Influence of management practices on weed communities in organic cereal production systems in Saskatchewan

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ABSTRACT

Management practices on organic farms in Saskatchewan are largely unstudied, as are their effect on weed populations and soil quality. The objective of this study was to document what management practices are used on organic farms, classify those practices into management systems and determine if those management systems affect weed populations and soil properties. During the 2002 growing season 73 organic fields in the province of Saskatchewan were surveyed. Three components comprised the data set for each field: a management questionnaire, weed counts, and soil samples that were collected and analyzed for various soil properties. Classification of the management practices identified farming systems: the diverse cropping system, the diverse cropping system using green manure, the low diversity cropping system using summerfallow, and the moderately diverse cropping system using perennials in rotation. Ordination of weed data and the four systems was done with redundancy analysis. It determined that the farm management systems only accounted for 5% of the variation in the weed populations. The only system that affected the weed populations was the moderately diverse cropping system using perennials in rotation. Soil properties were compared among the different management systems. Soil properties were not different between the diverse cropping system using green manure, and the low diversity cropping system using summerfallow. The system that included perennials in rotation had significantly lower pH, electrical conductivity, soil organic matter, phosphorous and potassium levels. The nutrient levels in all systems were low, underscoring the importance of nutrient additions to export farming systems.

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DEDICATION

To Maria Pauls Buhler.

One of the strongest women I have known.

Thanks for teaching me to stand tall.

I miss your laugh, Grandma.

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LIST OF ABBREVIATIONS
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SAF	Saskatchewan Agriculture and Food
PCA	Principal components analysis
TWINSPAN	Two-way indicator species analysis
CA	Correspondence analysis
RDA	Redundancy analysis
CCA	Canonical correspondence analysis
NMS	Non-metric multidimensional scaling
SAS	Statistical Analysis System
OCIA	Organic Crop Improvement Association
DCA	Detrended correspondence analysis
SOM	Soil organic matter
OM	Organic matter
EC	Electrical conductivity
N	Nitrogen
P	Phosphorous
K	Potassium
S	Sulphur
C	Carbon
NH_4^+	Ammonium
NO_3^-	Nitrate
RP	Rock phosphate

1 GENERAL INTRODUCTION

1.1 Project context and objectives

The Canadian agricultural census provided an accurate count of the number of organic producers in each of the Canadian provinces for the first time in 2001. According to the 2001 census, Saskatchewan has 720 certified organic field crop producers, the highest number in Canada (Statistics Canada, 2001b). However, with only a single year of data from the census, growth in the organic industry can still only be estimated. A recent study suggested that from 1999 to 2000 the number of organic producers in Saskatchewan increased by 64% (Macey, 2002).

With the increasing number of organic producers there is an increased demand and an increased interest in organic production research to develop and identify effective management practices. Effective management practices maintain or improve soil fertility and minimize weed competition on crop stands. The defining characteristic of organic production compared to conventional production is the prohibition of synthetic fertilizers and pesticides. Organic production systems therefore require different methods of management in order to control weeds and manage soil fertility.

Research into organic production is limited. Most of the scientific studies that have been published focus on comparisons of conventional and organic systems but do not focus specifically on organic agriculture (Bremer and Van Kessel, 1992b; Bromm, 2002; Bulluck et al., 2002; Hald, 1999; Reganold et al., 1987; Scullion et al., 2002; Shennan et al., 1991; Stopes et al., 2002; Wander et al., 1994). The literature that is available on organic farming practices is often written by organic producers themselves and is largely anecdotal. These documents are experientially-based and are distributed and published by the organic certifying bodies (Macey, 2002; Smith and Groenen, 2000).

A recent study conducted by Saskatchewan Agriculture and Food (SAF) assessed the needs of the organic industry in Saskatchewan (Jans, 2001). The critical production issues that producers identified as research priorities were weed control and the need to improve methods of maintaining soil fertility; especially P levels. In order to develop meaningful, relevant research, it is crucial to know what the current organic practices are in organically farmed production systems in Saskatchewan.

This thesis study was proposed to address the fertility and weed control issues identified as management areas that require research by the 2001 SAF needs assessment of the organic industry in Saskatchewan (Jans, 2001). The research questions addressed by this thesis study were multifaceted:

1. What management practices are used by organic producers in Saskatchewan?
2. Is there enough variation in the organic management practices used by producers in Saskatchewan to define different organic farm management systems?
3. What species make up the weed communities on organic farms in Saskatchewan and are they affected by the management system(s)?
4. What is the state of soil fertility of organic farms in Saskatchewan and is soil fertility affected by the management system(s)?

Multivariate statistical techniques were applied to the survey data collected in this study to identify management systems that incorporated similar management practices. The identified management systems were further applied to multivariate statistical techniques to determine possible correlations between weed populations and the management systems. Understanding these correlations consequently leads to further research opportunities to determine how to manipulate the environment so as to make the management practices available to organic producers as effective as possible.

The objective of this research is to identify the current organic management practices that correlate to low incidence of weed populations and the maintenance of soil fertility. Therefore, the hypothesis for this study is that organic management practices in Saskatchewan affect the incidence of weeds and field fertility levels.

2 LITERATURE REVIEW

2.1 Farming systems

The type of farm management practices used by producers defines their farm management system. Farm management systems are made up of five interacting components: cultivation, rotation, fertilizer inputs, pesticide and all are driven by the economics of the specific farm operation (Edwards, 1989). In organic farming, pesticides are not part of the farming system and fertilizer inputs are limited to mineral amendments, manure or plant material additions. It is reasonable therefore to assume that if different organic management systems exist their defining factors will be made up of four of the interacting components: cultivation, rotation, fertilizer and economics. Because of the wide array of management practices available to producers, a continuum rather than distinct systems would most accurately reflect how producers manage their farm operations (Shennan et al., 1991). However, for the purpose of simplification and understanding of how various management practices affect the agronomic system, classification into groups or systems is required.

Farming systems are often subjectively defined; classification will vary depending on the specific practice or component of the system that is of interest (Dumanski et al., 1987). A common example in farm research is no-till systems versus conventional tillage systems; in this case, tillage is the most defining management variable of these systems. Another type of distinction sometimes used in research is the level of inputs used in farm systems: high input systems or low input systems. Low input systems could include integrated pest management systems or organic systems.

Organic farming systems are often considered a single complete class or system of their own. The broad classification of 'organic farming' may not accurately define the differences between different organic farming operations due to the many different management techniques that can be used on an organic farm. Inputs, for example, can be applied at a high rate on organic farms as well; however, the inputs would be different than the inputs used on a high input conventional system. Not only can the level of inputs vary between different organic producers but many other management practices could vary as well. Classification is useful when communities that are essentially continuous in their variation require classification (Gauch, 1982). Because of the nature of farming systems being a continuum rather then distinct classes (Shennan et al., 1991), the use of multivariate classification methods can be effectively used to objectively group farms into management systems (Leeson et al., 1999). The classification method allows for a more objective way to reflect systems defined by the use of similar practices used by a producer instead of the often general and loosely defined systems used in common speech.

2.1.1 Definition of organic production

Organic production is a complex system of farming and production philosophies that have been developed over the past half-century. The Canadian General Standards Board developed a *National Standard for Organic Agriculture* that remains voluntary for certifying bodies to follow. This document is a precursor to national standards being developed to ensure the international trade of Canadian organic products. However, most certifying bodies not only adhere to the National Standard but require that their producers operate under stricter guidelines. Organic production is defined by the Canadian General Standards Board in their paper *National Standard for Organic Agriculture* as "a holistic system of production designed to optimize the productivity and fitness of diverse communities within the agro-ecosystem…The principle goal of organic agriculture is to develop productive enterprises that are sustainable and harmonious with the environment" (Lynch, 1999).

2.1.2 Organic industry

Organic farming began in Canada in the 1950's with a handful of producers (MacRae, 1995). The organic philosophies developed with writers like Sir Albert Howard (Howard, 1940; Howard, 1947), Rachel Carson (Carson, 1962) and Wendell Berry (Berry, 1981). Interest has continued into the 21st century. With increased consumer demand, the organic market has grown to be worth $23 billion US worldwide (Macey, 2004).

The organic industry in Saskatchewan is estimated to be worth $45 million per year (Macey, 2004). Saskatchewan has 720 certified organic producers growing field crops (Statistics Canada, 2001b). The 2001 agricultural census determined there were 2 230 organic producers certified in Canada, only 1 442 of whom produce field crops (Statistics Canada, 2001a). Fifty percent of Canada's organic field crop producers reside in Saskatchewan. Organic farms make up 2% of all farms in Saskatchewan (Jans, 2001). From 1999 to 2000 the number of certified organic producers in Saskatchewan increased 64% (Macey, 2002). There is an estimated 391 123 ha (966 482 acres) of organically certified crop and hay and pasture land in Canada.

The organic industry is not well researched in North America. Governments and the scientific community have begun research into organic production. Research is often reaches producers through agronomists hired by the local fertilizer and herbicide dealer. Because organic producers do not use this service the producers must seek out the information independently. The certification bodies have also fulfilled this role to some degree. Most organic certification bodies began as producer-run grass root organizations that hold regular meetings and encourage producers to share experiences and ideas. Information on how to farm organically is therefore most frequently acquired from the experience of other farmers, certification bodies, alternative press and some research field days that now may include organic components (Beckie, 2000).

2.2 Weed populations in organic systems

Weed populations in organic systems are more diverse than conventionally managed fields; that is, there are more weed species on organically managed fields (Leeson, 1998; Li and Kremer, 2000; Liebman and Davis, 2000). A large number of weed species does not mean that total weed populations will be large or cause greater yield losses (Ngouajio and McGiffen, 2002). Leeson (1998) found higher weed densities on organically managed fields compared to conventionally managed fields along with the increase in species but other studies found a decrease in weed densities (Li and Kremer, 2000; Liebman and Davis, 2000). The large number weed species on organic fields has been partially explained by noting that most of the new weed species found during the conversion process to organic production are weed species that are easily killed with herbicides (Hald, 1999). Research suggests that the reduction in weed densities in organic systems may be caused by the increase in microbial activity on organic farms and that these microbes deplete weed seedbanks by feeding on weed seeds and seedlings (Davis and Liebman, 2001).

2.3 Weed control

Prior to the widespread use of pesticides in the 1950's, the primary management practices for weed control were the use of crop rotations and tillage disturbances (Bullock, 1992). These practices are still the basis for weed control in organic systems. However, innovative producers and researchers have expanded these basic management practices to include tillage in crop with the use of harrows. Also crop rotations have become more diverse with advances in crop development and successfully adding more types of crops into the Saskatchewan farming rotation has made these traditional practices more effective for both conventional and organic producers.

2.3.1 Crop rotation

Crop rotation is designed to vary crop species in their planting order, proportion and the length of time they occur in the rotation (Mertens et al., 2002). Crop rotations by definition extend over several cropping seasons. The benefits of a good crop rotation extend beyond minimizing weed populations; crop rotation can also minimize disease and pest pressure, enhance the crop's ability to access soil nutrients and thereby increase crop quality (Zentner et al., 2001).

Studies examining the effect of management practices on weed populations have found that diverse crop rotations have more influence on weed populations than tillage disturbances. Crop rotations lowered weed seed densities more then the use of tillage (Cardina et al., 2002). Crop rotations were especially effective at reducing weed populations if a perennial forage crop was included in the rotation (Entz et al., 1995; Leeson, 1998). A Manitoba survey reported that 83% of producers recognized weed control benefits with the use of perennial forage crops in rotations for one to three years after the forage crop was terminated (Entz et al., 1995).

Weed species often mimic the life history of the crops with which they co-habit (Baker, 1974). Effective crop rotations therefore include diversity so as to disrupt this association. Planting perennial species in an annual cropping system interrupts the annual crop rotation and its associated annual weed species (Derksen et al., 2002).

2.3.2 Tillage

Organic systems rely on tillage for weed control. The type of tillage is often defined by the time of year the tillage operation occurs. Pre-seeding tillage is practiced by both organic and conventional farmers to prepare the seed bed for planting and to kill weeds, including surviving perennials and/or winter or spring annuals. The timing of the tillage can also affect weed populations. Delayed spring seeding allows for early flushes of weed seeds to germinate in the spring (Nalewaja, 1999). The weed seedlings can then be controlled or at least set back with pre-seeding tillage. Post-seeding tillage is a disturbance either prior to crop emergence or post-crop-emergence. In-crop tillage implements are most often harrows or rod-weeders although very shallow cultivation is also possible. Some crops that are deeply seeded and have their meristem at or below ground level (i.e., field peas and cereals) can withstand post-emergent tillage (Kirkland, 1995).

Fall tillage generally corresponds to post harvest field cultivation. This practice kills winter annual and biennial weeds. Fall tillage encourages some annual weeds to germinate, which can be beneficial, because the winter weather kills the fall germinated summer annuals before they are able to affect the crop. Fall tillage reduces stubble, which reduces the ability of the field to catch and retain snow, which can increase erosion.

Inter-row cultivation is commonly used for crops such as corn (McMullan and Blackshaw, 1995), soybeans (Vangessel et al., 1998) and potatoes (Ivany, 2002). There is no published literature about the usefulness of inter-row cultivation in cereal crops. However, at least one producer in Saskatchewan has modified a seeder and cultivator to allow for inter-row tillage in cereal stands (D. Amey, Pers Comm, 2002).

Summerfallow is the practice of leaving a field without a planted crop for one growing season. The purpose of summerfallow is to store soil moisture and allow time for nutrients to mineralize, especially N. Repeated tillage during summerfallow is used to destroy weeds and is a common practice in the Great Plains (Molberg et al., 1967; Schlegel and Havlin, 1997). Tillage during summerfallow as a weed management strategy does effectively reduce weed densities for the succeeding crop years (Derksen et al., 1994). Summerfallow, like most weed management strategies, provides a selective pressure allowing certain weed species to thrive because of their ability to survive fallow in rotation. In Saskatchewan, stinkweed and common lamb's-quarters are weed species associated with mechanical fallow (Hume, 1982).

2.3.3 Other weed control practices

Increasing crop competitiveness is another way to compete with weeds. Producers increase seeding rates to increase the competition for light and nutrients and thereby more aggressively compete with weeds. Increased seeding rates of wheat reduced the weed seed production and plant biomass of wild oats by 20% (Xue and Stougaard, 2002). Another approach is to sow a normal to high rate of seed but plant the seed in two passes; sowing the first pass perpendicular to the second. The theory is that the more area covered, the less space there is for weed species to establish. This method of planting is suggested for non-competitive crops such as flax (Stevenson and Wright, 1996).

Leaving crop residue or the application of a surface mulch is a method of reducing the germination of weed seedlings (Hutchinson and McGiffen, 2000; Ngouajio et al., 2003). A Manitoba study is looking at the potential weed control value of mulching legume crop biomass by silaging and blowing the material onto the adjacent strip of crop planted to a cereal (M. Weins, Pers. Comm., 2005). This strip cropping method works on the theory that the mulched crops blown onto the cereal at an early stage of growth will deter the germination of weed seeds and reduce evaporation. Flaming and mowing are other weed control options sometimes recommended by the organic industry. However, these practices such as flaming, mowing and mulching do not appear to be common practice in Saskatchewan. These practices appear to be limited by economics. The practices of flaming, mowing and mulching are more common in Europe, where fields are smaller, and the practices are used on high value crops in horticultural operations.

2.4 Soil fertility in organic systems

A Manitoba study looked at 170 fields on 14 organic farms over a six year period from 1991-1996 (Entz et al., 2001). Soil samples were analyzed for N, P, K, and S (Entz et al., 2001). Nitrogen, S and K levels on these organic fields were sufficient and similar to conventionally farmed fields but P levels were low, P ranged from deficient (4 kg ha^{-1}) to adequate (54 kg ha^{-1}). The lowest levels of P were found in fields that were managed organically for over 30 years (Entz et al., 2001). The soils on organically farmed systems are commonly deficient in N (Watson et al., 2002a) and available P (Malhi et al., 2002). These deficiencies are more challenging to correct in an organic system than a conventional system because the use of synthetic fertilizers is prohibited. The absence of P fertilization results in serious soil P deficiencies (Entz et al., 2001). Many producers depend on the soil's natural fertility instead of using soil amendments. The problem with this practice is that the crop material exported in the harvested material removes a high proportion of the nutrients. With years and years of continuous cropping, nutrient levels can be severely reduced. Therefore the replenishment of these nutrients has been of key importance to industrial agriculture. Organic producers may use mineral nutrients, such as rock phosphate, or organic materials, such as composted manure or plant materials.

2.4.1 Green manure

Green manure is a herbaceous crop ploughed under while green to enrich the soil (Webster, 2002). Green manure crops are planted for the sole purpose of being incorporated into the soil before seed set has occurred. Leguminous crops, such as yellow sweet clover (*Melilotus officinalis* (L.) Pall.), are usually used as green manure crops because of their ability to fix atmospheric N. Green manures are used to increase fertility (specifically N), help control weeds and insect pests, reduce soil erosion (Reganold et al., 1987) and increase microbial activity (Bremer and Van Kessel, 1992a).

Maximizing the amount of N fixed in the soil is critical to a successful green manure crop. In a northern Alberta study, lentils were incorporated at two different times; the later incorporation date had twice the plant biomass of the first, yet the N yield remained constant (Rice et al., 1993). Because N was not increased and the continued growth of biomass used moisture reserves, the early incorporation date is the recommended practice (Rice et al., 1993). Another benefit of early incorporation is that younger plants have a lower C:N ratio that allows N mineralization to occur more rapidly with minimal immobilization (Bremer and Van Kessel, 1992a; Bremer and Van Kessel, 1992b; Fox et al., 1990). One Saskatchewan study suggests that green manure crops are best incorporated by the first week in July (Zentner et al., 1996).

Sweet clover is the most common green manure used on the prairies (Agriculture and Agri-Food Canada, 1999). Sweet clover is a biennial and it has the ability to fix more N than annual legumes. Sweet clover can fix 120 kg/ha N under non-irrigated conditions (Agriculture and Agri-Food Canada, 1999). It is usually planted with an annual companion crop that is harvested in the establishment year. Sweet clover is incorporated into the soil at first bloom in the second year. Sweet clover establishes a deep taproot in its first year of growth and is able to access deep water reserves (Singh et al., 2003). Its aggressive growth can induce drought related stress to the following crop in dry regions.

Green manuring has traditionally not been practiced by producers in the Brown soil zone of southern Saskatchewan because of the belief that soil moisture will be depleted (Biederbeck and Bouman, 1994; Biederbeck et al., 1993). Studies in the drought prone regions of southern Saskatchewan used annual legumes as green manure crops. They found feedpea (*Pisum sativum* L.) and chickling vetch (*Lathyrus sativus* L.) were the most promising annual legumes, over Indianhead black lentil (*Lens culinaris* Medikus) and flatpea (*Lathyrus tingitanus* L.), for use as a green manure. Moisture reserves can be recharged after early incorporation of the annual green manure crop with the added benefit of N being fixed earlier in the year (Biederbeck et al., 1993).

Certain crops have allelopathic effects that are the result of the chemical secretion of toxins from a plant that suppress the growth of competing plants (Isaacs et al., 1999). This is an especially desirable characteristic in green manures. Buckwheat, fall rye, alfalfa, and even barley are listed as having allelopathic qualities that suppress growth of certain weeds (Bertholdsson, 2005; Finney et al., 2005; Li et al., 2005; Xuan et al., 2005).

Improvements in soil can also be seen with the inclusion of legumes in rotation even without the use of green manure cropping. Leguminous crops are able to fix 50-90% of their own N requirements. During growth, N is also exuded from roots and over time the plant material itself will break down releasing plant available N for future crops. Legumes are soil building crops, not only by supplying N, but by improving soil aeration, structure, organic matter (OM) reserves and biological activity and by reducing erosion (Biederbeck et al., 1996; Campbell et al., 1991a).

2.4.2 Summerfallow

The practice of summerfallow has some benefits but also many detriments. One of the benefits of summerfallow is the improvement of soil N levels by the mineralization of organic N. In Swift Current similar N levels were reported after a green manure and summerfallow period (Biederbeck et al., 1996). However, the potentially mineralizable N after a green manure crop have been shown to be 66% greater than on summerfallowed sites (Pikul et al., 1997).

Another reason producers use summerfallow is to increase water storage. However, when lentils were incorporated at full bloom, no difference in water use occurred between the green manure site and the fallow site (Pikul et al., 1997). Summerfallow often includes multiple tillage passes in a season. Tillage can be problematic because it enhances mineralization of soil organic matter (SOM) and increases the risk of soil erosion.

2.4.3 Soil Amendments

The soil P levels on organic farms in eastern Saskatchewan and Manitoba were found to be low (Entz et al., 2001). Acceptable sources of P in organic production include bone meal or dried ground fish, and are often expensive and not practical at a field scale. Rock phosphate can be applied but the neutral to alkaline pH of Saskatchewan soil prevents the P from converting to a plant available form. Some crops, such as buckwheat and oilseed radish, are known to create acidity around their roots which increases plant available P. The use of crops with the ability to exploit the soil P resources will increase P availability to future crops if crop residue stays on the field. Plants can also exploit the soil with either deep root systems or roots that are able to increase the acidity directly around them.

Compared to other soil nutrients, N is more easily managed in an organic system. The use of a leguminous species as a green manure crop is the most common practice. However, other amendments such as animal manure are permitted and can be a valuable source of N as well as other nutrients. Organic bone meal is an expensive, slow acting nitrogen fertilizer amendment.

Most Saskatchewan soils are abundant in K, with the exception of soils in the Gray and Dark Gray soil zones that are sandy or highly organic. According to the National Standard of Canada (Lynch, 1999), allowable amendments for K deficiencies are feldspars, langbeinite (a magnesium-bearing potassium sulphate) and mined potassium sulphate. Glauconite (greensand) is also an allowable mined mineral but it is expensive and has only 5% K which is not in a readily plant-available form (Gershuny and Simillie, 1986). Like rock phosphate, the mineral works best when it is ground up finely but application can be difficult due to dustiness and clogging or bridging (Havlin et al., 2004).

Allowable sulphur amendments include elemental S (90-99% S) or gypsum (0-0-0-17 or $CaSO_4$). These are relatively inexpensive minerals. Gypsum can supply Ca to high pH soils but has low solubility. Elemental S oxidizes to sulphate very slowly and must be applied a year or more before crop demand. Both forms of S work best with fine particle size since smaller granules increase the surface area and allow soil micro organisms to oxidize it more rapidly (Havlin et al., 2004).

2.4.4 Manure

Application of animal manures is seen as one of the best ways to increase the sustainability of an organic farming systems (Clark et al., 1998). The nutrient which has been shown to be particularly difficult to maintain on organic farms is P (Entz et al., 2001). Manure application was the only organic management practice that was able to increase soil P levels (Clark et al., 1998). Applying dairy cattle manure over the long term, even at the low rate of 20 t ha^{-1}, will maintain soil pools of P and improve its availability to crops (Tran and N'Dayegamiye, 1995).

All manure contains all of the essential plant nutrients in some form. However the amount of each nutrient is affected by many factors. For example, different animal species, the animal feed, manure storage, and how and when the manure is applied to a field can all affect nutrient content. Tests can be conducted in soil testing labs to determine the nutritional content of manure types and consequently help farmers to determine the appropriate application rates. Manure rarely, if ever, perfectly matches the crop’s needs. This concept is referred to as a nutrient imbalance (Wang et al., 2004). Applying manure to improve soil N for example may also increase the K and/or P to undesirably high levels (Wang et al., 2004).

Providing nutrients to plants is not manure’s only benefit; overall soil health can increase markedly with manure application. Some soil characteristics that are improved with manure application are: increased aeration, increased aggregation, increased SOM and a higher water holding capacity (Havlin et al., 2004).

Organic matter may be the most important soil factor affecting soil fertility. Organic matter can be increased with both the addition of animal manure or green manures. Organic matter improves soil quality by increasing granulation, increasing water storage, nutrient supply and soil organism activity and improving soil fertility and productivity (Reganold et al., 1987). Although changes are slow to occur in agronomic systems (Clark et al., 1998; Wander et al., 1994), it has been found that organic management systems have higher OM levels than conventional farms (Mäder et al., 2002; Pulleman et al., 2000; Sommerfeldt et al., 1988; Wander et al., 1994; Watson et al., 2002a). The afore mentioned studies all assume that animal manure is being used on the organic system. There are studies that show that without fertilization a reduction in OM occurs (Campbell and Zentner, 1993a; Campbell et al., 1991a).

The organic certifying bodies often require that producers compost their manure before field application. Benefits of composting manure are many: there is a reduction in the volume and weight of the manure, which decreases the energy required to spread the manure, the high temperatures reached in the composting procedure kill harmful pests such as pathogens and weed seeds, and less N is volatilized since stable forms of N are formed in the composting process (Smith and Groenen, 2000).

Due to the salt concentrations in animal urine there is a perceived threat that the addition of animal manures will increase the soil's salinity over time. Salt accumulation in the soil is a problem with intensive livestock operations and over-applying animal manure (Wu et al., 1997). However, with moderate additions of animal manure, electrical conductivity (EC) levels remained stable (Clark et al., 1998).

2.5 Multivariate approaches for ecological analysis of weed communities

Weed ecologists are interested in studying the relationships between weed populations and their environment. The agroecosystem is a complex mixture of biotic and abiotic factors that influence the presence of species. To determine which factors most influence species presence, multivariate analysis techniques are often employed.

Multivariate analyses allow the researcher to simultaneously analyze multiple measurements on each individual or object under investigation (Hair et al., 1998; Kenkel et al., 2002). Multivariate analysis techniques are able to organize complex, large data sets so that they may be described, classified, discussed and understood and the information used to develop hypotheses about the ability of weed management systems to affect weed population changes (Post, 1988). The purpose of multivariate methods in ecology is two-fold: to discover structure in data and summarize the data to aid in comprehension and communication. Multivariate methods are not able to determine causal relationships but it can point towards a greater understanding or recognition of them.

There are two main types of multivariate statistics: classification and ordination. Classification and ordination methods are often used in partnership (Gauch, 1982; Jongman et al., 1995) to solve ecological problems by grouping individuals and determining the various environmental factors affecting the groups. The use of these techniques in weed ecology has only recently been adopted (Post, 1988). In 1982 Hume published one of the first Canadian papers using principal components analysis (PCA), a multivariate technique, to describe weed communities (Derksen, 1996). Since the 1980's multivariate methods have become more commonly used in weed science to describe communities and understand the variables that affect where weeds appear.

2.5.1 Classification

Classification techniques are used to group similar data points into clusters. In weed science, classification techniques are used to group together similar plant species according to characteristic information collected by the researcher. There are two types of classification methods: divisive and agglomerative. Divisive methods start with the data set as a whole and slowly separate out dissimilar groups. Two-way indicator species analysis (TWINSPAN) is a common divisive method (Post, 1988). TWINSPAN was used to determine weed groupings, then a key weed species was applied as a representative from the identified groups that could indicate land quality in an agriculture region of the Peruvian Andes (Becker et al., 1998).

Agglomerative methods begin with each sample as an individual and group similar data into clusters until the dataset is a single large group (Gauch, 1982). Ward's (or minimum variance classification) is a common agglomerative method used to classify species. Ward's method has been used to group Saskatchewan farms into management systems based on similar chemical input level and cropping history (Leeson et al., 1999). The difference between Ward's classification and other similar methods such as centroid or group averaging is the way in which the Euclidian distance[1] is defined. The Euclidean distance is a measure of distance between two clusters or points. Ward's method determines the distance between two clusters or points and divides it by the sum of the reciprocal of the number of points in each of the clusters (Johnson and Wichern, 1998). This value is recorded in a distance matrix. The distance matrix is the measure of the distances between each pair of entities. The centroid of each cluster is redefined and recorded for each grouping level. Other classification methods such as nearest-neighbour or farthest-neighbour clustering use a single 'representative point' from which the clusters are built (Pielou, 1984).

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[1] Two methods of determining distance measures, other than Euclidean distance, are percentage distance or complemented coefficient of community (Gauch, 1982). These calculations begin with a measure of similarity (Gauch, 1982). The mathematical differences result in how the species community data is emphasized. Complemented coefficient of community considers only the presence or absence of species and gives major and minor species equal emphasis (Gauch, 1982). The percentage dissimilarity is a linear weighting of species abundances and will emphasize the dominant species but also considers minor species (Gauch, 1982). Euclidean distance, because it squares the abundance values, results in species with higher abundance measures being emphasized (Gauch, 1982).

When species samples or counts are taken randomly, instead of along a known gradient, Ward's is a preferred classification method. With a random sample it is unclear whether the species sampled will be considered from a single homogeneous class or whether they will form legitimate and distinct clusters. It is possible to conduct a statistical test to judge the validity of the classification done by Ward's. Another benefit of Ward's classification is the method's tendency to create clusters of relatively equal size (Pielou, 1984). One reason for more equal sized groups to form in Ward's is because if a point to be joined into a cluster is equidistant from two cluster centroids, that is, exactly between two separate groups, the method adds the new data point to the cluster with the fewest number of points (Pielou, 1984).

2.5.2 Ordination

Ordination is used in weed ecology to order species along environmental gradients. This reduces the complexity of the data and allows existent patterns in the composition of the species to be identified. The objective is to generate hypotheses to explain the relationship between the species composition and the environmental gradients affecting them (Digby and Kempton, 1987). There are two types of ordination analysis methods, indirect and direct gradient methods.

Indirect gradient analysis describes species in relation to environmental variables but in an indirect manner. Initially only the species data are considered. The species are displayed along axes of variation and are subsequently interpreted by environmental gradients. The species composition determines the gradients. Hume (1982) used PCA to determine the impact of fertilizer application on weed communities in Indian Head, Saskatchewan. The assumption in PCA is that the relationship between the weed species and the fertilizer is linear. Correspondence analysis (CA) is another indirect gradient method however it assumes a unimodal relationship. Correspondence analysis was used to determine whether producers who included forages in rotation had improved yield or decreased weed and whether it differed across soil zones in Saskatchewan and Manitoba (Entz et al., 1995). There are two disadvantages of CA: the compression of the ends of the gradient and the arch affect. The strength of detrended correspondence (DCA) is its ability to correct these two disadvantages of CA. The compression does not allow the amount of change in the species composition along the gradient or the primary axis to be accurately displayed. The arch affect distorts the species relationship to the secondary axis and is not easily interpretable. Detrending in DCA is done by breaking the primary axis up into segments. The points in each segment are centered around zero on the second axis. This process is done many times by DCA re-adjusting the border of the segments each time giving a consistent measure of the amount of change along the primary gradient. The length of the data along the primary gradient defines as of the data. A long gradient indicates almost no species are the same at opposite ends of the gradient. If the gradient length is short the species are similar to one another. The gradient length can be used further to determine the relationship of the species to the gradient. A gradient length of 4 species standard deviations or greater is representative of a unimodal relationship and a gradient of less than 4 standard deviations is considered linear which is useful for applying data into to direct gradient ordination analyses (ter Braak and Smilauer, 2002). Detrended correspondence analysis along with non-metric multidimensional scaling (NMS) are the two most popular methods of indirect gradient analysis (Palmer, 2005). Non-metric multidimensional scaling is the analysis of choice when the species composition is not following a clear gradient. Unlike other methods NMS does not optimize the variance accounted for by the axes, rather all axes are extracted simultaneously and is distance based. The analysis uses the rank of dissimilarity instead of actual values to ordinate the species. The analysis writes a new distance matrix in which the species identities and true values are hidden but the new rank order of distance is created (Palmer, 2005).

Direct gradient analysis describes species abundance in relation to environmental variables directly (ter Braak and Smilauer, 2002). Therefore knowledge of the underlying environmental factors must be known and measured. There are many types of direct gradient analysis methods. To determine which method is appropriate depends on whether the data is of a linear or unimodal nature, this can be done using the indirect method, detrended correspondence analysis (DCA) as previously described (ter Braak and Smilauer, 2002). If the species' data shows a linear response, the suggested method of direct gradient analysis is redundancy analysis (RDA). It is used less often since ecological species data usually shows a unimodal response curve to the environment. Redundancy analysis was used in studies to determine what environmental factors were affecting weed populations in spring cereals in Finland (Salonen, 1993). Thomas and Frick (1992) also used RDA to determine the effect of tillage on weed composition; they found that the crop planted and the year affected weeds more than tillage.

Weed species data displaying a unimodal response are best described by canonical correspondence analysis (CCA). Canonical correspondence analysis is a direct gradient analysis that is the most frequently used technique to describe weed communities as affected by environmental variables (Kenkel et al., 2002). Weed communities on Saskatchewan fields were correlated to management systems using CCA (Leeson et al., 2000). Management strategies and other agronomic factors such as the soil properties, can also be examined for their influence on weed communities using CCA (Dale et al., 1992).

2.5.3 Review of multivariate studies that determined what management or environmental factors affected weed communities

Ordination methods have been applied in ecological studies to determine what management and/or environmental factors most affect weed communities. A Saskatchewan study found that soil zone had the greatest influence on weed populations in Saskatchewan compared to other environmental factors including management practices (Dale et al., 1992). A similar study in Finland looked at 21 factors and found that the geographic location had the most influence on weed factors (Erviö et al., 1994). A Danish study determined that crop type and the soil clay content (one out of seven edaphic factors) had the greatest influence on weed species (Andreasen et al., 1991).

Management practices have had a measurable effect on weed communities. The management practice that was shown to have the most influence on weed communities was the use of crop rotation (Derksen et al., 1994; Thomas and Frick, 1992). Particularly, the use of perennial forage crops in rotation is believed to have an effect on weed communities according to a survey completed by producers (Entz et al., 1995). A Saskatchewan study found that when the effect of ecoregion and year was removed from the analysis, the management factor that most affected weed populations was the inclusion of perennials in rotation (Leeson et al., 2000). Tillage systems also affect weed communities since certain weeds have been found to associate with certain systems. Specifically annual broad-leaved weeds are associated with conventional tillage systems (Derksen et al., 1993; Légère and Samson, 1997) whereas weeds such as wild mustard, flixweed and peppergrass were associated with conservation tillage (Derksen et al., 1993). A Swedish study done on organic farms found that the practice of growing ‘beans and peas’, a ‘ley’ crop proceeding, ‘weed hoeing’, ‘fallowing the proceeding year’, and ‘animal husbandary’ all contributed to the variation in weed flora on the farm (Rydberg and Milberg, 2000). However none of these management practices were shown to reduce or change weed populations.

3 CLASSIFICATION OF FARM MANAGEMENT SYSTEMS ON ORGANIC FARMS IN SASKATCHEWAN

3.1 Introduction

Organic producers have a myriad of options available when deciding the best way to manage weeds and soil fertility (Edwards, 1989). Some definitions of organic production conjure up images of traditional production practices of the 1940's prior to the invention and use of pesticides. Although some of the 1940's production practices may include some useful and timeless methods of production, such as crop rotation or soil disturbance, this is not a fair representation of the organic industry today. Today, organic producers can use specially designed technologies such as weeding harrows that can selectively remove weed seedlings in-crop (Kirkland, 1995; Kurstjens et al., 2000; Mertens, 2002). Other weed management techniques include planting double rows (Stevenson and Wright, 1996), inter-cropping or strip-cropping (Edwards, 1989). Producers can use soil amendments such as applications of compost and various minerals to improve production (Berry et al., 2002; Berry et al., 2003).

In order to understand how these management practices affect weed control and soil fertility, a classification of similar management techniques is required to study the effectiveness of the management practices used. Farm management systems are made up of five interacting components: cultivation, rotation, fertilizer inputs, pesticide and the economics driving the specific farm operation (Edwards, 1989). In organic farming, pesticides are not part of the farming system and fertilizer inputs are limited to minerals, manure or plant material.

To understand agronomic systems within existing farm operations, groupings or classes of producers who use similar management techniques must be identified. Once different systems are identified, those defining management practices can be grouped and used to determine what if any effect the management practices have on the agro-ecosystem functioning.

There are no commonly used classification terms to describe different types of organic farms in Saskatchewan. In conventional production there are distinct systems of production such as no-till farming systems. One study included organic systems in a classification and found that organic farmers can be divided into two systems: a wheat-based system and a diversified-grain-forage system (Leeson et al., 1999). These resulting groups, and others including conventional systems, were used to study their consequential weed populations (Leeson, 1998).

Creating a classification system for organic production in Saskatchewan is challenging since there is no information on management practices used by organic farmers of Saskatchewan. The management surveys by Agriculture and Agri-Food Canada have been conducted on randomly chosen farms. It was not noted in the survey if the chosen farm was organically managed. Because only 2% of farms in Saskatchewan are organic, it is assumed that the surveys represent conventional systems of farming. It is reasonable to assume that organic systems might be different. To address this problem, a questionnaire was developed. The purpose of the questionnaire was to obtain a detailed five-year management record of a single field. The goal was to distribute the questionnaire to 10% of the organic producers in Saskatchewan.

Ecological research has used multivariate classification techniques to group similar species, habitats, (Orlóci, 1967) or practices (Leeson et al., 1999; Orlóci, 1967). Classifying farm management practices into systems is an artificial exercise since in reality farming practices range along a continuum rather than separate and exclusive groupings (Shennan et al., 1991). However, it is a useful endeavour to gain a generalized understanding of management systems that producers use to solve various problems. The objective of this study is to classify Saskatchewan organic fields into farm management systems based on management practices.

3.2 Materials and Methods

3.2.1 Questionnaire development

The survey was developed as a mail-out questionnaire. A mailed questionnaire was chosen for this survey due to the large sample size and the dispersion of the population over a large geographical region. Questionnaires are able to obtain accurate information in a short amount of time (Jessen, 1978). The questionnaire was designed to be self-explanatory so that the responding producer could complete it without supervision.

The development of the questionnaire began in 2001. The questionnaire was developed by Dr. J.D. Knight and Dr. S. Shirtliffe from the University of Saskatchewan in consultation with Dr. A.G. Thomas of Agriculture and Agri-Food Canada (Appendix A). The survey was distributed by mail in the winter of 2001.

3.2.2 Methodology for the selection of participating producers

All major organic certifying bodies were approached to participate in this study. A request was made to the certifying bodies for producer lists from which participants would be randomly selected. The goal was to select 10% of organic producers in the province with representation from all soil zones (Table 3.1) across Saskatchewan. Potential cooperating producers were contacted by telephone and asked if they would be willing to participate and then screened to ensure the following four criteria were met:

1. Willingness to complete a detailed questionnaire pertaining to a single field.
2. Allow surveyors to visit the identified field twice; once to collect soil samples in spring and again in mid-summer to count weed populations.
3. The survey field must have been fully certified with an organic certification body by the start of the 2002 season. This ensured the field was organically managed for a minimum of three years.
4. In 2002 the field would be planted to a cereal crop, preferably wheat.

Table 3.1 Regions of Saskatchewan classified by both ecoregion and soil zone (Acton et al., 1998).

Regions of Saskatchewan	Ecoregion	Soil zone
South West	Moist Mixed Grassland	Brown
South Central	Mixed Grassland	Dark Brown
Central	Aspen Parkland	Black
North East	Boreal Transition	Gray
North	Mid-Boreal Upland	Dark Gray

Each eligible producer was asked to identify up to two fields to be surveyed, as long as the management of the fields were not identical.

3.2.3 Derivation of management variables for the classification procedure

To simplify the questionnaire data so that similar management practices could classify the various fields into management systems, management variables were required. The management variables were derived from the raw data collected from the management questionnaire. The questionnaire contained questions about crop rotation history, seeding, weed control and fertility practices (Appendix A). To avoid repetition and to ensure the variables were a meaningful representation of common management practices, the raw data was reorganized to form more concise variables. The way in which variables were chosen in part depended on whether the answers from the questionnaire were complete. Variables that would have been of interest to include were seeding depth, row spacing, seeding rate, and type of seeder opener, however, these were poorly answered questions as many questions had no response given.

Fifteen management variables were derived from the questionnaire (Table 3.2). The first variable was field size. If the field size on a questionnaire was not specified, the median field size determined from the questionnaire was used.

The following two variables involved the recorded use of soil amendments in the questionnaire: the application of soil amendments (other than the application of animal manure) and animal manure. Soil amendments were defined as any addition to the soil, other than animal manure, to improve soil fertility. The use of seed inoculants was not included with the exception of *Penicillium bilaiae*. The purpose of applying *P. bilaiae* is to increase the solubility of unavailable forms of P (Kucey, 1983). Each addition of any amendment to the soil, over the five-year history, was counted and was expressed as a fraction of the total number of years the field was planted to a crop. The total number of manure applications to the field over the five-year

Table 3.2 Management variables and their derivation from the Saskatchewan organic management questionnaire (Appendix A).

	Management Variable	Derivation	Raw Data
1	Field Size	field size	Acres provided by the producer.
2	Soil Amendment	Amen / CrYr	Amen = Number of times soil amendment was applied CrYr[†] = Number of crop years
3	Manure	ManAp / CrYr	ManAp = Number of manure applications
4	Pre-seeding Tillage	STil / CrYr	STil = The number of tillage passes prior to seeding in spring
5	Post-seeding Pre-emergent Tillage	PTil / CrYr	PTil = The number of tillage passes after seeding prior to crop emergence
6	Post-seeding Post-emergent Tillage	PPTil / CrYr	PPTill = The number of tillage passes after seeding and after crop emergence
7	Fall Tillage	FTil / CrYr	FTil = The number of tillage passes after harvest
8	Crop rotation diversity	TyCr / CrYr	TyCr = Types of crops planted in the field (1996-2002)
9	Cereals	Cer / CrYr	Cer = Number of cereal crops planted from 1996-2002
10	Perennial forages	Per / CrYr	Per = Number of perennial forage crops planted or harvested from 1996-2001
11	Summerfallow	SumFal / CrYr	SumFal = Number of summerfallow seasons (1996-2001)
12	Biennial	Bien / CrYr	Bien = Number of biennial crops planted (1996-2002)
13	Annual legume	AnnLeg / CrYr	AnnLeg = Number of annual legumes (1996-2001)
14	Broad-leaved annual non-legumious	Brdlvd / CrYr	Brdlvd = Number of non-leguminous broad-leaved crops (1996-2001)
15	Green manure	GrMan / CrYr	GrMan = Number of green manure crops (1996-2001)

[†]CrYr= the number of years the field was 'in-crop'. That is, the number of years from the available data (2002 to 1996) minus the number of years no crop was planted (i.e., summerfallow). If a field had no record for 1996 and if 1999 was summerfallowed the CrYr = 4 (yrs: 97, 98, 00, 01). 2002 was not included for tillage or soil additions since no 2002 record was included in the survey; crop type (TyCr) did include 02 in CrYr.

history were counted and divided by the total number of years the field was planted to a crop.

Tillage as a management practice was divided into four possible seasonal categories depending on when the tillage occurred. Pre-seeding tillage, post-seeding pre-emergent tillage and post-seeding, post-emergent tillage were three of the four seasonal tillage categories. A tillage pass was defined as either the use of a cultivator or harrows. The number of tillage passes was summed for each seasonal category. Only those tillage practices prior to or during the growth of an annual spring crop were counted. The total number of passes was divided by the total number of years the field was planted to an annual spring crop. The fourth tillage category was fall tillage, a post-harvest tillage operation. For example, fall tillage that occurred in 1999 is considered to be part of the weed control strategy for the 2000 cropping year.

The final eight management variables defined the crop rotations. The first variable was a measure of the diversity in the crop rotation. Crop types planted between 1996 and 2002 were divided into six categories: cereal, legume, non-leguminous annual broad-leaved crop, biennial, perennial forage and green manure (Table 3.3). The number of different crop types grown from 1996 to 2002 was summed. If a producer did not own the land since 1996 or had previously rented the land out, the total number of cropping years was reduced to the available information. The number of crop types was divided by the total number of years the field was planted to a crop.

The next seven management variables defined the producer's crop rotation strategies. The seven variables included the six crop categories identified (Table 3.3) and the practice of summerfallowing. The number of years the field was planted to a specific crop category or summerfallow was divided by the total number of years that were recorded in the questionnaire (from the year 1996 up to and including 2002). If two different types of crop categories were planted together, such as sweet clover for a green manure and oat as a nurse crop, that crop year would have two crop categories, in this example, a biennial and a cereal. The second year when the sweet clover was

Table 3.3 Crop types included in the various crop categories used to define producer's crop rotation history.

Crop category	Common name	Scientific name
Cereal	Spring wheat	*Triticum aestivum* L.
	Durum wheat	*Triticum durum* Desf.
	Barley	*Hordeum vulgare* L.
	Oats	*Avena sativa* L.
	Kamut	*Triticum turanicum*
Perennial Forage	Alfalfa	*Medicago sativa* L.
Legume	Chick pea	*Cicer arietinum* L.
	Lentil	*Lens culinaris* Medic.
	Pea	*Pisum sativum* L. s.lat.
Non leguminous Annual broad-leaved	Borage	*Borago officinalis* L.
	Flax	*Linum usitatissimum* L.
Biennial	Sweet clover	*Melilotus officinalis* (L.) Lam. and *M. alba* Desr.
	Red clover	*Trifolium pratense* L.
Green manure†	-	-

† The green manure crop category was considered to be any crop that was grown for the purpose of green manuring and was only counted in the year the crop was terminated. For example if sweet clover was planted in 1999 but was only terminated as a green manure crop in 2000 the cropping category for 1999 would be "biennial" and in 2000 the cropping category would be "green manure."

incorporated it would be considered a green manure not a biennial: similarly an annual legume incorporated mid-season would be identified as a green manure.

The 15 management variables and their corresponding value for each of surveyed field made up the main matrix. The main matrix was used in the classification analysis (Appendix B, Table B.1).

3.2.4 Classification

The values for the management variables for each field (the main matrix) were standardized by dividing each of the variables by the maximum value for each management variable (Greig-Smith, 1983). The resultant values for the variables ranged between zero and one except for acres (because it is a quantitative variable) and the diversity (because it was a nominal variable). These standardized values made up the matrix used in the statistical program, PC-ORD 4.0 (McCune and Mefford, 1999a). Non-metric multidimensional scaling (NMS) was the ordination method used to determine the dimensionality of these data (McCune and Mefford, 1999b). The purpose of the NMS was to determine an appropriate number of axes to simplify the data, while losing as little explanatory material as possible. The initial run assumed high dimensionality; a 6-dimensional solution was the default setting. The program ran ordination solutions stepwise down from six to one dimension. Each of the six steps includes 400 iterations. Those six ordination solutions were compared to the runs with randomized data. The difference between the two solutions for each of the six steps was tested automatically by the NMS analysis in PC-ORD with a Monte Carlo test of significance (Franklin et al., 1995) for each dimensionality. The solution obtained by the ordination must be better than the results of the random solution. A check was done by examining the stress level versus the 400 iterations. Stress is a measure of the difference in the relationship between the original dimensional space provided with the standardized data matrix compared to the newly ordered data in the ordination space with reduced dimensions. If the stress level of the ordination is lower than the stress level of the random configuration of the data matrix, the ordination has found dimensions that explain the dissimilarity. Stated another way there is a significant separation between various data points. The stress level must stabilize or the solution was not determined with the NMS procedure. The stability of the solution was tested by using a plot of stress versus number of iterations. For a solution to be stable the stress must be reduced rapidly (with low iterations) and the stress level must remain unchanged for the remaining iterations.

The appropriate number of dimensions was determined by graphing the stress versus the number of dimensions. The resultant scree plot determined the optimal number of dimensions. The resultant NMS ordination scores for the optimal dimensional solution (determined by the scree plot) were entered into the classification analysis as the new main matrix. The NMS ordination filters out noise while keeping a large percentage of the original data. Unlike other ordination methods NMS does not optimize the variance accounted for by axes, but uses the best regression of distances between the ordination and original ranked order of distances. The use of the ordination scores ensures the preservation of the original data well since the ordination uses ranks of dissimilarity between sites, yet, reduces noise.

Classification is a multivariate method used to categorize data into groups or clusters of sampling units that display similar characteristics. Ward's classification was the method used in this study to group fields into similarly managed classes. Ward's classification in PC-ORD produced a dendrogram and a corresponding secondary matrix showing each field and its associated group for each grouping level. A dendrogram is a branch map or tree that shows all the grouping levels from the individual to one complete group. The percent chaining was listed with the dendrogram. Percent chaining is a measure of the addition of small groups to one or a few large groups (McCune and Mefford, 1999b). Chaining is a measure of quality of the dendrogram. Highly chained dendrograms are undesirable as they do not clearly define groups.

The dendrogram was pruned or simplified to a meaningful level. The decision as to where to prune the dendrogram can be done arbitrarily; that is, it can be cut where a natural break occurs that seems appropriate to the goals of the study (McCune and Grace, 2002). However, there are also computational methods to prune dendrograms. The method used in this study was indicator species analysis (Dufrene and Legendre 1997). In order to prune the dendrogram, 10 grouping levels were chosen as a starting point. These 10 groups from Ward's secondary matrix were entered into indicator species analysis.

Indicator species analysis is normally applied to determine which species in a community has the best predictive value for that community. In this study, the groups were not plant communities but were groups of similar farming systems. The groups of similar farming practices were used to identify systems. The resultant indicator values from the indicator species analysis determine the management practices that best predicted the various farm systems or groups identified in Ward's classification. A Monte Carlo test was used to test the significance of each management practice at each grouping level. The Monte Carlo test used the grouped data versus randomized data to test whether the groups were explained by the particular management practice of interest.

Indicator species analysis created an indicator value for each practice at each grouping level. The observed indicator value determined for each management variable was compared to a randomized value. The probability or the proportion of the randomized trials with an indicator value equal to or exceeding the observed indicator value was determined for each successive grouping level.

Two methods were used to determine the appropriate grouping level or the site of pruning in the dendrogram from the data provided from the indicator species analysis. First the number of significant *p*-values are counted and plotted for each successive grouping level. Secondly the indicator values for each significant management variable were summed for each successive grouping level. The maximum values in both cases indicate the ideal number of groups according to those groups created by Ward's classification.

Tests of significance were done using SAS (version 9) (SAS Institute Inc., 1996) to determine which management variables were the best predictors for the management groups or farming systems defined previously. Two tests were used to determine which management variables were correlated to the systems grouped by Ward's. Welch's T-test, otherwise known as T-test using Sattherwaite's formula for unequal variances, was the first. Second was the Kruskal-Wallis one-way analysis of variance by ranks (Siegel and Castellan Jr., 1988). Both significance tests were preformed using SAS (SAS Institute Inc., 1996). The *p*-values from the T-tests define the importance of the management variables for each system by indicating those management practices that best separates the system from the rest of the groups.

3.3 Results

3.3.1 Survey area

The survey was conducted so that all of the agricultural soil zones were represented. The Gray soil zone and Dark Gray soil zone were grouped under the heading of Gray soil zone. The Gray soil zone had 17 field sites, 26 in the Black, 16 in the Dark Brown and 14 sites in the Brown soil zone (Figure 3.1).

The surveyed fields were supposed to be planted to a cereal, preferably a wheat crop, in the sampling year (2002). All 73 fields were planted to a cereal crop, 43 were planted to spring wheat, 15 to oats, 6 to barley, 5 to durum wheat, 3 fields had more than one cereal planted and 1 field was planted to kamut.

3.3.2 Survey return rate

Originally 63 producers agreed to participate in the survey. From the initial contact and follow-up phone calls a return rate of 70% was realized. Not all of the returned questionnaires were included in the study as the unpredictable nature of prairie weather did not always enable all producers to follow their intended rotation to grow a cereal crop. Unfavourable weather conditions also caused the elimination of fields from the survey because the corresponding soil and weed surveys could not be carried out. The southern region of the province

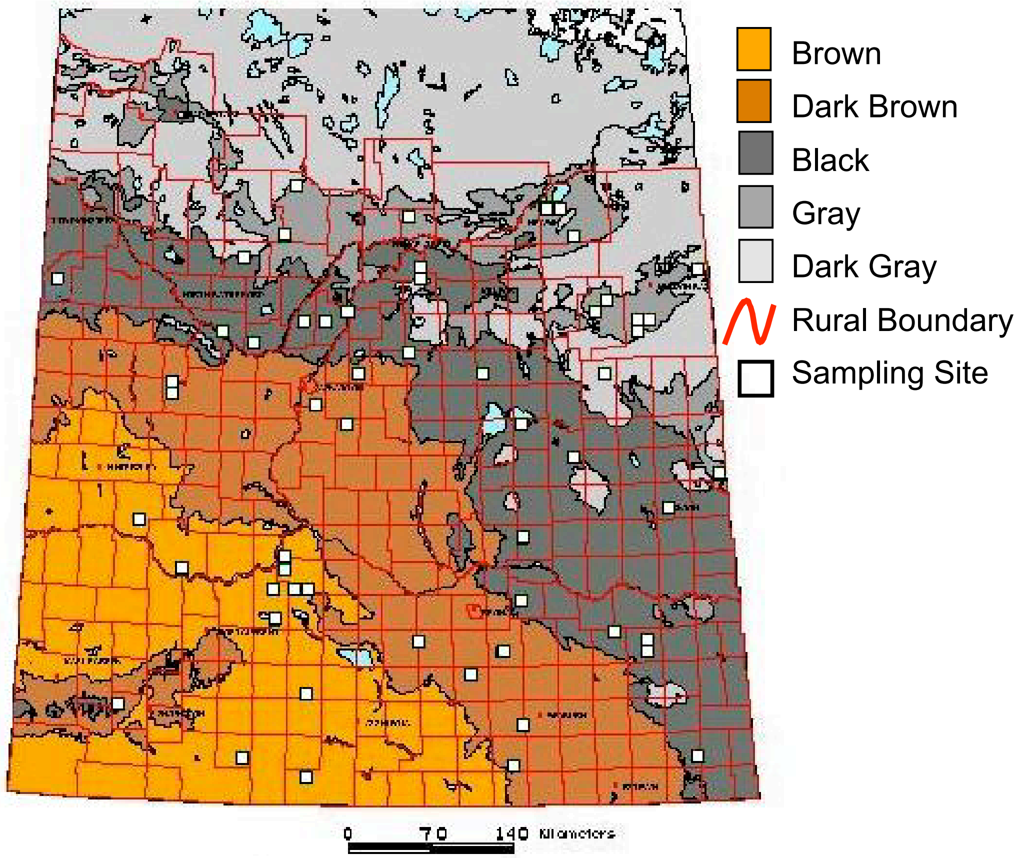

Figure 3.1 Provincial distribution of fields included in the organic management questionnaire and sampled for soil fertility and weed populations. White squares designate at least one sampling site located across the agricultural zones of Saskatchewan.

experienced heavy rainfall causing flooding, restricting access to some of the fields. Drought in the west central regions decimated some fields.

A total of 73 fields were identified from the 44 producers who participated. There are 720 certified organic producers of field crops in Saskatchewan, the resultant sample of 44 producers was 6% of all the organic producers in Saskatchewan, short of the set goal of 10%.

3.3.3 Nonmetric multidimensional scaling

The eigenanalysis used 106 iterations to reach stability (Figure 3.2). Stability of the solution was assessed by plotting the stress versus the iteration number. The distinct bends that occurred at each dimensional level were analyzed to determine the amount of stress reduced by the addition of another dimension (Figure 3.3). The program selected the dimensions that reduced the most stress. The greatest reductions in stress occurred in the first three dimensions therefore the NMS solution for this data set was three dimensions (Figure 3.3). The analysis used 40 runs with the real data and 50 runs with the randomized data. The real data stress is lower than the randomized data (Figure 3.3); therefore the variability in the data can be best explained by the NMS analysis. The Monte Carlo test determined that the probability that a similar final stress might occur by chance was 0.0196 that allows confidence that the differences seen were due to a clear separation of management practices and were not due to chance. The resultant ordination diagram shows a good spread of the data for each combination of the three axes (Figure 3.4, Figure 3.5, Figure 3.6). Correlation coefficients were determined for each dimension of the solution (Table 3.4). Management factors (identified as correlation coefficients in the NMS ordination) that are highly correlated with certain axes are the best descriptors for why the individual observations fall where they do. The correlation coefficients, greater than the arbitrarily chosen value of 0.7, indicated which management variables were the best explanatory variables for the fields in their new ordination space. Green manuring, perennial crops and crop diversity were the best correlated management variables for axes one to three, respectively (Table 3.4).

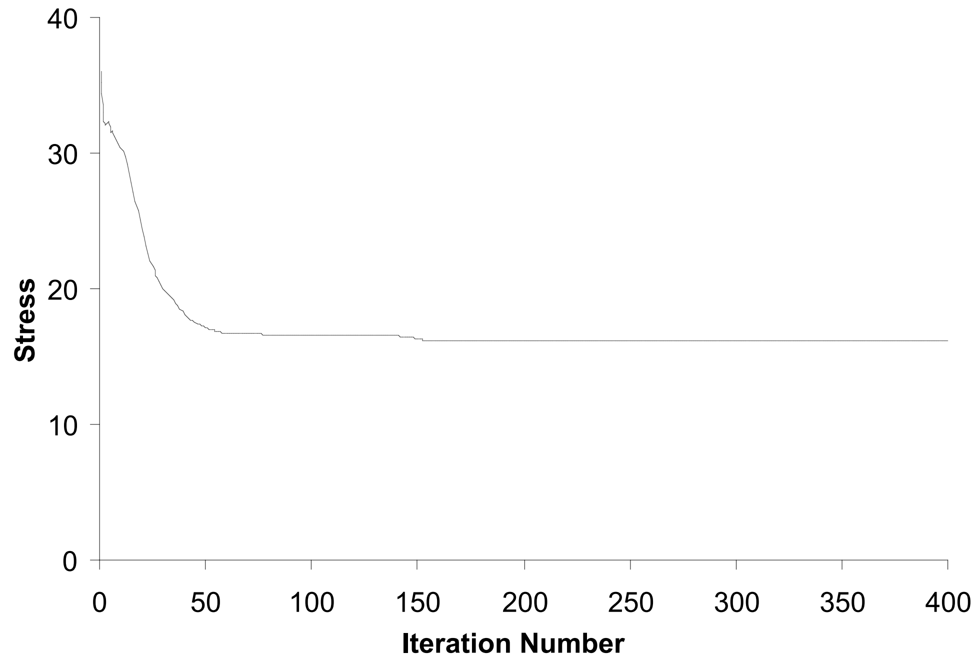

Figure 3.2 Stress versus iteration number of the NMS solution to illustrate the stability of the solution.

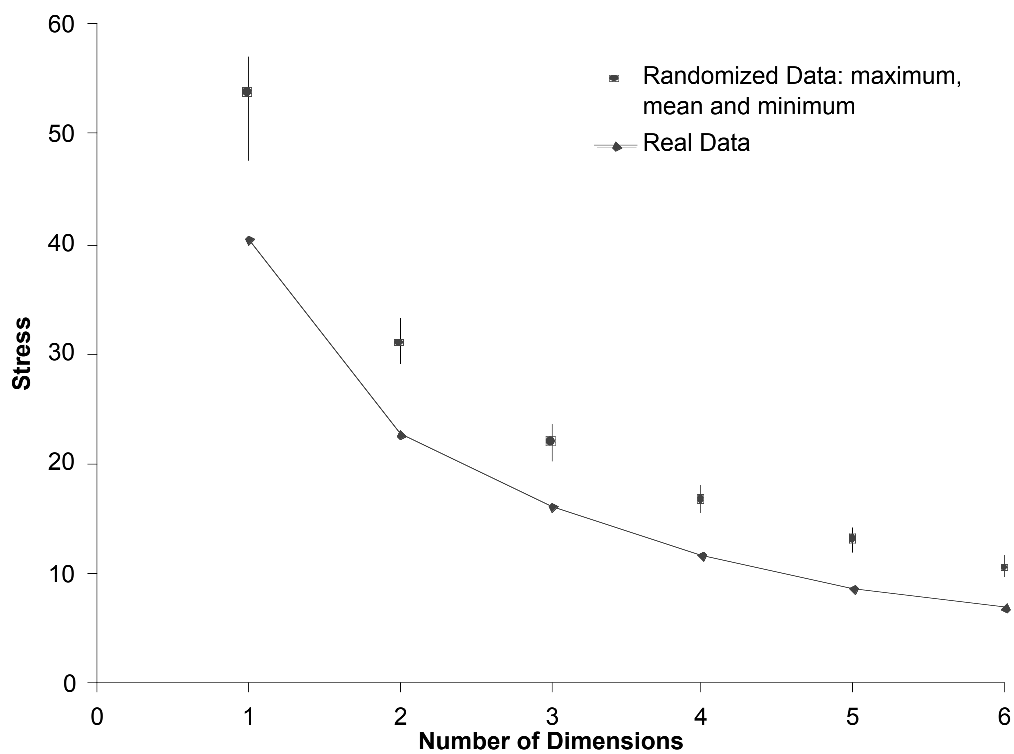

Figure 3.3 Skree diagram: stress versus the dimension in the NMS solution.

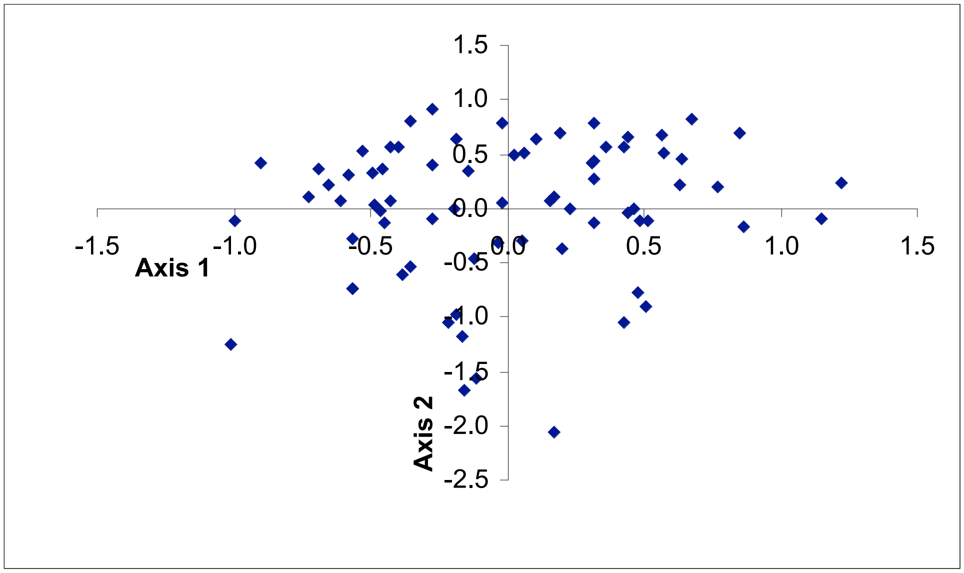

Figure 3.4 Nonmetric multidimensional scaling ordination of fields plotted along the first and second axes.

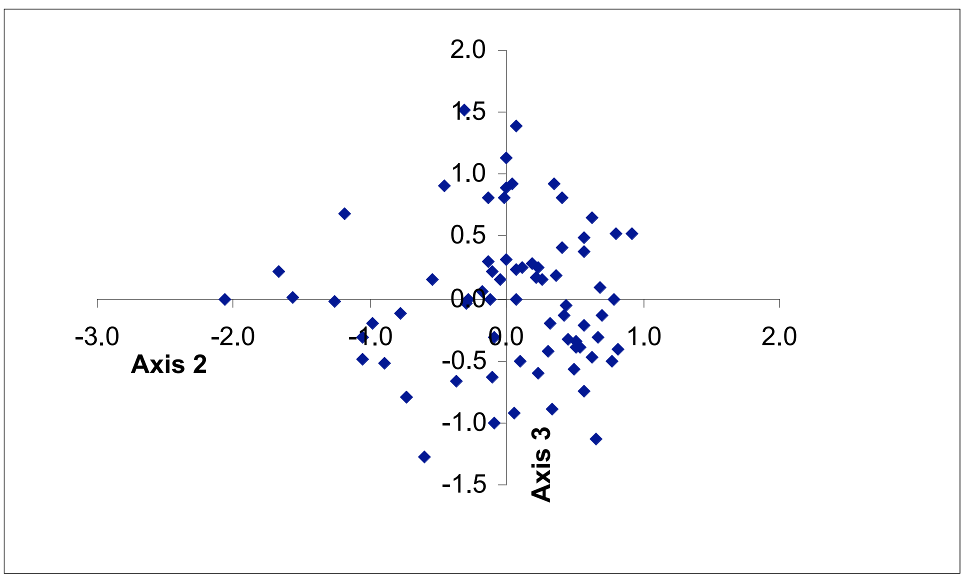

Figure 3.5 Nonmetric multidimensional scaling ordination of fields plotted along the second and third axes.

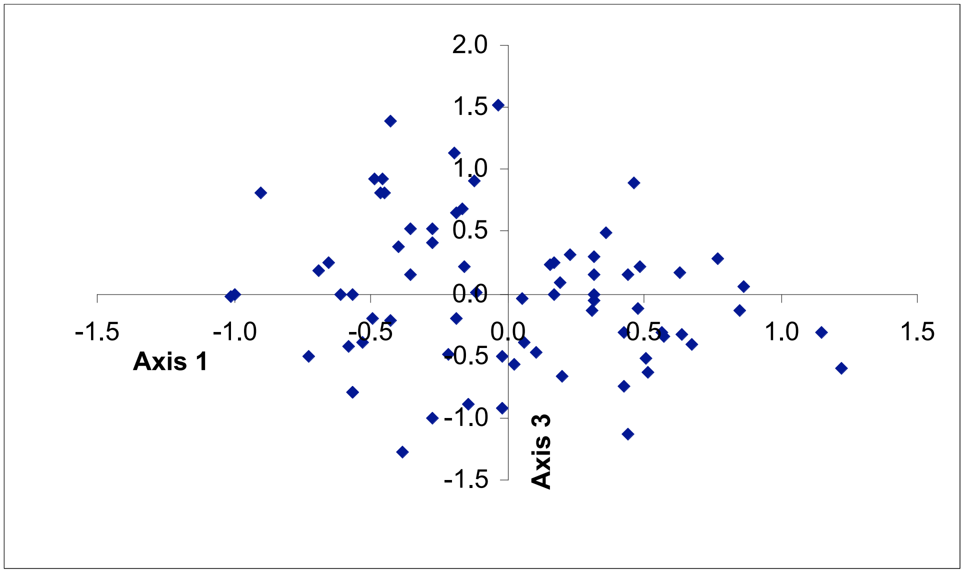

Figure 3.6 Nonmetric multidimensional scaling ordination of fields plotted along the first and third axes.

Table 3.4 Correlation coefficients of management variables to the NMS ordination axes. High r values indicate a strong correlation with the axis. The r values greater than 0.70 are listed in bold print.

Management Variable	Axis 1 r	Axis 2 r	Axis 3 r
Acres	-0.075	0.033	-0.259
Manure	-0.188	0.278	0.041
Soil amendments	-0.363	-0.178	-0.223
Spring tillage	-0.168	-0.406	-0.235
Post-seeding pre-emergent	0.039	0.483	-0.198
Post-seeding post-emergent	-0.070	-0.098	-0.063
Fall tillage	0.196	-0.022	-0.239
Diversity	0.479	0.297	**-0.762**
Cereal	0.150	0.498	0.325
Annual legume	0.201	0.521	-0.144
Summerfallow	-0.423	0.302	0.695
Perennial	-0.104	**-0.880**	-0.242
Broad-leaved non-leguminous	-0.455	0.152	-0.518
Biennial	0.514	0.298	-0.282
Green manure	**0.782**	0.287	-0.407

3.3.4 Ward's classification

The main matrix used to run the classification technique contained the ordination scores determined in the NMS analysis (Appendix B, Table B.2). Each field had an ordination value for each of the three axes determined as significant by NMS. Ward's method of classification resulted in a dendrogram with a low 2.45 percent chaining, resulting in a neatly formed and well distributed dendrogram.

3.3.5 Indicator species analysis

The secondary matrix created in Ward's classification analysis was a 73 field by one column matrix that listed 10 grouping levels. The main matrix was identical to the one used in the NMS analysis; that is a matrix of 73 fields by 15 management variables (Appendix B, Table B.1).

Two methods were used to determine the appropriate number of groups to prune from the dendrogram. Both methods determined that the fourth grouping level created in Ward's was the best place to prune the dendrogram (Figure 3.7 and Figure 3.8). The four groups created by the pruning were designated with symbols that were added to the original dendrogram created by Ward's (Figure 3.9). The triangular symbols designate each field's classification into one of the four farming systems (Figure 3.9).

3.3.6 Defining management variables in order to name the four farming systems

In order to understand what made each of the four farming systems unique enough to be classified required that the management variables for each system be re-examined. The four systems identified, and their corresponding management variable means, were analyzed separately by Ward's classification for each system identified in the dendrogram (Table 3.5, Table 3.6 and Table 3.7). The most distinguishing management variable for the first branch in the dendrogram is the inclusion of perennial forages. The perennial crop variable had a value of 0.50 in group 4 compared to 0.02 for fields not classified in group 4. The value of 0.50 suggests that for 50% of the crop history the field

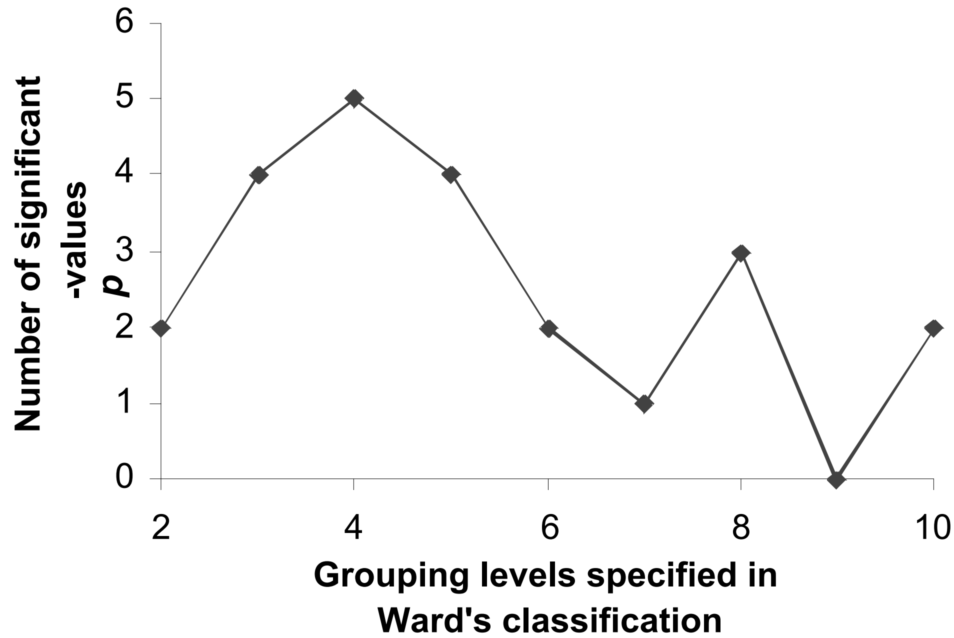

Figure 3.7 The number of significant (p = 0.0001) management variables from the Indicator Species Analysis at each grouping level; the maximum number of significant p-values determined the best grouping level for the data provided.

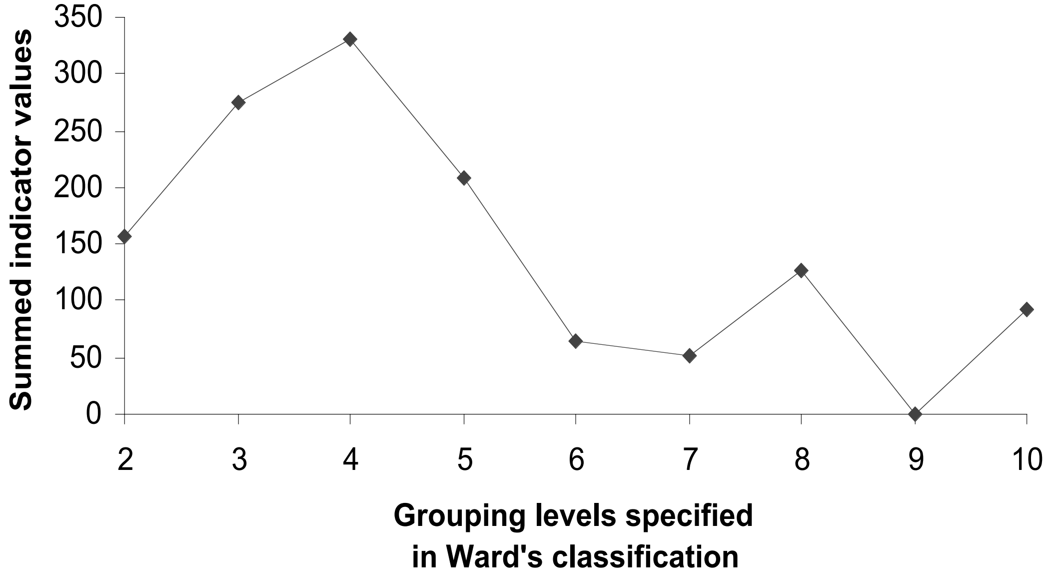

Figure 3.8 The indicator values from the Indicator Species Analysis are summed for each grouping level in order to determine the grouping level indicating the best number of groups to consider in Ward's classification dendrogram. The maximum value occurs at the fourth grouping level indicating the best place to prune the dendrogram.

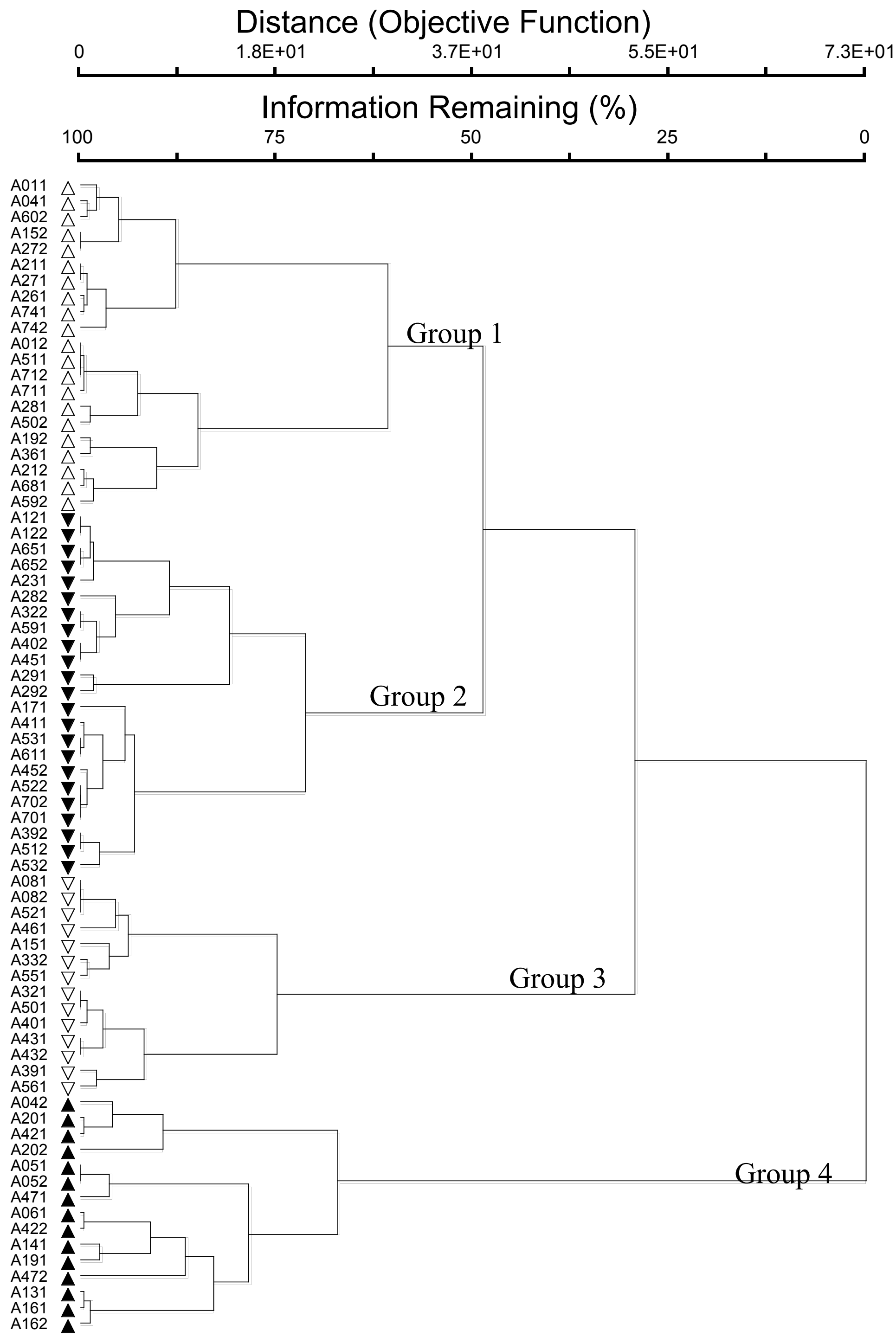

Figure 3.9 Dendrogram of organic fields in Saskatchewan showing four grouping levels as classified by Ward's method and pruned until the third branch or until four groups are dissected according to the indicator species analysis. Symbols designate the fields classified to the four groups.

Table 3.5 Mean values for management variables as well as the *p*-values for the T-tests for the first branch of the dendrogram (Figure 3.6) that separated Group 4 from the rest of the fields (Group 1c) that are still unclassified. Bolded values indicate a significant difference between the two groups compared.

Management Variable	1st branch mean values: Remaining fields	1st branch mean values: Group 4 fields	T-tests' *p*-values: Kruskal-Wallis	T-tests' *p*-values: Satterthwaite's unequal
Acres	67.47	72.80	0.9175	0.6330
Manure	**0.04**	0.00	0.1604	**0.0099** **
Soil amendments	0.04	0.13	0.1244	0.2129
Spring tillage	1.22	**2.12**	**0.0032** **	**0.0121** *
Post-seeding pre-emergent tillage	**0.99**	0.47	**0.0171** *	**0.0259** *
Post-seeding post-emergent tillage	0.19	0.32	0.8830	0.3670
Fall tillage	0.61	0.93	0.6268	0.4883
Diversity	2.86	2.53	0.1891	0.1469
Cereal	**0.56**	0.38	**<0.0001** ***	**<0.0001** ***
Annual legume	**0.06**	0.01	**0.0383** *	**0.0037** **
Summerfallow	**0.19**	0.05	**<0.0001** ***	**<0.0001** ***
Perennial	0.02	**0.50**	**<0.0001** ***	**<0.0001** ***
Broad-leaved non-leguminous	0.06	0.03	0.1558	0.1348
Biennial	**0.10**	0.00	**0.0004** **	**<0.0001** ***
Green manure	**0.10**	0.04	**0.0172** *	**0.0095** **
Number of Fields	58	15	-	-

Values with a $p < 0.0001$ are designated by ***, $p < 0.01$ by **, and $p < 0.05$ by *.

Table 3.6 Mean values and the resultant p-values for the T-tests comparing the management variables for the second branch of the dendrogram (Figure 3.6) that further separated Group 1c into Group 3 and the remaining unclassified fields in Group 1b. Bolded values indicate a significant difference between the two groups compared.

Management Variable	2nd branch mean values: Remaining fields	Group 3 fields	T-tests' *p*-values: Kruskal-Wallis	Satterthwaite's unequal
Acres	**71.36**	55.21	**0.0118 ***	**0.0073 *****
Manure	0.04	0.02	0.5629	0.5754
Soil amendments	0.04	0.02	0.5416	0.5038
Spring tillage	1.22	1.24	0.9927	0.9373
Post-seeding pre-emergent tillage	1.00	0.95	0.9395	0.8231
Post-seeding post-emergent tillage	0.18	0.23	0.7827	0.6551
Fall tillage	**0.74**	0.23	0.1857	**0.0148 ***
Diversity	**3.30**	1.50	**<0.0001 *******	**<0.0001 *******
Cereal	0.55	0.58	0.5732	0.4509
Annual legume	0.06	0.05	0.4949	0.7110
Summerfallow	0.15	**0.30**	**0.0022 *****	**0.0016 *****
Perennial	0.02	0.00	0.2467	0.0629
Broad-leaved non-leguminous	**0.08**	0.01	**0.0114 ***	**0.0005 *****
Biennial	**0.13**	0.01	**0.0001 *****	**<0.0001 *******
Green manure	**0.12**	0.03	**0.0004 *****	**0.0144 ***
Number of Fields	44	14	-	-

Values with a $p < 0.0001$ are designated by ***, $p < 0.01$ by **, and $p < 0.05$ by *.

Table 3.7 Mean values and the resultant P-values for the T-tests comparing the management variables for the third branch of the dendrogram (Figure 3.6) that finished the classification of Group 1b that separated Group 1 into Group 2. Bolded values indicate a significant difference between the two groups compared.

Management Variable	3rd branch mean value Group 1 fields	Group 2 fields	T-tests' *p*-values Kruskal-Wallis	Satterthwaite's unequal
Acres	76.52	66.65	0.1692	0.0998
Manure	0.06	0.02	0.0791	0.2480
Soil amendments	0.06	0.03	0.3150	0.2912
Spring tillage	1.27	1.17	0.6797	0.6675
Post-seeding pre-emergent tillage	1.06	0.95	0.3460	0.6719
Post-seeding post-emergent tillage	0.21	0.16	0.4969	0.5632
Fall tillage	0.62	0.85	0.5119	0.5166
Diversity	3.33	3.26	0.9795	0.7810
Cereal	0.51	**0.59**	**0.0132** *	**0.0133** *
Annual legume	0.05	0.07	0.8815	0.5825
Summerfallow	0.16	0.15	0.8178	0.8850
Perennial	**0.05**	0.00	**0.0302** *	0.0618
Broad-leaved non-leguminous	**0.16**	0.00	**<0.0001** ***	**<0.0001** ***
Biennial	0.09	**0.16**	**0.0379** *	**0.0304** *
Green manure	0.07	**0.17**	**0.0005** **	**0.0005** **
Number of Fields	21	23	-	-

Values with a $p < 0.0001$ are designated by ***, $p < 0.01$ by **, and $p < 0.05$ by *.

was planted to a perennial crop. Therefore group 4 is defined as the "moderately diverse perennial system" or simply the "perennial system" (Table 3.8). One defining characteristic unique to the perennial system was that animal manures were never used. The perennial system rarely, if ever, included summerfallow, biennials, green manure crops, nor annual legumes in rotation (Table 3.5). The use of cereal crops and the practice of post seeding pre-emergence tillage were significantly lower in the perennial system. The practice of spring tillage however was higher in the perennial system. Of course the practice of spring tillage would not be used while the field is planted to a perennial crop; however, the termination of the perennial crop would require many tillage passes in the spring prior to the seeding of another crop.

The most significant management variable for group 3 was the lack of crop rotation diversity (Table 3.6). Group 3 was further characterized by having a high rate of summerfallow, 0.30; twice as high as the 0.15 summerfallow value for groups outside of group 3 and 4. This suggests that every 3 to 4 years the fields are in summerfallow. Group 3 is therefore labelled the "low diversity summerfallow system" or simply the "summerfallow system." Although the use of cereal crop was not higher in group 3, it is reasonable to assume cereals were the primary crop in the rotation since other crop types such as biennials, broad-leaved non-leguminous, and perennial crop are significantly lower in this summerfallow system.

The third branch of the dendrogram separates the final two groups. The significant defining management variable between these two groups was the inclusion of green manure in the rotation by group 2 producers (Table 3.7). Group 1 included broad-leaved non-leguminous crops in their rotation 16% of the time, whereas group 2 did not include non-leguminous broad-leaved crops in their rotation. Group 1 and group 2 are both highly diverse in their crop rotation with values of 3.33 and 3.26 respectively. Diversity in groups 3 and 4 was substantially lower with values of 1.50 and 2.53 respectively. Although the cropping systems of group 1 and 2 have high diversity values, these systems did not include annual legume crops often, in fact, summerfallow was more

Table 3.8 Dendrogram groups and their corresponding system defining factors.

Dendrogram Group	Organic Farm System
Group 1	Diverse cropping system
Group 2	Diverse cropping green manure system
Group 3	Low diversity summerfallow system
Group 4	Moderately diverse perennial cropping system

common. Both group 1 and 2 had more than a 0.50 value for the cereals in rotation variable, in other words more than 50% of the time the field was planted to a cereal crop. Group 2 used cereals 8% more often in their rotation. The large difference in the rotation of group 2 producers was the use of biennial crops as green manure verses the use by group 1 of other broad-leaved crops that were non-leguminous. For the purpose of naming these groups, both were labelled as diverse. Group 1 was labelled as the "diverse crop system" whereas group 2 was further classified as the "diverse cropping green manure system."

Appling the groups back to the original NMS diagram allows us to see how the good spread in figures 3.4 to 3.6 represent the different systems. Again, the order of the axes does not represent importance. The first axis separates the green manured fields (Figure 3.10), the second axis separates the inclusion of perennials (Figure 3.11), and the third axis separates the practice of summerfallow (Figure 3.12).

3.4 Discussion

The objective of this study was to classify organic fields in Saskatchewan according to farm management systems. The four organic farming systems identified in this classification study were the diverse cropping system, the diverse cropping green manure system, low diversity summerfallow system, and the moderately diverse perennial cropping system. Each system has a unique combination of management variables that will be examined in more detail.

The most significant factor that defined the perennial system was the inclusion of perennial crops. In the survey, alfalfa was the only perennial crop reported. Occurrence of the perennial system was limited to the two most northeastern regions of the province (Table 3.9). The southwestern part of Saskatchewan is drier than other regions of the province. Because of alfalfa's deep roots and aggressive growth, it uses large amounts of water and can induce drought stress on the following crop (Bullied and Entz, 1999). Therefore alfalfa is not a commonly grown crop in the south.

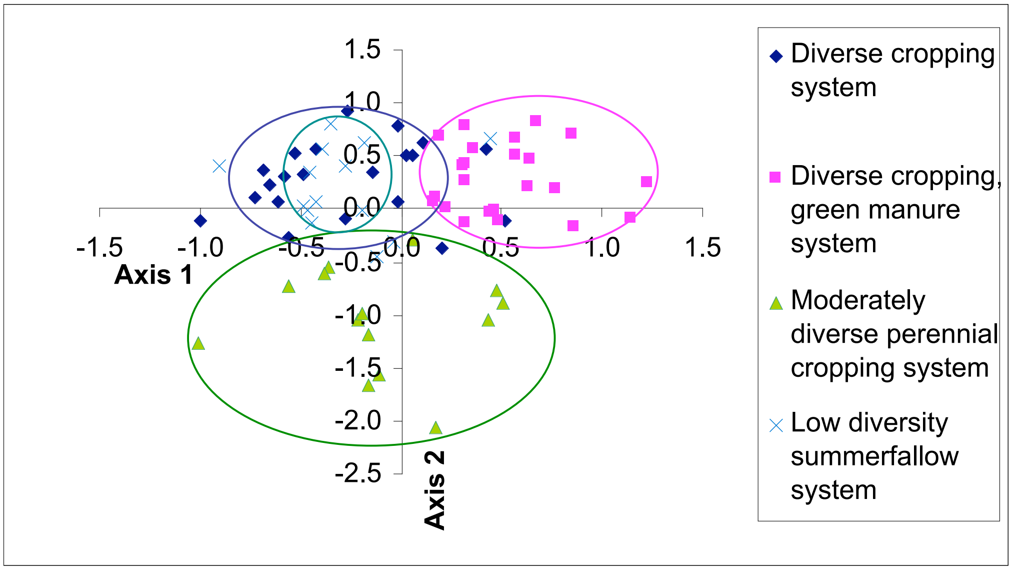

Figure 3.10 Nonmetric multidimensional scaling ordination diagram showing the first and second axes with symbols representing the systems for each field.

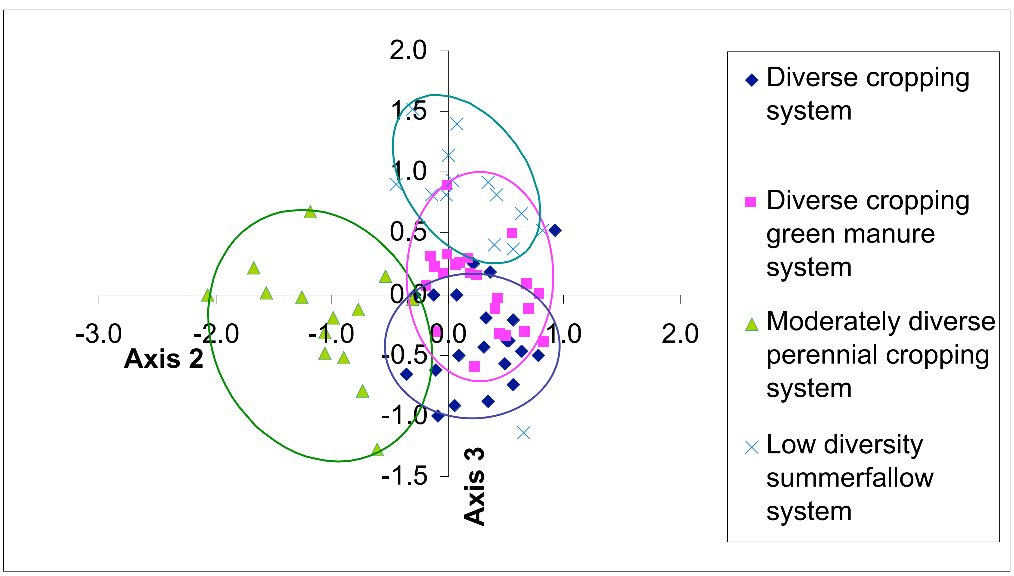

Figure 3.11 Nonmetric multidimensional scaling ordination diagram showing the second and third axes with symbols representing the systems for each field.

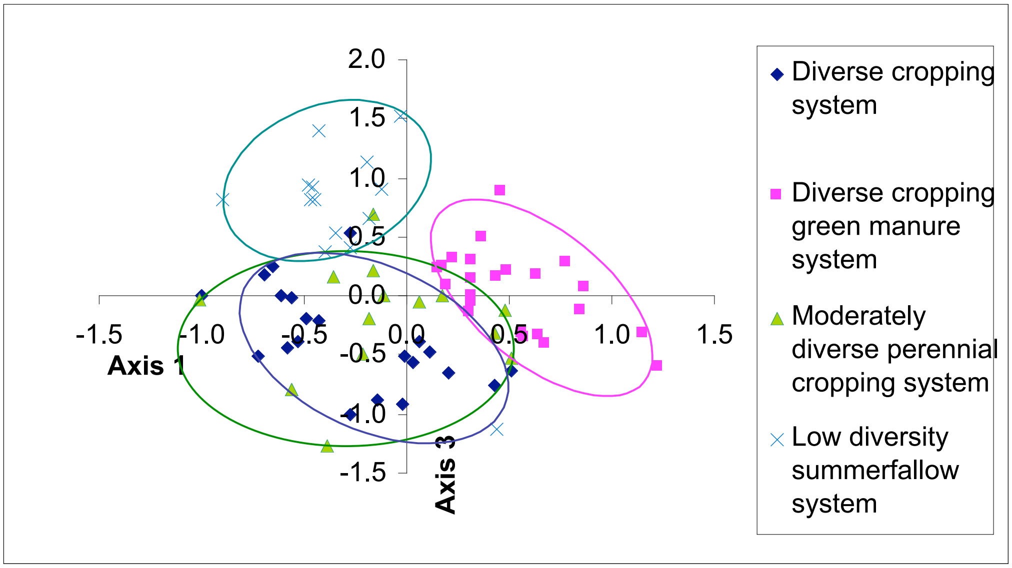

Figure 3.12 Nonmetric multidimensional scaling ordination diagram showing the first and third axes with symbols representing the systems for each field.

Table 3.9 Number of fields located in the various soil zones of Saskatchewan that correlate to the identified organic farming systems.

Organic Farming System	Soil zone: Brown	Soil zone: Dark Brown	Soil zone: Black	Soil zone: Gray	Total number of fields
Diverse cropping system	5	3	6	7	21
Diverse cropping system using green manure	5	10	6	2	23
Low diversity cropping system using summerfallow	4	3	7	0	14
Moderately diverse cropping system using perennials in rotation	0	0	7	8	15
Total number of fields	14	16	26	17	73

A further challenge to the inclusion of alfalfa in an organic system is the intensive tillage operations required for termination of the perennial crop (Bullied and Entz, 1999; Entz et al., 1995). Thus, the management variable, spring tillage, was significantly higher in the perennial system. Alfalfa is a deeply rooted, aggressive perennial forage and therefore requires many tillage passes to successfully terminate the stand without the use of herbicides.

Alfalfa stands are at their economic optimum after four to five years of growth (Jeffrey et al., 1993). The average length of an alfalfa stand in Saskatchewan is 6.5 years (Entz et al., 1995). The questionnaire for this study recorded a crop history over a 7 year period (1996-2002). For farm systems that included perennials, specifically alfalfa, in their rotation, this questionnaire may not have a long enough crop rotation history to see the entire rotation. The information that might be missing from the cropping history could be fertility inputs, as inputs are not easily added to a perennial stand, and a fuller understanding of the range of crops used in the rotation following or prior to alfalfa. A longer study of a crop rotation for organic farmers would be possible with the excellent record keeping required of organic producers.

The low diversity summerfallow system was the only system to be defined by a tillage practice. The summerfallow system was seen in all regions of the province except the northern most region (the Gray soil zone) of Saskatchewan (Table 3.9). The practice of summerfallow is generally associated with the southern regions of the province since it was a management strategy traditionally thought to conserve moisture. However the presence of summerfallow was prevalent even in the Black soil zone. The use of summerfallow in the Black and Gray soil zones has been labelled as an excessive practice in these regions (Campbell et al., 1990 in Rice et al., 1993). Other reasons for the inclusion of summerfallow in rotation are weed control and the maintenance of soil fertility.

Summerfallow can lower weed populations (Molberg et al., 1967). The minimum number of tillage operations required in southwestern Saskatchewan to control weeds is three tillage operations or four for the northern and eastern regions (Molberg et al., 1967). Tillage is practiced throughout the season to prevent the growth of plants. The lack of plant foliage taking up nutrients and the incorporation of crop residues makes summerfallow a strategy to improve soil fertility via the mineralization of certain nutrients such as N. However summerfallow has been shown to exacerbate soil degradation (Rice et al., 1993); specifically, reduction in the organic matter content of the soil results in a reduction of future nutrient supply and structural deterioration (Campbell and Zentner, 1993a). Traditionally, it was believed that summerfallow would reduce pests, not only weed populations but also the incidence of disease. However disease control has not been reduced with the inclusion of summerfallow. Wheat grown on fallow had more severe infection of tan spot compared to wheat grown in a continuously cropped rotation (Fernandez et al., 1999).

A low diversity of crop types was associated with the summerfallow farming system. Cereal crops were the only variable that had a high value of 0.58 although this was not significantly higher than the more diverse systems. This system appears to be a cereal-fallow based system.

The final two systems both had a high diversity of crops. The diverse cropping system split from the diverse cropping green manure system because of the inclusion of green manure crops in the rotation. The diverse cropping system included broad-leaved non-leguminous crops such as flax, mustard or borage in their rotation but used biennial crops significantly less than the green manure system.

Organic farms have been shown to have a more diverse crop rotation compared to conventional farm systems (Leeson et al., 1999). Diverse crop rotations are the best way to combat or avoid pest problems and can conserve soil fertility (Foster, 1996 in (Leeson et al., 1999). Both of these diverse systems occurred in all regions of the province (Table 3.9).

Green manure has been studied as an alternative to summerfallow in the southern portion of the province using annual legumes (Biederbeck and Bouman, 1994; Biederbeck et al., 1996; Biederbeck et al., 1993; Brandt, 1999;

Curtin et al., 2000; Pikul et al., 1997; Rice et al., 1993; Townley-Smith et al., 1993; Zentner et al., 1996). The most common green manure crop used in this survey was sweet clover. With early incorporation, it is still possible to gain some of the moisture benefits with a partial fallow. The true benefits of green manure come from the reduction in the loss of soil organic matter (SOM), and an improvement in the quality of SOM, specifically SOM N (Campbell et al., 1991a; Campbell et al., 1991b). The crop residues returned to the soil provide other rotational benefits of the biennial for pests, including weed control, insects, soil organisms and crop diseases. The use of sweet clover was found to have a beneficial effect on weed populations in most but not all years (Blackshaw et al., 2001). There was still a beneficial effect on weed populations even if the sweet clover was harvested and not used as a green manure crop (Blackshaw et al., 2001).

Classification of farm systems using multivariate methods is limited by the aspects chosen to study and by the resultant variables chosen from those initial measures. A similar farm system classification study found analogous organic systems with the exception of the green manure system (Leeson et al., 1999). The questionnaire in the current study was designed specifically for organic production unlike the Lesson et al. (1999) study; additionally, only 11 organic farms were studied by Leeson (1998). In this thesis study, a greater range of organic farming systems were defined in Saskatchewan compared to previous work done.

Due to the survey nature of this project bias is introduced in the selection of fields. The initial contact with producers was by phone and producers were asked if they would be willing to participate. This is known as self-selection and introduces bias towards those producers who are willing to participate. Also the producer was able to choose the field to be studied as long as a cereal was planted. The possible bias is that the producer might chose a field not representative of their entire farm but a field specially treated, or a field with the best quality soil on the farm. Perhaps the greatest bias introduced in this study is the fact that the OCIA was the only certifying body willing to share their producer names. Because certifying bodies encourage certain practices from their member producers, it is possible that the inclusion of other producers from other certifying bodies may have changed the management practices used.

There are five components to a farming system: economics, pesticides, fertilizers, crop rotation and tillage (Edwards, 1989). Because economics was not a component of this questionnaire, and pesticides are prohibited on organic farms, the three components remaining (fertility inputs, tillage and crop rotation) were expected to define different management systems. Fertility inputs, such as the use of soil amendments, including animal manure, were not only an uncommon occurrence in the survey but was not part of defining any of the classification systems, save the fact that those in the perennial system had significantly fewer incidences of manure application. Fertility amendments to the soil such as manure applications or rock phosphorous use were not common practices on the surveyed organic farms in Saskatchewan according to the questionnaire. The lack of fertility building practices, with the exception of the N building strategy of green manure, ought to be of serious concern to the organic industry in Saskatchewan.

The two components of cropping systems that defined the organic systems were crop rotation, which was the most important management practice in defining various management groups in this study, and the use of tillage. The only tillage practice that was unique enough to define a system was the use of summerfallow.

The fact that various systems were identified reflects the diversity of management techniques used by organic producers in Saskatchewan. Identification of these systems provides a designation to allow for comparisons to be made between these various systems to see how management practices may affect weeds and soil in the agro-ecosystem. Most commonly when organic production is referred to, it is referred to as a system in and of itself. There is no commonly used language to distinguish between different types of farming systems that may exist within the organic farming systems and determine how different management techniques affect the soil and weeds of those systems.

3.5 Conclusion

The different management practices used by organic producers in Saskatchewan were distinct enough to separate into four organic farming systems: a diverse cropping system, diverse green manure system, low diversity summerfallow system and the moderately diverse perennial system. This study suggests that the organic farming system is more diverse and complex than previously acknowledged in the literature.

The questionnaire conducted in this survey was distributed to more producers than any other survey of its kind previously done on the Canadian Prairies. Although the entire farm was not surveyed, the cropping history of a single surveyed field allowed us an insight into each producer's management practices. The survey provided us with an interesting and accurate picture of how organic producers approach agronomics in Saskatchewan.

4 WEED POPULATIONS ON ORGANICALLY MANAGED FIELDS IN SASKATCHEWAN AS AFFECTED BY MANAGEMENT PRACTICES OF ORGANIC FARM MANAGEMENT SYSTEMS

4.1 Introduction

The agricultural research community and the agricultural industry use weed survey data to understand composition and changing trends in weed populations. Although weed surveys are conducted approximately every decade by Agriculture and Agri-Food Canada in the province of Saskatchewan, the composition of weed populations had never before been examined exclusively on organically managed fields in Saskatchewan. A study determining the effect of different farming systems (both organic and non-organic) on weed populations in Saskatchewan found that species richness and weed densities were higher on organically managed farms, than on conventional farms (Leeson, 1998). A review of organic farming systems studied in the USA reported that although studies found species richness or the number of weed species present was reported to be greater on organic farms, the total weed density and biomass were not necessarily higher and in some cases, such as the use of cover crops and crop residue or intercropping, the weed biomass and densities were reduced (Ngouajio and McGiffen, 2002).

Weed management is a crucial element of successful agronomic production. Weed management is especially important in organic production because weed infestations can not be controlled with pesticides. Therefore, other management practices are required to control weed populations. Crop rotation has the most influence on weed communities (Haas and Streibig, 1982). The inclusion of perennial forage crops in crop rotations is particularly effective at influencing weed populations (Leeson, 1998; Loux and Berry, 1991; Ominski et al., 1999). It was also shown that organic systems with summerfallow in rotation had high densities of annual weeds (Leeson, 1998). Tillage disturbance does not affect weed communities as much as rotation (Dale et al., 1992; Derksen et al., 1994). However certain weeds, specifically Russian thistle and pigweed species, were attributed to organic systems with frequent tillage passes (Derksen et al., 1994; Hume, 1982; Leeson, 1998).

Ordination techniques have been used to study how management practices affect weed populations. Ordination is used in ecology to identify patterns in complex data (McCune and Grace, 2002). In ordination, data are spread along theoretical axes and the resultant relative distances between points provide insight into correlation between two sets of variables. Thomas and Frick (1992) used redundancy analysis to determine the relationship between weed abundance and tillage system. More commonly, canonical correspondence analysis is used to determine relationships between weed species and environmental variables (Dale et al., 1992; de la Fuente et al., 2003; Salonen, 1993; Suárez et al., 2001; Townley-Smith et al., 1993).

This study examined weed populations present on organic farms in Saskatchewan during the 2002 season. Weed survey data are used in conjunction with the management survey data (Chapter 3). The weed species with high relative abundance in the province are presented along with the species abundance for each of the four organic management systems defined previously in this study (Table 3.8). The objective is to explain the existing weed communities based on the farm management systems. The null hypothesis therefore is that organic management systems have no affect on weed species present on organic fields in Saskatchewan.

4.2 Materials and methods

4.2.1 Weed survey

Seventy-three organically managed fields were included in this study (field site selection is described in section 3.2). Weed data were collected between July 3rd and July 24th 2002. Weeds older than the first true leaf stage were identified and counted. Sampling in the second half of the growing season ensured that any management practices implemented had time to manifest their effect on the weed populations (Thomas, 1985) and that crop competition also had time to affect the weed populations (Andreasen et al., 1991).

The method used to obtain and summarize the weed survey data was based on Thomas' (1985) system of surveying weed populations. Sampling was performed in a "W" pattern across the field (Figure 4.1). Anomalies such as, ditches, bluffs, saline regions, oil wells, power lines, and paths were avoided. Extreme knolls and depressions were also avoided. One hundred paces along the field edge and 100 paces into the field marked the first weed sampling site. Each arm of the "W" contained five sample sites for a total of 20 sample sites per field (Figure 4.1). The sample site was defined by a quarter meter square frame (50 cm by 50 cm), called a quadrat, within which weed species were identified and quantified.

The raw weed data set was summarized following Thomas' (1985) weed survey protocol. The measure of relative abundance defined numerically the presence of a species on a field, and when present, how uniform the distribution was, as well as the total number of individual plants present for each species. Relative abundance was obtained by the summation of three descriptive components: relative density, relative frequency, and relative uniformity. Relative density is determined in three steps. First, the quarter meter square count for the species of interest was totalled for each field and divided by the 20 quadrats sampled per field and multiplied by 4 to get plants per m^2. The second step took field count of the individual species of interest (D_i) totalled for each field and divided by the total number of fields surveyed, this is called the mean field density (MFD) for all fields. In the final and third step the mean field density is divided by all of the species counted in the survey from all the surveyed fields and is expressed as a percent.

$$\text{Density of individual species } (D_i) = \frac{\text{Count for 20 quadrats for species I}}{\text{Number of quadrats (20)}} * 4 \qquad [4.1]$$

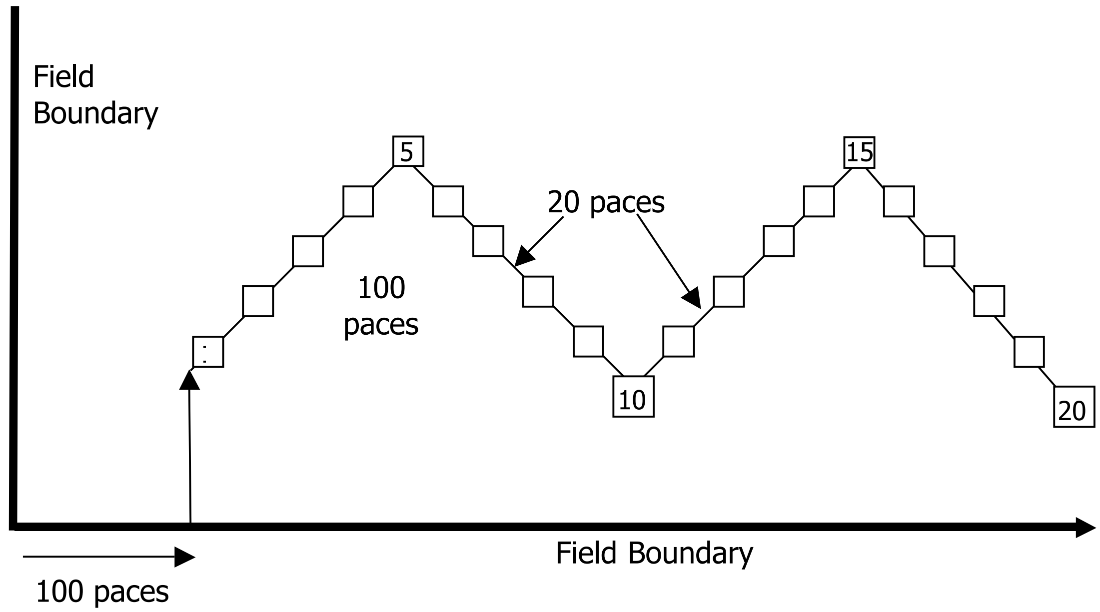

Figure 4.1 Weed survey W-sampling pattern used for weed counts. Each square represents one quadrat sampling site (modified from Thomas, 1985).

$$\text{Mean Field Density } (MFD_{\text{all fields}}) = \frac{\text{Density of individual species } (D_i) \text{ totalled for all fields}}{\text{Number of all fields}} \quad [4.2]$$

$$\text{Relative Density } (D_{sp}) = \frac{\text{Mean field density for an individual species (I) (all fields)}}{\text{Sum of the densities for all species present in all fields}} * 100\% \quad [4.3]$$

The calculation to report relative frequency requires two steps. First, the frequency is the number of fields where the species of interest appears divided by the total number of fields surveyed to give a percentage frequency. Second, the relative frequency is calculated by taking the frequency values for the species of interest and dividing it by the sum of all the frequency values for all of the species identified in the survey. Again this is expressed as a percentage.

$$\text{Frequency } (F_i) = \frac{\text{Number of fields where species I is present at least once in a field}}{\text{Total number all fields surveyed}} * 100\% \quad [4.4]$$

$$\text{Relative Frequency } (F_{sp}) = \frac{\text{The frequency value } (F_i) \text{ for species I}}{\text{Total sum of all frequency values for all species surveyed}} * 100\% \quad [4.5]$$

Relative uniformity was a measure of the number of quadrats where a species occurred expressed as a percentage of the total number of quadrats in the survey (20 quadrats x 73 fields).

$$\text{Uniformity } (U_i) = \frac{\text{Number of quadrats where species I occurred}}{\text{Total number of quadrats in all fields (20 x 73)}} * 100\% \quad [4.6]$$

$$\text{Relative Uniformity } (U_{sp}) = \frac{\text{The uniformity value } (U_i) \text{ for species I}}{\text{Total sum of all uniformity values for all species}} * 100\% \quad [4.6]$$

These three measures when summed provide a measure of relative abundance. The maximum value for relative abundance is 300. The measure of relative abundance has no units but is a useful tool for comparison between species.

$$\text{Relative Abundance} = \text{Relative density} + \text{relative frequency} + \text{relative uniformity} \quad [4.6]$$

4.2.2 Statistical analysis of organic management systems and weed data

The weed survey data, along with the management systems, were used to determine how management affected weed populations. The statistical analysis was done with Canoco 4.5 (ter Braak and Smilauer, 2002). The initial step in the analysis was detrended correspondence analysis (DCA) (ter Braak and Smilauer, 2002). The purpose of DCA was to determine whether the relationship in these data was linear or unimodal (Figure 4.2). If the maximum gradient length exceeds four standard deviations these data show a unimodal response; if the gradient length is less than four standard deviations these data show a linear response (ter Braak and Smilauer, 2002).

The rare weed species were not used in the analysis. A cut off value of 7% was used; each weed species must have been present on at least 7% of the surveyed fields. The 7% cut off level was not chosen arbitrarily but was chosen after examining the less common weed species and where occurred. This was to ensure that any weed species that might be a defining species were included. Thirty weed species were present on at least 7% of the surveyed fields. These 30 species were labelled in the Canoco analysis using Bayer codes (Table 4.1). Only the primary matrix was used in the DCA. The main matrix consisted of 30 weed species (columns) by the 73 surveyed fields (rows) (Appendix C, Table C.7). The species densities were log transformed by the analysis program in order to compress the high density values and increase the spread of the low values (McCune and Grace, 2002). In species data a value of zero is not uncommon. Because the log of zero is undefined, the program option to add a value of one to every observation in the Canoco program was selected (ter Braak and Smilauer, 2002). The default setting to detrend using segments was used.

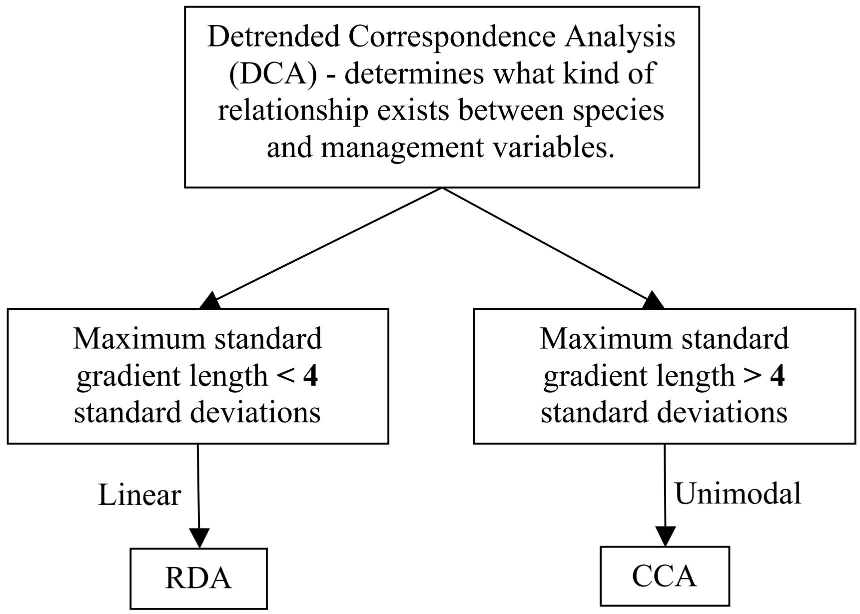

Figure 4.2 Decision process to determine whether to use redundancy analysis (RDA) or canonical correspondence analysis (CCA) ordination techniques (modified from McCune and Grace, 2002).

Table 4.1 Thirty weed species listed with their Bayer code, the Latin nomenclature, and common name (Darbyshire et al., 2000).

Bayer Codes	**Latin Nomenclature**	**Common Name**
AGRRE	*Elytrigia repens* (L.) Desv. ex B.D. Jacks	Quack grass
AMARE	*Amaranthus retroflexus* L.	Redroot pigweed
AVEFA	*Avena fatua* L.	Wild oats
CAPBP	*Capsella bursa-pastoris* (L.) Medik.	Shepherd's-purse
CHEAL	*Chenopodium album* L.	Lamb's-quarters
CHEHG	*Chenopodium simplex* (Torr.)Raf.	Maple-leaved goosefoot
CIRAR	*Cirsium arvense* (L.) Scop.	Canada thistle
DESSO	*Descurainia sophia* (L.) Webb ex Prantl	Flixweed
EPHSP	*Euphorbia serpyllifolia* Pers.	Thyme-leaved spurge
EQUAR	*Equisetum arvense* L.	Field horsetail
GAETE	*Galeopsis tetrahit* L.	Hemp-nettle
GALAP	*Galium aparine* L.	Cleavers
KCHSC	*Kochia scoparia* (L.) Schrad.	Kochia
LACSE	*Lactuca serriola* L.	Prickly lettuce
LIUUT	*Linum usitatissimum* L.	Flax
LPLSQ	*Lappula squarrosa* (Retz.) Dumort.	Bluebur
MEDLU	*Medicago lupulina* L.	Black medick
MEDSA	*Medicago sativa* L.	Alfalfa
MELNO	*Silene noctiflora* L.	Night-flowering catchfly
POLAV	*Polygonum aviculare* L.	Prostrate knotweed
POLCO	*Polygonum convolvulus* L.	Wild buckwheat
POLLA	*Polygonum lapathifolium* L.	Pale smartweed
SASKR	*Salsola kali* L. Subsp. *ruthenica* (Iljin) Soó	Russian thistle
SETVI	*Setaria viridis* (L.) P. Beauv.	Green foxtail
SINAR	*Sinapis arvensis* L.	Wild mustard
SONAR	*Sonchus arvensis* L. subsp. a*rvensis*	Perennial sow-thistle
TAROF	*Taraxacum officinale* G.H. Weber ex Wiggers	Dandelion
THLAR	*Thlapsi arvense* L.	Stinkweed
VAAPY	*Vaccaria hispanica* (Mill.) Rauschert	Cow cockle
VICXX	*Vicia* species	Vetch species

The primary and secondary matrices were entered into the Canoco 4.5 program for the final ordination. The secondary matrix was made up of four columns by 73 rows; one column for each of the four farm management systems (Appendix B, Table B.3). Zeros and ones denote which of the four farming systems best classified the management practices of the field surveyed.

Redundancy analysis (RDA) was chosen following the DCA results (section 4.3.1). The primary matrix was analyzed by RDA in the Canoco program without the use of forward selection. A Monte Carlo permutation test (Franklin et al., 1995) was used to test for statistical significance of 9 999 random simulations ran by the computer program. The permutation test determined if the variation in the weed populations was correlated to the management systems or whether similar results would occur if the data were simply random. To determine the dimensionality of the solution the significance of all the axes must be calculated. The program only reports the significance of the first axis and then all axes together. Therefore to determine the significance of the second and third axes the sample scores for axes one to three were taken from the RDA result file. The sample scores for each field along each axis became a new environmental variable. The new secondary matrix was made up of 7 columns: the four farming systems and three columns one for each of the axes' sample scores. The analysis was repeated removing one axis at a time as a co-variable. The test of significance for the "first" axis could then determine whether the *p*-value of the second and third axes were significant or not. The final results are displayed in an ordination diagram using the RDA species scores and centroid values for the management systems.

4.2.2.1 Understanding the ordination diagram

An ordination diagram is most often a 2-dimensional diagram plotting the synthetic axes created by ordination analyses against each other. These synthetic axes define relationships or correlations among the observed species. The positions of the sample units on the axes are important to define relationships among the sample units. The distances between sample units in the ordination are proportional to the dissimilarities between the entities (McCune and Grace, 2002). The position of the weed species points is important. Weed species points that occur near the origin are considered to be ubiquitous and not associated specifically with either end of the ordination axis. The management systems are displayed as centroids, which are a multivariate average. Therefore, the management system centroids that appear close together in the diagram have similar weed populations. The placement of weed species points along the continuum of the axis defines the relationship of the weed species to the management system centroids. It is not important how close the weeds are to the centroids, but rather how far along the species are on the axis. A strong relationship will have a higher absolute value and will be placed further from the origin.

The canonical axes created by ordination methods such as RDA are limited by the number of environmental variables; in this case, because there are only four management systems, a maximum of four canonical axes can be determined.

4.3 Results and discussion

4.3.1 Weed survey: weed species density and abundance

A total of 63 weed species were identified from the 73 organically certified fields surveyed. Seven grassy species and 56 broad-leaved weed species were identified. Twenty-one of the 63 species were found in all four of the organic management systems. The management system with the fewest number of weed species was the summerfallow system although all systems are similar (Table 4.2). The summerfallow system had the lowest number of annual weed species present and the perennial system had the lowest number of perennial weed species compared all to the other systems, with 21% of the weed species present being perennial weeds (Table 4.2) (differences were not tested).

The weed survey measured weed densities (plants m^{-2}). The weed survey data were summarized using relative abundance (Appendix C). Relative abundance is the sum of relative frequency, relative density and relative uniformity measures. These numerical measures from the weed survey allow us

Table 4.2 The total number of weed species and the number and percent of weeds according to their respective life cycle designations for the four organic management systems.

Organic Management System	Total number of weed species present	Life history of the weed species present			
		Annual	Perennial†	Biennial	Unknown
Diverse	45	32 (71 %)	10 (22%)	1 (2 %)	2 (4%)
Green Manure	42	30 (71%)	11 (26%)	0	1 (2%)
Summerfallow	38	29 (77 %)	9 (23%)	0	0
Perennial	39	30 (77%)	8 (21%)	0	1 (2%)

† Field horsetail was counted as a perennial weed. Although the stems of field horsetail are officially annuals those stems appear from a perennial creeping and forking rhizomes (Cody and Wagner, 1980).

to understand how important certain species might be at the field scale. The relative abundance values can be used to determine the weed species that are most abundant in certain defined boundaries, for example Saskatchewan or each of the four organic management systems. Biomass was not sampled due to the distorting effect that a single large plant can cause (Erviö et al., 1994); as well, the extra time, equipment and storage space required to obtain such a sample was determined to be disadvantageous. It is important to note that density measures alone also introduce bias. The limitation of density is that not all weeds are equally competitive with the crop. If there are many small weeds that complete there life cycle quickly such as chickweed, its importance is not equal to the same number of a more competitive weed like wild buckwheat, wild oats, or Canada thistle.

The most abundant weed species sampled on organic farms in Saskatchewan was green foxtail (SETVI) (Table 4.3, Table 4.4). Wild mustard (SINAR) was second followed by lamb's-quarters (CHEAL) and wild oats (AVEFA). Wild buckwheat (POLCO) and stinkweed (THLAR) were fifth and sixth respectively. Four of the six most abundant weeds were annual broad-leaved species.

Six of the ten most abundant weeds were shared between the four different organic cropping systems (Table 4.4). Green foxtail, wild mustard, lamb's-quarters, and wild buckwheat were all listed in the top six most abundant species for all cropping systems. The remaining two species present in all systems were: wild oats, which had a higher relative abundance value in the diverse and summerfallow cropping systems, and stinkweed, which was lowest in the summerfallow system.

Green foxtail was the most abundant species in the diverse system and the summerfallow system. In the perennial and green manure systems, green foxtail was only second to lamb's-quarters. The relative abundance values for green foxtail were substantially higher in the summerfallow system. The highest value making up the relative abundance measure was density. Green foxtail

Table 4.3 The ten most abundant weed species on organic farms in the province according to the organic weed survey.

Saskatchewan Organic Survey 2002					
Relative abundance Rank	Weed Species	Relative abundance	Percent Frequency	Percent Uniformity	Mean Field Density /m^2
1.	SETVI	56.3	72.6	48.7	574
2.	SINAR	40.1	72.6	41.2	357
3.	CHEAL	32.9	90.4	57.7	164
4.	AVEFA	25.1	71.2	37.3	147
5.	POLCO	25.1	89.0	46.0	35
6.	THLAR	17.8	64.4	30.5	71
7.	CIRAR	9.6	52.0	16.9	12
8.	SASKR	7.2	31.5	10.4	28
9.	MEDSA	7.5	38.4	13.4	13
10.	AMARE	6.7	41.1	11.3	5

Table 4.4 The top 10 most abundant species according to their relative abundance scores for each of the organic management systems.

Relative abund. Rank	Diverse		Green Manure		Summerfallow		Perennial	
	Weed Species	Relative Abund.	Weed Species	Relative Abund.	Weed Species	Relative Abund.	Weed Species	Relative Abund.
1.	SETVI	46.8	CHEAL	59.2	SETVI	83.8	CHEAL	59.2
2.	SINAR	43.2	SETVI	31.8	SINAR	41.6	SETVI	31.8
3.	CHEAL	42.1	POLCO	30.2	AVEFA	23.9	POLCO	30.2
4.	AVEFA	24.3	SINAR	24.8	CHEAL	22.8	SINAR	24.8
5.	THLAR	20.0	THLAR	23.9	POLCO	20.5	THLAR	23.8
6.	POLCO	19.7	MEDSA	19.9	CIRAR	11.8	MEDSA	19.8
7.	CIRAR	11.4	AGRRE	15.9	THLAR	9.6	AGRRE	15.8
8.	LPLSQ	7.9	AVEFA	15.8	TAROF	7.0	AVEFA	15.8
9.	VAAPY	7.8	TAROF	9.0	AMARE	6.9	TAROF	9.0
10.	SASKR	7.0	POLLA	6.3	SASKR	6.7	POLLA	6.3

made up 58% of all the weeds counted in the summerfallow system (Table C4) with an average density of 921 plants per m^2 (Table C6).

The 2003 Saskatchewan weed survey reports relative abundance values for 2046 fields (Leeson et al., 2003). The most abundant species in the conventional survey were similar to the weed species found in the organic survey. The most abundant species in both the conventional provincial survey and the organic survey for the province was green foxtail (Table 4.3, Table 4.5). Wild oats were the second most abundant weed species, in the conventional survey followed by wild buckwheat, Canada thistle (CIRAR), and lamb's-quarters.

The organic fields in this survey had a high abundance of annual broad-leaved weeds such as wild mustard, wild buckwheat, lamb's-quarters and stinkweed. The annual broad-leaved weed populations in the 2002 organic survey were similar to the conventional weed surveys of the 1970 and 1980's. The conventional weed surveys conducted in Saskatchewan in 1976-1979, 1986, 1995 and 2003 have been summarized and show changing trends in relative abundance of weeds with different life histories over this three decade period (Leeson et al., 2003). The greatest decrease in annual broad-leaved weed density and relative abundance occurred over the 20 year, period from the 1970's to 1995. During these 20 years a major shift in conventional production in Saskatchewan occurred with producers adopting reduced tillage management practices such as direct seeding, increased pesticide use, lower frequency of fallow periods, and increased crop diversity. An increase in the relative abundance of perennial weeds in 1995 and higher than average perennial levels in 2003 was reported on conventional farms (Leeson et al., 2003); which could be due to the reduction in tillage.

Relative abundance of annual grassy weeds fluctuated with no overall trend over the 30 years of conventional weed surveys. The frequency and density of wild oats decreased from 1976 to 1995, whereas green foxtail increased slightly in frequency but density decreased markedly (Leeson et al., 2005). The horizontal leaf morphology of most annual broad-leaved weeds

Table 4.5 The ten most abundant weed species according to the conventional weed survey completed in 2003 (Leeson et al., 2003).

Conventional Saskatchewan Weed Survey 2003					
Relative abundance Rank	Weed Species	Relative abundance	Percent frequency	Percent uniformity	Field density (#/m^2)
1.	SETVI Green foxtail	67	43.5	17.9	10.6
2.	AVEFA Wild oats	42	50.9	16.7	3.7
3.	POLCO Wild buckwheat	29	50.8	13	1.4
4.	CIRAR Canada Thistle	17	34.8	6.9	0.7
5.	CHEAL Lamb's-quarters	15	22.0	0.2	1.3
6.	AMARE Redroot pigweed	12	17.3	3.4	1.1
7.	THLAR Stinkweed	11	18.0	3.7	1.0
8.	KCHSC Kochia	10	16.9	3.2	0.7
9.	TRZAS Wheat, spring	9	10.7	2.8	0.8
10.	SASKR Russian Thistle	7	11.8	1.7	0.5

make them easier to kill with the current application technology for herbicides whereas the vertical orientation and narrow leaf of grassy plants decreases the effectiveness of herbicide application.

Green foxtail was the most abundant weed in the 2002 organic survey and occurred in high densities. Large green foxtail populations in 2002 may be attributed to its ability to tolerate drought since many areas of the province experienced drought in the 2002 growing season. However, a Danish study found that no change in the frequencies of weed populations occurred even though there were substantial differences in climate over three years of weed sampling (Andreasen et al., 1991). This suggests that once a weed population is established, the seed banks continue to allow weed populations to propagate.

4.3.2 Determination of the relationship of weed species to management systems using redundancy analysis (RDA)

4.3.2.1 Detrended correspondence analysis

The results of the DCA determined that the maximum gradient length for the primary species matrix of the organic farm data was 3.577 standard deviations (data not shown). Because the gradient length was less than four standard deviations these data were best explained by a linear relationship. Redundancy analysis was therefore determined as the best analysis technique (ter Braak and Smilauer, 2002).

4.3.2.2 Redundancy analysis

The RDA solution had a single dimension solution; that is, only the first axis was significantly associated with the organic management systems (Table 4.6). The species and management systems based on the first axis explain 5.1% of the variation in the species data (Table 4.6). Even though only 5% of the variation is explained in this analysis, the Monte Carlo permutation test indicates that the analysis provides significant information about the patterns between the weed species and the management variables in the first axis. A high correlation indicated by a high percentage of variation, does not necessarily mean the species data are explained by environmental variables (ter Braak and Smilauer,

Table 4.6 Summary statistics from the redundancy analysis (RDA) with the results of the test of significance of the axes using the Monte Carlo test.

Statistics	Axis 1	Axis 2	Axis 3
p-value	0.003	1.000	1.000
F-ratio	3.735	1.054	0.753
Eigenvalues	0.051	0.014	0.010
Percentage variance of the cumulative species data	5.1	6.6	7.6
Percentage variance of species-management system relation	67.8	86.7	100

2002). The high *p*-values of axis two and three demonstrate that there is no information about the patterns in these data.

If the purpose of this study was to define where weed species occurred and why more environmental variable could have been included in the RDA. This could have accounted for a greater percentage of the variation in the weed data. However, the purpose was to determine the effect that various organic management practices had on the weeds present in the fields studied. A similar study conducted by Leeson (1998) found that 10% of weed species variance was explained by management factors. The management factors that affected the weed populations most were the use of herbicides and the use of perennials in rotation (Leeson, 1998). A study by study comparison of the percentage of variance accounted for is not valuable since the types of variables used and the species data are different. What is important from other ordination studies are the patterns that emerge from the data.

Ecological data is inherently noisy. Weed recruitment on arable land is complex; the determination of when, why, and where weeds occur is the resultant of many variables. Because of the complexity involved in the seedling recruitment of weeds it would be unexpected to be able to account for a high percentage of the variance. The complexity of weed seedling recruitment includes a mixture of biotic and abiotic, anthropomorphic and natural variables that add to the noise in species data. The noise in ecological data can make it difficult to determine meaningful patterns. However an ordination that explains even a low percentage of variance can provide important information (Gauch, 1982).

The purpose of ordination is to take complex data and simplify it to represent a lower-dimensionality (McCune and Grace, 2002). Only a small fraction of the variation will be explained if the variables entered in the matrix are largely independent of one another (McCune and Grace, 2002). The proportion of the variance represented tells us nothing about the sensitivity of the apparent pattern to the inclusion of particular rows or columns of the matrix (McCune and Grace, 2002). The strength of the pattern is represented against the null hypothesis, in this case that the management systems have no effect on the weed species distribution. The low *p*-value for axis 1 suggests that the null hypothesis is false and that the organic management systems did have an effect on the species of weeds present in the fields (Table 4.6).

4.3.2.3 Redundancy analysis diagram

Species scores and management systems were plotted as centroids and placed along the first axis (Figure 4.3). The greatest separation of the organic cropping systems along the first axis was explained by the crop rotation component of the management systems, specifically, the inclusion of perennial forages. Therefore, the separation of the weed populations along the axis was best explained by the inclusion of perennial crops.

The weed species most strongly associated with the inclusion of perennials in rotation included three of the seven perennial species: quackgrass (AGRRE), volunteer alfalfa (MEDSA) and dandelion (TAROF). The weed species most strongly associated with the positive side of the first axis were maple-leaved goosefoot (CHEHG), volunteer alfalfa and quackgrass. Smartweed (POLLA) was less strongly associated than the previous three but was more strongly associated than hemp-nettle (GAETE), dandelion and shepherd's purse (CAPBP), which also were associated with the inclusion of perennials in rotation. Lamb's-quarters, wild buckwheat and cleavers (GALAP) were more abundant in fields of the perennial cropping system. Species able to grow back after cutting multiple times in a growing season or else species with prostrate or rosette growth that are low enough to avoid cutting are able to survive in a perennial cropping system (Baker, 1974). In this study, these weed species include dandelion, alfalfa, and quack grass, all of these have species a perennial life history. Another weed species associated with perennials is hemp-nettle which is a serious competitor with cultivated crops and is known to form dense stands in pastures (Royer and Dickinson, 1999). This annual weed has a slender taproot making it able to compete effectively even with perennial stands. Four other annual weed species, shepherd's purse, wild buckwheat, maple-leaved goosefoot and smartweed, were associated with perennial crops. Wild

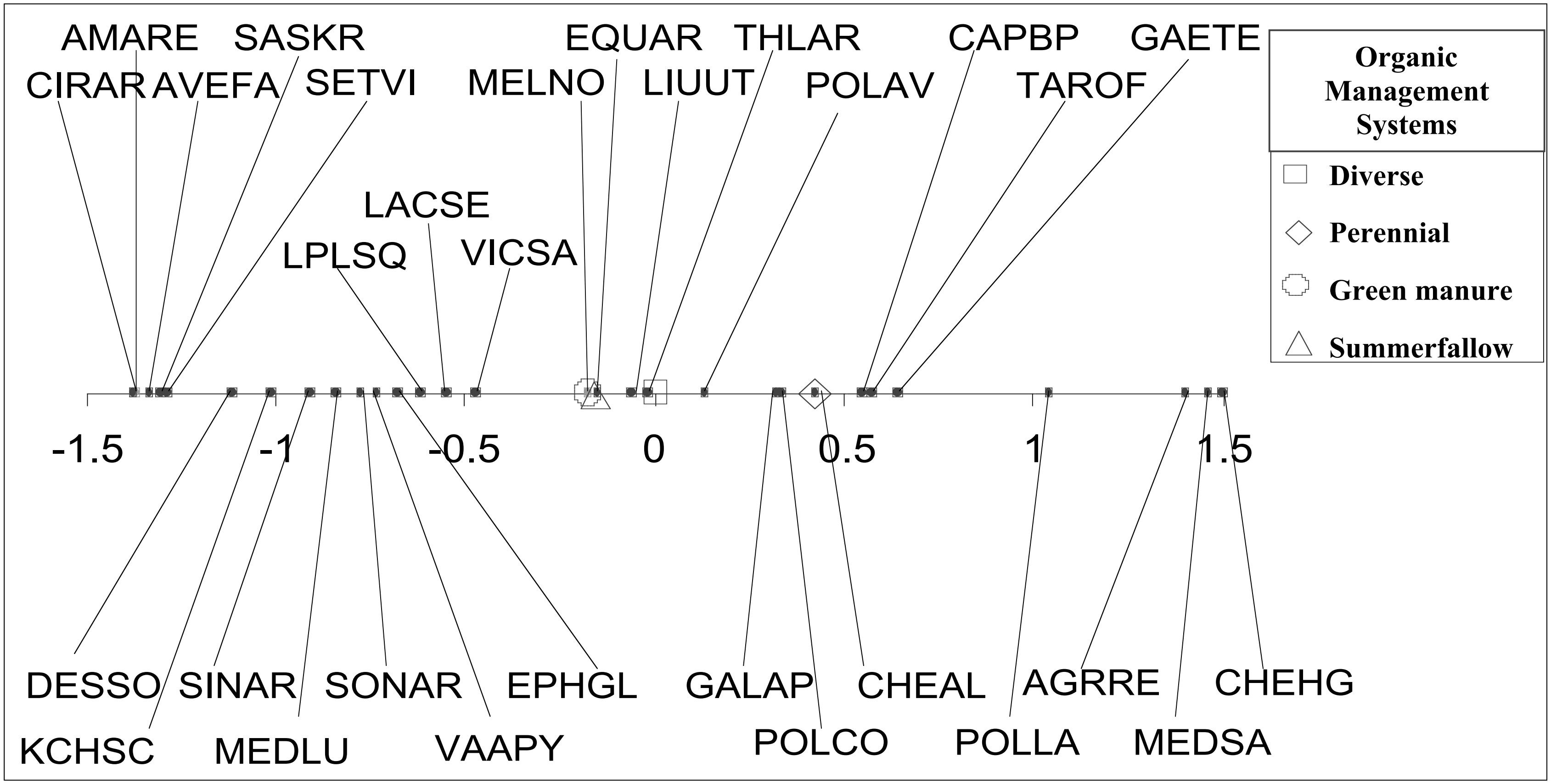

Figure 4.3 Ordination diagram of first axis of the Redundancy (RDA) for organically managed systems and their weed communities. Organic management systems are represented by the open shape symbols and the weed species are represented by the filled circles. Weed species' codes are defined in Table 4.1.

buckwheat is a stronger competitor than is shepherd's purse (Hume et al., 1983). Wild buckwheat's climbing habit allows it to get sunlight while growing in taller crops (Hume et al., 1983). Maple-leaved goosefoot is native to North America and smartweed is native to western North America (Royer and Dickinson, 1999) and therefore they may have adapted well to survive in perennial stands of grasses common in the grasslands. Maple-leaved goosefoot is a prolific seed producer, with long lasting seeds and commonly occurs in harsh growing areas like roadsides and in field edges.

Other studies have found the inclusion of perennial forage crops in rotation to be important to weed community composition (Cardina et al., 2002; Entz et al., 1995; Leeson et al., 2000; Légère and Samson, 1997; Ominski et al., 1999). The use of perennials in crop rotation was the most strongly correlated management practice in a Saskatchewan study of both conventional and organic farms (Leeson, 1998). The rotational benefits of forage crops have been well documented. A wheat crop following a perennial crop such as alfalfa had fewer weeds than wheat planted in a annual cropping system (Ominski et al., 1999). Producers realize the utility of forages to reduce weed populations. Eighty-three percent of producers surveyed in a Manitoba and Saskatchewan study indicated that the grain crops following forages had fewer weeds present (Entz et al., 1995). Specifically producers noted a reduction in wild oat, Canada thistle, green foxtail and wild mustard (Entz et al., 1995). Perennial crops in rotation have been shown to reduce weed seed production (Kegode et al., 1999).

The green manure and summerfallow systems are very closely related (Figure 4.3). Furthermore, the diverse system is also located close to the green manure and summerfallow systems along the first axis, indicating that in these three systems the weed species are not substantially different. The green manure and summerfallow systems are positioned on the negative side of the first axis. The weed species positioned on the negative end of the first RDA axis are species associated with these cropping systems.

The use of biennial clover species in the green manure system did not have a unique affect weed species on organic farms in Saskatchewan (Figure

4.3). Leeson (1998), however, saw a difference in weed populations with the use of green manure versus tillage systems such as summerfallow. Perhaps this contradiction can be explained by the increased use of tillage implemented in organic systems to terminate the growth of biennial species and to prepare the seedbed compared to conventional production. This may have negated the pattern seen in the Leeson study (1998), which looked at both organic and conventional sites. Wild oat, redroot pigweed (AMARE), lamb's-quarters, green foxtail, field horsetail (EQUAR), wild buckwheat, and stinkweed are species that are commonly found together in systems that include tillage (Sharma and Vanden Born, 1978). These species are all located on the negative side of the ordination diagram in the organic study except for lamb's-quarters and wild buckwheat.

One of the perennial weeds most strongly associated with the absence of perennial crop was Canada thistle. Canada thistle was one of the top ten most abundant weed species in the three cropping systems that did not include perennials in rotation. Canada thistle is a perennial herb with horizontal roots that spread rapidly and give rise to aerial shoots (Moore, 1975). Cultivation alone was not successful at deterring Canada thistle populations unless repeated at least in 21 day intervals, due to the ability of root fragments to produce aerial shoots (Moore, 1975). Repeated mowing weakens the plant's root reserves. Alfalfa, if harvested twice a year reduces the number of Canada thistle plants after one year and eliminated the weed after four years (Hodgson, 1969 in Moore, 1975). This explains the high association with the annual or biennial cropping systems and those systems that rely on tillage. Perennial sow thistle is the other perennial weed found in the absence of perennial crops. Canada thistle and perennial sow thistle reproduce with a wind dispersed seed (Moore, 1975). Perhaps these species are more prevalent in the annual systems because their seed could more easily establish on a tilled field with no crop growing on it in spring. Wind dispersed seeds, that is, seeds spread with a tumbling plant or seeds with a pappus (for wind dispersal) were all associated with the negative side of the ordination axis or were associated with the absence of perennials in rotation. The only exception was dandelion.

Green foxtail increases with shallow tillage in early spring followed by delayed seeding for wild oat control (Douglas et al., 1985). Summerfallow may delay population increases of green foxtail in drier areas but the population increases in the years following summerfallow (Alex and Switzer, 1972). Green foxtail is also highly influenced by soil texture. On fine textured soils in Saskatchewan the occurrence of green foxtail was only 6%, whereas on moderately coarse to coarse textured soils the occurrence was 77% (Douglas et al., 1985).

Russian thistle (SASKR), like green foxtail, was associated with the lack of perennials in rotation. Both weeds thrive in hot dry regions because they both photosynthesize using the C_4 pathway. Russian thistle, unlike green foxtail, was completely absent from fields that had perennials in their management system. The perennial system was only present in the Black and Gray soil zones of Saskatchewan. Russian thistle is a species found mostly in the Brown and Dark Brown soil zones of the province. Other species not found in the perennial management system were Russian pigweed, prostrate pigweed, cow cockle (VAAPY), barnyard grass and annual sow thistle.

The majority of weed species in this study produce large numbers of seeds and rely on seed production alone for survival. This type of survival strategy is known to be the successful strategy for weeds in arable cropland situations. The few species that are able to reproduce vegetatively occurred on opposite ends of the axis. Quack grass was associated with perennials in rotation. Quack grass is able to tolerate cutting whereas the other weed species capable of vegetative reproduction, Canada thistle and perennial sow-thistle, do not tolerate cutting and occurred at the opposite end of the negative side of the axis.

Wild mustard was found in high relative abundance in most systems. Although easily controlled with tillage, wild mustard is not often killed during pre-seeding tillage because the germination time of wild mustard and most cereal crops are very similar. An increased planting density of wheat reduced wild mustard populations (Mulligan and Bailey, 1975). In our management survey, the crop planting density question was very poorly answered and therefore was not part of the defining characteristics of the organic management systems. Although much of the literature published by the organic certification bodies encourages producers to increase planting densities, we do not know whether producers are implementing this practice or not. The high abundance of this weed species suggests the producers who wish to increase control should consider experimenting with increased planting densities.

Another effective strategy for weed control promoted by certification bodies is the practice of delayed seeding. Again this was a poorly answered question in the management survey and the management systems do not reflect planting times. Certain weed species are controlled well by this practice. By delaying spring wheat seeding, the stinkweed population was decreased by 90% (Best and McIntyre, 1975). Certain weed species have the ability to emerge over a wide time span. Black medick (MEDLU) for example, was documented to emerge after any disturbance from March to November in London, Ontario (Turkington and Cavers, 1979).

A western Canadian study of weed communities in conventional farming systems found that the factor that best determined the presence of weed populations was the soil type; however, they also found that management practices had a lesser, but measurable, effects on weed populations from the previous crop (Dale et al., 1992). Other practices found to affect weed populations are perennials in rotation (Entz et al., 1995; Leeson, 1998; Ominski et al., 1999), pesticide application and to a lesser extent tillage disturbances (Leeson et al., 2000).

4.4 Conclusion

This study examined the existent weed populations on certified organic land in Saskatchewan and used an ordination technique to associate the weed populations with different management systems. The only management system that caused a significant difference in weed populations was the inclusion of a perennial forage crop. Using perennials in rotation reduced the populations of weeds commonly associated with cereal rotations including green foxtail, wild oat, and Canada thistle. Although only 5.1% of the weed species variation was explained by the four management systems (diverse, diverse green manure, summerfallow and perennial systems), the ordination showed a significant pattern suggesting that management, specifically the inclusion of perennials, did affect the weed populations.

The knowledge that perennials in rotation change the weed community structure could be crucial for successful organic production. Weed control is a major deterrent to producers who are thinking about or involved in organic production. One of the major tenants of non-chemical weed control is the use of crop rotation. Changing the life history of the crop is one way to disrupt the growth habits of weed populations (Baker, 1974). With the disruption of weed populations, it is reasonable to hypothesize that the number or density of the weed species themselves would decrease with the changes in weed communities.

5 SOIL PROPERTIES OF FOUR ORGANIC MANAGEMENT SYSTEMS IN SASKATCHEWAN

5.1 Introduction

Organic producers can not use the synthetic fertilizers that their conventional counterparts use to replace the nutrients removed with the harvested crop. Organic farm management systems rely on preventative measures to manage nutrient cycling, that is slow acting or products that don't dramatically and instantaneously change the soil nutrient levels, instead of the reactive and instant solutions that conventional producers use (Watson et al., 2002a). Practices that are acceptable to the organic industry include the use of composted manure or other mineral soil amendments such as rock phosphorous or elemental sulphur (S). Fertility can also be enhanced through careful crop rotation. Specifically, the alternation of crops that require large amounts of certain nutrients, with crops that require less, allows for certain nutrients to become plant available. The use of a green manure crop in a crop rotation can add OM to the soil.

Organic producers in Saskatchewan are concerned about the soil fertility of their fields according to the Saskatchewan Agriculture and Food needs assessment (Jans, 2001). Producers ranked soil fertility as one of the top three research concerns. Soil phosphorous (P) was the nutrient that specifically concerned producers.

Nitrogen (N) has been shown to be the most limiting nutrient in both organic and conventional systems (Watson et al., 2002a). The main input for N in organic farming systems is N-fixing plants, although manure additions and the mineralization of SOM can provide additional sources of N (Watson et al., 2002b).

A Manitoba study found P levels on organic farms in Manitoba and eastern Saskatchewan to be limiting (Entz et al., 2001). The study found that those fields in organic production for long periods of time (>30 years) had the lowest available P levels.

The OM fraction of the soil is made up of non-decayed residues of plants or animals (Brady, 1974). Organic matter is made up of two fractions: the passive fraction (mostly made up of humus, including lignin, which is slow to breakdown) and the active fraction (sugars, starches and proteins, which degrade rapidly). These OM fractions both store cations to quickly supply some nutrients to growing plants and OM itself breaks down to slowly release nutrients. Organic matter is important for maintaining soil fertility (Stockdale et al., 2002) and improves the soil's health (Brady, 1974). Organic matter affects physical soil properties by increasing water holding capacity, granulation and reduces plasticity problems (Brady, 1974). Soil organic matter can have anywhere from 2-30-times the cation adsorption capacity compared to mineral colloids (Brady, 1974).

The objective of this study is to determine whether organic management systems affect soil properties. To achieve this objective, soil samples were taken prior to seeding from each certified organic fields in Saskatchewan included in the management questionnaire (Appendix A). Soil samples were analyzed for soil properties including soil macro-nutrients and basic soil properties such as pH, texture and EC. The soil properties were associated with the organic farm management systems (determined in chapter 3).

5.2 Materials and Method

5.2.1 Soil sampling

Soil samples were collected in the spring of 2002 prior to seeding. Sampling was performed in a "W" pattern across a field (adapted from (Thomas, 1985). On a uniform field, the first corner of the field encountered by the sampling team was the starting point. One hundred paces along the field edge and 100 paces into the field marked the first soil sample site. If the field was not uniform, care was taken to ensure that anomalies such as extremely steep slopes, potholes, ditches, bluffs, saline regions, oil wells, power lines, and paths were not sampled. The collection of a representative sample was considered to be more important than following a rigid collection regime. The sampling pattern and starting point were both recorded so as to repeat a similar sampling pattern for the weed survey done later in the season.

A hydraulically driven soil probe was used to collect soil samples. Each arm of the "W" contained four sampling points for a total of 16 sampling points per field (Figure 5.1). Soil cores were separated into three 15 cm sections up to a 45 cm depth. Each of the 15 cm cores from a specific depth were bulked together for three composite samples from each field. For the analysis of soil properties the two deeper depths (15-30 cm and 30-45cm) were bulked together to reduce cost of the analysis. The only exception was OM. Studies have found that the surface 15 cm of the soil showed treatment effects (Campbell and Zentner, 1993a). Therefore the deepest soil depth was not included as the surface depths were expected to be much richer in OM than soil from deeper in the profile.

5.2.2 Soil analysis

Determination of soil properties (pH, salinity, texture, and organic matter) and macro-nutrients (N, P, K, and S) followed standard procedures used in the Canadian prairies. The modified Kelowna method (Ashworth and Mrazek, 1995) was used to extract P and K from the soil samples. Ten grams of soil was mixed with 8 mL of the modified Kelowna solution and was shaken for approximately 30 minutes. The extract was analysed colormetrically for the P fraction with a Technicon auto analyser (Pulse Instrumentation Ltd., Saskatoon, Canada) and the K fraction with a SpectrAA 220 Varian flame atomic absorption spectrometer (Varian Australia Pty. Ltd., Mulgrave Victoria, Australia). A KCl extraction procedure (Keeney and Nelson, 1982) was used to obtain the nitrate and ammonium and sulphate extractable fractions. Ten grams of soil was mixed with 100 mL of 2 M KCL solution and was shaken for approximately 30 minutes. The soil extractants were analyzed colorimetrically (Technicon Industrial Method No. 325-74W, Tarrytown, N.Y. 10591) with a Technicon Auto

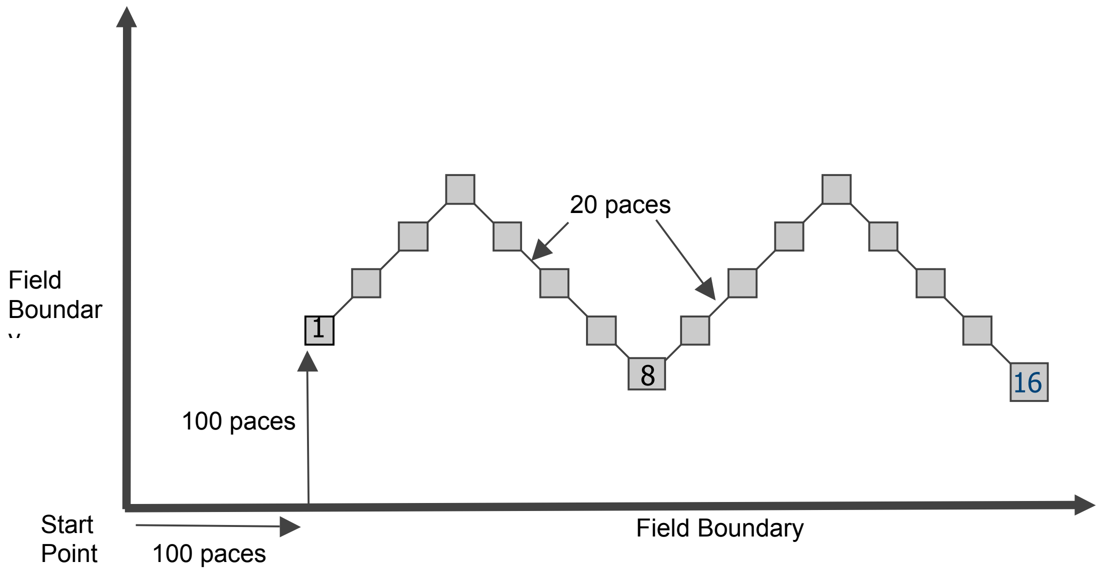

Figure 5.1 Soil sampling pattern used following the W-pattern modified from Thomas et al. (1985). Each square represents a position on the field from which a soil core was taken.

Analyser II (Pulse Instrumentation Ltd., Saskatoon, Canada) (Biederbeck et al., 1996; Wall et al., 1980).

Electrical conductivity (EC) and pH were determined with the saturated paste method (Rhoades, 1996). The pH reading was done with a Radiometer Copenhagen PHM82 standard pH meter (Corning Medicare and Scientific Instruments, Essex, UK) after the soil/water pastes had soaked overnight. The sample kept at room temperature (25^{o}C) was then vacuum filtered and the extractant was measured for salinity with an EC meter Radiometer Copenhagen CDM83 (Corning Medicare and Scientific Instruments, Essex, UK).

Texture was determined by the hydrometer method. The method is dependant on Stoke's Law or the principle of sedimentation, in order to determine the sand, silt, and clay fractions. Proportions of sand, silt and clay were then applied to the Canadian classification system referred to as the texture triangle (Gee and Bauder, 1986).

Organic matter was determined with the dry combustion method. The Leco CR-12 carbon determinator (LECO Corporation, St. Joseph, MI, USA) was set to combust the sample at 804^{o}C. The combustion method measures the organic carbon (C) in the soil sample. Because C is the principle element present in SOM a mathematical constant can be used to determine the OM (Nelson and Sommers, 1982). The percent organic C value from the carbon determinator was entered in to the equation

$$\text{\% organic matter} = 0.35 + (1.80 \times \text{\% organic C}) \quad (5.1)$$

to determine the percent organic matter (Nelson and Sommers, 1982).

5.2.3 Statistical analysis

Fields were grouped into the four organic management systems: diverse, diverse green manure, low diversity summerfallow and moderately diverse perennials (Chapter 3). Each field and its corresponding soil property data were analyzed using the Kruskal-Wallis test, a non-parametric one-way analysis of variance by ranks, run with SAS (version 9) (SAS Institute Inc., 1996). Non-parametric statistics were required because the population was non-normal and the sample size was relatively small. The Kruskal-Wallis test was used to determine whether there were significant differences in soil properties between the four organic cropping systems. Soil properties were defined as significant if the probability of a Type I error (α) was less than 0.1. A typical significance level of 0.05 is often used in experimental situations with controlled parameters. Because of its survey nature, a higher significance level of 0.1 was used in this study in the hope of identifying more differences in soil properties between the identified organic systems. The soil properties that were significantly different were further analyzed with SAS (version 9) (SAS Institute Inc., 1996) using a multiple comparison test of the median for each organic management system to determine where significant differences occurred. Median values are used often in surveys where outliers can easily distort the mean (Gomez and Gomez, 1984).

5.3 Results and discussion

5.3.1 Association of soil properties with the different organic farming systems

Eight soil properties displayed significant differences in the four organic farming systems (Table 5.1). These properties included: pH in the top 15 cm of the soil sample, electrical conductivity (at both depths, 0-15 cm and 15-45 cm), organic matter in the deeper profile (15-30 cm range), P and K levels (both nutrients at both depths, 0-15 cm and 15-45 cm). The system that was significantly lower compared to the other three systems for all eight soil properties was the moderately diverse perennial system. The diverse green manure system and the low diversity summerfallow were not significantly different from one another for any of the eight soil properties. The highly diverse crop rotation was significantly different from the perennial rotation in all cases except the deep P level.

Soil texture (percent sand, silt and clay) did not differ between the four organic management systems. The type of management system chosen by producers did not seem to be affected by the soil texture. The management systems therefore were representative of the effect of management not the inherent soil properties. Soil texture varies throughout the province, the most common texture in this survey were the loam particle-size classes.

Table 5.1 Median soil properties values of the four different organic management systems of Saskatchewan.

Soil properties	Organic management systems				
	Diverse	Diverse green manure	Low diversity summerfallow	Moderate diversity perennials	Kruskal-Wallis *P*-value
Clay (%)	23	22	20	22	0.6713
Sand (%)	37	41	44	43	0.5953
Silt (%)	32	34	38	32	0.5462
pH 0-15 cm	**7.3**	**7.5**	**7.5 ab**	**6.7 c**	**0.0002**
pH 15-45 cm	7.6	7.6	7.7	7.2	0.1366
EC dS/cm 0-15 cm	**0.8**	**0.9**	**0.7 a**	**0.6 b**	**0.0245**
EC dS/cm 15-45 cm	**0.7**	**1.6**	**1.2 ab**	**0.6 c**	**0.0109**
O.M. g kg^{-1} 0-15 cm	4.3	3.0	4.0	4.5	0.4216
O.M. g kg^{-1} 15-30 cm	**1.7**	**1.9**	**1.8 a**	**1.4 b**	**0.0323**
NO_3 mg kg^{-1} 0-15 cm	28	21	14	14	0.3288
NO_3 mg kg^{-1} 15-45 cm	6	9	6.5	6	0.1512
NH_4 mg kg^{-1} 0-15 cm	3	3	3	3	0.8234
NH_4 mg kg^{-1} 15-45 cm	3	3	3	3	0.9758
P mg kg^{-1} 0-15 cm	**17 a**	**18 a**	**16 a**	**12 b**	**0.0781**
P mg kg^{-1} 15-45 cm	**13 ab**	**15 a**	**14 a**	**9 b**	**0.0339**
K mg kg^{-1} 0-15 cm	**670 a**	**830 a**	**705 a**	**400 b**	**0.0006**
K mg kg^{-1} 15-45 cm	**420 a**	**400 a**	**415 a**	**300 b**	**0.0398**
S mg kg^{-1} 0-15 cm	4	3	6	3	0.7688
S mg kg^{-1} 15-45 cm	4	22	19	4	0.2915

The p-values from the Kruskal-Wallis test compares the soil property levels among the four organic management systems and are listed for each soil property. Significant differences ($P < 0.1$) are presented in bold and the median values show the result of a multiple comparisons test of the median with lower case letters to determine which system(s) displays a significantly different soil property value.

The moderately diverse perennial system had significantly lower pH compared to the other three management systems in the top 15 cm of the soil. Any change in pH would most likely occur on the surface of the soil since processes of weathering and any soil additions affect the surface soil. Soil pH changes occur with the displacement of cations or the addition of acidity (Havlin et al., 2004). Long term use of forage legumes in rotation has been shown to dramatically lower soil pH (Robertson, 1992 in Entz et al., 2002). Not only perennial systems have been found to affect pH levels, studies comparing organic systems to conventional systems have found significantly higher pH levels, to a depth of 30 cm, in the organic systems (Clark et al., 1998). In the organic system studied by Clark et al. (1998) manure applications and cover crops were used, and both practices were found to increase pH levels due to the addition of cations. Perhaps this explains the higher levels of pH the diverse green manure compared to the diverse systems.

None of the soils tested were considered saline. However the system containing perennial forages had a significantly lower EC than the other organic management systems. Alfalfa is a heavy water user; its deep roots can reduce the effects of salinity by reducing the height of the water table so that salts are unable to rise to the soil surface with evaporating water. The heavy water use is not desirable in dry climates and may be the reason that no producers in the Brown and Dark Brown regions of Saskatchewan grow alfalfa in their rotations as it can induce drought effects. The median EC values were significantly higher in the 15-30 cm depth for both the diverse green manure system and the low diversity summerfallow system. The practice of green manuring is similar to a summerfallow treatment since a green manure field is left fallow for half of the growing season. Although summerfallow does not cause salinity, summerfallow can make a soil salinity problem worse by allowing subsoil salinity to translocate to the surface via evaporation (Henry, 2003). Salinity is low in all systems and overall does not seem to be a limiting factor to organic production in Saskatchewan.

In this study, organic matter levels at the 0-15 cm depth were similar in all organic management systems. However, it is interesting to note that the rotation that includes the practice of green manuring had the lowest median organic matter value, although it is not significantly lower. This is of interest since one would expect the addition of a green manure crop to increase organic matter levels. Because many of these surveyed producers have not been certified organic for a long period of time perhaps their rotations have not existed long enough to induce a change in soil organic matter levels. Studies have also found that dry years directly correlate to a reduction in soil organic matter. Because crop residues directly influence soil organic matter, a poor crop means less crop residue is returned to the soil and therefore either a reduction, or at least no increase in SOM would be realized (Campbell and Zentner, 1993a). The year of the study (2002) and two years prior were drought years in most of the prairies; this too may have contributed to the low SOM levels in the green manure system.

A difference was seen in the level of organic matter at the 15-30 cm depth. The moderately diverse perennial system had the lowest organic matter level in the deeper layer. Other studies have found that only the surface 15 cm showed treatment effects (Campbell and Zentner, 1993a). The overall levels of SOM analyzed found greater OM levels in the surface (0-15 cm) soil compared to the lower (15-30 cm) depth.

A study in organic systems measured increased OM levels over time (Campbell and Zentner, 1993a). However OM changes occur slowly (Campbell and Zentner, 1993a) and in certain circumstances, practices such as green manure crops, do not improve OM levels. In places such as Melfort Saskatchewan, where moisture is rarely limiting OM levels are high and when green manure crops are used they do not significantly raise the organic C of the soil (Campbell et al., 1991a). However in the drier regions of Indian Head, SK and Lethbridge, AB green manuring significantly improved the SOM level (Campbell et al., 1991a).

The final set of measured soil properties were N, P, K and S. In this study, N and S levels are not significantly different between the four organic management systems. Phosphorous and K levels are significantly lower in the moderately diverse perennial system.

Nitrogen levels in table 5.1 appear to show differences between the systems; however, because of the wide range of N levels across all the systems there is no significant difference detected. Nitrogen is the most limiting nutrient in both conventional and organic systems (Berry et al., 2002). In an organic system where nitrogen is not added in large amounts but rather slowly released from the organic matter present in the soil, it is not surprising that any available soil N present would be taken up and fixed in the plant material. Many organic producers use leguminous plants that fix atmospheric N to provide soil N into their system. Ideally, in organically managed systems, rotations should be thought of in terms of N depleting and N increasing cycles (Berry et al., 2002). Nitrogen depleting cycles include the harvest of any crop. Removal of plant biomass or the seed, removes large amounts of N. The N increasing cycle would be the addition of N-rich plant material such as a green manured legume or the addition of N-rich animal manure. Twenty percent of the N produced by a green manured legume crop is taken up by succeeding crop in the first year (Biederbeck et al., 1996). Nitrogen levels are also the greatest in the first year following alfalfa termination (Mohr et al., 1999). Because the green manure systems are all at different points in their rotation, the possible effect of a leguminous crop providing increased nitrogen could be hidden since it may be up to four years since the leguminous crop was planted on the sampled field. It is therefore important to have N increasing cycles often in rotation.

Soil S levels vary greatly. The northern region of Saskatchewan is known to show S deficiencies for crops that require large amounts of S, such as canola (Wen et al., 2003). The lowest S levels, although not significantly different, are seen in the perennial forage stands, which are located in the two most northern soil zones.

A significant difference in the levels of P and K is present between the perennial management systems and the other management systems. Forage legumes are known to remove minerals from the soil at a high rate (Entz et al., 2001). Specifically P (Campbell and Zentner, 1993b) and K depletion was exacerbated with the inclusion of forages in rotation (Campbell et al., 1990).

Macro-nutrients tested on organic farms in the Northern Great Plains had sufficient levels of N, K and S, but P levels were deficient (Entz et al., 2001). Nutrient budgets studied in other organic systems have documented that the greatest amounts of P and K were received from manure applications (Clark et al., 1998). Other studies of organic systems have found that animal manure is the most common amendment applied to the soil (Berry et al., 2002). However this study found that only 7 of 73 fields received manure applications (Appendix A, Table A.31). No field tested had a sufficient level of P according to prairie averages provided by NorWest Labs (Appendix D, Table D.2). There is controversy in organic research about whether tests taken at one point in time, sampling for the currently *available* nutrients is representative of what is actually available to plants growing in an organic system where perhaps more nutrients are continually becoming available via mineralization. A long term study of organic systems located in Switzerland found reduced levels of inorganic P in the soil solution in the organically managed system (Mäder et al., 2002). However, when the flux of P was measured between the soil matrix and soil solution they found that the organic system had a higher flux. Because P is cycled via microbes it is believed that the higher overall microbial activity in organic systems as measured by dehydrogenase, protease, and phosphatase activities explain the increased flux of P (Mäder et al., 2002). This fluctuation in P via the soil matrix through the microbial population to the soil solution is believed to contribute to the plants' P supply. It is important to note that Mäder's organic system included manure applications and a legume-based crop rotation (Mäder et al., 2002). Organic management systems have the potential to supply adequate nutrient levels (Berry et al., 2002; Stockdale et al., 2002). Green manure crops and legumes are important but without the inclusion of livestock, the successful long term management of nutrients is difficult (Berry et al., 2002).

Soil nutrients and other soil properties were measured at one point in time. It is important to note that this 'snapshot' is not representative of the dynamics of nutrient flow in these organic systems. Research is required over a long period of time to determine whether the nutrient and soil properties of these soils are affected by the management system producers use.

5.4 Conclusion

This study found that management systems did affect certain soil properties. Soil properties such as pH, EC, OM, plant available P, and K were all reduced in the moderate diversity perennial system. Electrical conductivity was higher in the 15-30 cm depth increment in the green manure and summerfallow systems. The soil properties that were unaffected by management were soil texture, plant available N and S. Every field sampled was deficient in P. The fields that had the lowest levels of P were from the moderately diverse perennial forage crop system.

6 GENERAL DISCUSSION

The purpose of this study was to respond to Saskatchewan Agriculture and Food's call for research into the practices used by the organic industry of Saskatchewan to control weed populations and to maintain soil fertility. Forty-four producers shared information on their farm management techniques. These producers were all passionate and committed to the production of food-grains without the use of chemical additions and were excited to be involved with research that was focused on analyzing their systems as a legitimate and complex farming practice. They were willing to participate by allowing researchers to peer into their systems and critique its various components. The initial part of the study identified four unique organic systems, defined by the producer's management practices. The weed and soil characteristics were analyzed against these four systems to determine if certain systems preformed better in managing these farm components.

This survey did not produce a glowing report of the health of the soils' with regards to nutrient status. The perennial cropping system was significantly lower in most soil nutrients. None of the management systems were able to maintain a nutrient level that was at or above the estimated 'optimum' level of N, P, K or S to produce a wheat crop as estimated by NorWest Labs. However other research on organic systems has shown that soil fertility can be improved if animal manures or other amendments are used to counteract the loss of nutrients that occurs with harvest and cultivation of the soil. Cultivation of the soil for the purpose of grain production removes nutrients and reduces organic C by about 1% per year of cultivation for up to 70 years (Tiessen et al., 1982). In order to best maintain nutrient levels, the importance of livestock as a crucial component of the agro-ecosystem cannot be overlooked. Organic producers need to ask themselves what is required in order to reach a balance to put back the nutrients that are removed in an export cropping system.

The survey of Saskatchewan organic farmers reported that less than five producers used some kind of mineral soil amendment. According to this survey of organic fields in Saskatchewan and according to Entz et al. (2001) survey on organic fields in Manitoba, the nutrient levels of organic fields are critically low for crop production. This should be of great concern for organic producers on the prairies. Although research has reported that organic matter can be increased in organic systems (Mäder et al., 2002; Reganold et al., 1987; Watson et al., 2002a) it is important to note that all of these studies were done on small scale research sites and that manure application was a component of the organic management practices used. In this survey, although 48% of producers had cattle on their farm, less than 10% used their manure as a soil amendment on the fields surveyed. This raises serious questions of the sustainability of organic farming in Saskatchewan without animals as part of the agronomic system.

Sustainability is a crucial aspect of organic farming according to most definitions; therefore, the current practices being applied to organic farms ought to be talked about in terms of sustainability. Sustainable agriculture is defined as production practices that over the long term will provide human food and fiber needs, enhance environmental quality and the natural resources upon which the agricultural economy depends, efficiently use the non-renewable resource and on-farm resources, sustain the economic viability of farm operations and finally enhance the quality of life for farmers and society as a whole (Congress, 1990) in (Wyse, 1994). Sustainability, specifically with regard to the soil environment, was particularly disturbing according to this study.

The ability of a system to effectively compete with weeds is another important component of creating a viable and sustainable system of production. Weeds can cause major crop yield losses. This survey found weed population densities to be higher than the densities reported in the Saskatchewan conventional weed survey. Many of the weed control techniques used in organic production such as in-crop tillage or delayed seeding were not a significant factor separating the organic systems. These management practices may affect weed populations more than this study indicated as the lack of correlation may be due to poor answers to the survey questionnaire. The statistical analysis may have been unable to detect differences because not enough producers used the techniques.

The one promising management practice was the inclusion of perennial forages such as alfalfa in rotation to control weeds. The use of a perennial in an otherwise annual cropping system changes the weed selection pressure. This disrupts the weed populations present and results in a method of controlling otherwise difficult to control weed in annual crops (wild oats is one such example). Entz et al. (2002; 1995) has encouraged the use of perennial forages on the prairies for years. It is not a new concept but unfortunately because dairy, swine and beef operations are moving to fewer and larger operations so that animals are no longer a regular component of the average farm there is less demand for alfalfa (Wyse, 1994). Wyse (1994) points out some non-feed uses for alfalfa such as plastics, pharmaceuticals, paper pulp or electrical production might increase the demand for alfalfa in the future. However, there is not yet a demand for alfalfa outside of livestock feed; therefore, producers themselves must determine whether it is a viable crop to be grown or not. The benefits of this forage are significant and hopefully it is a practice that can be increased in producer's rotations especially on organic farms.

Although the rotational benefits of forages are understood largely in western Canada, it is important to note that the use of certain forages such as alfalfa may not be appropriate in all regions of Saskatchewan. The only perennial forage seen in our survey was alfalfa. The use of alfalfa in rotation enhanced grain yields in the moister Black and Gray regions; however, in the Brown and Dark Brown soil zones crop yields can be reduced due to lack of moisture (Weir and Matthews, 1971) in (Entz et al., 1995). There are other perennial forage crops such as various grass species that may be appropriate in the southern portion of the province. Research on other perennial forage crops for the southern portion of the province would be valuable to determine if the same weed control benefits exist for another perennial more appropriate for the south. The benefits of perennial forage are not limited to changing the life history of the plants in a field; perennials also have the ability to stabilize soil by reducing soil erosion. Benefits from variation in crop rotation are not limited to the inclusion of perennials. Annual forage crops can also provide weed control due to the earlier harvest time as compared to an annual cereal crop. Even a single year annual forage crop was shown to provide weed control (Schoofs and Entz, 2000).

The Saskatchewan organic industry uses practices like green manuring and crop rotations to control weeds and manage fertility. These are seen as good management practices that minimize the need for intensive tillage operations. The survey documented that a large number of organic producers are still reliant on summerfallow in their rotations. The practice of summerfallow involves many tillage passes and has been shown to reduce organic matter and increase the erosion of soil (Campbell and Zentner, 1993a; Rice et al., 1993).

Weed scientists are encouraging their peers to keep agronomic solutions broader than the herbicide driven research that dominates the weed science research field (Kropff and Walter, 2000; Wyse, 1992; Wyse, 1994). Studying systems requires more time and consistently sound production instead of a chemical ‘quick fix’. If weed research in Canada focused more on weed management instead of weed control, which is almost solely focused on chemical pesticide use, perhaps there could be more helpful solutions to organic producers. Perhaps new research work on agronomic principles in organic situations such as seeding rates, multiple seeding passes and seed direction, crop varieties and competitiveness, and intercropping might lead to more effective strategies for the management of weeds on organic farms. Biological pest control methods are being researched in the prairies and are a promising solution to weed problems in organic situations.

Agriculture is shifting in the Canadian prairies. Farms are disappearing at a rapid rate and profit margins are tighter than ever before for producers (Lind, 1995). The green revolution that was fuelled by scientific research with the discovery of pesticides in the 1950's and the improvements in breeding programs have succeeded in creating a surplus of food-grains in the world. The producers I met in my research were less interested in improving yields and were more interested in creating a healthy, high quality product that gave them a fair monetary return and allowed them to follow their ethics, protect their own health and allow them to continue farming. Organic production with its current premium prices is a viable alternative for some family farms. The strength of organic production is that it is an accepted, profitable, alternative to conventional production that provides many producers and their families' financial stability while reducing their exposure to chemical pesticides.

Organic producers require a high level of management skills. Producers must work harder than their conventional counterparts to seek out agronomic production information because there are still relatively few organic farmers in the province (2% of farms in Saskatchewan are organic) and one of the important sources of information to producers comes from agronomists hired by the local chemical and fertilizer company. The tools that organic farmers have in their agronomic arsenal involve many conventional practices such as manure application and careful crop rotation. However, in addition, organic producers also have practices that are often unique although not exclusive to their management system such as the practice of green manuring. This research suggests that for farms in the northern region of Saskatchewan including alfalfa in rotation is beneficial for weed control. Alfalfa takes up large amounts of P and K and so the use of animal manures would be beneficial to ensure productive soil nutrient levels. The southern regions of the province due to their drier climate do not benefit from alfalfa in rotation. However, the inclusion of another perennial crop or forage crop could make a difference in managing weed populations. These producers would also benefit greatly by the inclusion of animal manures being incorporated into their systems.

The question remains: which, if any, of the organic systems identified best meet the goals of the organic definition by creating a sustainable, healthy and productive environment? None of the defined systems was a silver bullet answer to the common problems of weed control and fertility management in organic systems. Perennial crops in rotation with annual crops are best able to reduce the number of weed species. The management of soil nutrients requires action on the part of organic producers. Many producers use green manure crops; however, this practice did not improve the soil conditions according to this survey. A more proactive approach is required to maintain the soil's fertility. It is this author's opinion that the use of animal manure would greatly increase the sustainability of all of the organic production systems.

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APPENDICES

Appendix A: Organic grower's management survey

2001 Organic Grower's Management Survey

University of Saskatchewan

INTRODUCTION:

The 2001 Organic Grower's Management Survey is being conducted by the University of Saskatchewan with funding from Saskatchewan Agriculture and Food. The purpose of the survey is to gather information about organic management techniques aimed at maintaining/improving soil fertility and weed management. The information will be used to **identify appropriate areas of research**, from which research results will be made available to farmers. In most cases two fields were identified in an initial telephone contact. These same fields will be soil sampled and surveyed for weed populations in the Spring/Summer of 2002. Please complete a separate survey for each field.

1. Please read all questions carefully and answer as many questions as possible. Even a partially completed question is useful.

2. Answer the questions only as they apply to the field **location** and **crop** shown below on the label. These fields were identified through the initial telephone contact, when you agreed to participate in the survey.

Legal Land Description: Site Number:
Field Number or Description:
Crop: Acreage:

SECTION A: Cropping Practices

A1. What crop (including variety) was planted in the survey field in **2001?**

____

A2. What was the seed source for the crop planted in the survey field in **2001?**

☐ Homegrown ☐ Certified seed purchased ☐ Other farmer

A3. Was the seed used in **2001** treated (including inoculants)?

☐ No *Continue with question A4*
☐ Yes *If yes, please provide details of any products used:*

Product	Anticipated Benefits (eg., N fixation)	Success (1=Very poor to 5=Very good)
________________	_________________________	1 2 3 4 5
________________	_________________________	1 2 3 4 5
________________	_________________________	1 2 3 4 5

A4. When was the **2001** crop seeded in the survey field?

Month ______________ Day _________

A5. What seeding rate was used for the **2001** crop in the survey field?

_____ bu/acre or _____ lb/acre or _____ plants/m^2 or _____ plants/ft^2

A6. What depth was the crop seeded in the survey field in **2001?**

- ☐ Broadcast
- ☐ Less than 1 inch
- ☐ 1 to 2 inches
- ☐ Greater than 2 inches

A7. What row spacing was used to seed the crop in the survey field in **2001?** ___________inches

A8. Which system was used to seed the crop in the survey field in **2001?**

- ☐ Air seeder
- ☐ Broadcast and harrowed
- ☐ Gravity feed drill box
- ☐ Broadcast and cultivated
- ☐ Precision seeder
- ☐ Other (specify)__________

A9. What type of opener was used to seed the crop in the survey field in **2001?**

- ☐ Double disc
- ☐ Knife (1 inch or narrower)
- ☐ Discer
- ☐ Hoe
- ☐ Spoon (2 to 5 inches wide)
- ☐ Other (specify)_________________
- ☐ Offset single disc (Barton)
- ☐ Sweeps (5 inches or wider)

A10. Was any other equipment used in seeding the crop in the survey field in **2001** (check all that apply)?

- ☐ None
- ☐ On-row packing
- ☐ Tine harrow
- ☐ Other (specify)_________________
- ☐ Fluted coulters
- ☐ Harrow packer
- ☐ Rotary harrow
- ☐ Smooth coulters

A11. What was the estimated yield of the survey field in **2001?**

bu/acre or lb/acre __________________

A12. How did you handle the crop residue on the survey field in **2001?** (check all that apply):

☐ None ☐ Chopped ☐ Chaff collected ☐ Baled ☐ Burned ☐ Grazed

SECTION B: Tillage Practices

B1. Was the survey field tilled **after harvest** in the fall of **2000?**

- ☐ No *Continue with question B2*
- ☐ Yes *If yes, specify the number of times that you used each implement:*

Implement	**# of times**	**Implement**	**# of times**
Cultivator (heavy duty-spikes)		Heavy harrow	
Cultivator (heavy duty-sweeps)		Harrow	
Cultivator (field)		Harrowpacker	
Tandem disc (3" deep or less)		Rodweeder	
Tandem disc (more than 3" deep)		Packer	
Moldboard plough		Other (specify)__________________	
Discer		Other (specify)__________________	

B2. Was the survey field tilled **before seeding** in the spring of **2001?**

- ☐ No *Continue with question C1*
- ☐ Yes *If yes, specify the number of times that you used each implement:*

Implement	**# of times**	**Implement**	**# of times**
Cultivator (heavy duty-spikes)		Heavy harrow	
Cultivator (heavy duty-sweeps)		Harrow	
Cultivator (field)		Harrowpacker	
Tandem disc (3" deep or less)		Rodweeder	
Tandem disc (more than 3" deep)		Packer	
Moldboard plough		Other (specify)__________________	
Discer		Other (specify)__________________	

SECTION C: Weed Management

C1. Were any operations used in the survey field to control weeds **after seeding and before crop emergence** in **2001?**

☐ No *Continue with question C2*
☐ Yes *If yes, specify the number of times that you used each implement:*

Implement	# of times	Implement	# of times
Rod weeder		Heavy harrow	
Rotary harrow		Tine harrow	
Diamond-toothed harrow		Other (specify)________________	

C2. Were any operations used in the survey field to control weeds **after crop emergence** in **2001?**

☐ No *Continue with question C3*
☐ Yes *If yes, specify the number of times that you used each implement:*

Implement	# of times	Implement	# of times
Inter-row cultivator		Heavy harrow	
Rod weeder		Tine harrow	
Rotary harrow		Flex-tine harrow	
Diamond-toothed harrow		Other (specify)________________	

C3. Which troublesome weeds were you trying to manage in the surveyed field?

Most Troublesome 1. ____________________________________
2. ____________________________________
3. ____________________________________
4.____________________________________
Less Troublesome 5. ____________________________________

C4. Please rate the following practices as to their usefulness for weed management on your farm.

Practice	Not useful at all				Very useful	
Rotate crops	1	2	3	4	5	_____ Not applicable
Grow competitive crops	1	2	3	4	5	_____ Not applicable
Grow competitive varieties	1	2	3	4	5	_____ Not applicable
Grow green manure crops	1	2	3	4	5	_____ Not applicable
Use fall tillage	1	2	3	4	5	_____ Not applicable
Use spring tillage	1	2	3	4	5	_____ Not applicable
Use post-seeding tillage	1	2	3	4	5	_____ Not applicable
Mow weed patches	1	2	3	4	5	_____ Not applicable
Cultivate field edges	1	2	3	4	5	_____ Not applicable
Hand weeding	1	2	3	4	5	_____ Not applicable
Narrow row spacing	1	2	3	4	5	_____ Not applicable
Increase seeding rate	1	2	3	4	5	_____ Not applicable
Vary seeding date	1	2	3	4	5	_____ Not applicable
Clean equipment	1	2	3	4	5	_____ Not applicable
Tarp trucks	1	2	3	4	5	_____ Not applicable
Collect chaff	1	2	3	4	5	_____ Not applicable
Fall or spring grazing	1	2	3	4	5	_____ Not applicable
Delayed seeding	1	2	3	4	5	_____ Not applicable
Inter-cropping	1	2	3	4	5	_____ Not applicable
Inter-row cultivation	1	2	3	4	5	_____ Not applicable
Weed clipping above crops	1	2	3	4	5	_____ Not applicable
Mowing annual crops	1	2	3	4	5	_____ Not applicable
Summer fallow (no cover crop)	1	2	3	4	5	_____ Not applicable
Night tillage	1	2	3	4	5	_____ Not applicable
Tillage timed to lunar phase	1	2	3	4	5	_____ Not applicable
Flaming	1	2	3	4	5	_____ Not applicable
Soil inoculants	1	2	3	4	5	_____ Not applicable
Other: _______________________	1	2	3	4	5	_____ Not applicable
Other: _______________________	1	2	3	4	5	_____ Not applicable

C5. Please rank the top three management practices from above. Which of the practices in question C4 are the **MOST USEFUL** on your farm?

#1 ____

#2 ____

#3 ____

SECTION D: Insect and Disease Management

D1. Were any of the following practices used specifically for insect control on the survey field in **2001?** (check all that apply)

- ☐ Resistant crop
- ☐ Modified seeding date
- ☐ Residue removal
- ☐ Insect hormones
- ☐ Crop rotation
- ☐ Modified seeding rate
- ☐ Tillage
- ☐ Biological control
- ☐ Trap or guard strips
- ☐ Other (specify)_______________________________

D2. Were any of the following practices used specifically for disease control on the survey field in **2001?** (check all that apply)

- ☐ Resistant crop
- ☐ Modified seeding date
- ☐ Residue removal
- ☐ Tillage
- ☐ Crop rotation
- ☐ Modified seeding rate
- ☐ Other (specify)____________________

SECTION E: Fertility Practices

E1. Was animal manure applied to the survey field in the last five years (**1997 to 2001**)**?**

- ☐ No *Continue with question E2*
- ☐ Yes *If yes, provide details in the table below.*

Year	Time of application *(fall, spring, in-crop)*	Type *(e.g. cattle, swine, poultry)*	Acres treated	Amount applied	Source *(on-farm, off-farm)*	How long was manure composted? *(months)*
2001						
2000						
1999						
1998						
1997						

E2. Was a crop grown on the survey field specifically as a green manure crop in the last five years **(1997 to 2001)?**

☐ No *Continue with question E3*
☐ Yes *If yes, provide details in the table below*

Year	Green Manure crop grown (including variety)	Grown for weed control (yes/no)	Target weed(s)	Grown for fertility improvement (yes/no)	Approximate crop stage at termination	Method of termination
2001						
2000						
1999						
1998						
1997						

E3. Were any other products applied to the surveyed field to improve **soil fertility** (eg. gypsum, borax, extracts etc.) from **1997 to 2001?**

☐ No *Continue with question E4*
☐ Yes *If yes, provide details in table below. Please be as specific as possible regarding brand names, manufacturer and ingredients.*

Year	Time of application *(fall, spring, in-crop)*	Product *(e.g. gypsum)*	Acres treated	Rate of the product applied *(e.g. 30 lb/acre)*	Placement *(broadcast, banded, seed placed, foliar)*
2001					
2000					
1999					
1998					
1997					

E4. Were any of the products identified in E3 applied **specifically to improve phosphorous fertility**?

☐ No *Continue with question F1*
☐ Yes *If yes, indicate which one(s)* ____
____
____
____

SECTION F: Field History - the same set of questions are asked for the last five years (2000, 1999, 1998, 1997, and 1996).

F1. What crop (or summer fallow) was grown on the surveyed field in **2000?**________

F2. What was the **principal** reason for growing this crop in **2000?**

☐ Grain/seed production (i.e., harvest removal)
☐ Forage production (i.e., harvest removal or grazing)
☐ Green manure for improving fertility
☐ Weed control
☐ Other (specify)____

F3. What date was the field seeded in **2000?**__________________________________

F4. Was the field tilled **before seeding** in **2000?**

☐ No *Continue with question F5*
☐ Yes *If yes, indicate the number of times* ______________________________

F5. Were any operations used in the survey field to control weeds **after seeding and before crop emergence** in **2000?**

☐ No *Continue with question F6*
☐ Yes *If yes, specify the number of times* _____________________________

F6. Were any operations used in the surveyed field to control weeds **after crop emergence** in **2000?**

☐ No *Continue with question F7*
☐ Yes *If yes, specify the number of times* ______________________________

F7. What crop (or summer fallow) was grown on the survey field in **1999?**

F8. What was the **principal** reason for growing this crop in **1999?**

☐ Grain/seed production (i.e., harvest removal)
☐ Forage production (i.e., harvest removal or grazing)
☐ Green manure for improving fertility
☐ Weed control
☐ Other (specify)____

F9. What date was the field seeded in **1999?**___________________________________

F10. Was the field tilled **before seeding** in **1999?**

☐ No *Continue with question F11*
☐ Yes *If yes, indicate the number of times* ________________________________

F11. Were any operations used in the survey field to control weeds **after seeding and before crop emergence** in **1999?**

☐ No *Continue with question F12*
☐ Yes *If yes, specify the number of times* ______________________________

F12. Were any operations used in the surveyed field to control weeds **after crop emergence** in **2000**?

☐ No *Continue with question F13*
☐ Yes *If yes, specify the number of times* _______________________________

F13. Was the field tilled **after harvest** in **1999?**

☐ No *Continue with question F14*
☐ Yes *If yes, indicate the number of times* ________________________________

F14. How did you handle the crop residue on the survey field in **1999?** (check all that apply)

☐ None ☐ Chopped ☐ Chaff collected ☐ Baled ☐ Burned ☐ Grazed

F15. What crop (or summer fallow) was grown on the surveyed field in **1998?**_______________________

F16. What was the **principal** reason for growing this crop in **1998?**

☐ Grain/seed production (i.e., harvest removal)
☐ Forage production (i.e., harvest removal or grazing)
☐ Green manure for improving fertility
☐ Weed control
☐ Other (specify)____

F17. What date was the field seeded in **1998?**___________________________________

F18. Was the field tilled **before seeding** in **1998?**

☐ No *Continue with question F19*
☐ Yes *If yes, indicate the number of times* ________________________________

F19. Were any operations used in the survey field to control weeds **after seeding and before crop emergence** in **1998?**

☐ No *Continue with question F20*
☐ Yes *If yes, specify the number of times* ______________________________

F20. Were any operations used in the surveyed field to control weeds **after crop emergence** in **1998?**

☐ No *Continue with question F21*
☐ Yes *If yes, specify the number of times* ______________________________

F21. Was the field tilled **after harvest** in **1998?**

☐ No *Continue with question F22*
☐ Yes *If yes, specify the number of times* ______________________________

F22. How did you handle the crop residue on the survey field in **1998?** (check all that apply)

☐ None ☐ Chopped ☐ Chaff collected ☐ Baled ☐ Burned

F23. What crop (or summer fallow) was grown on the surveyed field in **1997?**________

F24. What was the **principal** reason for growing this crop in **1997?**

☐ Grain/seed production (i.e., harvest removal)
☐ Forage production (i.e., harvest removal or grazing)
☐ Green manure for improving fertility
☐ Weed control
☐ Other (specify)____

F25. What date was the field seeded in **1997?**__________________________________

F26. Was the field tilled **before seeding** in **1997?**

☐ No *Continue with question F27*
☐ Yes *If yes, indicate the number of times* ______________________________

F27. Were any operations used in the survey field to control weeds **after seeding and before crop emergence** in **1997?**

☐ No *Continue with question F28*
☐ Yes *If yes, specify the number of times* ______________________________

F28. Were any operations used in the surveyed field to control weeds **after crop emergence** in **1997**?

☐ No *Continue with question F29*
☐ Yes *If yes, specify the number of times* ______________________________

F29. How did you handle the crop residue on the survey field in **1997?** (check all that apply)

☐ None ☐ Chopped ☐ Chaff collected ☐ Baled ☐ Burned

F30. What crop (or summer fallow) was grown on the surveyed field in **1996?**________

F31. What was the **principal** reason for growing this crop in **1996?**

☐ Grain/seed production (i.e., harvest removal)
☐ Forage production (i.e., harvest removal or grazing)
☐ Green manure for improving fertility
☐ Weed control
☐ Other (specify)____

F32. What date was the field seeded in **1996?**___________________________________

F33. Was the field tilled **before seeding** in **1996?**

☐ No *If no, skip to question F34*
☐ Yes *If yes, indicate the number of times* ________________________________

F34. Were any operations used in the survey field to control weeds **after seeding and before crop emergence** in **1996?**

☐ No *Continue with question F35*
☐ Yes *If yes, specify the number of times* ______________________________

F35. Were any operations used in the surveyed field to control weeds **after crop emergence** in **1996?**

☐ No *Continue with question F36*
☐ Yes *If yes, specify the number of times* ______________________________

F36. How did you handle the crop residue on the survey field in **1996?** (check all that apply)

☐ None ☐ Chopped ☐ Chaff collected ☐ Baled ☐ Burned

SECTION G: General – Please answer these questions only once for your farm – not once for each survey field.

G1. How many cultivated acres do you have on your farm (owned and rented)? __________ acres

G2. On average, how many acres do you seed each year? __________ acres

G3. What are the main commodities produced on your farm? (check all that apply)

☐ Cereals ☐ Oilseeds ☐ Pulses ☐ Other crops (specify)_________________
☐ Forages ☐ Cattle ☐ Hogs ☐ Other livestock (specify)______________

G4. What year did the surveyed field attain full organic certification?_______________

G5. What other farm implements (cultivators, seeders, harrows, weeders) do you use on your farm that were not identified in the survey (both fields)?

COMMENTS:

Do you have any additional comments to make on the weeds in the field, field management, or this survey?

Thank you for completing the survey! You will be receiving a copy of the soil test results for your field(s) and a summary of the management survey results. It does take time to process samples and compile all of the information, so please be patient with us. We will get this information to you as soon as we can.

Results of the organic grower's management survey.

Table A.1 Introduction question: acreage of surveyed fields.

Acerage (acres)	All fields
1 – 40	11
41 – 80	31
81 – 120	9
121 – 160	3
No response	19

Table A.2 Introduction question: Cereal crop planted in the surveyed field in the year of the survey, 2002.

Crop of 2002 season	All fields
Wheat	43
Oats	15
Barley	6
Durum wheat	5
Mixed cereal	3
Kamut	1

Table A.3 Section A: Question A1. Crop planted in 2001 on the surveyed field.

Crop 2001	All fields
Wheat	23
Oats	7
Sweet clover	5
Peas	4
Lentil	3
Clover	3
Alfalfa	3
Mixed Forage	2
Flax	2
Barley	2
Red clover	2
Yellow peas	1
Canaryseed	1
Summerfallow	15

Table A.4 Section A: Question A2. Seed source for the crop planted in 2001.

Seed Source	All fields
Homegrown	19
Certified seed purchased	22
Other Farmer	16
No response	1
Summerfallow	15

Table A.5 Section A: Question A3. The use of seed treatments used for the 2001 crop.

Seed treatment	All fields
No	43†
Yes	20
No response	10

† note: 15 fields were in summerfallow in 2001.

Table A.6 Section A: Question A3. The specific seed treatments used for 2001.

Seed treatments used	Number of fields treated with a specific product	Anticipated benefit	Success†
Tag team	5	1 – no response	Level 2
		2 – N and P	Level 1 and 3
		2 – N fixation	Level 4
Fish fertilizer and kelp	2	2 – starter N	None given
Rhizobium	2	2 – N fixation	None given
Evergreen product	1	1 – faster emergence	Level 2
MBR	1	1 – N fixation	Level 3
Liphatee	1	1 – N fixation	Level 3
Nitragin and compost tea	1	1 – N fixation and rhizobial activity	Level 4 and 4
Dormal	1	1 – N fixation	Level 1
Provide	1	1 – N fixation	Level 5
N- prove	2	2 – N fixation	Level 5 and 3
Lipha tech	1	1 – N fixation	Level 5
No response	2	-	-

† note: Level 1 is a rank for very poor benefit and a level 5 rank meant the product provided a very good benefit to the crop.

Table A.7 Section A: Question A4. Planting date for 2001.

Planting date	Producers response
Late April	2
Early May	6
Mid May	13
Late May	22
Early June	4
Mid June	1
Late June	1
No response	9
Summerfallow	15

Table A.8 Section A: Question A5. Seeding rate for the crop planted in 2001.

2001 crop	Number of fields with a reported seeding rate	Seeding rate (lb/ac)				Number of fields with no reported seeding rate
		Mean	Median	Maximum	Minimum	
Wheat	7	74	70	100	50	16
Oats	3	100	100	120	80	4
Barley	1	100	100	100	100	1
Flax	2	46	46	50	40	0
Lentils	3	57	36	100	34	0
Peas	0	-	-	-	-	4
Yellow peas	0	-	-	-	-	1
Alfalfa	0	-	-	-	-	3
Mixed forage	0	-	-	-	-	2
Clover	0	-	-	-	-	3
Sweet clover	4	8	8	10	5	1
Red clover	1	6	6	6	6	1
Canaryseed	1	30	30	30	30	0

Table A.9 Section A: Question A6. Depth of seeding for 2001.

Seeding depth	All fields
Broadcast	2
Less than 1 inch	6
1 to 2 inches	23
Greater than 2 inches	20
No response	7
Summerfallow	15

Table A.10 Section A: Question A6. Depth of seeding for the specific crops planted in 2001.

2001 crop	Broadcast	Less than 1 inch	1 to 2 inches	Greater than 2 inches
Wheat	-	1	10	12
Oats	-	-	4	2
Barley	-	-	1	1
Flax	-	1	1	-
Lentils	-	-	3	-
Peas	-	-	1	3
Yellow peas	-	-	-	1
Alfalfa	-	-	-	1
Mixed forage	-	-	-	-
Clover	-	-	3	-
Sweet clover	2	2	-	-
Red clover	-	1	-	-
Canaryseed	-	1	-	-

Table A.11 Section A: Question A7. Row spacing used for planting in 2001.

Row spacing	All fields
6 inches	20
7 inches	12
8 inches	6
9 inches	1
10 inches	3
12 inches	5
No response	11
Summerfallow	15

Table A.12 Section A: Question A8. Seeding system used for planting in 2001.

Seeding system	All fields
Air seeder	16
Broadcast and harrowed	3
Gravity feed drill box	31
Broadcast and cultivated	0
Precision seeder	0
Other (press drill specified)	1
No response	7
Summerfallow	15

Table A.13 Section A: Question A9. Type of opener used for planting in 2001.

Type of opener	All fields
Double disc	11
Hoe	7
Offset single disc (Barton)	0
Knife (1 inch or narrower)	0
Spoon (2 to 5 inches wide)	1
Sweeps (5 inches or wider)	13
Discer	15
Other: 16 inch sweeps specified	2
Other: Press drill	1
Other: Stealth opener	1
No response	7
Summerfallow	15

Table A.14 Section A: Question A10. Other seeding equipment used for planting in 2001 on the surveyed fields.

Other seeding equipment	All fields
No other equipment used[†]	18
On-row packing	7
Tine harrow	14
Fluted coulters	0
Harrow packer	11
Rotary harrow	1
Smooth coulters	0
Other: Rod weeder	4
Other: Dead rods	1
Other: Flexible harrows	1
Other: Diamond harrows	1
No response[†]	15

[†] note: there were 15 fields that were summerfallowed in 2001.

Table A.15 Section A: Question A11. Estimated yield of the field in 2001, specified for the crop planted in 2001.

2001 crop	Number of fields with a response provided	Estimated yield (bu/ac, unless otherwise specificed)			Number of fields with no response provided
		Average	Median	Maximum / Minimum	
Summerfallow	15	n/a	n/a	n/a	n/a
Flax	2	9.5	9.5	11 / 8	n/a
Wheat	7	21.7	21	40 / 1	16
Lentil	1	600 lbs/ac	600 lbs/ac	600 lbs/ac	2
Barley	2	22.5	22.5	30 / 15	n/a
Oats	6	42.5	41.5	65 / 22	1
Peas	2	19	19	28 / 10	2
Yellow peas	n/a	n/a	n/a	n/a	1
Clover	n/a	n/a	n/a	n/a	3
Sweet clover	n/a	n/a	n/a	n/a	2
Red clover	n/a	n/a	n/a	n/a	5
Alfalfa	2	22	22	30 / 14	1
Mixed forage	1	2000 lb/ac	2000 lb/ac	2000 lb/ac	1
Canaryseed	1	250 lb/ac	250 lb/ac	250 lb/ac	n/a

Table A.16 Section A: Question A12. Handling of the crop residue for the 2001 season.

Handling of crop residue	All fields
None	11
Chopped	20
Chaff collected	1
Baled	15
Burned	2
Grazed	0
Other: Ploughdown	13
No response	14

note: This table totals to more than 73 fields because 3 fields had more than one method listed to handle the crop residue. They were: chopped and baled, chopped and ploughed down, and baled and ploughed down.

Table A.17 Section A: Question A12. Handling of the crop residue for the specific crops of the 2001 season.

2001 crop	None	Chopped	Chaff collected	Bailed	Burned	Plough down	Fields with no response
Summerfallow	2	1	0	0	0	0	12
Flax	0	1	0	0	1	0	0
Wheat	6	11	0	6	0	1	0
Lentil	1	0	0	1	0	1	0
Barley	0	2	0	0	0	0	0
Oats	0	2	1	5	0	0	0
Peas	1	1	0	0	0	2	0
Yellow peas	0	0	0	0	0	1	0
Clover	0	1	0	0	0	3	0
Sweet clover	0	0	0	0	0	3	1
Red clover	0	0	0	1	0	2	0
Alfalfa	0	0	0	0	1	0	1
Mixed forage	1	0	0	1	0	0	0
Canaryseed	0	1	0	0	0	0	0

Table A.18 Section B: Question B1. After harvest tillage in 2000, in preparation for the 2001 season.

Fall tillage	All fields
No	42
Yes	31

Table A.19 Section B: Question B1. Number of tillage passes used for after harvest tillage in 2000, in preparation for the 2001 season.

Implement used for fall tillage	Number of fields where the implement was used			
	Once	Twice	Three times	Never used
Cultivator (heavy duty-spikes)	7	5	1	60
Cultivator (heavy duty-sweeps)	1	3	1	68
Cultivator (field)	7	2	0	64
Tandem disc (3” deep or less)	4	2	2	65
Tandem disc (more than 3” deep)	0	0	0	73
Moldboard plough	0	0	0	73
Discer	0	0	0	73
Heavy harrow	0	0	0	73
Harrow	4	6	0	63
Harrowpacker	1	0	0	72
Rodweeder	0	0	1	71 †
Packer	0	0	0	73
Other: rotary harrow	1	0	0	72

† note: The row does not add up to 73 because one producer used a rodweeder and reported going over the field 9 times which is not shown in this table.

Table A.20 Section B: Question B2. Before seeding tillage in the 2001 season.

Before seeding tillage	All fields
No	36
Yes	37

Table A.21 Section B: Question B2. Number of before seeding tillage passes used in the 2001 season.

Implement used for before seeding tillage	Number of fields where the implement was used			
	Once	Twice	Three times	Never used
Cultivator (heavy duty-spikes)	3	0	0	70
Cultivator (heavy duty-sweeps)	12	3	0	58
Cultivator (field)	12	2	2	57
Tandem disc (3” deep or less)	1	0	0	72
Tandem disc (more than 3” deep)	1	0	0	72
Moldboard plough	0	0	0	73
Discer	0	0	0	73
Heavy harrow	1	0	0	72
Harrow	13	1	1	58
Harrowpacker	2	0	0	71
Rodweeder	4	2	0	67
Packer	2	0	0	71
Other: rotary harrow	1	0	0	72

Notes to access the relation between questions B1 and B2.

1. There were 21 fields that were did not have fall or before seeding tillage.
2. There were 16 fields that had both fall and before seeding tillage.
3. There were 36 fields that had only one of the afore mentioned tillage operations applied.

Table A.22 Section C: Question C1. Operations used after seeding but before crop emergence in the 2001 season.

Post seeding, pre-emergent	All fields
No	47
Yes	26

Table A.23 Section C: Question C1. The implement used to control weeds after seeding but before emergence in the 2001 season.

Implement used after seeding but pre-emergent	Number of fields where the Implement was used for 1 to 3 passes			
	Once	Twice	Three times	Never used
Rodweeder	8	0	0	65
Rotary harrow	2	0	0	71
Diamond-toothed harrow	2	0	1	70
Heavy harrow	0	0	0	73
Tine harrow	14	0	0	59
Other: flexible harrows	1	0	0	72
Other: harrow packer	1	0	0	72
Other: field cultivator	1	0	0	72

Table A.24 Section C: Question C2. Operations used after seeding and after crop emergence in the 2001 season.

Post seeding, post emergence	All fields
No	62
Yes	11

Table A.25 Section C: Question C2. The implement used to control weeds after seeding and after emergence in the 2001 season.

Implement used post seeding and post emergent	Number of fields where the implement was used for 1 to 3 passes			
	Once	Twice	Three times	Never used
Inter-row cultivator	0	0	0	73
Rodweeder	1	0	0	72
Rotary harrow	4	0	0	69
Diamond-toothed harrow	1	0	0	72
Heavy harrow	0	0	0	73
Tine harrow	5	0	0	68
Flex-tine harrow	0	0	0	73
Other: roving for weeds	n/a	n/a	n/a	72
Other: cultivator	0	1	0	72

Note: the total number of fields does not add up to the 11 fields that answered yes in the first part of question C2 as some fields were tilled with more than one implement.

Table A.26 Section C: Question C3. The top five most troublesome weeds on the surveyed field in the 2001 season.

	Number of fields given a rank for important weeds				
Weed	**1**	**2**	**3**	**4**	**5**
Wild oats	25	17	8	2	1
Wild mustard	18	10	4	1	1
Canada thistle	10	8	4	5	9
Quack grass	6	3	0	0	4
Redroot pigweed	3	2	4	3	2
Green foxtail	2	6	5	4	3
Wild buckwheat	2	4	4	6	1
Pale smartweed, lady's thumb	1	0	1	1	0
Persian darnel	1	0	0	0	1
Stinkweed	0	4	3	1	2
Flixweed	0	2	0	1	1
Chickweed	0	1	0	0	0
Dandelion	0	1	1	1	0
Cow cockle	0	1	1	2	0
Russian thistle	0	0	3	0	1
Narrow-leaved hawk's-beard	0	0	1	1	0
Perennial sow-thistle	0	0	1	0	0
Kochia	0	0	1	0	3
Lamb's-quarters	0	0	1	2	3
Field horsetail	0	0	0	1	0
Volunteer barley	0	0	0	0	1
Broadleaved weeds	0	0	1	0	1
"redtop"	0	1	0	0	0
No response	5	13	30	42	39

Table A.27 Section C: Question C4. The perceived usefulness of weed management practices on the producer's farm. (note: as the question was about the farm and not the individual field there are a total of 44 producers included not the 73 surveyed fields).

Weed management technique	Total management technique score[†]	Weed management usefulness rank provided by producers				
		1	**2**	**3**	**4**	**5**
Rotate crops	190	0	1	7	8	27
Grow competitive crops	192	0	1	2	11	28
Grow competitive varieties	165	0	2	6	12	19
Grow green manure crops	172	0	0	8	12	20
Use fall tillage	152	2	1	5	17	13
Use spring tillage	183	2	2	5	8	26
Use post-seeding tillage	134	3	5	9	1	10
Mow weed patches	88	5	4	7	6	6
Cultivate field edges	66	6	7	9	1	3
Hand weeding	75	4	7	9	5	2
Narrow row spacing	121	3	1	10	9	10
Increase seeding rate	190	1	0	4	13	25
Vary seeding date	165	3	0	6	16	16
Clean equipment	180	0	4	7	9	23
Tarp trucks	137	2	6	14	4	13
Collect chaff	75	2	1	10	4	5
Fall or spring grazing	62	3	2	8	4	3
Delayed seeding	186	0	1	5	21	17
Inter-cropping	96	2	8	14	4	4
Inter-row cultivation	31	6	1	3	1	2
Weed clipping above crops	58	3	6	5	2	4
Mowing annual crops	71	4	7	4	4	5
Summerfallow (no crop)	143	3	6	13	6	13
Night tillage	50	6	4	5	4	1
Tillage timed to lunar phase	66	4	6	5	5	3
Flaming	29	8	2	3	2	0
Soil inoculants	111	4	1	6	8	11
Other #1	61	0	1	2	2	9
Other #2	8	0	0	0	2	0

[†] note: Total score for the usefulness of the management practices was calculated by multipling the number of producers that ranked a practice times the value of that score, and summing each rank. (1 * # of producers) + (2 * #) + … + (5 * #).

Other #1: greenfeed + seeded late, fall harrowing, fall heavy harrowing, cut for feed, hay for feed, lunar phase planting, lunar phase cultivation, plowing, burning swaths, weed plough down, direction (E-W), tolerant crops, alfalfa, clover, underseeding green manure, timing of operations, rodweeder.
Other #2: Baling weedy crops, seed inoculants.

Table A.28 Section C: Question C5. The top 3 weed management practices on the producer's farm. (note: as the question was about the farm and not the individual field there are a total of 44 producers included not the 73 surveyed fields).

Weed management technique	Score†	Number of producers listing the usefulness of the weed management technique		
		1	2	3
Rotate crops	77	16	10	9
Vary seeding date	9	0	3	3
Grow competitive crops	68	16	5	10
Grow green manure crops	53	8	12	5
Underseed with green manure crop	2	0	1	0
Use spring tillage	34	5	3	13
Use post-seeding tillage	30	4	8	2
Use fall tillage	12	2	2	2
Timing	6	2	0	0
Summerfallow	29	7	1	6
Deep tillage spring and fall	2	0	1	0
Lunar phase cultivation	5	2	0	1
Lunar phase planting	2	0	1	0
Lunar phase seeding	2	0	1	0
Mow weed patches	4	0	1	2
Fall or spring grazing	2	0	1	0
Fall harrowing	2	0	0	2
Grow green manure crops & hay cropping	1	0	0	1
Weed ploughdown	1	0	0	1
Weed clipping	1	0	0	1
Narrow row spacing	4	1	0	1
Increase seeding rate	36	1	14	5
Delayed seeding	52	9	9	7
Timing of operations	2	0	0	2

† note: Total score for the rank of the top 3 weed management practices was calculated by multipling the number of producers that ranked a practice times the value of that score, and summing each rank. 1 is the top ranking and is therefore given a value of 3. Therefore the calucation of "rotate crops" was as follows… (3 * 16) + (2 * 10) + (1 * 9) = 77.

Table A.29 Section D: Question D1. Management practices applied to specifically control insect pests in 2001.

Insect control practices	All surveyed fields
Resistant crop	6
Modified seeding date	9
Residue removal	0
Insect hormones	0
Crop rotation	20
Modified seeding rate	5
Tillage	19
Biological control	0
Trap or guard strips	1
Other: freeze up	1
Other: midge flush	2
No response	34

Note: this table totals to more than 73 since multiple practices can be applied to a field in order to control insects.

Table A.30 Section D: Question D2. Management practices applied to specifically control disease in 2001.

Disease control practices	All surveyed fields
Resistant crop	18
Modified seeding date	8
Residue removal	2
Tillage	14
Crop rotation	29
Modified seeding rate	4
No response	36

Note: this table totals to more than 73 since multiple practices can be applied to a field in order to control diseases.

Table A.31 Section E: Question E1. The application of animal manures to the surveyed field.

Use of animal manure on field	All fields
No usage of animal manure	66
Yes animal manure was applied	7

Table A.32 Section E: Question E1. Timing of application, type of manure, number of acres treated, amount applied, source of the animal manure and the length of time it was composted reported for all surveyed years.

	Time of application			Type of manure				Source of manure		Length of compost treatment (months)
Year	**Fall**	**Spring**	**In-crop**	**Cattle**	**Sheep & cattle**	**Acres treated**	**Amount applied[†]**	**On-farm**	**Off-farm**	
2001	1	0	1	1	1	40, 4	4, 2	1	1	4, 48
2000	1	0	0	1	0	25	2	1	0	Not given
1999	1	0	0	1	0	20	Not given	1	0	3
1998	2	1	0	3	0	25, 70, 25	720, not given	3	0	3, 6, not given
1997	1	0	0	1	0	30	Not given	1	0	2

[†] note: no measurement or units were provided with these responses, therefore the values are meaningless, but reported.

note: There are 8 reported applications of manure according to the time of application, but only 7 fields had manure applied according to Table A.31; this is because 1 field had 2 applications of manure applied in fall in 1998 and 2000.

Table A.33 Section E: Question E2. The use of animal manures to increase the soil fertility.

Use of a green manure on a field	All fields
No usage of green manure	32
Yes a green manure was grown	41

Table A.34 Section E: Question E2. The type of green manure crop grown in all surveyed years.

Green manure crop	2001	2000	1999	1998	1997
Sweet clover	8	10	3	5	6
Peas	3	0	1	0	0
Lentil	1	1	2	1	1
Barley and wheat	2	0	0	0	0
Red clover	1	2	1	0	0
Chickling vetch	0	1	0	0	0
Alfalfa	0	2	3	3	3
Greenfeed	0	1	0	0	0
Total green manure crops	15	17	10	9	10

Note: The total number of green manure crops does not equal 41 as in table A.33 because crops like sweet clover are listed for more than a single year.

Table A.35 Section E: Question E2. The green manure crop grown in order to control the listed targeted weed(s).

Weed targeted	2001	2000	1999	1998	1997
Wild oats	5	11	4	4	5
Wild mustard	2	3	1	1	4
Kochia	1	1	0	0	0
Stinkweed	2	0	0	0	0
Wild buckwheat	2	0	0	0	0
Grass	0	0	0	1	0
Broadleaved	0	0	0	1	0

Table A.36 Section E: Question E2. The purpose of growing a green manure crop: to control weeds and/or improve fertility.

Year	Grown for weed control		Grown for fertility improvement	
	Yes	No	Yes	No
2001	12	1	15	0
2000	15	2	17	0
1999	7	3	10	0
1998	8	1	9	0
1997	9	1	10	0

Table A.37 Section E: Question E2. Stage of green manure crop when the crop was terminated for all surveyed years.

Termination stage	2001	2000	1999	1998	1997
Pre-bloom	3	2	3	0	0
Early bloom	4	7	1	1	5
Mid-bloom	0	0	1	0	0
Late bloom	1	1	0	0	0
Bloom	0	0	0	0	1
Flower	0	0	0	1	0
Flowering	0	0	0	1	1
Mature	0	1	0	0	0
15% bloom	0	0	0	1	0
20% bloom	0	1	0	1	0
25% bloom	1	1	1	0	0
50% bloom	0	1	0	0	0
6 inches after growth	0	2	0	0	0
Milk stage	0	1	0	0	0
Harvested	0	0	1	0	0
Hayed	0	0	1	2	2

Table A.38 Section E: Question E2. Method of green manure termination.

Method of termination	**2001**	**2000**	**1999**	**1998**	**1997**
Tandem disc	5	3	0	1	0
Disc	9	4	4	3	4
Rodweeder	0	1	0	0	0
Swath or cut	0	1	0	0	0
Ploughed	0	0	0	1	0
Cultivated	0	3	1	1	0
Cut for feed or hayed or baled	1	0	0	0	2
Double disc	0	4	1	1	0
Heavy disc	0	2	0	0	0
Offset disc	0	0	0	0	1
Cut then ploughed in	0	1	1	0	0
No response					

Table A.39 Section E: Question E3. The use of soil amendments to increase the soil fertility.

Use of a soil amendments	**All fields**
No usage of soil amendments	62
Yes a soil amendment was used	11

Table A.40 Section E: Question E3. Use of soil amendments in order to increase soil fertility.

	Time of application		Type of soil amendment used					
Year	**Fall**	**Spring**	**Product #1**	**Product #2**	**Product #3**	**Acres treated**	**Rate of application**	**Placement of soil amendment**
2001	-	-	-	-	-	-	-	-
2000	0	2	2 x Humic C	-	-	150, 150	75 lb/ac 75 lb/ac	2 x Broadcast
1999	0	3	N inoculant	2 x RP	-	60, 50, 35	75, 40, 50 lb/ac	Broadcast, broadcast and incorporate, seed treatment
1998	0	4	Tag team	RP	2 x N fixing bacteria	58, 40, 20, 48	70 lb/ac, 3 x “recommended”	3 x seed treatment, seed placed
1997	2	1	2 x gypsum & RP	RP	-	100, 78, 60	105, 230, 60 lb/ac	2 x broadcast, seed placed

Table A.41 Section E: Question E4. The use of soil amendments to specifically to increase the soil P.

Use of a soil amendments specifically soil P improvement	All fields
No usage of soil amendments	65
Yes a soil amendment was used	8
Rock phosphate	6/8
Tag team	1/8
Compost tea	1/8

Table A.42 Section F: Question F1. Crop grown on the surveyed field in 2000

Crop grown in 2000	Number of fields
Summerfallow	16
Flax	6
Wheat	7
Kamut	1
Durum wheat	3
Spring wheat	3
Lentil	3
Barley	4
Oats	8
Peas	2
Clover	3
Sweet clover	5
Red clover	1
Alfalfa	4
Mixed forage	2
Mixed cereals	1
Coriander	1
Fall rye	1
Chickling vetch	1

Table A.43 Section F: Question F2. Reason for growing the crop on the surveyed field in 2000.

Reason for growing the crop	Number of fields
Grain / seed production	37
Forage production	6
Green manure for fertility	15
Weed control	26
Other	11

Other: soil tilth, N and crop rotation, soil fertility, experimentation, rotation, too wet, greenfeed, conserve moistur x 2, nurse crop to clover, wait 2 years to get rid of clover weevil.
Note that the total number of fields adds to more than 73 as there can be more than one reason for growing the crop.

Table A.44 Section F: Question F3. Date the crop was seeded on the surveyed field in 2000.

Date of seeding	Number of fields
Late April (21-30)	1
Early May (1-10)	7
Mid May (11-20)	9
Late May (21-31)	12
Early June (1-10)	6
Mid June (11-20)	1
Late June (21-30)	0
Mid July	1
Previous fall	1
No response	35

Table A.45 Section F: Question F4. Tillage operations used before seeding in the 2000 season.

Before seeding 2000	All fields
No	37
Yes	35
One tillage pass used	17
Two tillage passes used	14
Three tillage passes used	3
Four tillage passes used	1
No response	1

Table A.46 Section F: Question F5. Tillage operations used after seeding, before emergence in the 2000 season.

After seeding, before emergence 2000	All fields
No	51
Yes	21
One tillage pass used	14
Two tillage passes used	5
Three tillage passes used	2
No response	1

Table A.47 Section F: Question F6. Tillage operations used after crop emergence in the 2000 season.

After emergence 2000	All fields
No	62
Yes	10
One tillage pass used	7
Two tillage passes used	2
No amount given	1
No response	1

Table A.48 Section F: Question F7. Crop grown on the surveyed field in 1999.

Crop grown in 1999	Number of fields
Summerfallow	10
Flax	6
Wheat	10
Kamut	5
Durum wheat	2
Spring wheat	2
Lentil	4
Barley	7
Oats	4
Peas	5
Clover	1
Sweet clover	1
Red clover	3
Alfalfa	7
Mixed forage	2
Mixed cereals	0
Coriander	0
Fall rye	2
None given	2

Table A.49 Section F: Question F8. Reason for the crop grown on the surveyed field in 1999.

Reason for growing the crop	Number of fields
Grain / seed production	45
Forage production	13
Green manure for fertility	10
Weed control	20
Other	9

Other: improving fertility, soil fertility, nurse crop, work in alfalfa and wild hay, rotation, crop rotation, moisture conservation, green manure in 2000 x 2.
Note that the total number of fields can sum to more than 73 fields as there can be more than one reason for growing the crop.

Table A.50 Section F: Question F9. Date that the crop grown on the surveyed field in 1999 was seeded.

Date of seeding	Number of fields
Late April (21-30)	0
Early May (1-10)	4
Mid May (11-20)	9
Late May (21-31)	19
Early June (1-10)	8
Mid June (11-20)	1
Late June (21-30)	2
Early July (1-10)	0
Mid July	0
Previous fall	2
No response	28

Table A.51 Section F: Question F10. Tillage operations used before seeding in the 1999 season.

Before seeding 1999	All fields
No	35
Yes	36
One tillage pass used	16
Two tillage passes used	13
Three tillage passes used	6
Four tillage passes used	1
No response	2

Table A.52 Section F: Question F11. Tillage operations used after seeding, before emergence in the 1999 season.

After seeding, before emergence 1999	All fields
No	46
Yes	25
One tillage pass used	17
Two tillage passes used	4
Three tillage passes used	3
Number of tillage passes not specificed	1
No response	2

Table A.53 Section F: Question F12. Tillage operations used after crop emergence in the 1999 season.

After emergence 1999	All fields
No	56
Yes	15
One tillage pass used	10
Two tillage passes used	1
Three tillage passes used	0
Four tillage passes used	3
Number of tillage passes not specificed	1
No response	2

Table A.54 Section F: Question F13. Tillage operations used after harvest in the 1999 season.

After harvest 1999	All fields
No	45
Yes	23
One tillage pass used	2
Two tillage passes used	5
Three tillage passes used	3
Four tillage passes used	1
No response	5

Table A.55 Section A: Question F14. Handling of the crop residue for the 1999 season.

Handling of crop residue	All fields
None	18
Chopped	29
Chaff collected	0
Baled	19
Burned	4
Grazed	0
No response	3

note: This table totals to more than 73 fields because 3 fields had more than one method listed to handle the crop residue. They were: chopped and baled, chopped and ploughed down, and b

Table A.56 Section F: Question F15. Crop grown on the surveyed field in 1998.

Crop grown in 1998	Number of fields
Summerfallow	17
Flax	4
Wheat	3
Kamut	1
Durum wheat	6
Spring wheat	3
Lentil	4
Barley	1
Oats	4
Peas	2
Clover	1
Sweet clover	1
Red clover	0
Alfalfa	9
Mixed forage	7
Mixed cereals	1
Coriander	0
Fall rye	2
Canola	3
None given	3

Table A.57 Section F: Question F16. Reason for the crop grown on the surveyed field in 1998.

Reason for growing the crop	Number of fields
Grain / seed production	36
Forage production	16
Green manure for fertility	8
Weed control	24
Other	5

Other: nurse crop to clover, rotation, moisture conservation, establish a hay crop x 2.

Table A.58 Section F: Question F17. Seeding date for the crop grown on the surveyed field in 1998.

Date of seeding	Number of fields
Late April (21-30)	1
Early May (1-10)	5
Mid May (11-20)	12
Late May (21-31)	8
Early June (1-10)	3
Mid June (11-20)	2
Late June (21-30)	0
Early July (1-10)	0
Mid July	0
Previous fall	2
No response	40

Table A.59 Section F: Question F18. Tillage operations used before seeding in the 1998 season.

Before seeding 1998	All fields
No	43
Yes	28
One tillage pass used	18
Two tillage passes used	5
Three tillage passes used	4
Number of tillage passes not specified	1
No response	2

Table A.60 Section F: Question F19. Tillage operations used after seeding, before emergence in the 1998 season.

After seeding, before emergence 1998	All fields
No	52
Yes	19
One tillage pass used	15
Two tillage passes used	1
Three tillage passes used	3
No response	2

Table A.61 Section F: Question F20. Tillage operations used after crop emergence in the 1998 season.

After emergence 1998	All fields
No	63
Yes	8
One tillage pass used	4
Two tillage passes used	3
Three tillage passes used	0
Number of tillage passes not specified	1
No response	2

Table A.62 Section F: Question F21. Tillage operations used after crop harvest in the 1998 season.

After emergence 1998	All fields
No	58
Yes	11
One tillage pass used	7
Two tillage passes used	2
Three tillage passes used	2
No response	4

Table A.63 Section F: Question F22. Handling of the crop residue for the 1998 season.

Handling of crop residue	All fields
None	31
Chopped	23
Chaff collected	2
Baled	8
Burned	3
No response	6

note: This table totals to more than 73 fields because fields can have more than one method listed to handle the crop residue.

Table A.64 Section F: Question F23. Crop grown on the surveyed field in 1997.

Crop grown in 1998	Number of fields
Summerfallow	9
Flax	3
Wheat	10
Kamut	1
Durum wheat	1
Spring wheat	6
Lentil	1
Barley	8
Oats	6
Peas	1
Clover	3
Sweet clover	1
Red clover	0
Alfalfa	8
Mixed forage	4
Canaryseed	1
Buckwheat	1
Fall rye	2
Canola	3
None given	4

Table A.65 Section F: Question F24. Reason for the crop grown on the surveyed field in 1997.

Reason for growing the crop	Number of fields
Grain / seed production	44
Forage production	13
Green manure for fertility	7
Weed control	15
Other	2

Other: N fixation, moisture conservation.

Table A.66 Section F: Question F25. Date that the crop was seeded grown on the surveyed field in 1997.

Date of seeding in 1997	Number of fields
Late April (21-30)	0
Early May (1-10)	5
Mid May (11-20)	3
Late May (21-31)	19
Early June (1-10)	7
Mid June (11-20)	0
Late June (21-30)	0
Early July (1-10)	0
Mid July	0
Previous fall	1
No response	38

Table A.67 Section F: Question F26. Tillage operations used before seeding in the 1997 season.

Before seeding 1997	All fields
No	33
Yes	37
One tillage pass used	22
Two tillage passes used	9
Three tillage passes used	5
Number of tillage passes not specified	1
No response	3

Table A.68 Section F: Question F27. Tillage operations used after seeding, before emergence in the 1997 season.

After seeding, before emergence 1997	All fields
No	48
Yes	22
One tillage pass used	16
Two tillage passes used	6
No response	3

Table A.69 Section F: Question F28. Tillage operations used after crop emergence in the 1997 season.

After emergence 1998	All fields
No	61
Yes	9
One tillage pass used	7
Two tillage passes used	1
Three tillage passes used	1
No response	3

Table A.70 Section F: Question F29. Handling of the crop residue for the 1997 season.

Handling of crop residue	All fields
None	24
Chopped	28
Chaff collected	1
Baled	15
Burned	3
No response	2

note: This table totals to more than 73 fields because fields can have more than one method listed to handle the crop residue.

Table A.71 Section F: Question F30. Crop grown on the surveyed field in 1996.

Crop grown in 1996	Number of fields
Summerfallow	14
Flax	2
Wheat	12
Kamut	0
Durum wheat	2
Spring wheat	3
Lentil	0
Barley	4
Oats	3
Peas	2
Clover	0
Sweet clover	1
Red clover	1
Alfalfa	8
Mixed forage	4
Mixed grain	1
Borage	1
Canaryseed	2
Canola	4
None given	9

Table A.72 Section F: Question F31. Reason for the crop grown on the surveyed field in 1996.

Reason for growing the crop	Number of fields
Grain / seed production	36
Forage production	17
Green manure for fertility	6
Weed control	13
Other	3

Other: moisture conservation, moisture, nurse crop to clover.

Table A.73 Section F: Question F32. Date that the crop grown on the surveyed field in 1996 was seeded.

Date of seeding	Number of fields
Late April (21-30)	0
Early May (1-10)	2
Mid May (11-20)	3
Late May (21-31)	18
Early June (1-10)	3
Mid June (11-20)	0
Late June (21-30)	0
Early July (1-10)	0
Mid July	0
Previous fall	1
No response	46

Table A.74 Section F: Question F33. Tillage operations used before seeding in the 1996 season.

Before seeding 1996	All fields
No	32
Yes	32
One tillage pass used	18
Two tillage passes used	8
Three tillage passes used	5
Number of tillage passes not specified	1
No response	9

Table A.75 Section F: Question F34. Tillage operations used after seeding, before emergence in the 1996 season.

After seeding, before emergence 1996	All fields
No	45
Yes	20
One tillage pass used	14
Two tillage passes used	5
Three tillage passes used	1
No response	8

Table A.76 Section F: Question F35. Tillage operations used after crop emergence in the 1996 season.

After emergence 1996	**All fields**
No	52
Yes	11
One tillage pass used	11
No response	0

Table A.77 Section A: Question F36. Handling of the crop residue for the 1996 season.

Handling of crop residue	**All fields**
None	25
Chopped	23
Chaff collected	2
Baled	10
Burned	3
No response	10

note: This table totals to more than 73 fields because fields can have more than one method listed to handle the crop residue.

Section G: Note that because the questions in section G are about the farm not the specific field the numbers in this section are reported for the 44 producers not the 73 surveyed fields.

Table A.78 Section G: Question G1 and G2. The use of animal manures to increase the soil fertility.

	Acerage			
Type of farm acers	**Medium**	**Mean**	**Maximum**	**Minimum**
Total cultivated acres owned and rented	980	1144	3400	160
Number of acres seeded each year	710	890	3400	70

Table A.79 Section G: Question G3. Main commodity produced by the producer of the surveyed farm.

Main commodities produced on farm	Number of producers
Cereals	43
Forages	28
Oilseeds	27
Cattle	20
Pulses	26
Hogs	1
Other crops: alfalfa for seed	3
Other crops: buckwheat	3
Other crops: kamut	1
Other crops: coriander	1
Other livestock: sheep	1
Other livestock: bison	1
Other livestock: goats	1
Other livestock: horses	1
Other livestock: poultry	1
Other livestock: turkey	1
Other livestock: honey bees	1

Table A.80 Section G: Question G4. The year the farm organically certified. Often farms are certified one field at a time. If this was the case for 2 surveyed fields on a single farm, the average year was taken for the farm, otherwise it was the year that specific field was certified.

Year of organic certification	**Number of producers**
2002	3
2001	5
2000	6
1999	5
1998	1
1997	3
1996	3
1995	5
1994	4
1993	1
1992	1
1991	2
1990	1
1989	0
1988	1
1987	1
1986	1
1985	0
1984	0
1983	0
1982	0
1981	0
1980	1

Table A.81 Section G: Question G5. Farm implements that are used on the farm but were not reported previously on any of the survey questions.

Other farm implements on farm	**Number of producers**
Tandom disc	1
Moldboard plough	1
Offset heavy disc	1
Rod weeder	2
Diamond harrow	2
Air seeder	1
Straight harrow bar	2
Coil packers	1
Hoe drill	1
Heavy duty cultivator	1

Appendix B: Main and secondary matrices for the NMS ordination and classification procedures.

Table B.1 Primary matrix of organic management practices for the classification procedure to determine management systems.

Fields	acres	diversity	manure	SoilAm	SprTill	PostSPre	PostPos	FallTil	Cereal	AnnLeg	SumFal	Perenn	BrdlfNL	Bienn	GreMan
1.1	70	2	0.00	0.25	2.00	0.50	0.00	0.00	0.43	0.00	0.29	0.00	0.30	0.00	0.00
1.2	90	5	0.25	0.00	2.25	1.33	0.00	0.00	0.43	0.17	0.17	0.00	0.15	0.15	0.15
4.1	68	3	0.00	0.00	1.67	0.00	0.00	0.00	0.43	0.00	0.29	0.14	0.15	0.00	0.00
4.2	68	2	0.00	0.00	0.00	0.00	0.00	0.00	0.14	0.00	0.00	0.86	0.00	0.00	0.00
5.1	150	3	0.00	0.33	2.33	0.00	0.00	0.50	0.43	0.00	0.00	0.43	0.15	0.00	0.00
5.2	150	3	0.00	0.33	2.33	0.00	0.00	0.50	0.43	0.00	0.00	0.43	0.15	0.00	0.00
6.1	90	2	0.00	0.00	1.50	2.00	0.50	6.00	0.43	0.00	0.00	0.57	0.00	0.00	0.00
8.1	65	1	0.00	0.00	2.00	1.00	0.00	0.00	0.57	0.00	0.43	0.00	0.00	0.00	0.00
8.2	50	1	0.00	0.00	2.50	1.00	0.00	0.00	0.71	0.00	0.29	0.00	0.00	0.00	0.00
12.1	71	4	0.00	0.00	1.40	1.00	0.00	0.67	0.57	0.29	0.00	0.00	0.00	0.15	0.14
12.2	48	4	0.00	0.25	1.00	1.00	0.00	0.50	0.57	0.14	0.00	0.00	0.00	0.15	0.14
13.1	70	3	0.00	0.00	2.00	0.00	0.00	0.00	0.29	0.00	0.00	0.67	0.00	0.00	0.14
14.1	68	2	0.00	0.00	3.00	1.00	0.67	3.00	0.57	0.00	0.14	0.29	0.00	0.00	0.00
15.1	40	1	0.00	0.00	0.00	0.00	0.00	0.00	0.50	0.00	0.14	0.00	0.00	0.00	0.00
15.2	70	2	0.25	0.00	0.75	1.00	0.50	1.00	0.57	0.00	0.29	0.00	0.16	0.00	0.00
16.1	68	3	0.00	0.00	3.67	0.00	1.33	1.00	0.43	0.00	0.00	0.50	0.00	0.00	0.14
16.2	68	3	0.00	0.00	4.00	0.00	1.33	1.00	0.43	0.00	0.14	0.33	0.00	0.00	0.15
17.1	100	2	0.00	0.00	0.33	0.00	0.00	0.00	0.67	0.00	0.20	0.00	0.00	0.29	0.00
19.1	120	3	0.00	0.00	1.50	1.00	1.00	0.00	0.50	0.00	0.14	0.17	0.00	0.00	0.15
19.2	90	4	0.00	0.00	1.33	1.50	0.00	1.50	0.43	0.14	0.00	0.33	0.00	0.00	0.14
20.1	45	2	0.00	0.00	2.00	0.00	0.00	0.00	0.29	0.00	0.00	0.71	0.00	0.00	0.00
20.2	58	2	0.00	0.00	0.00	0.00	0.00	0.00	0.33	0.00	0.14	0.43	0.00	0.00	0.00
21.1	78	3	0.25	0.25	1.25	2.00	0.75	0.50	0.57	0.00	0.20	0.00	0.16	0.29	0.00
21.2	60	4	0.00	0.50	2.75	1.00	0.00	3.00	0.57	0.00	0.00	0.14	0.16	0.29	0.00

Table B.1. Continued

Fields	Acres	diversity	manure	SoilAm	SprTill	PostSPre	PostPos	FallTil	Cereal	AnnLeg	SumFal	Perenn	BrdlfNL	Bienn	GreMan
23.1	68	3	0.00	0.00	0.00	1.25	0.00	1.67	0.57	0.14	0.00	0.00	0.00	0.00	0.29
26.1	50	3	0.25	0.00	1.50	1.00	0.00	0.00	0.57	0.00	0.20	0.00	0.16	0.29	0.00
27.1	136	3	0.00	0.00	1.00	1.00	0.20	0.00	0.57	0.17	0.14	0.00	0.16	0.00	0.00
27.2	55	2	0.00	0.00	1.00	1.00	0.50	0.00	0.57	0.00	0.29	0.00	0.16	0.00	0.00
28.1	68	5	0.00	0.00	0.60	0.00	0.00	1.50	0.57	0.17	0.00	0.00	0.16	0.15	0.14
28.2	58	3	0.00	0.33	0.75	0.00	0.00	0.50	0.43	0.14	0.29	0.00	0.00	0.00	0.15
29.1	68	3	0.00	0.00	1.67	0.00	0.00	1.50	0.57	0.00	0.00	0.00	0.00	0.43	0.43
29.2	80	3	0.00	0.00	1.00	3.75	0.00	0.00	0.43	0.00	0.00	0.00	0.00	0.43	0.43
32.1	35	2	0.00	0.00	0.75	1.67	0.75	0.00	0.57	0.14	0.29	0.00	0.00	0.00	0.00
32.2	50	4	0.50	0.00	0.75	1.00	0.50	0.00	0.57	0.14	0.17	0.00	0.00	0.15	0.15
33.2	68	1	0.00	0.00	0.50	0.00	0.00	0.00	0.60	0.00	0.29	0.00	0.00	0.00	0.00
36.1	70	5	0.00	0.00	2.00	0.00	0.00	0.00	0.29	0.00	0.17	0.33	0.15	0.14	0.15
39.1	70	1	0.00	0.00	0.33	1.00	0.33	0.50	0.57	0.00	0.43	0.00	0.00	0.00	0.00
39.2	60	3	0.00	0.00	0.50	0.00	0.50	4.00	0.71	0.00	0.17	0.00	0.00	0.14	0.15
40.1	75	2	0.00	0.00	1.00	1.00	0.00	0.67	0.43	0.29	0.29	0.00	0.00	0.00	0.00
40.2	77	4	0.00	0.00	1.00	1.00	0.00	0.67	0.57	0.14	0.17	0.00	0.00	0.15	0.15
41.1	68	3	0.00	0.00	3.00	0.00	0.00	0.00	0.57	0.00	0.33	0.00	0.00	0.14	0.15
42.1	7	2	0.00	0.00	1.00	0.00	0.00	0.00	0.43	0.00	0.00	0.57	0.00	0.00	0.00
42.2	70	2	0.00	0.00	2.50	2.00	0.00	2.00	0.43	0.00	0.00	0.57	0.00	0.00	0.00
43.1	68	2	0.00	0.00	2.25	2.00	0.25	1.00	0.57	0.14	0.29	0.00	0.00	0.00	0.00
43.2	68	2	0.00	0.00	2.25	2.00	1.00	1.00	0.57	0.14	0.29	0.00	0.00	0.00	0.00
45.1	80	4	0.00	0.00	1.75	1.25	0.50	2.00	0.57	0.14	0.17	0.00	0.00	0.15	0.15
45.2	68	3	0.00	0.00	0.75	1.00	0.50	0.00	0.71	0.00	0.17	0.00	0.00	0.14	0.15
46.1	68	1	0.00	0.00	2.00	0.00	0.00	0.00	0.86	0.00	0.14	0.00	0.00	0.00	0.00

Table B.1. Continued

Fields	acres	diversity	manure	SoilAm	SprTill	PostSPre	PostPos	FallTil	Cereal	AnnLeg	SumFal	Perenn	BrdlfNL	Bienn	GreMan
47.1	40	4	0.00	0.33	3.00	0.00	0.00	0.00	0.29	0.17	0.00	0.43	0.15	0.00	0.00
47.2	20	2	0.00	1.00	3.00	1.00	0.00	0.00	0.29	0.00	0.14	0.57	0.00	0.00	0.00
50.1	57	2	0.25	0.00	0.25	2.50	0.25	0.50	0.57	0.14	0.29	0.00	0.00	0.00	0.00
50.2	23	4	0.00	0.00	0.40	1.60	0.20	0.00	0.43	0.00	0.00	0.00	0.15	0.14	0.43
51.1	68	5	0.00	0.00	1.00	1.00	0.00	0.00	0.43	0.17	0.17	0.00	0.15	0.15	0.15
51.2	38	3	0.00	0.00	1.25	1.00	0.25	4.00	0.71	0.00	0.17	0.00	0.00	0.14	0.15
52.1	45	1	0.00	0.00	1.67	1.00	0.00	0.00	0.57	0.00	0.43	0.00	0.00	0.00	0.00
52.2	65	3	0.00	0.00	1.67	1.00	0.00	0.00	0.57	0.00	0.33	0.00	0.00	0.14	0.15
53.1	90	3	0.00	0.00	1.33	0.00	0.00	0.00	0.67	0.00	0.17	0.00	0.00	0.14	0.15
53.2	40	3	0.00	0.00	1.50	0.00	0.00	0.00	0.75	0.00	0.00	0.00	0.00	0.14	0.14
55.1	30	1	0.00	0.00	0.67	0.00	0.00	0.00	0.57	0.00	0.43	0.00	0.00	0.00	0.00
56.1	68	1	0.33	0.33	1.00	1.00	0.67	0.00	0.57	0.00	0.43	0.00	0.00	0.00	0.00
59.1	68	3	0.00	0.00	0.50	2.00	0.50	0.00	0.50	0.14	0.14	0.00	0.00	0.00	0.15
59.2	68	3	0.00	0.33	0.60	1.33	0.20	0.00	0.50	0.00	0.00	0.00	0.15	0.00	0.29
60.2	100	2	0.00	0.00	1.20	1.00	0.20	0.50	0.71	0.00	0.14	0.00	0.16	0.00	0.00
61.1	40	3	0.00	0.00	2.00	0.00	0.00	0.00	0.60	0.00	0.17	0.00	0.00	0.14	0.15
65.1	80	4	0.00	0.00	0.75	2.33	0.50	2.00	0.67	0.14	0.00	0.00	0.00	0.15	0.14
65.2	80	4	0.00	0.00	0.00	2.25	0.50	2.00	0.57	0.14	0.00	0.00	0.00	0.29	0.14
68.1	40	3	0.00	0.00	2.75	2.00	0.50	4.00	0.71	0.00	0.00	0.00	0.16	0.00	0.14
70.1	68	3	0.00	0.00	2.00	1.00	0.00	0.00	0.43	0.00	0.50	0.00	0.00	0.14	0.15
70.2	68	3	0.00	0.00	2.00	1.00	0.00	0.00	0.57	0.00	0.33	0.00	0.00	0.14	0.15
71.1	78	4	0.00	0.00	0.00	1.50	0.00	0.00	0.43	0.17	0.14	0.00	0.15	0.00	0.15
71.2	79	4	0.00	0.00	0.00	1.50	0.00	0.00	0.57	0.00	0.17	0.00	0.16	0.14	0.15
74.1	106	3	0.00	0.00	1.00	1.00	0.50	0.50	0.43	0.00	0.17	0.00	0.30	0.14	0.00
74.2	106	3	0.00	0.00	1.75	0.00	0.75	0.00	0.43	0.00	0.17	0.00	0.30	0.14	0.00

Table B.2. Ordination scores from the NMS analysis used as the new main matrix for the Ward's classification procedure.

Field	Axis 1	Axis 2	Axis 3
1.1	-0.9991	-0.1158	-0.0003
1.2	0.0280	0.4976	-0.5663
4.1	-0.5626	-0.2764	-0.0111
4.2	0.1723	-2.0621	-0.0023
5.1	-0.5637	-0.7314	-0.7892
5.2	-0.5637	-0.7314	-0.7892
6.1	-0.2145	-1.0491	-0.4917
8.1	-0.4654	-0.0160	0.8160
8.2	-0.4472	-0.1323	0.8132
12.1	0.6410	0.4573	-0.3276
12.2	0.5724	0.5052	-0.3459
13.1	0.4286	-1.0518	-0.3132
14.1	-0.3573	-0.5438	0.1534
15.1	-0.0342	-0.3111	1.5236
15.2	-0.6891	0.3584	0.1842
16.1	0.5087	-0.8971	-0.5217
16.2	0.4806	-0.7729	-0.1189
17.1	0.4622	-0.0049	0.8923
19.1	0.0579	-0.2936	-0.0453
19.2	0.5135	-0.1075	-0.6317
20.1	-0.1144	-1.5636	0.0037
20.2	-0.1655	-1.1876	0.6831
21.1	-0.5328	0.5319	-0.3889
21.2	-0.2732	-0.0877	-0.9979
23.1	0.8494	0.6988	-0.1288
26.1	-0.4891	0.3196	-0.1937
27.1	-0.4249	0.5617	-0.2144
27.2	-0.6514	0.2246	0.2443
28.1	0.4284	0.5609	-0.7515
28.2	0.3625	0.5646	0.4914
29.1	1.1494	-0.0944	-0.3164
29.2	1.2262	0.2377	-0.6003
32.1	-0.3512	0.8050	0.5261
32.2	0.3192	0.7888	-0.0061
33.2	-0.1928	-0.0038	1.1398
36.1	0.2003	-0.3646	-0.6592
39.1	-0.4574	0.3535	0.9216

Field	Axis 1	Axis 2	Axis 3
39.2	0.7716	0.1917	0.2898
40.1	-0.1865	0.6300	0.6554
40.2	0.3206	0.4346	-0.0484
41.1	0.3148	-0.1340	0.3001
42.1	-0.1599	-1.6727	0.2146
42.2	-0.1884	-0.9835	-0.1979
43.1	-0.2749	0.4074	0.4104
43.2	-0.3948	0.5612	0.3736
45.1	0.3090	0.4154	-0.1354
45.2	0.3139	0.2629	0.1458
46.1	-0.1239	-0.4543	0.9061
47.1	-0.3857	-0.6035	-1.2708
47.2	-1.0124	-1.2599	-0.0283
50.1	-0.2712	0.9189	0.5309
50.2	0.4425	0.6564	-1.1314
51.1	0.1086	0.6320	-0.4662
51.2	0.6327	0.2100	0.1721
52.1	-0.4833	0.0358	0.9317
52.2	0.1714	0.1146	0.2485
53.1	0.4393	-0.0404	0.1590
53.2	0.8626	-0.1743	0.0652
55.1	-0.4274	0.0739	1.3979
56.1	-0.9010	0.4103	0.8135
59.1	0.1910	0.6860	0.0848
59.2	-0.1405	0.3399	-0.8821
60.2	-0.6127	0.0692	0.0009
61.1	0.4874	-0.1100	0.2111
65.1	0.5659	0.6738	-0.3191
65.2	0.6740	0.8222	-0.4099
68.1	-0.0154	0.0591	-0.9214
70.1	0.2282	0.0037	0.3183
70.2	0.1573	0.0704	0.2356
71.1	-0.0151	0.7792	-0.5079
71.2	0.0596	0.5051	-0.3929
74.1	-0.5802	0.3042	-0.4312
74.2	-0.7284	0.0976	-0.5036

Table B.3. Secondary matrix expressing the management system determined by the classification procedure for each field in the organic survey.

Fields	Diverse system	Green manure	Summer fallow	Perennial system
1.1	1	0	0	0
1.2	1	0	0	0
4.1	1	0	0	0
4.2	0	0	0	1
5.1	0	0	0	1
5.2	0	0	0	1
6.1	0	0	0	1
8.1	0	0	1	0
8.2	0	0	1	0
12.1	0	1	0	0
12.2	0	1	0	0
13.1	0	0	0	1
14.1	0	0	0	1
15.1	0	0	1	0
15.2	1	0	0	0
16.1	0	0	0	1
16.2	0	0	0	1
17.1	0	1	0	0
19.1	0	0	0	1
19.2	1	0	0	0
20.1	0	0	0	1
20.2	0	0	0	1
21.1	1	0	0	0
21.2	1	0	0	0
23.1	0	1	0	0
26.1	1	0	0	0
27.1	1	0	0	0
27.2	1	0	0	0
28.1	1	0	0	0
28.2	0	1	0	0
29.1	0	1	0	0
29.2	0	1	0	0
32.1	0	0	1	0
32.2	0	1	0	0
33.2	0	0	1	0
36.1	1	0	0	0
39.1	0	0	1	0
39.2	0	1	0	0
40.1	0	0	1	0
40.2	0	1	0	0

Table B.3. Continued

Fields	Diverse system	Green manure	Summer fallow	Perennial system
41.1	0	1	0	0
42.1	0	0	0	1
42.2	0	0	0	1
43.1	0	0	1	0
43.2	0	0	1	0
45.1	0	1	0	0
45.2	0	1	0	0
46.1	0	0	1	0
47.1	0	0	0	1
47.2	0	0	0	1
50.1	0	0	1	0
50.2	1	0	0	0
51.1	1	0	0	0
51.2	0	1	0	0
52.1	0	0	1	0
52.2	0	1	0	0
53.1	0	1	0	0
53.2	0	1	0	0
55.1	0	0	1	0
56.1	0	0	1	0
59.1	0	1	0	0
59.2	1	0	0	0
60.2	1	0	0	0
61.1	0	1	0	0
65.1	0	1	0	0
65.2	0	1	0	0
68.1	1	0	0	0
70.1	0	1	0	0
70.2	0	1	0	0
71.1	1	0	0	0
71.2	1	0	0	0
74.1	1	0	0	0
74.2	1	0	0	0

Appendix C: Weed species data

Table C.1. Life histories† of the identified weed species listed by both common name, Latin nomenclature and Bayer codes (for the 30 species included in the RDA) (Darbyshire et al., 2000).

Weed common name	**Latin nomenclature**	**Bayer code**	**Life history†**
Absinth	*Artemisia absinthium* L.	-	Per
Alfalfa	*Medicago sativa* L.	MEDSA	Per
American dragonhead	*Dracocephalum parviflorum* Nutt.	-	Ann
Annual sow-thistle	*Sonchus oleraceus* L.	-	Ann
Ball mustard	*Neslia paniculata* (L.) Desv.	-	Ann
Barley	*Hordeum vulgare* L.	-	Ann
Barnyard grass	*Echinochloa crusgalli* (L.) Beauv.	-	Ann
Bicknell's geranium	*Geranium bicknellii* Britton	-	Ann
Black medick	*Medicago lupulina* L.	MEDLU	Ann
Bladder campion	*Silene cucubalus* Wibel.	-	Per
Bluebur	*Lappula squarrosa* (Retz.) Dumort.	LPLSQ	Ann
Borage	*Borago officinalis* L.	-	Ann
Broad-leaved plantain	*Plantago major* L.	-	Per
Canada thistle	*Cirsium arvense* (L.) Scop.	CIRAR	Per
Chickweed	*Stellaria media* (L.) Cyrill.	-	Ann
Cleavers	*Galium aparine* L.	GALAP	Ann
Common groundsel	*Senecio vulgaris* L.	-	Ann
Cow cockle	*Vaccaria hispanica* (Mill.) Rauschert	VAAPY	Ann
Dandelion	*Taraxacum officinale* Weber	TAROF	Per
Dog mustard	*Erucastrum gallicum* (Willd.) Schultz	-	Ann
Field horsetail	*Equisetum arvense* L.	EQUAR	Per
Field pea	*Pisum saivumt* L.	-	Ann
Flax	*Linum usitatissimum* L.	LIUUT	Ann
Flixweed	*Descurainia sophia* (L.) Webb	DESSO	Ann
Green foxtail	*Setaria viridis* (L.) Beauv.	SETVI	Ann
Hemp-nettle	*Galeopsis tetrahit* L.	GAETE	Ann
Kochia	*Kochia scoparia* (L.) Schrad.	KCHSC	Ann
Lamb's-quarters	*Chenopodium album* L.	CHEAL	Ann
Lentil	*Lens culinaris* Medic.	-	Ann
Maple-leaved goosefoot	*Chenopodium gigantospermum* Aellen	CHEHG	Ann
Narrow-leaved hawk's-beard	*Crepis tectorum* L.	-	Ann
Night-flowering catchfly	*Silene noctiflora* L.	MELNO	Ann
Northern bedstraw	*Galium boreale* L.	-	Per

† For species able to display multiple life histories, the shortest life history listed was chosen. Per = Perennial; Ann = Annual; Bie = Biennial.

Table C.1. Continued

Weed common name	***Latin nomenclature***	**Bayer codes**	**Life history**†
Pale smartweed	*Polygonum lapathifolium* L.	POLLA	Ann
Perennial sow-thistle	*Sonchus arvensis* L.	SONAR	Per
Persian darnel	*Lolium persicum* Boiss. & Hohen. ex Boiss.	-	Ann
Prairie rose species	*Rosa* spp.	-	Per
Prickly lettuce	*Lactuca serriola* L.	LACSE	Ann
Prostrate knotweed	*Polygonum aviculare* L.	POLAV	Ann
Prostrate pigweed	*Amaranthus blitoides* S. Watson	-	Ann
Quack grass	*Elytrigia repens* (L.) Desv. Ex B.D. Jacks.	AGRRE	Per
Red clover	*Trifolium pratense* L.	-	Bie
Redroot pigweed	*Amaranthus retroflexus* L.	AMARE	Ann
Rough cinquefoil	*Potentilla norvegica* L.	-	Ann
Round-leaved mallow	*Malva pusilla* Sm.	-	Ann
Russian pigweed	*Axyris amaranthoides* L.	-	Ann
Russian thistle	*Salsola kali* L. subsp. *ruthenica* (Iljin) Soó	SASKR	Ann
Scentless chamomile	*Matricaria perforata* Mérat	-	Ann
Shepherd's-purse	*Capsella bursa-pastoris* (L.) Medic.	CAPBP	Ann
Spear-leaved goosefoot	*Monolepis nuttalliana* (Schult.) Greene	-	Ann
Spreading dogbane	*Apocynum androsaemifolium* L.	-	Per
Stinkweed	*Thlapsi arvense* L.	THLAR	Ann
Thyme-leaved spurge	*Euphorbia serpyllifolia* Pers.	EPHSP	Ann
Vetch species	*Vicia* spp.	VICXX	Per
Wheat	*Triticum aestivum* L.		Ann
Wild buckwheat	*Polygonum convolvulus* L.	POLCO	Ann
Wild mustard	*Sinapis arvensis* L.	SINAR	Ann
Wild oats	*Avena fatua* L.	AVEFA	Ann
Wild tomato	*Solanum triflorum* Nutt.	-	Ann
Wormseed mustard	*Erysimum cheiranthoides* L.	-	Ann
Unknown weed species 1	-	-	-
Unknown weed species 2	-	-	-
Unknown weed species 3	-	-	-

† For species able to display multiple life histories, the shortest life history listed was chosen. Per = Perennial; Ann = Annual; Bie = Biennial.

Table C.2. Relative abundance, relative frequency, relative uniformity and relative density measures for the Diverse Organic Cropping System.

Diverse System	Relative Frequency (%)	Relative Uniformity (%)	Relative Density (%)	Relative Abundance	Rank
Green foxtail	5.86	11.16	29.81	46.82	1
Wild mustard	6.76	10.46	26.01	43.23	2
Lamb's-quarters	9.46	16.04	16.57	42.07	3
Wild oats	7.21	8.02	9.04	24.27	4
Stinkweed	5.86	8.08	6.09	20.02	5
Wild buckwheat	7.66	10.05	1.97	19.68	6
Canada thistle	5.41	5.17	0.80	11.37	7
Bluebur	3.60	3.49	0.82	7.91	8
Cow cockle	3.15	3.37	1.30	7.83	9
Russian thistle	2.70	2.21	2.09	7.00	10
Redroot pigweed	4.50	1.98	0.21	6.69	11
Flixweed	2.70	1.92	0.28	4.90	12
Dandelion	2.70	1.98	0.19	4.86	13
Perennial sow-thistle	2.70	1.34	0.20	4.24	14
Pale smartweed	2.25	1.51	0.21	3.97	15
Vetch species	2.25	1.45	0.23	3.93	16
Black medick	1.80	1.28	0.66	3.74	17
Cleavers	2.25	0.99	0.26	3.50	18
Quack grass	1.80	0.87	0.68	3.36	19
Alfalfa	1.80	1.34	0.15	3.29	20
Thyme-leaved spurge	1.80	1.22	0.13	3.15	21
Night-flowering catchfly	1.80	1.05	0.16	3.01	22
Prostrate knotweed	1.80	1.05	0.14	2.99	23
Red clover	1.35	1.16	0.14	2.66	24
Kochia	1.80	0.41	0.04	2.24	25
Flax	0.00	0.00	1.63	1.63	26
Maple-leaved goosefoot	0.90	0.17	0.01	1.08	27
Prickly lettuce	0.45	0.23	0.03	0.71	28
Bladder campion	0.45	0.23	0.02	0.70	29
Chickweed	0.45	0.17	0.02	0.64	32
Unknown weed species #1	0.45	0.17	0.02	0.64	32
Field pea	0.45	0.17	0.02	0.64	32
Annual sow-thistle	0.45	0.17	0.01	0.64	32
Prostrate pigweed	0.45	0.17	0.01	0.64	32
Barley	0.45	0.12	0.01	0.58	35.5
Unknown weed species #2	0.45	0.12	0.01	0.58	35.5
Shepherd's-purse	0.45	0.12	0.01	0.57	38
American dragonhead	0.45	0.12	0.00	0.57	38
Broad-leaved plantain	0.45	0.12	0.00	0.57	38
Northern bedstraw	0.45	0.06	0.02	0.53	40
Spreading dogbane	0.45	0.06	0.00	0.51	43
Narrow-leaved hawk's-beard	0.45	0.06	0.00	0.51	43
Persian darnel	0.45	0.06	0.00	0.51	43
Wheat	0.45	0.06	0.00	0.51	43
Wormseed mustard	0.45	0.06	0.00	0.51	43

Table C.3. Relative abundance, relative frequency, relative uniformity and relative density measures for the Green Manure Organic Cropping System.

Green Manure System	Relative Frequency (%)	Relative Uniformity (%)	Relative Density (%)	Relative Abundance	Rank
Green foxtail	7.22	10.65	38.92	56.79	1
Wild mustard	6.50	10.33	24.34	41.17	2
Wild oats	6.50	10.79	12.58	29.87	3
Lamb's-quarters	7.58	10.92	5.00	23.51	4
Wild buckwheat	7.94	9.41	2.49	19.85	5
Stinkweed	6.14	8.14	4.43	18.7	6
Russian thistle	3.61	4.11	3.04	10.76	7
Canada thistle	4.69	4.02	0.94	9.66	8
Redroot pigweed	4.69	3.98	0.37	9.04	9
Black medick	2.17	3.56	1.71	7.44	10
Flixweed	3.97	2.56	0.17	6.7	11
Alfalfa	3.25	2.47	0.94	6.66	12
Cow cockle	3.25	2.47	0.32	6.04	13
Bluebur	3.61	1.87	0.13	5.61	14
Thyme-leaved spurge	2.17	1.87	1.23	5.27	15
Kochia	3.25	1.23	0.32	4.8	16.5
Perennial sow-thistle	3.25	1.37	0.18	4.8	16.5
Night-flowering catchfly	1.44	1.55	0.42	3.42	18
Prostrate knotweed	1.81	1.14	0.06	3.01	19
Dandelion	1.81	1.01	0.15	2.96	20
Field horsetail	1.44	0.69	0.59	2.72	21
Persian darnel	0.72	0.96	0.80	2.48	22
Hemp-nettle	1.08	0.96	0.23	2.27	23
Pale smartweed	1.44	0.50	0.04	1.99	24
Dog mustard	0.72	0.96	0.22	1.9	25
Prickly lettuce	1.44	0.23	0.01	1.68	26
Round-leaved mallow	1.08	0.23	0.04	1.35	27
Vetch species	1.08	0.14	0.01	1.23	28
Narrow-leaved hawk's-beard	0.72	0.46	0.03	1.21	29
Annual sow-thistle	0.36	0.46	0.14	0.96	30
Quack grass	0.72	0.14	0.04	0.9	31
Prairie rose species	0.72	0.14	0.01	0.87	32
Barnyard grass	0.36	0.14	0.03	0.53	33
Maple-leaved goosefoot	0.36	0.14	0.01	0.50	34
Cleavers	0.36	0.09	0.01	0.46	35
Broad-leaved plantain	0.36	0.05	0.01	0.42	36
Absinth	0.36	0.05	0.00	0.41	39.5
American dragonhead	0.36	0.05	0.00	0.41	39.5
Unknown weed species #3	0.36	0.05	0.01	0.41	39.5
Russian pigweed	0.36	0.05	0.00	0.41	39.5
Spear-leaved goosefoot	0.36	0.05	0.00	0.41	39.5
Wild tomato	0.36	0.05	0.00	0.41	39.5

Table C.4. Relative abundance, relative frequency, relative uniformity and relative density measures for the Low Diversity Summerfallow Organic Cropping System.

Summerfallow System	Relative Frequency (%)	Relative Uniformity (%)	Relative Density (%)	Relative Abundance	Rank
Green foxtail	7.50	18.33	57.97	83.79	1
Wild mustard	6.25	11.37	24.01	41.63	2
Wild oats	6.88	9.25	7.73	23.85	3
Lamb's-quarters	6.88	12.42	3.46	22.76	4
Wild buckwheat	8.13	11.10	1.25	20.48	5
Canada thistle	6.25	4.85	0.74	11.83	6
Stinkweed	5.00	3.79	0.82	9.61	7
Dandelion	3.75	3.00	0.25	7.00	8
Redroot pigweed	3.13	3.26	0.49	6.87	9
Russian thistle	4.38	2.11	0.20	6.69	10
Flixweed	4.38	1.50	0.12	5.99	11
Bluebur	3.13	2.56	0.28	5.96	12
Perennial sow-thistle	3.75	1.76	0.13	5.65	13
Alfalfa	2.50	2.29	0.55	5.34	14
Prostrate knotweed	3.75	0.62	0.04	4.41	15
Vetch species	2.50	0.62	0.06	3.18	16
Kochia	1.88	0.88	0.06	2.82	17
Shepherd's-purse	1.25	1.15	0.31	2.70	18
Cleavers	1.88	0.70	0.10	2.68	19
Persian darnel	1.25	1.15	0.20	2.60	20
Dog mustard	1.25	0.70	0.12	2.07	21
Night-flowering catchfly	1.25	0.70	0.10	2.06	22
Thyme-leaved spurge	0.63	1.15	0.25	2.02	23
Cow cockle	1.25	0.35	0.10	1.71	24
Pale smartweed	1.25	0.35	0.02	1.62	25
Borage	0.63	0.88	0.10	1.61	26
Field horsetail	1.25	0.26	0.09	1.60	27
Hemp-nettle	1.25	0.26	0.02	1.54	28
Wheat	0.63	0.79	0.07	1.49	29
Quack grass	1.25	0.18	0.01	1.44	30
Black medick	0.63	0.53	0.05	1.21	31
Barnyard grass	0.63	0.35	0.13	1.11	32
Prickly lettuce	0.63	0.26	0.02	0.91	33
Scentless chamomile	0.63	0.18	0.01	0.81	34
Broad-leaved plantain	0.63	0.09	0.07	0.78	36
Round-leaved mallow	0.63	0.09	0.04	0.75	36
Prairie rose species	0.63	0.09	0.00	0.72	37.5
Spear-leaved goosefoot	0.63	0.09	0.00	0.72	37.5

Table C.5. Relative abundance, relative frequency, relative uniformity and relative density measures for the Moderately Diverse Perennial Organic Cropping System.

Perennial System	Relative Frequency (%)	Relative Uniformity (%)	Relative Density (%)	Relative Abundance	Rank
Lamb's-quarters	8.78	18.09	32.28	59.15	1
Green foxtail	5.41	7.54	18.83	31.78	2
Wild buckwheat	8.78	16.05	5.33	30.17	3
Wild mustard	6.76	6.38	11.66	24.80	4
Stinkweed	6.08	8.22	9.53	23.83	5
Alfalfa	7.43	8.99	3.38	19.81	6
Quack grass	3.38	5.13	7.33	15.83	7
Wild oats	4.73	6.29	4.80	15.81	8
Dandelion	5.41	3.00	0.54	8.95	9
Pale smartweed	2.70	2.80	0.81	6.32	10
Hemp-nettle	2.70	1.84	0.80	5.35	11
Prostrate knotweed	2.03	2.03	0.55	4.61	12
Maple-leaved goosefoot	2.03	1.26	1.01	4.30	13
Canada thistle	2.03	1.45	0.44	3.92	14
Shepherd's-purse	2.03	1.26	0.49	3.78	15
Night-flowering catchfly	2.70	0.68	0.14	3.52	16
Field horsetail	2.03	0.87	0.53	3.42	17
Cleavers	2.03	0.87	0.14	3.03	18
Common groundsel	1.35	0.77	0.45	2.57	19
Bluebur	1.35	0.97	0.18	2.50	20
Perennial sow-thistle	2.03	0.29	0.07	2.39	21
Redroot pigweed	1.35	0.68	0.12	2.15	22.5
Prairie rose species	1.35	0.68	0.12	2.15	22.5
Rough cinquefoil	1.35	0.58	0.10	2.03	24
Flax	1.35	0.58	0.00	1.93	25
Flixweed	1.35	0.39	0.08	1.82	26
American dragonhead	1.35	0.29	0.02	1.67	27
Kochia	1.35	0.19	0.03	1.58	28
Black medick	1.35	0.19	0.02	1.56	29.5
Unknown weed species #2	1.35	0.19	0.02	1.56	29.5
Spear-leaved goosefoot	0.68	0.39	0.06	1.12	31
Bicknell's geranium	0.68	0.29	0.04	1.01	32
Lentil	0.68	0.19	0.04	0.91	33
Thyme-leaved spurge	0.68	0.10	0.02	0.80	34
Dog mustard	0.68	0.10	0.02	0.79	35
Ball mustard	0.68	0.10	0.01	0.78	37.5
Bladder campion	0.68	0.10	0.01	0.78	37.5
Round-leaved mallow	0.68	0.10	0.01	0.78	37.5
Wormseed mustard	0.68	0.10	0.01	0.78	37.5

Table C.6. Mean field densities (mean density per m^2) for the weed species found in the province and the four organic farming systems listed in ranked order.

Ranked weed species	Mean Field Density Saskat-chewan	Ranked weed species	Mean Field Density Diverse Cropping System	Ranked weed species	Mean Field Density Diverse Cropping Green Manure System	Ranked weed species	Mean Field Density Low Diversity Summer-fallow System	Ranked weed species	Mean Field Density Moderately Diverse Perennial Cropping System
Green foxtail	2868.11	Green foxtail	2512.76	Green foxtail	3592.87	Green foxtail	4608.29	Lamb's-quarters	1080.27
Wild mustard	1784.99	Wild mustard	2192.95	Wild mustard	2246.78	Wild mustard	1908.86	Green foxtail	630.13
Lamb's-quarters	822.19	Lamb's-quarters	1397.14	Wild oats	1161.57	Wild oats	614.29	Wild mustard	390.13
Wild oats	736.00	Wild oats	762.10	Lamb's-quarters	461.91	Lamb's-quarters	275.14	Stinkweed	318.93
Stinkweed	354.58	Stinkweed	513.14	Stinkweed	409.04	Wild buckwheat	99.43	Quack grass	245.33
Wild buckwheat	176.05	Russian thistle	175.81	Russian Thistle	280.70	Stinkweed	65.43	Wild Buckwheat	178.40
Russian thistle	142.08	Wild buckwheat	166.10	Wild buckwheat	230.26	Canada thistle	58.57	Wild oats	160.53
Quack grass	68.38	Flax	137.71	Black medick	157.91	Alfalfa	43.71	Alfalfa	113.07
Black medick	66.63	Cow cockle	109.90	Thyme-leaved spurge	113.39	Redroot pigweed	38.57	Maple-leaved goosefoot	33.87
Alfalfa	62.58	Bluebur	69.14	Alfalfa	86.96	Shepherd's-purse	24.29	Pale smartweed	27.20
Canada thistle	60.93	Canada thistle	67.24	Canada thistle	86.78	Bluebur	22.57	Hemp-nettle	26.93

Table C.6. –continued-

Ranked weed species	Mean Field Density Saskat-chewan	Ranked weed species	Mean Field Density Diverse Cropping System	Ranked weed species	Mean Field Density Diverse Cropping Green Manure System	Ranked weed species	Mean Field Density Low Diversity Summer-fallow System	Ranked weed species	Mean Field Density Moderately Diverse Perennial Cropping System
Thyme-leaved spurge	42.74	Quack grass	57.71	Persian darnel	73.74	Dandelion	20.00	Prostrate knotweed	18.40
Cow cockle	42.58	Black medick	55.43	Field horsetail	54.09	Thyme-leaved spurge	19.71	Dandelion	18.13
Flax	39.67	Flixweed	23.24	Night-flowering catchfly	38.96	Persian darnel	16.29	Field horsetail	17.60
Bluebur	29.21	Cleavers	21.90	Redroot pigweed	34.61	Russian thistle	16.00	Shepherd's-purse	16.53
Persian darnel	26.41	Vetch species	19.05	Cow cockle	29.74	Perennial sow-thistle	10.57	Common groundsel	14.93
Redroot pigweed	24.27	Redroot pigweed	17.90	Kochia	29.39	Barnyard grass	10.57	Canada thistle	14.67
Field horsetail	21.97	Pale smartweed	17.52	Hemp-nettle	21.04	Flixweed	9.71	Bluebur	6.13
Night-flowering catchfly	18.85	Perennial sow-thistle	16.76	Dog mustard	20.00	Dog mustard	9.43	Night-flowering catchfly	4.80
Dandelion	16.44	Dandelion	15.62	Perennial sow-thistle	16.87	Cow cockle	8.29	Cleavers	4.53
Flixweed	14.03	Night-flowering catchfly	13.90	Flixweed	15.65	Night-flowering catchfly	8.29	Redroot Pigweed	4.00

Table C.6. –continued-

Ranked weed species	Mean Field Density Saskat-chewan	Ranked weed species	Mean Field Density Diverse Cropping System	Ranked weed species	Mean Field Density Diverse Cropping Green Manure System	Ranked weed species	Mean Field Density Low Diversity Summer-fallow System	Ranked weed species	Mean Field Density Moderately Diverse Perennial Cropping System
Perennial sow-thistle	12.66	Alfalfa	12.38	Dandelion	13.91	Cleavers	8.00	Prairie rose species	4.00
Hemp-nettle	12.49	Prostrate knotweed	12.00	Annual Sow-Thistle	13.04	Borage	8.00	Rough cinquefoil	3.20
Pale smartweed	12.16	Red clover	12.00	Bluebur	11.83	Field horsetail	6.86	Flixweed	2.67
Kochia	11.29	Thyme-leaved spurge	10.67	Prostrate knotweed	5.91	Broad-leaved plantain	5.71	Perennial sow-thistle	2.40
Prostrate knotweed	9.70	Kochia	3.05	Pale smartweed	3.83	Wheat	5.71	Spear-leaved goosefoot	1.87
Cleavers	8.99	Prickly lettuce	2.67	Quack grass	3.83	Vetch species	5.14	Bicknell’s geranium	1.33
Shepherd’s-purse	8.22	Northern bedstraw	2.10	Round-leaved mallow	3.30	Kochia	4.86	Lentil	1.33
Dog mustard	8.22	Unknown #1	1.52	Barnyard grass	3.13	Black medick	4.29	Kochia	1.07
Maple-leaved goosefoot	7.29	Field pea	1.52	Narrow-leaved hawk’s-beard	2.78	Prostrate knotweed	3.14	Thyme-leaved spurge	0.80
Vetch species	6.79	Chickweed	1.52	Vetch species	1.04	Round-leaved mallow	3.14	American Dragonhead	0.80

Table C.6. –continued-

Ranked weed species	Mean Field Density Saskat-chewan	Ranked weed species	Mean Field Density Diverse Cropping System	Ranked weed species	Mean Field Density Diverse Cropping Green Manure System	Ranked weed species	Mean Field Density Low Diversity Summer-fallow System	Ranked weed species	Mean Field Density Moderately Diverse Perennial Cropping System
Annual sow-thistle	4.38	Bladder campion	1.33	Broad-leaved plantain	1.04	Pale smartweed	1.71	Black medick	0.53
Red clover	3.45	Annual sow-thistle	0.95	Prickly lettuce	0.87	Hemp-nettle	1.71	Dog Mustard	0.53
Common groundsel	3.07	Barley	0.95	Prairie rose species	0.87	Prickly lettuce	1.43	Unknown #2	0.53
Barnyard grass	3.01	Prostrate pigweed	0.95	Cleavers	0.70	Quack grass	0.86	Round-leaved mallow	0.27
Round-leaved mallow	1.70	Unknown #2	0.76	Unknown #3	0.70	Chamomile	0.57	Bladder campion	0.27
Broad-leaved plantain	1.53	Maple-leaved goosefoot	0.57	Maple-leaved goosefoot	0.52	Flax	0.29	Wormseed mustard	0.27
Borage	1.53	Shepherd's-purse	0.57	Absinth	0.35	Prairie rose species	0.29	Ball mustard	0.27
Prickly lettuce	1.32	American dragonhead	0.38	American dragonhead	0.17	Spear-leaved goosefoot	0.29	Russian thistle	-
Prairie rose species	1.15	Broad-leaved plantain	0.38	Spear-leaved goosefoot	0.17	Maple-leaved goosefoot	-	Cow cockle	-

Table C.6. –continued-

Ranked weed species	Mean Field Density Saskat-chewan	Ranked weed species	Mean Field Density Diverse Cropping System	Ranked weed species	Mean Field Density Diverse Cropping Green Manure System	Ranked weed species	Mean Field Density Low Diversity Summer-fallow System	Ranked weed species	Mean Field Density Moderately Diverse Perennial Cropping System
Wheat	1.15	Narrow-leaved hawk's-beard	0.38	Russian pigweed	0.17	American dragonhead	-	Vetch species	-
Narrow-leaved hawk's-beard	0.99	Spreading dogbane	0.38	Wild tomato	0.17	Narrow-leaved hawk's-beard	-	Flax	-
Rough cinquefoil	0.66	Persian darnel	0.19	Flax	-	Unknown #2	-	Prickly lettuce	-
Northern bedstraw	0.60	Wheat	0.19	Shepherd's-purse	-	Red clover	-	Persian darnel	-
Spear-leaved goosefoot	0.49	Wormseed Mustard	0.19	Wheat	-	Spreading dogbane	-	Broad-leaved plantain	-
Bladder Campion	0.44	Field horsetail	-	Unknown #2	-	Northern bedstraw	-	Narrow-leaved hawk's-beard	-
Unknown #1	0.44	Hemp-nettle	-	Red clover	-	Common groundsel	-	Wheat	-
Field pea	0.44	Prairie rose species	-	Spreading dogbane	-	Bladder campion	-	Red clover	-
Chickweed	0.44	Dog Mustard	-	Northern bedstraw	-	Wormseed mustard	-	Spreading dogbane	-

Table C.6. –continued-

Ranked weed species	Mean Field Density Saskat-chewan	Ranked weed species	Mean Field Density Diverse Cropping System	Ranked weed species	Mean Field Density Diverse Cropping Green Manure System	Ranked weed species	Mean Field Density Low Diversity Summer-fallow System	Ranked weed species	Mean Field Density Moderately Diverse Perennial Cropping System
American Dragonhead	0.33	Round-leaved mallow	-	Common groundsel	-	Rough cinquefoil	-	Northern bedstraw	-
Unknown #2	0.33	Spear-leaved goosefoot	-	Bladder campion	-	Annual sow-thistle	-	Barnyard grass	-
Bicknell's geranium	0.27	Common groundsel	-	Wormseed mustard	-	Unknown #3	-	Annual sow-thistle	-
Lentil	0.27	Rough cinquefoil	-	Rough cinquefoil	-	Bicknell's geranium	-	Borage	-
Barley	0.27	Barnyard grass	-	Borage	-	Lentil	-	Unknown #3	-
Prostrate pigweed	0.27	Borage	-	Bicknell's geranium	-	Barley	-	Barley	-
Unknown #3	0.22	Unknown #3	-	Lentil	-	Russian pigweed	-	Chamomile	-
Spreading dogbane	0.11	Bicknell's geranium	-	Barley	-	Wild tomato	-	Russian pigweed	-
Wormseed mustard	0.11	Lentil	-	Chamomile	-	Ball mustard	-	Wild tomato	-
Chamomile	0.11	Chamomile	-	Ball mustard	-	Absinth	-	Absinth	-
Absinth	0.11	Russian pigweed	-	Prostrate pigweed	-	Prostrate pigweed	-	Prostrate pigweed	-
Russian pigweed	0.05	Wild tomato	-	Unknown #1	-	Unknown #1	-	Unknown #1	-

Table C.6. –continued-

Ranked weed species	Mean Field Density Saskat-chewan	Ranked weed species	Mean Field Density Diverse Cropping System	Ranked weed species	Mean Field Density Diverse Cropping Green Manure System	Ranked weed species	Mean Field Density Low Diversity Summer-fallow System	Ranked weed species	Mean Field Density Moderately Diverse Perennial Cropping System
Wild tomato	0.05	Ball mustard	-	Field pea	-	Field pea	-	Field pea	-
Ball mustard	0.05	Absinth	-	Chickweed	-	Chickweed	-	Chickweed	-

Table C.7. Main matrix, species data, used in the ordination of organic fields presented as the total counts (weed count per $5m^2$).

Field	POLCO	CHEAL	THLAR	SETVI	AVEFA	CIRAR	SONAR	SASKR
1.1	450	2356	79	605	0	0	0	879
1.2	22	1511	169	1224	0	0	0	33
4.1	31	150	49	333	5	0	0	0
4.2	78	120	0	1	0	0	0	0
5.1	0	0	0	0	0	0	0	0
5.2	0	0	0	0	0	0	0	0
6.1	28	1241	0	329	18	0	0	0
8.1	33	286	0	4091	804	12	0	5
8.2	12	45	1	2412	137	0	0	0
12.1	12	643	10	2281	310	11	1	335
12.2	1	933	1	1123	373	4	0	200
13.1	18	129	2	45	7	0	0	0
14.1	151	17	0	1635	8	0	0	0
15.1	6	68	7	0	181	51	0	0
15.2	18	51	0	0	11	18	0	0
16.1	122	1366	331	0	0	0	0	0
16.2	17	159	90	0	0	0	0	0
17.1	28	78	1	0	2461	0	0	0
19.1	38	106	9	0	251	52	6	0
19.2	18	199	6	0	2	1	0	0
20.1	32	1	4	1	0	1	1	0
20.2	28	641	610	0	0	0	2	0
21.1	31	520	0	0	29	0	0	0
21.2	23	368	49	71	102	1	0	0
23.1	133	7	0	0	689	14	6	0
26.1	13	424	0	2378	0	79	0	5
27.1	37	177	2	2373	715	60	19	1
27.2	90	215	10	4196	1221	39	55	0
28.1	21	40	1	62	79	27	0	0
28.2	21	21	0	11	491	0	0	0
29.1	3	0	13	2	1	0	0	0
29.2	1	0	0	5	0	0	0	0
32.1	63	14	141	1359	239	15	11	0
32.2	10	46	7	338	264	13	2	0
33.2	106	6	0	508	99	3	3	0
36.1	0	934	0	0	293	3	1	0
39.1	14	43	11	693	451	0	0	12
39.2	620	143	37	7587	3	0	0	975
40.1	5	9	0	1	3	3	0	1

Table C.7. –continued-

Field	POLCO	CHEAL	THLAR	SETVI	AVEFA	CIRAR	SONAR	SASKR
40.2	15	125	0	201	797	3	0	2
41.1	4	1	0	5315	0	0	0	0
42.1	41	237	70	70	3	0	0	0
42.2	2	9	0	0	0	0	0	0
43.1	10	78	4	244	103	19	2	1
43.2	9	132	7	599	114	7	1	8
45.1	36	206	0	2	27	164	29	0
45.2	7	14	115	9	137	48	17	0
46.1	41	267	0	5837	0	6	0	26
47.1	20	1	3	202	175	2	0	0
47.2	94	24	77	80	140	0	0	0
50.1	0	5	0	0	19	0	0	0
50.2	0	0	0	0	0	0	0	0
51.1	10	21	814	33	617	0	0	0
51.2	48	129	111	130	336	0	2	59
52.1	20	15	46	148	2	88	19	0
52.2	55	42	132	520	311	113	35	0
53.1	8	30	672	1278	7	0	0	6
53.2	7	13	120	1152	71	39	0	9
55.1	13	0	0	94	17	0	0	0
56.1	16	0	12	143	0	1	1	3
59.1	68	192	860	0	292	0	2	2
59.2	17	89	449	79	195	0	1	0
60.2	22	19	704	782	4	2	1	2
61.1	202	6	102	304	102	0	0	22
65.1	0	2	26	1	0	41	0	0
65.2	31	1	139	4	0	3	0	0
68.1	67	211	349	1043	698	92	0	0
70.1	5	21	4	39	0	39	3	0
70.2	9	3	2	357	7	7	0	4
71.1	0	2	0	0	0	0	0	3
71.2	1	2	13	0	10	0	0	0
74.1	0	4	0	0	1	28	11	0
74.2	1	37	0	13	0	3	0	0

Table C.7. –continued-

Field	POLAV	DESSO	SINAR	CAPBP	TAROF	AMARE	MEDLU	LPLSQ
1.1	52	0	1	0	0	19	0	35
1.2	0	0	0	0	0	0	4	0
4.1	0	0	0	0	0	2	0	8
4.2	0	0	0	0	2	0	0	0
5.1	0	0	0	0	0	0	0	0
5.2	0	0	0	0	0	0	0	0
6.1	4	0	4	0	4	0	0	0
8.1	0	0	235	0	0	5	0	0
8.2	0	1	1378	0	0	0	15	7
12.1	14	0	3	0	0	0	3	3
12.2	4	0	259	0	0	0	48	34
13.1	3	1	232	0	12	1	0	0
14.1	0	0	0	0	0	0	0	0
15.1	1	0	5	0	2	0	0	0
15.2	0	0	1	0	0	0	0	0
16.1	0	9	20	0	4	0	1	0
16.2	0	0	0	0	0	0	1	0
17.1	0	3	3	0	0	0	0	0
19.1	0	0	1107	0	14	0	0	0
19.2	0	0	897	0	42	3	0	0
20.1	0	0	2	60	28	0	0	0
20.2	0	0	63	1	0	0	0	0
21.1	0	0	1321	0	0	0	0	4
21.2	0	0	2	0	0	1	0	0
23.1	1	0	715	0	0	0	191	0
26.1	0	0	3433	0	0	0	1	2
27.1	1	1	47	0	6	0	0	9
27.2	1	0	7	0	25	17	285	242
28.1	0	0	112	0	0	2	0	0
28.2	0	0	301	0	0	0	0	0
29.1	0	0	888	0	0	14	0	0
29.2	0	0	7117	0	0	0	0	0
32.1	0	0	117	0	23	9	0	0
32.2	4	1	1	0	18	1	0	0
33.2	2	3	0	84	21	67	0	0
36.1	0	0	8	0	0	0	1	2
39.1	0	1	0	0	0	0	0	0
39.2	0	17	0	0	0	3	0	3
40.1	0	0	1	1	0	0	0	3

Table C.7. –continued-

Field	POLAV	DESSO	SINAR	CAPBP	TAROF	AMARE	MEDLU	LPLSQ
40.2	0	0	1277	0	0	0	0	5
41.1	0	0	0	0	0	0	0	0
42.1	62	0	1	0	2	14	0	19
42.2	0	0	2	0	0	0	0	0
43.1	3	13	1130	0	1	0	0	10
43.2	3	5	1310	0	0	0	0	55
45.1	0	0	449	0	0	0	0	5
45.2	0	1	5	0	3	6	0	0
46.1	0	0	37	0	0	53	0	0
47.1	0	0	2	0	2	0	0	0
47.2	0	0	30	1	0	0	0	4
50.1	0	1	2805	0	3	6	0	0
50.2	0	0	2459	0	0	0	0	0
51.1	0	94	0	0	0	26	0	0
51.2	0	8	2	0	0	19	0	1
52.1	1	1	0	0	22	1	0	4
52.2	0	6	74	0	56	0	0	9
53.1	0	9	7	0	2	10	301	2
53.2	0	0	0	0	0	16	127	0
55.1	1	0	0	0	0	0	0	0
56.1	0	10	9	0	1	0	0	0
59.1	11	13	0	0	0	14	0	0
59.2	9	21	0	0	0	13	0	0
60.2	0	3	0	0	0	5	0	0
61.1	0	21	0	0	0	44	238	0
65.1	0	6	829	0	0	9	0	0
65.2	0	5	590	0	1	5	0	0
68.1	0	0	1	3	3	0	0	61
70.1	0	0	393	0	0	56	0	4
70.2	0	0	6	0	0	2	0	2
71.1	0	0	1949	0	0	0	0	0
71.2	0	0	878	0	0	0	0	0
74.1	0	0	0	0	3	0	0	0
74.2	0	2	51	0	0	0	0	0

Table C.7. –continued-

Field	AGRRE	KCHSC	MEDSA	GALAP	EQUAR	MELNO	VICSA	POLLA
1.1	0	1	0	0	0	0	0	0
1.2	0	0	0	0	0	0	0	0
4.1	42	0	8	0	0	0	0	0
4.2	10	0	2	1	2	0	0	0
5.1	0	0	0	0	0	0	0	0
5.2	0	0	0	0	5	0	0	0
6.1	64	0	18	0	0	0	0	0
8.1	0	0	0	1	0	3	0	1
8.2	0	0	11	0	22	0	1	0
12.1	0	11	0	0	0	0	0	0
12.2	0	13	0	0	0	0	0	0
13.1	0	0	2	0	0	0	0	0
14.1	0	0	49	0	59	0	0	21
15.1	0	0	0	2	0	0	0	5
15.2	0	0	0	6	0	0	0	1
16.1	0	1	0	0	0	0	0	0
16.2	0	3	0	0	0	0	0	0
17.1	0	0	1	0	0	11	0	0
19.1	0	0	17	12	0	2	0	21
19.2	0	0	49	1	0	0	0	6
20.1	0	0	9	4	0	14	0	48
20.2	0	0	3	0	0	1	0	12
21.1	0	0	7	0	0	4	0	27
21.2	0	0	0	0	0	0	0	41
23.1	0	0	0	0	52	0	0	1
26.1	0	0	0	0	0	0	2	0
27.1	10	0	0	0	0	0	0	0
27.2	237	10	0	1	0	30	0	0
28.1	0	0	1	0	0	0	0	0
28.2	0	0	1	0	0	0	0	0
29.1	0	0	321	0	0	0	0	0
29.2	0	0	23	0	0	0	0	0
32.1	0	3	139	0	0	0	0	0
32.2	0	2	146	0	0	0	0	0
33.2	1	8	0	0	0	0	0	0
36.1	0	1	0	0	0	12	0	17
39.1	0	0	0	0	0	0	0	0
39.2	21	0	0	0	50	0	0	0
40.1	0	6	0	25	2	0	0	0

Table C.7. –continued-

Field	AGRRE	KCHSC	MEDSA	GALAP	EQUAR	MELNO	VICSA	POLLA
40.2	0	1	0	4	0	0	0	1
41.1	0	0	0	0	0	0	0	0
42.1	172	0	142	0	0	0	0	0
42.2	671	0	128	0	0	0	0	0
43.1	0	0	2	0	0	0	1	0
43.2	2	0	1	0	0	26	0	0
45.1	0	0	4	0	0	12	0	1
45.2	0	0	2	0	190	0	0	19
46.1	0	0	0	0	0	0	0	0
47.1	3	0	37	0	0	0	0	0
47.2	0	0	17	0	0	1	0	0
50.1	0	0	0	0	0	0	2	0
50.2	0	0	0	0	0	0	6	0
51.1	0	4	0	0	0	0	0	0
51.2	0	59	0	0	0	0	0	0
52.1	0	0	0	0	0	0	10	0
52.2	0	10	0	0	0	0	3	0
53.1	0	1	0	0	0	0	0	0
53.2	0	0	0	0	0	0	2	0
55.1	0	0	0	0	0	0	0	0
56.1	0	0	0	0	0	0	0	0
59.1	0	0	0	0	0	5	0	0
59.2	0	0	0	0	0	0	0	0
60.2	0	0	0	0	0	0	1	0
61.1	0	0	0	0	0	0	0	0
65.1	0	0	1	0	0	0	1	0
65.2	1	0	1	0	0	0	0	0
68.1	14	0	0	105	0	27	0	0
70.1	0	65	0	0	19	196	0	0
70.2	0	7	0	0	0	0	0	0
71.1	0	0	0	0	0	0	60	0
71.2	0	0	0	0	0	0	35	0
74.1	0	0	0	2	0	0	0	0
74.2	0	0	0	0	0	0	0	0

Table C.7. –continued-

Field	VAAPY	EPHSP	GAETE	CHEHG	LIUUT	LACSE
1.1	0	0	0	0	0	0
1.2	0	0	0	0	0	0
4.1	0	0	0	0	0	0
4.2	0	0	0	0	0	0
5.1	0	0	0	0	0	0
5.2	0	0	0	0	0	0
6.1	0	0	0	0	0	0
8.1	0	0	0	0	0	0
8.2	0	0	0	0	0	0
12.1	11	0	0	0	0	0
12.2	1	0	0	0	0	0
13.1	0	3	0	0	0	0
14.1	0	0	0	0	0	0
15.1	0	0	1	0	0	0
15.2	0	0	0	0	0	0
16.1	0	0	17	110	0	0
16.2	0	0	76	0	0	0
17.1	0	0	84	3	0	0
19.1	0	0	2	2	0	0
19.2	0	0	0	2	2	0
20.1	0	0	6	2	0	0
20.2	0	0	0	13	0	0
21.1	0	0	0	0	0	0
21.2	0	0	0	0	3	0
23.1	0	0	34	0	0	0
26.1	0	0	0	0	0	0
27.1	1	0	0	0	3	0
27.2	3	7	0	0	327	0
28.1	0	0	0	0	0	0
28.2	0	0	0	0	0	0
29.1	7	0	0	0	0	0
29.2	0	0	0	0	0	0
32.1	0	0	0	0	0	0
32.2	1	14	3	0	0	1
33.2	0	0	0	0	0	0
36.1	0	0	0	0	0	0
39.1	0	0	0	0	0	0
39.2	0	591	0	0	0	0
40.1	0	0	5	0	0	0

Table C.7. –continued-

Field	VAAPY	EPHSP	GAETE	CHEHG	LIUUT	LACSE
40.2	0	0	0	0	0	0
41.1	0	0	0	0	0	0
42.1	0	0	0	0	0	0
42.2	0	0	0	0	0	0
43.1	0	0	0	0	0	0
43.2	3	0	0	0	0	0
45.1	0	0	0	0	0	0
45.2	0	0	0	0	0	0
46.1	0	0	0	0	0	0
47.1	0	0	0	0	0	0
47.2	0	0	0	0	0	0
50.1	0	8	0	0	0	0
50.2	26	69	0	0	0	0
51.1	238	0	0	0	0	14
51.2	32	4	0	0	0	1
52.1	0	0	0	0	0	0
52.2	0	0	0	0	0	0
53.1	0	0	0	0	0	2
53.2	17	0	0	0	0	1
55.1	0	0	0	0	1	0
56.1	0	0	0	0	0	5
59.1	5	0	0	0	0	0
59.2	64	0	0	0	0	0
60.2	233	0	0	0	0	0
61.1	0	0	0	0	0	0
65.1	3	6	0	0	0	0
65.2	94	27	0	0	0	0
68.1	0	0	0	0	327	0
70.1	0	10	0	0	0	0
70.2	0	0	0	0	0	0
71.1	1	12	0	0	0	0
71.2	37	29	0	0	0	0
74.1	0	0	0	0	0	0
74.2	0	0	0	1	61	0

Appendix D: Deficiency levels of soil fertility averaged for the Canadian prairie provinces.

Table D.1. The deficient levels for N determined for a crop of wheat in the Alberta, Saskatchewan or Manitoba (Norwest labs).

Nitrogen (Kg/ha)	Nutrient level
< 67	Deficient
67 – 112	Marginal
113 – 168	Optimum
> 246	Excess

Table D.2. The deficient levels for P determined for a crop of wheat in the Alberta, Saskatchewan or Manitoba (Norwest labs).

Phosphorous (Kg/ha)	Nutrient level
< 33	Deficient
3 – 56	Marginal
57 – 134	Optimum
> 134	Excess

Table D.3. The deficient levels for K determined for a crop of wheat in the Alberta, Saskatchewan or Manitoba (Norwest labs).

Potassium (Kg/ha)	Nutrient level
< 179	Deficient
179 – 280	Marginal
280 – 1120	Optimum
> 1120	Excess

Table D.4. The deficient levels for S determined for a crop of wheat in the Alberta, Saskatchewan or Manitoba (Norwest labs).

Sulphur (Kg/ha)	Nutrient level
< 9	Deficient
9 – 36	Marginal
36 – 90	Optimum
> 90	Excess