the control of certain weeds, diseases, and insects.

Fertilizers are assuming progressively greater importance in cropping systems as indigenous soil fertility declines and cropping systems are intensified. Appropriate application of fertilizers generally increases expected net returns, except in rotations having high frequency of fallow or forage and when costs of fertilizers are high. Aside from directly increasing yields, fertilizer application has three effects. It increases the efficiency of moisture use by stimulating root growth; it improves moisture conservation and snow-trapping by increasing surface crop residue, and it enhances long-term soil productivity by increasing the content and quality of organic matter. Ammonium-based fertilizers may depress soil pH, though significant acidification will likely occur only over the long term in most soils.

Long-term crop rotations indicate that agronomic practices greatly affect soil quality. They demonstrate, further, that soil productivity can be maintained indefinitely by adoption of economically viable, conservation-oriented management practices. Although most soils have exhibited an inevitable decline in concentrations of organic matter following initial cultivation, this trend has been halted or even reversed by the use of appropriate crop sequences and fertilizer strategies. Crop yields have generally increased over the decades since inception of arable agriculture, though the relative contributions of technological advances and soil quality dynamics to this trend are uncertain. Results of these studies therefore suggest that the dire predictions of inevitable declines in soil productivity are not necessarily a fait accompli, at least not for all producers.

The ideal cropping system, in most conditions, retains considerable flexibility for crop selection in response to dynamics in soil moisture reserves, economic variables, and infestations of weeds or other pests. Although most rotation experiments have adopted rigid cropping sequences to facilitate the interpretation of data, the results can be interpreted to assist in the design of crop sequences with sufficient flexibility to exploit changes in economic and agronomic conditions. Although most producers have long-term general cropping strategies, short-term revisions in response to economic and climatic factors are both anticipated and recommended.

Decisions regarding cropping strategies should take into consideration not only short-term benefits but also their long-term effects on soil and environmental quality. Crop rotation studies have demonstrated that agronomic practices exert strong influence on the concentration of organic matter, soil erodibility, soil pH, soil biota activity, and various other indices of soil quality. Less well known, but of equal importance, are the effects of various cropping practices on the environment through mechanisms such as nitrate leaching, carbon dioxide evolution, groundwater contamination with pesticides, and accumulation of pesticides in soil and farm produce. All these ramifications deserve consideration in the design of optimum cropping systems.

The findings reported in the book by Campbell et al. (1990) and the bulletin by Zentner et al. (1990) will benefit both the agricultural extension and scientific communities. Results presented represent the basis for the formulation of agronomic strategies which could be disseminated to producers. For the scientific community, the findings not only provide background information, but also serve to identify areas requiring research attention. As well, these studies may represent opportunities for the development or verification of simulation models, and in-depth, critical examinations of specific mechanisms.

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