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TRANSITIONAL DYNAMICS IN CONVERTING
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Major Professor's Signature

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TRANSITIONAL DYNAMICS IN CONVERTING CONVENTIONAL FIELD CROPPING SYSTEMS TO CERTIFIED ORGANIC

By

Andrew Thomas Corbin

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ABSTRACT

TRANSITIONAL DYNAMICS IN CONVERTING CONVENTIONAL FIELD CROPPING SYSTEMS TO CERTIFIED ORGANIC

By

Andrew Thomas Corbin

Transitional management strategies for certified organic field crop production are of great concern for Midwestern U.S. producers. Rotational tactics during the three-year transition period set the stage for sustainable organic production through improved soil quality, a manageable weed seedbank and acceptable revenues. This study was conducted over four years in order to compare two separate transitional organic systems: a four-year annual crop rotation of corn, soybean, wheat/alfalfa and corn (C-S-W/A-C), which incorporated dairy manure, cover, and interseeded crops, and one year of conventional corn followed by two years of continuous alfalfa (no manure or cover crops), followed again by corn (C-A-A-C). The C-S-W/A-C treatment was split in year three to investigate two separate wheat harvest methods, as grain or as forage.

Soil quality characteristics which include aggregate size distribution, bulk density, and water filled pore space were determined after the first year and at the end of the transition period. We quantified weed seedbank populations through two seasons in the greenhouse and observed weed surface density and above-ground weed biomass in the field. Soil bulk density showed an overall decrease over the

Dedicated to Ming-Li Chai, my inspiration.

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KEY TO ABBREVIATIONS

C-A-A-C	Corn, Alfalfa, Alfalfa, Corn
C-S-W/A-C	Corn, Soybean, Wheat/Alfalfa, Corn
CBOT	Chicago Board of Trade
DTM	Days to Maturity
GDD	Growing Degree Days
FSC	Farming Systems Center
FYM	Farmyard Manure
KBS	Kellogg Biological Station
LSD	Least Significant Difference
LTER	Long Term Ecological Research
MSU	Michigan State University
NASS	National Agriculture Statistics Service
NCDC	National Climatic Data Center
NOAA	National Oceanic and Atmospheric Administration
OCIA	Organic Crop Improvement Association
OFRF	Organic Farming Research Foundation
OTA	Organic Trade Association
PET	Potential Evapotranspiration
SAN	Sustainable Agriculture Network
SARE	Sustainable Agriculture Research & Education
SAS	Statistical Analysis Software
SMA	Société de Mathématiques Appliquées
SOM	Soil Organic Matter
USDA	United States Department of Agriculture
WFPS	Water Filled Pore Space

INTRODUCTION

Certified organic crop production is the fastest growing segment of agriculture in the United States today, increasing at a rate of more than 20 percent annually. According to the Organic Trade Association, U.S. organic food sales increased by 22.1 percent and totaled nearly $17 billion in 2006, approaching 3 percent of all retail sales of food and beverages. Total organic food sales have nearly tripled since the U.S. Department of Agriculture's National Organic Program implemented organic labeling standards in October of 2002 (OTA, 2007). The transition from conventional farming practices to organic can be complicated, yet growers maintain interest in organic farming for host of reasons, and until recently have had limited scientific guidance in making the transition.

Although studies specific to agronomic management practices during the transition period from conventional to organic farming have been sparse, reports on crop production costs and rates of return have been examined for decades, perhaps making the possibility of increased profits one of the more compelling reasons to attempt the conversion (Archer et al., 2007; Greene et al., 1999; Greene, 2003; Shearer et al., 1981; Welsh, 1999).

In order to maintain competitiveness in the marketplace, organic farmers like all farmers consider economic sustainability just as important - if not more so -

as environmental sustainability. To that end, organic farmers have consistently ranked weed management, soil quality and crop rotational systems as top priorities for targeted research areas necessary to expand their knowledge base and improve the bottom line (Walz, 1999). Since the USDA organic standards have been in place, research in these areas has been increasing, certified and transitional organic growers are gaining production experience and are focusing more on getting a foothold in the marketplace (Walz, 2004).

Organic crop production standards specific to the transition period require producers to maintain land which will have no prohibited substances applied at least three years before the harvest of an organic crop (USDA, 2008 a). The transition - a change in agricultural management practices - is a shift from agriculture based upon synthetically derived inputs to one which is based upon certified organic practices (MacCormack et al., 1989). Soil fertility and crop nutrients are managed through tillage cultivation practices, crop rotations, and cover crops, supplemented with animal and crop waste materials. Crop pests, weeds, and diseases are managed through practices including physical, mechanical, and biological controls (USDA, 2008 a). Successful transition periods for agronomic crops typical of the Corn Belt often include a rotation of alfalfa, corn, soybeans and small grain. The legumes fix nitrogen, providing for the subsequent non-legumes in the rotation. Pest cycles are interrupted, plant diseases are suppressed, and weed control is enhanced when perennial weeds are destroyed through cultivation of annual grains, while annual weeds are smothered or eliminated by mowing when alfalfa is in production (Friedman, 2003). Research and extension activities focusing on cost-effective improvements of fundamental aspects of successful transitional strategies designed to increase and maintain soil organic matter, ecological diversity, and crop rotations will position growers to maximize profits once the transition period ends and organic certification begins (Lipson, 1997).

Early investigations on the economic returns of organic farming did not focus on price premiums (as there were no standards at the time), but rather cited increasing prices of energy in the form of fuel, nitrogen fertilizers and pesticides as a cost savings for the producer. Organic production was thought to be less energy intensive, and thus net revenues approaching those of crops produced conventionally were viewed as success stories (Lockeretz et al., 1981; Shearer et al., 1981). While these earlier studies examined the profitability of organic versus conventional farming, rigorous experimentation was difficult due to the relatively low numbers of organic producers and lack of university research dedicated to organic management practices. These studies commonly based their findings on surveys, estimations and economic modeling which often showed economic returns competitive with conventional systems without providing any hard data to support their claims. As a result, critical reviews ensued almost immediately (Helmers, 1986; Lockeretz et al., 1981b; Lockeretz et al., 1978; Shearer et al., 1981). Cacek and Langner (1986) evaluated the competitiveness of organic farming with that of conventional using results from experimental plot data and made the case that previous studies showing lower returns from organic farming were generally based on data resulting from simulations and economic modeling. Research conducted during the latter half of the 1980's at the Northeast Research Station in South Dakota showed net returns without including the potential price premiums of organic field crop systems to be equal to or greater than conventional systems with less variability (Corselius, 2001; Dobbs and Smolik, 1996; Smolik and Dobbs, 1991).

Reviews of later studies alleged that organic or "alternative" farming consistently provided lower returns on investment as compared to conventional systems and attributed the lower profitability to additional labor, lower crop yields, longer rotations that included low value cover crops, high costs associated with weed management and government programs which gave preferential support for conventional production (Crosson and Ostrov, 1990; Lee, 1992; Ricker, 1997). The incongruity among results of these comparative studies throughout the late 1970's and 1980's provoked researchers to consider caveats and pitfalls in approaches to rigorously compare economic returns of organic to conventional production methods.

Perhaps one of the first to recognize the difficulty with comparing organic to conventional production was Knoblauch and colleagues (1990) when they reached the conclusion that the differences between the two types of production systems were far too variable to make proper economic evaluations. Others soon followed, ascertaining that the discrepancies among results to date were dependent on multiple factors such as production system variability, differences between crops produced, and climatic and soil physical aspects, as well as varying economic assumptions (Fox, 1991).

Welsh (1999) recognized Thomas Dobbs as setting up a series of critical queries necessary for a cost-effective evaluation of comparisons between organic and conventional agriculture whereby principles such as the state of the system (transitional vs. long-established), governmental provisions, labor issues, environmental costs (now referred to as ecosystem services), organic price premiums and climatic regions should all be taken into account. By analyzing and drawing upon the research of several investigators throughout the late twentieth century, Welsh (1999) proposed what he considered "*Ideal Components of Studies Evaluating the Profitability of Organic Cropping Systems*" where issues such as the involvement of farm-level workers, statistical comparisons of varying rotations, multi-year experiments, organic price premiums, governmental policies, net present value of economic returns, risk management, actual yield data, agro-ecosystem region, managerial requirements and ecosystem services were collectively considered for profitability comparisons between organic and conventional production systems (Diebel et al., 1995; Dobbs and Smolik, 1996; Fox, 1991; Hanson, 1997; Hewitt and Lohr, 1995; Knoblauch, 1990; Smolik and Dobbs, 1991).

By this time, multi-year studies were under development through mainstream agricultural research at universities such as Iowa State University (Chase and Duffy, 1991), Kansas State University (Diebel et al., 1995), University of Minnesota (Mahoney et al., 2004), University of Nebraska (Helmers, 1986) and South Dakota State University (Smolik et al., 1995; Smolik and Dobbs, 1991). Although results of these studies report the ability of Midwestern organic farmers to compete with their conventional contemporaries, they were all generally designed to be comparisons between the two types of production in order to inform producers of associated costs and returns of each type of practice (Welsh, 1999).

Long-term experiments of this kind continue today (Archer et al., 2007; Delate and Cambardella, 2004; Delate et al., 2003; Russo and Taylor, 2006) with more concentrated focus on the transition period prior to organic certification. This is an important distinction since growers who show interest in making the transition often express reluctance due to the perceived increase in management costs and lower yields associated with organic farming (Lohr, 1998; Tu et al., 2006).

Weed management has been held by organic farmers as the number one barrier to long term success for certified production systems, with maintenance of soil fertility and quality a close second (Walz, 1999). Commercial growers and researchers alike have taken strides to address both issues by investigating rotational strategies and through the use of cover or companion crops which suppress weeds, add organic matter and supply nitrogen and carbon to the soil (Hiltbrunner et al., 2004; Katsvairo et al., 2007; Larsson et al., 1997; Liebman and Dyck, 1993; Liebman and Davis, 2000). While the addition of organic matter can improve soil fertility and structure, the beneficial properties often depend on type, timing, climatic conditions, soil texture and current crop. For example, living mulches or companion crops interseeded for the purpose of weed suppression have been shown to contribute to the reduction in yield of the target crop by competing for available soil moisture (Thelen et al., 2004).

Transitioning systems that rely on mechanical weed management and the incorporation of green manures and farmyard manure (FYM) often show increases in the weed seedbank (Huxham et al., 2005; Riemens et al., 2007). Other studies have shown an increase in weed species richness with an overall decline in total weed populations under organic or pesticide free systems (Liebman and Davis, 2000; van Elsen, 2000). This was the case for Ngouajio and McGiffen (2002) who attributed a significant decline in the weed seedbank under organic management to changes in soil properties associated with incorporated allelopathic plant residues and an increase in seed colonizing microbes as well as predatory arthropods. Farmyard manure, particularly cattle manure additions, are generally expected to increase the weed seedbank, although responses of the seedbank are not necessarily associated with negative interference of weeds which cause a reduction in yield of target crops (Maxwell et al., 2007; Stevenson et al., 1998). Determining the long term trends of weed seedbanks associated with row crop agriculture has been a challenge for investigators due to the rapid seasonal transformations in weed species composition and abundance, and the influence of the most recent crop, therefore our understanding of weed seedbank community dynamics within varying row crop systems remains ambiguous (Davis et al., 2005; Smith and Gross, 2006).

It has been claimed by growers and investigators that long, diverse crop rotations incorporating cover crops and manure, often used on organic farms, help to stabilize yield, augment plant protective mechanisms, and improve soil quality and economic returns compared to conventional systems with shorter rotations and more synthetic inputs (Delate, 2002; Teasdale et al., 2004). However, the magnitude and value attributable to these systems tend to be spatially and temporally quite variable as well as very dependent on the timing and effectiveness of particular agronomic management practices (Davis et al., 2005; Huxham et al., 2005; Liebman and Davis, 2000; Wang et al., 2006; Welsh et al., 1999).

Additions of FYM to organic systems have been shown to improve crop yields, possibly by enriching soil organic matter (SOM) and improving soil properties such as numbers of soil macroaggregates, microfauna, and macro and micronutrients and (Edmeades, 2003; Ghoshal and Singh, 1995; Gupta et al., 1992; Jiang et al., 2006; Jiao et al., 2006; Mikha and Rice, 2004). However, nutrient availability to crops from manure sources, by and large, can be extremely variable and can depend a great deal on agronomic management (Muñoz et al., 2004; Salazar et al., 2005). Adding to the complicated character of this variability, Paré and colleagues (1999) have shown that the addition of stockpiled FYM to conventionally tilled systems significantly increased the percent of water stable aggregates as compared to the same addition to a no-till system. Many studies show the opposite, in which no-till systems result in an increase of total water stable soil aggregates (Denef et al., 2001b; Grandy and Robertson, 2006; Green et al., 2005; Mikha and Rice, 2004; Park and Smucker, 2005; Six et al., 2000;

Taboada-Castro et al., 2006; Zotarelli et al., 2007). The variability in results of those studies examining soil quality via soil aggregate distribution is further complicated by the variable methodology utilized by investigators (Angers and Giroux, 1996; Ashman et al., 2003; Barral et al., 1998; Collis-George and Laryea, 1972; Marquez et al., 2004; Niewczas and Witkowska-Walczak, 2005; Sainju, 2006; Srzednicki and Keller, 1984).

The increase in demand for organic products and the authorization of the organic standards with the USDA label has moved the organic industry from a niche market to a mainstream phenomenon with no signs of decline (OTA, 2007), hence the motivation of this study was based on the assumption that a producer has decided beforehand to make the transition from conventional to organic farming. Rather than strictly compare conventional vs. organic management for three years (the required length of transition time for organic certification), we are contrasting two separate organic transitional methods and their effects on yield and economic returns, weed seedbank dynamics and soil quality characteristics. The fourth year (year one of certification) was also investigated.

This study focuses on the agronomic and economic dynamics during the critical three-year transition phase from conventional to certified organic farming. This research was designed to contribute to the development of best management practices for Midwestern growers transitioning to a certified organic system in corn, soybean, wheat and alfalfa. Two different transitional organic cropping systems are compared here: A four-year organic rotation of corn, soybean, wheat/alfalfa and corn (C-S-W/A-C), which incorporates dairy manure and cover crops, vs. one year of conventional corn followed by two years of continuous transitional alfalfa (no manure or cover crops), followed again by corn (C-A-A-C). During the fourth year of the study (2006) both treatments were in the first fully certified organic season and were managed identically. Results of this study as they relate to yield and economic returns are presented in Chapter 1. Factors such as weed seed-bank responses and associated field weed densities are presented in Chapter 2. Soil quality parameters as they relate to aggregate size distribution were also examined and are presented in chapter 3.

CHAPTER 1

ECONOMICS OF TRANSITIONAL STRATEGIES

ABSTRACT

Transitional management strategies for certified organic field crop production are of great concern for Midwestern U.S. producers. Rotational tactics during the three-year transition period, which set the stage for sustainable organic production and acceptable revenues, have just recently been investigated by university researchers. This study was conducted over four years in order to compare two separate transitional organic systems: A four-year organic rotation of corn, soybean, wheat/alfalfa and corn (C-S-W/A-C), which incorporates dairy manure and cover crops, vs. one year of conventional corn followed by two years of continuous transitional alfalfa followed again by corn (C-A-A-C). Results show both systems to be profitable, with the C-S-W/A-C system generating the highest rates of return when wheat interseeded with alfalfa is harvested as forage. Net revenues for the C-A-A-C treatment during the transitional period were \$559 U.S. dollars ha^{-1} and including the certified year were \$1393 dollars ha^{-1}. Net revenues for the C-S-W/A-C F treatment were \$647 dollars ha^{-1} and \$1493 dollars ha^{-1} for the transition period and four-year rotation respectively. The C-S-W/A-C G treatment returned \$441 dollars ha^{-1} and \$1335 dollars ha^{-1} for the transition period and four-year rotation respectively. Returns increased

considerably when expressed in 2008 dollars due to recent increases in crop prices.

INTRODUCTION

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The increase in demand for organic products and the authorization of the organic standards with the USDA label has moved the organic industry from a niche market to a mainstream phenomenon with no signs of decline (OTA, 2007). The purpose of this study was based on the assumption that a producer has decided beforehand to make the transition from conventional to organic farming. Rather than strictly compare conventional vs. organic management for three years (the required length of transition time for organic certification), we are contrasting two separate organic transitional methods and their effects on yield and economic returns, weed seedbank dynamics and soil quality characteristics. The fourth year (year one of certification) was also investigated.

This study focuses on the agronomic and economic dynamics during the critical three-year transition phase from conventional to certified organic farming. This research was designed to result in the development of best management practices for Midwestern growers to follow when transitioning to a certified organic system in corn, soybean, wheat and alfalfa. We compare two different transitional organic cropping systems: A four-year organic rotation of corn, soybean, wheat/alfalfa and corn (C-S-W/A-C), which incorporates dairy manure and cover crops, vs. one year of conventional corn followed by two years of continuous transitional alfalfa (no manure or cover crops), followed again by corn (C-A-A-C). During the fourth year of the study (2006) both treatments were in the first fully certified organic season and were managed identically. Our objective was to determine if the less complicated C-A-A-C rotational strategy would be more cost effective than the C-S-W/A-C strategy.

MATERIALS AND METHODS

Field Experiment

Experimental Site

Experimental plots were located at the W.K. Kellogg Biological Station (KBS) Farming Systems Center (FSC) site in southwest Michigan on the northeastern portion of the U.S. corn belt, 50 km east of Lake Michigan in the SW corner of the state (85°24' W, 42°24' N, elevation 288 m). The twenty-year average number of growing degree days (GDD; base 10° C) from May to October at this site is 1326 (KBS-LTER, 2008). Mean annual precipitation is 920 mm with about half falling as snow, and potential evapotranspiration (PET) exceeds precipitation for about 4 months of the year. Average monthly temperatures range from -4.61° C in January to 23.1° C in July, with a mean annual temperature of 9.83° C (NOAA-NCDC, 2008).

Transitional treatments were established in 2003 in four replicated 0.04-ha plots organized in a randomized complete block design. Two soil series are identified at this site: Kalamazoo (fine-loamy, mixed, semiactive, mesic Typic Hapludalfs) and Oshtemo (coarse-loamy, mixed, active, mesic Typic Hapludalfs), two to four percent slope, developed on glacial outwash (Crum and Collins, 1995). The two series co-occur and differ mainly in their Ap horizon texture, though in these particular soil series variation within a series can be as great as variation between the series (Robertson et al., 1997).

Agronomic Methods

Treatments consisted of two organic transitional rotation systems. The first was a four-year annual crop rotation of corn, soybean, wheat/alfalfa and corn (C-S-W/A-C), which incorporated dairy manure, cover crops, and interseeded crops. The second was a transitional rotation including perennial alfalfa which consisted of one year of conventional corn followed by two years of continuous alfalfa (no manure or cover crops), followed again by corn (C-A-A-C). Interseeded crops in the C-S-W/A-C treatment consisted of a medium red clover cover broadcast into the first corn phase, and alfalfa drilled into winter wheat. Treatments were replicated four times in a randomized complete block design in 13.7 m x 27.4 m plots. Both treatments followed an eight-year old stand of alfalfa (established in 1996). The C-S-W/A-C treatment was split in year three (2005) to investigate two separate wheat harvest methods. The C-S-W/A-C F treatment had wheat harvested as forage, while the C-S-W/A-C G treatment was harvested for wheat grain. During the fourth year of the study (2006) both treatments were in the first fully certified organic season and were managed identically.

A graphic timeline of all agronomic management practices is displayed in Appendix A. Field operations (Table 1) were performed as follows:

For year one (2003), standing alfalfa was chisel plowed in May with 46 cm wide sweeps just below the crown in the (C-S-W/A-C) treatment, solid dairy manure was broadcast at a rate of 30 Mg ha^{-1} and incorporated into the soil along with the alfalfa, followed by a disk and soil finisher prior to planting corn. Pioneer Hybrid® 38P05 93 days to maturity (DTM) corn (treated with Fludioxonil and Metenoxam) was planted at a rate of 69,000 seeds ha^{-1} in 76 cm rows for both treatments (untreated seed was not available in time). All subsequent weed management for the C-S-W/A-C treatment was performed mechanically with a rotary hoe (once) and between row field cultivation (twice). Medium red clover seed was banded at a rate of 16.8 kg ha^{-1} after the last cultivation (early July). Alfalfa was harvested from the C-A-A-C treatment for first cutting, followed by the same chisel plow with wide sweeps, disk, finisher and 33.6 kg ha^{-1} N (as 28% ammonium nitrate) for a starter fertilizer prior to planting corn. Pre-emergence herbicides (0.07 kg ha^{-1} of flumetsulam and 1.17 l ha^{-1} of S-metolachlor) were used for weed control, followed by between row field cultivation (twice) and 84 kg ha^{-1} N (as 28% ammonium nitrate) side-dress fertilizer at last pass in early July. The side-dress treatment was the last prohibited substance (according to NOP standards) applied to either system (USDA, 2008 a). Yield measurements were taken at the end of the season using two methods, triplicate 1 m^2 quadrat hand-harvest and a two-row small plot (Massey Ferguson Duluth, Georgia) combine harvester.

Year two (2004) agronomic management in the C-S-W/A-C treatment included chisel plowing to incorporate standing clover, soil finish and culti-pack prior to planting food grade, clear hilum Vinton 81 certified organic soybean seed at a rate of 400,000 seeds ha^{-1} in 76 cm rows. Weed management consisted of rotary hoe (three times) followed by between row cultivation (twice). Soybeans were harvested in early October using a Wintersteiger® plot combine with a cutting width of 152 cm, followed one week later by a broadcast of 20.5 Mg ha^{-1} solid dairy manure, worked in with a chisel plow and soil finisher. Sisson certified organic soft red winter wheat seed was then planted at a rate of 170 kg ha^{-1} in 19 cm rows. Agronomic management (year two) in the C-A-A-C treatment consisted of flail mowing corn stubble, followed by chisel plow, soil finish and culti-pack. WL 346 LH (untreated) alfalfa seed was then planted (drilled) at a rate of 25 kg ha^{-1} in late March. Due to a particularly wet and cold spring, alfalfa establishment was poor. Two attempts were made in late spring and mid summer to mow weeds prior to setting seed in order to favor the alfalfa; however the establishment deficiency was enough to require a re-plant. Therefore, the plots were moldboard plowed (due to the high weed population), and the same variety was replanted after soil finishing and culti-packing operations were complete.

In 2005 (year 3) WL 346 LH (untreated) alfalfa seed was broadcast as a frost-seeded application in mid-March at a rate of 25 kg ha^{-1} in the wheat for the C-S-W/A-C treatment. Poor establishment of the alfalfa resulted due to dry spring conditions, so the same variety was drilled between the wheat rows at a rate of 20 kg ha^{-1} in late April. This treatment was split on the basis of harvestable product: one half harvested as forage (alfalfa and wheat grass) in late May and early July, the other half as wheat grain in early July. The C-A-A-C treatment was second year alfalfa, and two cuttings were harvested, first in late May and again in early July. Drought conditions followed the second cutting in a manner severe enough to cause drought induced dormancy and prohibit growth requirements for a third cutting, so a management decision was made to retain the stand and utilize the remaining productivity the following year when it was to be incorporated along with dairy manure prior to planting corn.

Year four (2006) was the first certified organic season for both treatments. At this point, each of the two systems was managed identically. Standing alfalfa was chisel plowed in late April with 46 cm wide sweeps just below the crown, disked twice and solid dairy manure was broadcast at a rate of 52 Mg ha^{-1} then incorporated along with the alfalfa two times with a soil finisher, prior to planting corn. Blue River Organics® 26K21 88 DTM certified organic seed was planted at a rate of 69,000 seeds ha^{-1} in 76 cm rows in early June. Weed management was performed mechanically with a rotary hoe (twice) and between row field cultivation (twice). Yield measurements were taken with a two-row small plot (Massey Ferguson Duluth, Georgia) combine harvester from a central strip within each plot.

Table 1. Field operations by system rotation and year.

Procedure	Corn-Alfalfa-Alfalfa-Corn	Corn-Soybean-Wheat/Alfalfa-Corn Forage	Corn-Soybean-Wheat/Alfalfa-Corn Grain	Year
Mow/Rake/Bale	X			2003
Chisel Plow	X	X	X	
Manure		X	X	
Disk	X	X	X	
Soil Finish	X	X	X	
Starter N	X			
Plant Corn	X	X	X	
Herbicide	X			
Rotary Hoe		X	X	
Row Cultivate	2X	2X	2X	
Side-dress N	X			
Plant Clover		X	X	
Harvest Corn	X	X	X	
Flail Mow	3X			2004
Chisel Plow	X	2X	2X	
Soil Finish	2X	2X	2X	
Culti-Pack	2X	X	X	
Plant Alfalfa	2X			
Plant Soybean		X	X	
Moldboard	X			
Disk	X			
Rotary Hoe		3X	3X	
Row Cultivate		2X	2X	
Manure		X	X	
Harvest Soy		X	X	
Drill Wheat		X	X	
Mow/Rake/Bale	2X	2X		2005
Plant Alfalfa		2X	2X	
Harvest Wheat			X	
Chisel Plow	X	X	X	2006
Disk	2X	2X	2X	
Manure	X	X	X	
Soil Finish	2X	2X	2X	
Plant Corn	X	X	X	
Rotary Hoe	2X	2X	2X	
Row Cultivate	2X	2X	2X	
Harvest Corn	X	X	X	

Statistical Analysis

Yield comparisons between treatments for corn and forage cuttings were analyzed through analysis of variance (ANOVA) utilizing the mixed procedure (PROC MIXED) in Statistical Analysis Software (SAS) version 9.1.3 (SP4) (SAS, 2008), where treatments were considered as fixed effects with yield (Mg ha^{-1}) as the continuous response variable. Mean separations were obtained by the Least Significant Difference (LSD) test and considered significantly different at $p < 0.05$.

Economic Analysis

Since this study was not intended to compare organic versus conventional farming methods, but rather to contrast two separate transitional strategies with three possible harvesting schemes, we have based our economic analysis on profits (revenue after expenses) utilizing enterprise budgets as opposed to net present value during (and one year after) the transition period. We have also taken a conservative approach to determining production costs for each of the transitional systems by estimating them through the use of custom machine work rates for Michigan (Dartt and Schwab, 2002) and updated machine work rates for Michigan and Iowa (Edwards and Smith, 2008; Stein, 2006). We also did not include currently available transitional prices for crops (Delate et al., 2006), but used conventional prices during the transition period. By using custom machine work rates, we are able to include costs of machinery and labor together as one fee. Labor costs included in the work rates take into account all labor performed for all system operations. These systems were designed to avoid any hand labor (hand-weeding for example), using typical conventional farm implements. Hand weeding row crops represents a significant cost to the grower and can become a barrier to profitability (Riemens et al., 2007) so this was not considered an option in this study.

All crop prices throughout the transition period were based on conventional prices (CBOT, 2008; Hilker et al., 2006; Hilker et al., 2008; USDA-NASS, 2006), while certified crops (year four) included organic price premiums (NewFarm, 2006; NewFarm, 2008; Streff and Dobbs, 2004). Costs of manure vary extensively depending on source, distance and available transportation (Araji et al., 2001; Archer et al., 2007); however, the purchase costs of manure for this study were not considered since it was an on-farm source and abundantly available. The costs of manure application were based on Michigan and Iowa custom rates (Dartt and Schwab, 2002; Edwards and Smith, 2008; Stein, 2006). Seed, fertilizer and herbicide costs reflect actual purchase prices for each commodity for each year and were obtained through unpublished purchase order records. Projected costs (2008) of seed, fertilizer and herbicide were gathered through personal communications with local and regional distributers, producers and researchers.

RESULTS

Corn yields after the first transitional year (2003) showed no significant differences ($\alpha = 0.05$) between the C-S-W/A-C and C-A-A-C treatments (Table 2) and were 8.73 and 8.93 Mg ha^{-1} respectively. Yields from both treatments were equal to or greater than local and regional averages for corn grown conventionally (USDA-NASS, 2006; USDA-NASS., 2003). Preceding establishment of these plots the field was in an eight-year continuous alfalfa stand. We harvested alfalfa from the C-A-A-C treatment prior to planting corn (first cutting); and this yield averaged 3.52 Mg ha^{-1}. Standing alfalfa was tilled-in (pre-plant) to the C-S-W/A-C treatment in an amount approximately equal to that which was removed from the C-A-A-C treatment.

No acceptable yield was produced for either treatment during year two (2004) (see Methods and Appendix A). Alfalfa establishment in the C-A-A-C treatment was poor in the spring due to extreme wet conditions; as a result, weeds were the dominant biomass. Efforts to mow weeds throughout the season failed to promote alfalfa growth and the crop was replanted in August. Soybean yield estimations were included in the economic analysis because the crop in this study did not fail as a result of climate or agronomic management practices; rather all four replications were browsed so heavily by deer as to not produce a viable yield. Although we cannot report the statistical significance of these mean values, it seems reasonable for the purposes of estimating economic returns using data from a study conducted at the same research station during the same year using the same variety and similar rotational strategy (Mutch and Martin, 2005). Deer exerted a particularly strong influence on these small research plots because of their proximity to forest cover and the limited hunting in this area.

During year three (2005) the C-S-W/A-C treatment plots were split based on harvestable product (see Methods), and there were significant treatment differences for the first ($p < 0.01$) and second forage harvests as well as annual totals ($p < 0.05$) (see Table 2). Total forage harvest yield was 4.8 and 2.1 Mg ha^{-1} for C-S-W/A-C F and C-A-A-C treatments, respectively. Wheat grain yield in the C-S-W/A-C G treatment averaged 2.41 Mg ha^{-1}.

The fourth year (2006) was the first fully certified organic season and both treatments were managed identically. There were no significant differences ($\alpha = 0.05$) between any of the treatments.

Revenues, costs and returns by treatment, year and crop are displayed in Table 3. Net revenue for the C-A-A-C treatment during the transitional period was \$559 U.S. dollars ha^{-1}. Total revenue for this system (including the certified year) was \$1393 U.S. dollars ha^{-1}. Net revenue for the C-S-W/A-C F treatment during the transition period was

$647 U.S. dollars ha^{-1}. Total four-year revenue for this treatment was $1493 U.S. dollars ha^{-1}.

The C-S-W/A-C G treatment had the lowest net returns during the transition period at $440.62 U.S. dollars ha^{-1} and the lowest total net revenues of any treatment (including the certified year) at $1334.91 U.S. dollars ha^{-1} (see Table 3). A comprehensive breakdown of custom costs by year, treatment and operation is displayed and available in Appendix B.

Table 2. Yield results by year, rotation and crop.

Year	Rotation‡	Crop	Mg Ha^{-1}
2003	C-A-A-C	Alfalfa	3.52
		Corn	8.93[a]
	C-S-W/A-C	Corn	8.73[a]
2004	C-A-A-C	Alfalfa	0.00
	C-S-W/A-C	Soybean§	2.49
2005	C-A-A-C	Alfalfa	
		1st Cutting	1.23[c]
		2nd Cutting	0.87[c]
		Total	2.10[b]
	C-S-W/A-C F	Wheat/Alfalfa	
		1st Cutting	4.03[a]†
		2nd Cutting	0.77[c]
		Total	4.80[a]
	C-S-W/A-C G	Wheat	2.41
2006	C-A-A-C	Corn	6.66[a]
	C-S-W/A-C F	Corn	6.73[a]
	C-S-W/A-C G	Corn	6.98[a]

Mean values followed by the same letter within each year are not significantly different ($\alpha = 0.05$).

† Significant at the 0.01 probability level.

‡ C = Corn, A = Alfalfa, S = Soybean, W = Wheat.
F = Wheat harvested as Forage, G = Wheat harvested as Grain.

§ Actual yield based on same variety on separate study.

Table 3. Costs and returns by treatment, year and crop. Yield is expressed as dry weight in Mg Ha^{-1}. Prices, costs and revenues are expressed in U.S. dollars Ha^{-1}.

Rotation		Revenues			Costs						Profits
Year	Crop	Crop Yield	Crop Price	Gross Revenue	Crop Seed	Cover Seed	Fertilizer	Herbicide	Custom	Total	Net Revenue
C-A-A-C *											
2003	alfalfa	3.52	143.30	504.42	0.00	0.00	0.00	0.00	61.73	61.73	442.69
2003	corn	8.93	95.27	850.76	95.93	0.00	18.64	54.79	210.62	379.98	470.79
2004	alfalfa	0.00	154.32	0.00	362.96	0.00	0.00	0.00	256.17	619.14	-619.14
2005	alfalfa	2.10	160.94	337.97	0.00	0.00	0.00	0.00	72.84	72.84	265.13
2006	corn	6.66	190.54	1269.00	100.25	0.00	0.00	0.00	335.43	435.68	833.32
									Three-year Net Revenue		**559.47**
									Four-year Net revenue		**1392.79**
C-S-W/A-C-F †											
2003	corn	8.73	95.27	831.71	95.93	46.02	0.00	0.00	267.53	409.48	422.23
2004	soybean	2.49	238.83	594.69	69.63	0.00	0.00	0.00	278.27	347.90	246.79
2005	wheat/alfalfa	4.80	110.23	529.10	45.19	345.68	0.00	0.00	160.62	551.48	-22.38
2006	corn	6.73	190.54	1282.33	100.25	0.00	0.00	0.00	335.43	435.68	846.66
									Three-year Net Revenue		**646.64**
									Four-year Net revenue		**1493.29**
C-S-W/A-C-G ‡											
2003	corn	8.73	95.27	831.71	95.93	46.02	0.00	0.00	267.53	409.48	422.23
2004	soybean	2.49	238.83	594.69	69.63	0.00	0.00	0.00	278.27	347.90	246.79
2005	wheat	2.41	125.66	302.84	45.19	345.68	0.00	0.00	140.37	531.23	-228.39
2006	corn	6.98	190.54	1329.97	100.25	0.00	0.00	0.00	335.43	435.68	894.29
									Three-year Net Revenue		**440.62**
									Four-year Net revenue		**1334.91**

* Corn-Alfalfa-Alfalfa-Corn. † Corn-Soybean-Wheat/Alfalfa-Corn where wheat and alfalfa were harvested as forage. ‡ Corn-Soybean-Wheat/Alfalfa-Corn where wheat was harvested as grain.

DISCUSSION and CONCLUSIONS

Both strategies for conversion from conventional to organic cropping systems proved to be profitable over the 3- and 4-year periods of analysis. The C-S-W/A-C F treatment was the most cost effective management strategy both during the three-year transition period as well as the for the four-year total which included the first certified organic year. This was despite the difficulty in establishing alfalfa as a companion crop during the wheat year (2005). The highest rate of return for the first certified year alone was obtained with the C-S-W/A-C G treatment, but corn yield that year did not differ significantly among treatments. We hypothesized that the highest economic returns would be realized with the C-A-A-C treatment, mainly as a consequence of fewer field operations required and the higher rates of return for alfalfa. This would most likely have been the case if poor establishment of alfalfa in year two (2004) had not led to no harvestable product that year. We would have also been able to better explain the merits of these systems had we been able to include each rotational entry point for each year. Comprehensive studies which include all entry points also have the advantage of incorporating annual fluctuations in crop prices into estimates of economic returns (Archer et al., 2007; Delate and Cambardella, 2004; Delate et al., 2006). Archer and colleagues (2007) investigated similar rotations with all entry points and two different tillage and fertilization practices. They reported average yields of corn, soybean and wheat strikingly similar to those shown in this study for years two, three and four, however in this study we show first-year corn yield on par with corn grown conventionally in the Archer study. The average alfalfa yield reported by Archer and colleagues (2007) was much higher than we obtained, which exemplifies the previous statement regarding the expected higher rates of return for the C-A-A-C treatment. In today's market, both costs of production and rates of return would be much higher (CBOT, 2008; Edwards and Smith, 2008; Hilker et al., 2008; NewFarm, 2008; Stein, 2006; USDA, 2006; USDA-NASS., 2008). We have therefore expressed results of this study reflecting 2008 work rates and crop prices in Table 4. The high grain prices for conventional and organic corn, and conventional soybeans and wheat in this analysis has proven the C-S-W/A-C system, when wheat was harvested as grain to be the most profitable of the three strategies, allowing producers to choose which transitional method best fits their operation. A comprehensive breakdown of current custom costs by year, treatment and operation is displayed in Appendix C. A comparison of actual and projected (2008) profitability from each system can be found in Figure 1. In this study, we determined that the C-A-A-C rotational strategy was less cost effective than the more complicated C-S-W/A-C strategy for the transition to a certified organic system although both strategies were profitable.

Table 4. Projected costs and returns by treatment, year and crop. Yield is expressed as dry weight in Mg ha^{-1}. Prices, costs and revenues are expressed in U.S. dollars ha^{-1} as of May 2008.

Rotation		Revenues			Costs						Profits
Year	Crop	Crop Yield	Crop Price	Gross Revenue	Crop Seed	Cover Seed	Fertilizer	Herbicide	Custom	Total	Net Revenue
C-A-A-C *											
2003	alfalfa	3.52	176.41	620.95	0.00	0.00	0.00	0.00	76.79	76.79	544.16
2003	corn	8.93	232.06	2072.33	121.85	0.00	19.75	60.20	236.67	438.47	1633.86
2004	alfalfa	0.00	176.41	0.00	362.96	0.00	0.00	0.00	269.51	632.47	-632.47
2005	alfalfa	2.10	176.41	370.45	0.00	0.00	0.00	0.00	80.74	80.74	289.71
2006	corn	6.66	432.66	2881.53	103.70	0.00	0.00	0.00	368.40	472.10	2409.43
								Three-year Net Revenue			1835.26
								Four-year Net revenue			4244.69
C-S-W/A-C-F †											
2003	corn	8.73	232.06	2025.92	121.85	55.56	0.00	0.00	300.37	477.78	1548.14
2004	soybean	2.49	488.62	1216.66	97.53	0.00	0.00	0.00	337.16	434.69	781.97
2005	wheat/alfalfa	4.80	126.79	608.60	80.00	345.68	0.00	0.00	191.85	617.53	-8.93
2006	corn	6.73	432.66	2911.82	103.70	0.00	0.00	0.00	368.40	472.10	2439.72
								Three-year Net Revenue			2321.18
								Four-year Net revenue			4760.90
C-S-W/A-C-G ‡											
2003	corn	8.73	232.06	2025.92	121.85	55.56	0.00	0.00	300.37	477.78	1548.14
2004	soybean	2.49	488.62	1216.66	97.53	0.00	0.00	0.00	337.16	434.69	781.97
2005	wheat	2.41	287.81	693.63	80.00	345.68	0.00	0.00	173.58	599.26	94.37
2006	corn	6.98	432.66	3019.98	103.70	0.00	0.00	0.00	368.40	472.10	2547.88
								Three-year Net Revenue			2424.48
								Four-year Net revenue			4972.36

* Corn-Alfalfa-Alfalfa-Corn. † Corn-Soybean-Wheat/Alfalfa-Corn where wheat and alfalfa were harvested as forage. ‡ Corn-Soybean-Wheat/Alfalfa-Corn where wheat was harvested as grain.

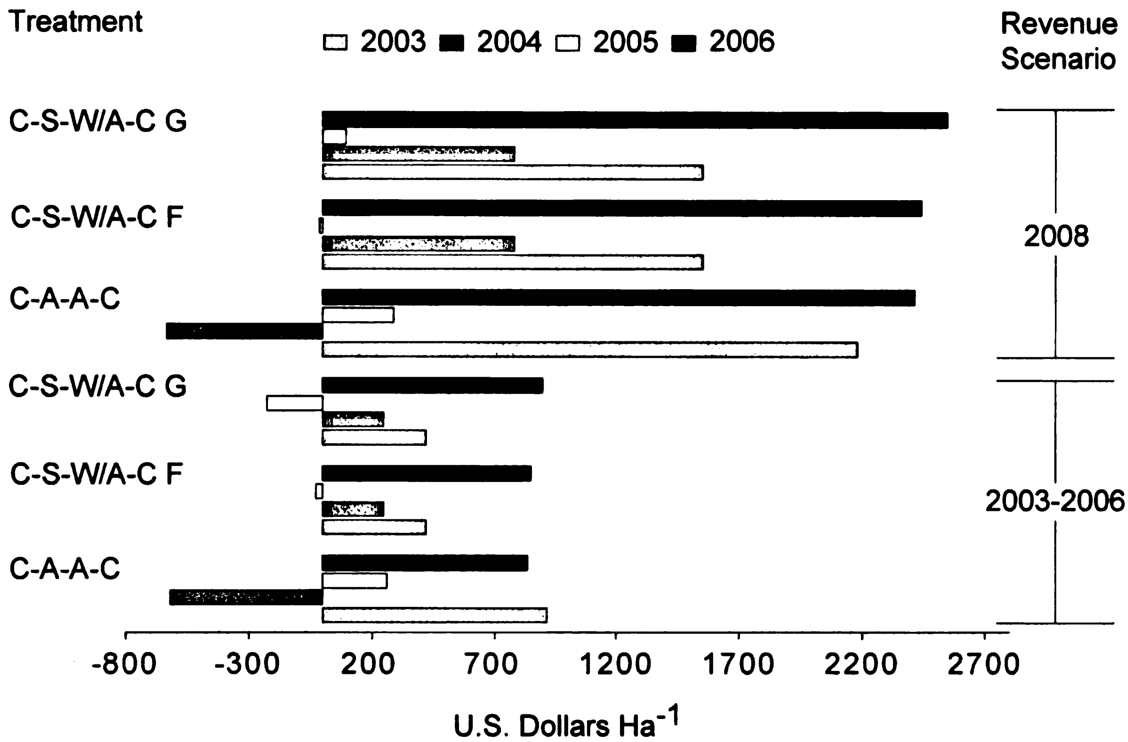


Figure 1. Actual (2003-2006) and projected (May 2008) net revenues generated from each treatment in each of the four production years. C = Corn, A = Alfalfa, S = Soybean, W = Wheat. F = Wheat harvested as Forage, G = Wheat harvested as Grain.

CHAPTER 2

TRANSITIONAL WEED DYNAMICS

Abstract

Weed management during the required three-year transition period to organic certification significantly influences the weed seedbank for the initial years in the certified organic system. We studied two transitional field cropping systems during the three-year transition period and the first fully certified organic season (year four). We quantified weed seedbank populations through two seasons (year three and four) in the greenhouse and observed weed surface density (year three) and above-ground weed biomass in the field. Using a modified sampling technique designed to capture spatial variability by increasing the number of soil cores of a reduced core diameter, we were able to show potential weed seedling densities using a greenhouse germination assay. A four-year rotation of corn, soybean, wheat/alfalfa, corn (C-S-W/A-C) produced with organic sources of nutrients (dairy manure and cover crop residue) was compared to a corn, alfalfa, alfalfa, corn (C-A-A-C) rotation for the transition to a certified organic system. Results of the greenhouse assay, field density and biomass estimations show a sixty to nearly three hundred percent increase in total weed seeds germinated in the greenhouse, with a sixty to over five hundred percent decreased response in the field for the more complicated C-S-W/A-C system.

INTRODUCTION

Weed management has been held by organic farmers as the number one barrier to long term success for certified production systems, with soil fertility and quality a close second (Walz, 1999). Commercial growers and researchers alike have taken strides to address both issues by investigating rotational strategies and by the use of cover or companion crops that suppress weeds, add organic matter and supply nitrogen and carbon to the soil (Hiltbrunner et al., 2004; Katsvairo et al., 2007; Larsson et al., 1997; Liebman and Dyck, 1993; Liebman and Davis, 2000). While the addition of organic matter can improve soil fertility and structure, benefits often depend on type, timing, climatic conditions, soil texture and current crop. For example, living mulches or companion crops interseeded for the purpose of weed suppression have been shown to contribute to the reduction in yield of the target crop by competing for available soil moisture (Thelen et al., 2004).

Transitioning systems, which rely on mechanical weed management and the incorporation of green manures and farmyard manure (FYM), often show increases in the weed seedbank (Huxham et al., 2005; Riemens et al., 2007). Other studies have shown an increase in weed species richness with an overall decline in total weed populations under organic or pesticide free systems (Liebman and Davis, 2000; van Elsen, 2000). Ngouajio and McGiffen (2002) attributed a significant decline in the weed seedbank under organic management to changes in soil properties associated with incorporated allelopathic plant residues and an increase in seed colonizing microbes as well as predatory arthropods.

Farmyard manure, particularly cattle manure additions, are generally expected to increase the weed seedbank; however, responses of the seedbank are not necessarily associated with negative interference of weeds that cause a reduction in yield of target crops (Maxwell et al., 2007; Stevenson et al., 1998). Determining the long term trends of weed seedbanks associated with row crop agriculture has been a challenge for investigators due to the rapid seasonal transformations in composition, abundance and influence of the most recent crop. Our understanding of weed seedbank community dynamics within varying row crop systems thus remains ambiguous (Davis et al., 2005; Smith and Gross, 2006).

Forcella (1992) found the greenhouse germination assay to be a more reliable technique as a predictive tool to more accurately estimate weed field seedling density with a smaller sample size taken in early spring as apposed to seed extraction by elutriation in spring or fall. Attempting to predict weed seedling densities from buried seed reserves has been enhanced when considering specific sampling size, date, number and technique.

It has been claimed by growers and investigators that long, diverse crop rotations incorporating cover crops and manure, often used on organic farms, help to stabilize yield, augment plant protective mechanisms, improve soil quality, reduce weed populations, and increase economic returns compared to conventional systems with shorter rotations and more synthetic inputs (Delate, 2002; Derksen et al., 2002; Gallandt, 2006; Teasdale et al., 2004). However, the magnitude and value attributable by these systems tend to be spatially and temporally quite variable as well as very dependent on the timing and effectiveness of particular agronomic management practices (Davis et al., 2005; Huxham et al., 2005; Liebman and Davis, 2000; Wang et al., 2006; Welsh et al., 1999).

This study is part of a larger one that focuses on the agronomic and economic dynamics during the critical three-year transition phase from conventional to certified organic farming. This research was designed to result in the development of best management practices for Midwestern growers to follow in transitioning to a certified organic system in corn, soybean, wheat and alfalfa. Two different transitional organic cropping systems are compared here: A four-year organic rotation of corn, soybean, wheat/alfalfa and corn (C-S-W/A-C), which incorporates dairy manure and cover crops vs. one year of conventional corn followed by two years of continuous transitional alfalfa (no manure or cover crops), followed again by corn (C-A-A-C). During the fourth year of the study (2006) both treatments were in the first fully certified organic season and were managed identically. This study focuses on factors such as weed seedbank dynamics and responses associated with field weed densities. Our objective was to determine if a four-year rotation of alfalfa, corn, soybean, wheat/alfalfa and corn (C-S-W/A-C) produced with organic sources of nutrients (manure and crop residue), and no synthetic chemical inputs, would decrease the weed seed bank responses compared to one year of conventionally grown corn followed by two years of transitional alfalfa and one year of organic corn (C-A-A-C) for the transition to a certified organic system.

MATERIALS AND METHODS

Field Experiment

Experimental Site

Experimental plots were located at the W.K. Kellogg Biological Station (KBS) Farming Systems Center (FSC) site located in southwest Michigan in the eastern portion of the U.S. corn belt, 50 km east of Lake Michigan in the SW corner of the state (85°24' W, 42°24' N, elevation 288 m). The twenty-year average growing degree days (base 10° C) from May to October at this site is 1326 (KBS-LTER, 2008). Mean annual precipitation is 920 mm with about half falling as snow, where potential evapotranspiration (PET) exceeds precipitation for about 4 months of the year. Average monthly temperatures range from -4.61° C in January to 23.1°

C in July, with a mean annual temperature of 9.83° C (NOAA-NCDC, 2008).

Transitional treatments were established in 2003 in four replicated 0.04-ha plots organized in a randomized complete block design. Two soil series are identified at this site: Kalamazoo (fine-loamy, mixed, semiactive, mesic Typic Hapludalfs) and Oshtemo (coarse-loamy, mixed, active, mesic Typic Hapludalfs), two to four percent slope, developed on glacial outwash (Crum and Collins, 1995). The two series co-occur and differ mainly in their Ap horizon texture, though variation within a series can be as great as variation between a series (Robertson et al., 1997).

Agronomic Methods

Treatments consisted of two organic transitional rotation systems. The first was a four-year annual crop rotation of corn, soybean, wheat/alfalfa and corn (C-S-W/A-C), which incorporated dairy manure, cover crops and interseeded crops. The second was a transitional rotation including perennial alfalfa which consisted of one year of conventional corn followed by two years of continuous alfalfa (no manure or cover crops), followed again by corn (C-A-A-C). Interseeded crops in the C-S-W/A-C treatment consisted of a medium red clover cover broadcast into the first corn phase, and alfalfa drilled into winter wheat. Treatments were replicated four times in a randomized complete block design in 13.7 m x 27.4 m plots. Both treatments followed an eight-year old stand of alfalfa (established in 1996). The C-S-W/A-C treatment was split in year three (2005) to investigate two separate wheat harvest methods. The C-S-W/A-C F treatment had wheat harvested as forage, while C-S-W/A-C G treatment was harvested for wheat grain. During the fourth year of the study (2006) both treatments were in the first fully certified organic season and were managed identically. A graphic timeline of all agronomic management practices is available and displayed in appendix A.

Weed Seedbank Germination Assay

Weed seedbank sampling in each of the two (2005) and three (2006) systems was conducted each year prior to planting in early spring. Ten soil cores (2 cm diameter to a depth of 7 cm) were collected from three 25 by 25 cm quadrats along a diagonal transect within each plot. The ten cores were composited for each of the three sampling locations. In this study, we used a modified sampling technique from three previous direct germination studies that showed direct relationships between the readily germinable fraction of the weed seedbank and the response of the aboveground weed community (Forcella, 1992; Menalled et al., 2001; Smith and Gross, 2006).

Soil samples were thinly spread (approx 0.5 cm) over a four cm deep layer of soil-less seedling mix (Sun Gro Horticulture Bellevue, WA) in 25 by 25 cm plastic greenhouse flats. Flats were randomized on benches in a temperature-controlled greenhouse and kept well watered under natural light from late April through late July in 2005 and mid-May through early November in 2006 (when both years' soil was monitored). Typical greenhouse temperatures ranged between 20° and 30°C. Emerging seedlings were monitored weekly at first, then, as fewer new seedlings emerged, at intervals of varying length. Seedlings were counted, identified and removed from the flats. As seedling emergence ceased, the soil mix was stirred and re-watered until all emergence was exhausted. See Appendix D for a graphical depiction of assay methodology.

Weed Surface Field Density Estimations

A stationary position was chosen at random and used for repeated measures of weed surface density on all plots. Digital images were taken from the stationary position using a tripod at the same height, in the same location above a 1 m^2 quadrat. Sampling interval frequency was one image per week for each plot from late April to late June during the 2005 growing season. Images were stored until the end of the growing season, then all images were analyzed for percentage of crop, soil and weed surface densities by scanning one thousand points per image using Surfaces™ (SMA, 2005) software.

Percent weed cover was then compared to weed seedling germination from the greenhouse assays.

Above Ground Weed Biomass Measurements

Weed species net primary production was estimated by annual maximum plant biomass accumulation or, in the case of cover crops, biomass just prior to incorporation (KBS-LTER, 2001). Plant biomass was measured by quantifying the peak dry mass of weeds per m^2 in each plot. Two or three random sampling locations in each plot were sampled for weed biomass. Prior to corn harvest (2003 and 2006), 1.5 m x 0.65 m quadrats were oriented with the long side in a north/south direction. This direction was perpendicular to the crop rows and allowed for assessment of both the row and inter-row plant communities. Prior to clover incorporation (2004), three random sampling locations in each plot were sampled for clover and weed biomass using a 0.5 by 2 m quadrat. Plant biomass was quantified by clipping all plants within the sampling area at ground level. Weeds were combined (2003, 2004) and were identified to species in 2006, dried at 60° C for 48 h and weighed.

Statistical Analysis

Weed seedbank emergence (density) and number of species (richness) comparisons between treatments and years were analyzed by analysis of variance (ANOVA) utilizing the mixed procedure (PROC MIXED) in Statistical Analysis Software (SAS) version 9.1.3 (SP4) (SAS, 2008). Treatments were considered as fixed effects with density and richness as the continuous response variables within and between years, and weed surface density as the continuous response variable within season and above ground biomass as the continuous response variable within individual years. Mean separations were obtained by the Least Significant Difference (LSD) test and considered significantly different at $p < 0.05$. The Mixed Procedure was especially appropriate for this study since we had two or more variance components such as replicate, subsample and years as random effects. The Mixed Procedure allowed data obtained through repeated measures of surface density and other measurements in the unbalanced design (our split-plot of one treatment but not the other) to be analyzed with a wider variety of correlation structures.

Results

Weed Seedbank Germination Assay

There was a significant effect of transitional management strategy on seedbank density ($p < 0.05$) for the final transitional year (2005), when the C-A-A-C treatment had a lower seedbank density than the C-S-W/A-C treatment (Figure 1). Prior to the first certified organic season (spring 2006) the seedbank densities of the C-A-A-C and the C-S-W/A-C G treatments changed relatively little, and there was no significant effect of year on the C-A-A-C treatment. However the seedbank in this treatment was significantly lower ($p < 0.01$) in weed seedbank density than in the C-S-W/A-C G treatment. There was a significant effect of harvest management on the split treatment where C-S-W/A-C F had the highest level of seedbank density in 2006 as compared to either of the other two management systems ($p < 0.001$; Figure 1A).

Neither of the three-year transitional management strategies had an effect on weed species richness ($\alpha = 0.05$) until the end of the transition period. Just prior to the first certified organic season (spring 2006) both C-S-W/A-C treatments had significantly higher weed species richness than the C-A-A-C treatment ($p < 0.05$).

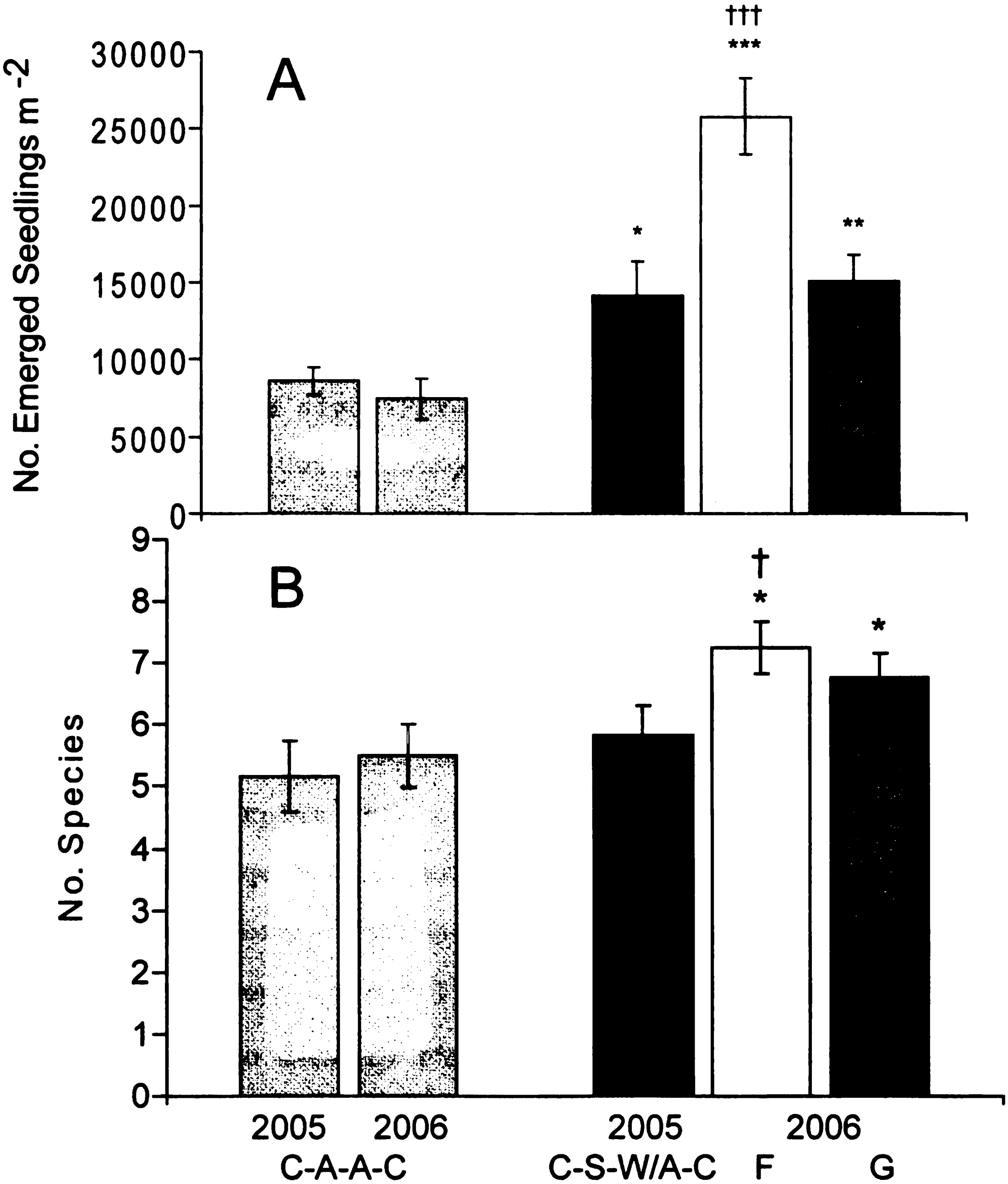


Figure 1. Density (A) and species richness (B) of weed seedlings emerged from spring 2005 and 2006 soil seedbank samples. C = Corn, A = Alfalfa, S = Soybean, W = Wheat. F = wheat harvested as Forage, G = wheat harvested as Grain. Bar values are mean ± one standard error for *n* = 12. *Significant treatment differences at the 0.05 probability level. **Significant at the 0.01 probability level. ***Significant at the 0.001 probability level. †Significant split treatment difference at the 0.05 probability level. †††Significant split treatment difference at the 0.001 probability level.

The C-S-W/A-C treatment harvested as forage had significantly higher weed species richness than the same treatment harvested as grain ($p < 0.05$). There was no effect of year on weed species richness for the C-A-A-C treatment ($\alpha = 0.05$; Figure 1B).

Weed Surface Field Density Estimations

Despite the significantly higher weed potential throughout the 2005 growing season as indicated by germination assays (Figures 1A and 1B), the percent surface cover of weeds was significantly less ($p < 0.05$ to 0.001) in the more complicated C-S-W/A-C treatment as compared to the C-A-A-C treatment until the latter treatment was split into two separate harvest methods (Figure 1B). Once this treatment was split, the percent surface cover of weeds began to diverge to the point where the C-S-W/A-C treatment harvested as forage did not differ significantly from the C-A-A-C treatment ($\alpha = 0.05$), but was significantly higher in weed surface density than the C-S-W/A-C treatment harvested as grain ($p < 0.05$). The C-A-A-C treatment was also significantly higher ($p < 0.05$) in weed surface density at this point than that of the C-S-W/A-C treatment harvested as grain (Figures 2A and 2B).

Figure 2. Boxplots showing 2005 weed surface density for the C-A-A-C treatment (A), and the C-S-W/A-C treatments (B).

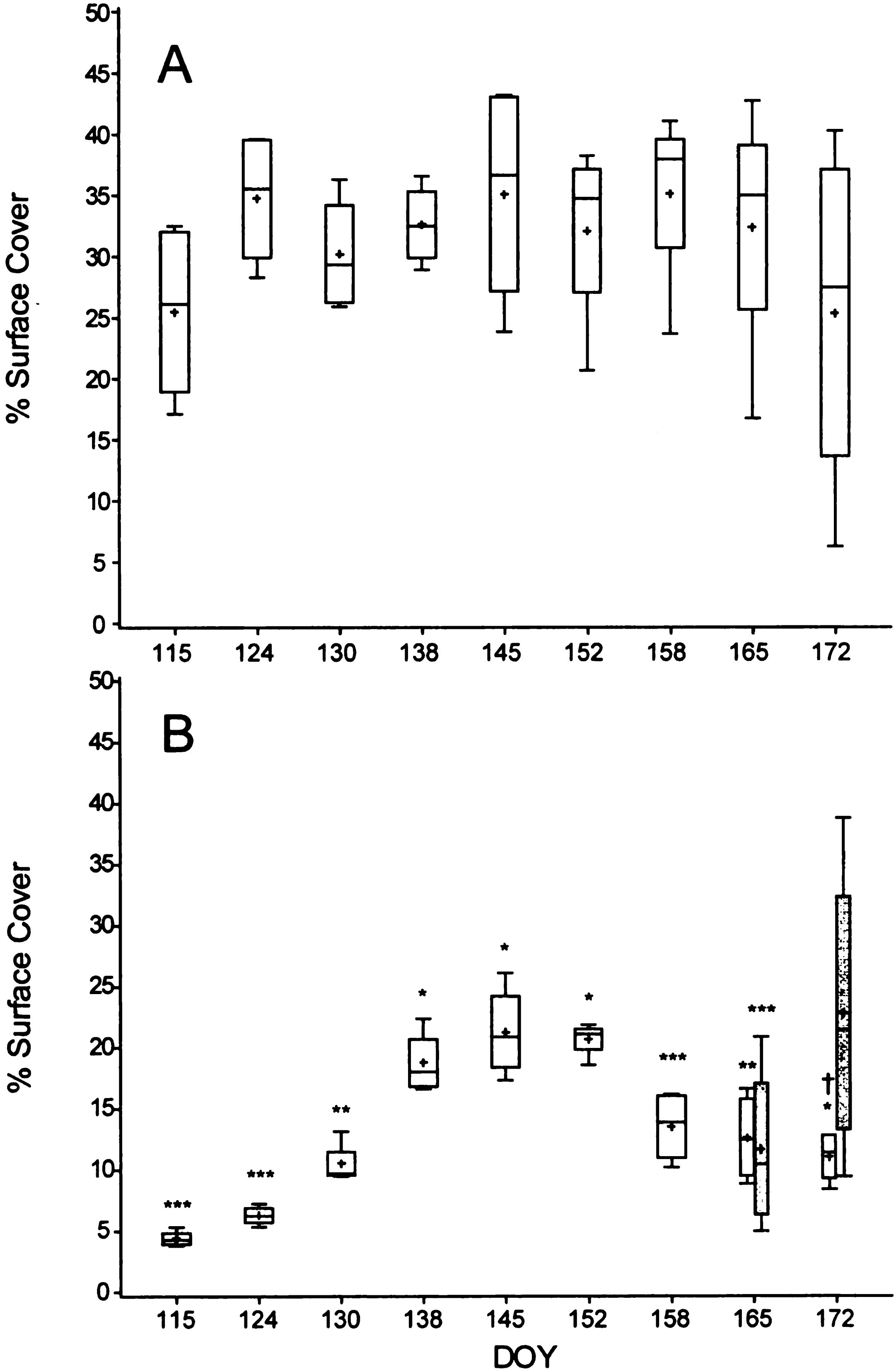


Figure 2(cont.). C = Corn, A = Alfalfa, S = Soybean, W = Wheat. Shaded boxes (B) represent the split from C-S-W/A-C where wheat was harvested as grain (open boxes) to wheat harvested with alfalfa as forage (shaded boxes). *Significant treatment differences on specific day of year at the 0.05 probability level. **Significant at the 0.01 probability level. ***Significant at the 0.001 probability level. †Significant split treatment difference ($p < 0.05$).

Above Ground Weed Biomass Measurements

Fall above-ground weed biomass in the field did not differ significantly between treatments ($\alpha = 0.05$) after the first transitional management year (2003) when the harvested crop was corn (Figure 3). Corn yield also did not differ significantly between treatments ($\alpha = 0.05$; data not shown) that year.

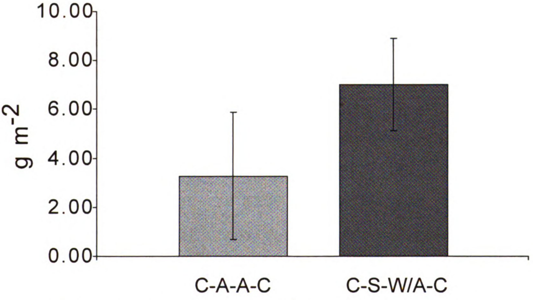


Figure 3. Fall 2003 weed biomass by treatment. C = Corn, A = Alfalfa, S = Soybean, W = Wheat. Bar values are mean ± one standard error.

Spring above-ground weed biomass was significantly higher ($p < 0.05$) than red clover (cover crop) biomass at the start of the second transitional season (May 2004) prior to tillage in the C-S-W/A-C treatment where mean values were 73.7 and 177.4 g m^{-2} for clover and weeds, respectively (Figure 4).

Figure 4. Spring 2004 cover crop (red clover) and weed biomass for the C-S-W/A-C treatment. C = Corn, A = Alfalfa, S = Soybean, W = Wheat
Bar values are mean ± one standard error.

Despite the significantly higher weed potential (Figures 1A and 1B) for the more complicated C-S-W/A-C treatments throughout the 2006 growing season, there was no significant effect of transitional management strategy (α = 0.05) on total weed biomass in the field at the end of the first certified organic season (fall 2006) when all transitional treatments were managed identically (Figure 5). There was also no significant effect of transitional management strategy on corn yield (α = 0.05; see chapter 1) that year.

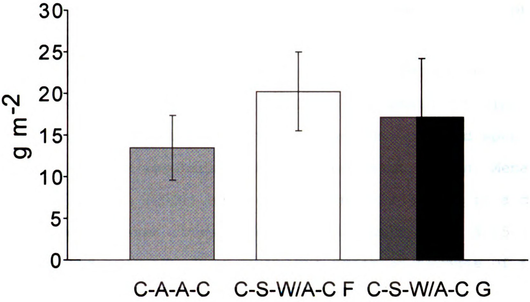


Figure 5. Fall 2006 weed biomass by treatment.
C = Corn, A = Alfalfa, S = Soybean, W = Wheat. F = wheat harvested as Forage. G = wheat harvested as Grain. Bar values are mean ± one standard error.

Discussion and Conclusions

Results of this study indicate particular transitional management strategies such as the more complicated C-S-W/A-C treatment can overcome an increase in weed seedbank (through the incorporation of green manure and FYM) by maintaining companion or cover crops in a diverse rotation and performing disruptive mechanical practices such as rotary hoe and row cultivation during critical weed emergence periods. Weed biomass and density in the C-S-W/A-C treatments were equal to or considerably lower than in the C-A-A-C treatment irrespective of the significantly higher weed potential indicated by weed seedbank germination assays. Seedbank samples were collected prior to the wheat phase of the rotation (2005) and the following season prior to planting corn.

Gross (1990) found that the direct germination technique, while requiring a substantial amount of time and space, offers a more comprehensive account of weed species present in the seedbank than does seed elutriation. Menalled and colleagues (2001) sampled soil in this manner to a depth of 15 cm, however cores were divided from 0-5 and 5-15 cm depths and only the 5 cm depth was reported because of the tendency of agricultural weeds to germinate and emerge from the top few centimeters of soil (Buhler, 1995). Smith and Gross (2006) sampled soil in a similar pattern to a depth of 5 cm, and reported the germinable fraction of the weed seedbank experienced relatively rapid change in composition and abundance because significantly higher measures of weed seedbank density and richness had occurred after the wheat phase of a similar rotation. Here, we saw a significant treatment effect on weed seedbank density prior to planting wheat, with a rapid increase in density and richness the year following the wheat phase. The increase in weed species richness in the C-S-W/A-C F treatment was most likely due to the first forage cutting in 2005 which opened up the canopy, allowing sunlight and exposing bare soil, minimizing competition with the alfalfa and providing an opportunity for recruitment. Forage crops such as alfalfa have been utilized in herbicide-free rotations for their effects on the weed community through competition, mowing, and suppression of weed seed germination (Bellinder et al., 2004).

We did not investigate the weed seedbank after the final year (corn phase), however Smith and Gross (2006) found increased weed seeds associated with the winter wheat phase of the rotation were relatively immeasurable after successive plantings of corn and soybean. Albrecht (2005) also found a significant increase in the weed seedbank during the winter cereal phase of a rotation, and as in this study, provided evidence that the conversion (transition to organic) did not necessarily encourage the dominance of weeds in the field. While these and other studies have reported rotational effects on the weed seedbank (Cardina et al., 2002; Menalled et al., 2001), others have found tillage practices to more significantly influence the seedbank than crop rotation (Barberi and Lo Cascio, 2001). Sosnoskie and colleagues (2006) showed how both crop sequence and tillage system influenced weed species density and diversity, suggesting the manipulation of these factors could help reduce the negative impact of weeds on crop production.

Interactions between weed management practices, weed populations, and crop yields are very complex. Initial weed densities and species composition interact with weed management strategies and weather patterns to generate weed seedbank responses in the field (Buhler, 1999). While the predictive value of weed seedbank estimations from soil remains questionable (Grundy, 2003; Menalled et al., 2001;

Sjursen, 2001; Smith and Gross, 2006), in rotational systems, weed seedbanks can provide insights into cropping and management history as well as potential weed problems. By managing weed seedbanks through intensive focused practices, using a variety of strategies such as tillage, crop rotation, cover crops and mulches, established weed populations can diminish over time (Swanton and Booth, 2004).

Climatic conditions most certainly had an effect on weed populations in this study. The extreme wet conditions that prevented proper establishment of alfalfa in the C-A-A-C treatment early in 2004, followed by drought conditions during the 2005 growing season, probably accounted for the great differences between treatments in weed surface density.

This study has accentuated the implications for transitional organic growers to employ rotational strategies designed to minimize weed emergence and endure short term increases in the weed seedbank. Results of this study show the four-year rotation of alfalfa, corn, soybean, wheat/alfalfa and corn (C-S-W/A-C) produced with organic sources of nutrients (manure and crop residue), despite an increase in weed potential, decreased the weed seed bank responses as compared to one year of conventionally grown corn followed by two years of transitional alfalfa and one year of organic corn (C-A-A-C) for the transition to a certified organic system.

CHAPTER 3

TRANSITIONAL SOIL QUALITY CHARACTERISTICS

ABSTRACT

This study was conducted over four years in order to compare the soil quality characteristics of two distinct transitional organic systems: A four-year organic rotation of corn, soybean, wheat/alfalfa and corn (C-S-W/A-C), with incorporated dairy manure and cover crops vs. one year of conventional corn followed by two years of continuous transitional alfalfa followed by corn (C-A-A-C). Results show an overall increase in percent macroaggregates in the $>$ 2000 μm size class at 0-7 cm depth over the transition period for both systems. There were 2.7 and 3.4 fold increases in aggregates of this size class for the C-A-A-C, C-S-W/A-C treatments, respectively. The C-S-W/A-C system generated a 4.5 fold increase in aggregates of this class when wheat interseeded with alfalfa was harvested as forage. Bulk density showed an overall decrease over the transition period for both systems with a fourteen percent and a six percent drop for the C-S-W/A-C and the C-A-A-C systems, respectively. We saw no significant treatment differences in water filled pore space at the end of the transition period. We conclude from this study that either rotation will improve soil quality characteristics during the transition from conventional to organic cropping systems.

INTRODUCTION

Soil quality is considered by organic farmers to be a major barrier to long term success of certified production systems (Walz, 1999). Commercial growers and researchers alike have taken strides to address these issues by investigating rotational strategies involving the use of cover or companion crops to add organic matter and supply nitrogen and carbon to the soil (Berry et al., 2002; Hiltbrunner et al., 2004; Katsvairo et al., 2007; Larsson et al., 1997; Liebman and Dyck, 1993; Liebman and Davis, 2000). While the addition of organic matter can improve soil fertility and structure, the beneficial properties often depend on type, timing, climatic conditions, soil texture and current crop.

The aggregation of soil is an essential function in soil physicochemical and biological processes, and has been shown to influence soil quality through demonstrated increases in soil organic matter (SOM), moisture holding capacity and soil nutrient retention (Angers and Giroux, 1996; Angers and Caron, 1998; Jiao et al., 2006).

It has been claimed by growers and investigators that long, diverse crop rotations incorporating cover crops and manure, often used on organic farms, help to stabilize yield, augment plant protective mechanisms, and improve soil quality compared to conventional systems with shorter rotations and more synthetic inputs (Delate, 2002; Teasdale et al., 2004; Watson et al., 2002). However, the magnitude and value attributable by these systems tend to be spatially and temporally quite variable as well as very dependent on the timing and management of particular agronomic practices (Davis et al., 2005; Huxham et al., 2005; Liebman and Davis, 2000; Wang et al., 2006; Welsh et al., 1999).

Additions of farmyard manure (FYM) to organic systems have been shown to enrich soil organic matter (SOM) and improve soil properties such as increased numbers and distribution of soil macroaggregates, microfauna, macro and micro nutrients and improved crop yields (Edmeades, 2003; Ghoshal and Singh, 1995; Gupta et al., 1992; Jiang et al., 2006; Jiao et al., 2006; Mikha and Rice, 2004). However, nutrient availability to crops from manure sources, by and large, can be extremely variable and can depend a great deal on agronomic management (Muñoz et al., 2004; Salazar et al., 2005). Adding to the complicated character of this variability, Paré and colleagues (1999) have shown that the addition of stockpiled FYM to conventionally tilled systems significantly increased the percent of water stable aggregates as compared to the same addition to a no-till system. Many studies show the opposite, in general, no-till systems result in an increase of total water stable soil aggregation (Denef et al., 2001b; Grandy and Robertson, 2006; Green et al., 2005; Mikha and Rice, 2004; Park and Smucker, 2005; Six et al., 1999; Six et al., 2000; Taboada-Castro et al., 2006; Zotarelli et al., 2007).

One of the chief reasons a less complicated system including perennial alfalfa was incorporated into this study was less reliance on tillage. Perennial legumes such as alfalfa have been shown to accumulate soil carbon faster than annual crop rotations, most likely due to the plant residue quality and quantity as well as root growth, which influences aggregation, and rates of carbon accumulation appear related to changes in soil aggregate size classes (Grandy and Robertson, 2007). The variability in results of those studies examining soil quality via soil aggregate distribution is further complicated by the methodology utilized by investigators when determining the distribution (Angers and Giroux, 1996; Ashman et al., 2003; Barral et al., 1998; Collis-George and Laryea, 1972; Marquez et al., 2004; Niewczas and Witkowska-Walczak, 2005; Sainju, 2006; Srzednicki and Keller, 1984).

Qualities of an ideal transition period include a manageable weed seedbank, optimal nutrient levels, and good soil structure in order to maximize production once certification is obtained. Organic producers must implement a crop rotation including but not limited to sod, cover crops, green manure crops, and catch crops that provide functions which maintain or improve soil organic matter content, manage deficient or excess plant nutrients and provide erosion control (USDA, 2008 b). There is however no definitive rule on the use of perennial crops in rotational strategies during or after the transition period. It is generally understood that perennial legumes such as alfalfa, which build soil quality and prevent erosion, are a longer term crop (three years is common) and organic certification inspectors will evaluate these systems on a case by case basis (OCIA, OFRF personal communication), (USDA, 2008 b).

This study focuses on the changes in soil quality indicators such as aggregate size distribution during the critical three-year transition phase from conventional to certified organic farming. This research was designed to contribute to the development of best management practices for Midwestern U.S. growers to follow in transitioning to a certified organic system in corn, soybean, wheat and alfalfa. Two different transitional organic cropping systems are compared here: A four-year organic rotation of corn, soybean, wheat/alfalfa and corn (C-S-W/A-C), which incorporates dairy manure and cover crops vs. one year of conventional corn followed by two years of continuous transitional alfalfa (no manure or cover crops), followed again by corn (C-A-A-C). During the fourth year of the study (2006) both treatments were in the first fully certified organic season and were managed identically. The objective of this research was to evaluate soil quality as affected by these two distinct three-year rotations for the transition to a certified organic system.

MATERIALS AND METHODS

Field Experiment

Experimental Site

Experimental plots were located at the W.K. Kellogg Biological Station (KBS) Farming Systems Center (FSC) site located in southwest Michigan in the eastern portion of the U.S. corn belt, 50 km east of Lake Michigan in the SW corner of the state (85°24' W, 42°24' N, elevation 288 m). The twenty-year average growing degree days (base 10° C) from May to October at this site is 1326 (KBS-LTER, 2008). Mean annual precipitation is 920 mm with about half falling as snow, where potential evapotranspiration (PET) exceeds precipitation for about 4 months of the year. Average monthly temperatures range from -4.61° C in January to 23.1° C in July, with a mean annual temperature of 9.83° C (NOAA-NCDC, 2008).

Transitional treatments were established in 2003 in four replicated 0.04-ha plots organized in a randomized complete block design. Two soil series are identified at this site: Kalamazoo (fine-loamy, mixed, semiactive, mesic Typic Hapludalfs) and Oshtemo (coarse-loamy, mixed, active, mesic Typic Hapludalfs), two to four percent slope, developed on glacial outwash (Crum and Collins, 1995). The two series co-occur and differ mainly in their Ap horizon texture, though variation within a series can be as great as variation between a series (Robertson et al., 1997).

Agronomic Methods

Treatments consisted of two organic transitional rotation systems. The first was a four-year annual crop rotation of corn, soybean, wheat/alfalfa and corn (C-S-W/A-C), which incorporated dairy manure, cover and interseeded crops. The second was a transitional rotation including perennial alfalfa which consisted of one year of conventional corn followed by two years of continuous alfalfa (no manure or cover crops), followed again by corn (C-A-A-C). Interseeded crops in the C-S-W/A-C treatment consisted of a medium red clover cover broadcast into the first corn phase, and alfalfa drilled into winter wheat. Treatments were replicated four times in a randomized complete block design in 13.7 m x 27.4 m plots. Both treatments followed an eight-year old stand of alfalfa (established in 1996). The C-S-W/A-C treatment was split in year three (2005) to investigate two separate wheat harvest methods. The C-S-W/A-C F treatment had wheat harvested as forage, while C-S-W/A-C G treatment was harvested for wheat grain. During the fourth year of the study (2006) both treatments were in the first fully certified organic season and were managed identically. A graphic timeline of all agronomic management practices is available and displayed in appendix A.

Soil Quality Measurements

Six 40 mm diameter intact soil cores were taken in late April of 2004 and 2006 to a depth of 7 cm at three locations along a diagonal transect for each replicate plot. Bulk density and water filled pore space were measured on three of the six cores as described by Elliott (1999). Aggregate size distribution was measured in triplicate 25 g sub-samples of the remaining soil using a wet sieving apparatus similar to Yoder's model (1936) and designed to hold nested sieves. We incorporated a procedure described by Kemper (1965). Four aggregate size classes were collected from each treatment, replicate and subsample (core): > 2000, 1000 to 2000, 53 to 1000, and < 53 µm diameter. Macroaggregates were defined as the > 2000 and 1000 to 2000 µm diameter size fractions. Microaggregates were defined as the 53 to 1000 and < 53µm diameter size fractions. Soils were air dried for a minimum of 48 h and the 25 g subsamples were placed on the top sieve of each nest. To slake the air-dried soil, the sieve nest was lowered into water just above the top sample for a period of five minutes before the start of the wet-sieving motion. The apparatus specifications of oscillation time (3 min), stroke length (4 cm), and frequency (45 cycles min^{-1}) were held constant.

Following wet sieving, material remaining on each sieve was backwashed into pre-weighed 250 ml glass beakers and dried at 60° C for 24 h. The dried aggregates retained from each size class were weighed and stored at room temperature.

Floating organic matter (plant debris) was removed from the > 2000 µm aggregate size class. Organic matter associated with other aggregate size classes was not removed from the final (sand-free) aggregate weight. Aggregates falling into the < 53 µm diameter size class were discarded. The sand-free water stable aggregates were measured by adding 30 ml of 5 g L^{-1} sodium hexametaphosphate and shaking on an orbital shaker at 150 revolutions per minute for 24 h. The dispersed organic matter and sand was collected on a 53-µm mesh sieve, washed with deionized water, and dried at 60°C for 48 h; these weights were subtracted from the other sample weights to yield the sand-free portion of the samples.

Statistical Analysis

Soil quality (aggregate distribution, bulk density and water filled pore space) comparisons between treatments and years were analyzed by analysis of variance (ANOVA) utilizing the mixed procedure (PROC MIXED) in Statistical Analysis Software (SAS) version 9.1.3 (SP4) (SAS, 2008), where treatments were considered as fixed effects with percent soil aggregation as the continuous response variable within each size class between years, and bulk density as the continuous response variable within and between years and water filled pore space as the continuous response variable within individual years. Mean separations were obtained by the Least Significant Difference (LSD) test and considered significantly different at $p < 0.05$. The Mixed Procedure was especially appropriate for this study since we had two or more variance components such as replicate, subsample and years as random effects. The Mixed Procedure allowed data obtained through measurements in the unbalanced design (our split-plot of one treatment but not the other) to be analyzed with a wider variety of correlation structures.

Results

Size distributions of soil aggregates from 0-7 cm depth did not differ significantly ($\alpha=0.05$) at year one of the transition period in 2004 (Table 1).

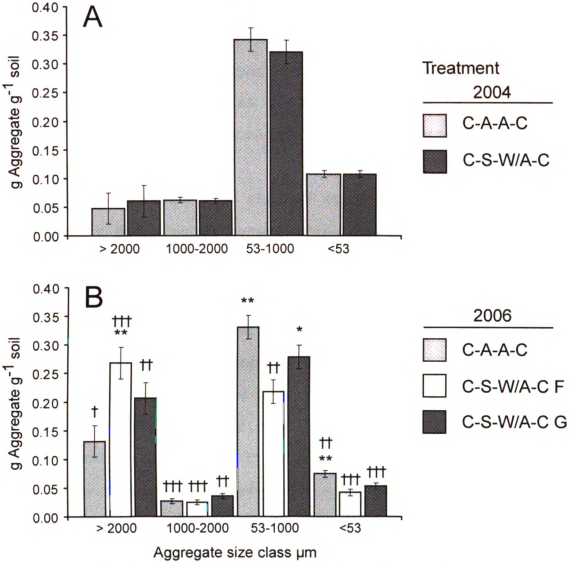
Table 1. Mean weight percent of soil aggregates at 0-7 cm depth distributed by class, treatment and year.

	2004		2006	
Aggregate Size Class µm	Treatment‡	Aggregate $g\ g^{-1}$	Treatment‡	Aggregate $g\ g^{-1}$
> 2000	C-A-A-C	0.048[c†]	C-A-A-C	0.131[b]
	C-S-W/A-C	0.060[bc]	C-S-W/A-C F	0.268[a]
			C-S-W/A-C G	0.206[a]
1000-2000	C-A-A-C	0.062[a]	C-A-A-C	0.027[b]
	C-S-W/A-C	0.061[a]	C-S-W/A-C F	0.025[b]
			C-S-W/A-C G	0.037[b]
53-1000	C-A-A-C	0.342[a]	C-A-A-C	0.330[ab]
	C-S-W/A-C	0.321[ab]	C-S-W/A-C F	0.218[c]
			C-S-W/A-C G	0.278[b]
< 53	C-A-A-C	0.108[a]	C-A-A-C	0.074[b]
	C-S-W/A-C	0.108[a]	C-S-W/A-C F	0.042[c]
			C-S-W/A-C G	0.053[c]

†Means followed by the same letter within a size class are not significantly different ($\alpha=0.05$).
‡C = Corn, A = Alfalfa, S = Soybean, W = Wheat. F = Wheat harvested as Forage, G = Wheat harvested as Grain.

After the three year transition period there were significant increases in the > 2000 µm macroaggregate size class both between treatments and years. There were no significant differences in this size class between the split treatment of C-S-W/A-C, however percent aggregates in this size class increased as compared to the C-A-A-C treatment for both years (Table 1). No significant differences were apparent in the 1000-2000 µm size class among treatments in 2006, while there was a decline in weight percent of aggregates in this size class between years. There were no significant differences between years or treatments in the 53-1000 µm microaggregate size class except for the C-S-W/A-C F treatment which showed a significant decline in 2006 as compared to the other two treatments that year as well as both treatments in 2004. Microaggregates in the < 53 µm size class were identical between treatments in 2004, but showed a significant decline for all treatments in 2006. There were also significant treatment differences in this size class after the three year transition period. The mean weight percent values for each size class and year are displayed in Table 1 however there were varying levels of significance between treatments and years. A comparison between treatment, year and aggregate size class showing varying probability levels is displayed in Figure 1. The split treatment of C-S-W/A-C did not differ between the two types of harvest methods, but both were significantly lower than the C-A-A-C treatment for this size class in 2006.

Figure 1. Mean weight percent of soil aggregates at 0-7 cm depth distributed by aggregate size class and treatment for years 2004 (A) and 2006 (B).



*Significant treatment differences within the same year at the 0.05 probability level. ** Significant treatment differences within the same year at the 0.01 probability level. † Significant within treatment differences between years at the 0.05 probability level. †† Significant within treatment differences between years at the 0.01 probability level. ††† Significant within treatment differences between years at the 0.001 probability level. Bar values are mean ± one standard error.

Results for aggregate size distribution between treatment, replication and subsample (individual intact soil core) were remarkably variable (Figures 2 and 3), especially for those in the > 2000 μm macroaggregate size class and the 53-1000 μm microaggregate size class sampled at the end of the transition period compared to the same aggregate size classes in 2004 (Figures 2A and 3A). This variability among results for 2006 was not unique to any particular treatments.

Soil bulk density in the 0-7 cm depth showed significant differences between treatments ($p < 0.05$) after the first year of the transition period (2004), where the average bulk density was 1.28 and 1.37 for the C-A-A-C and C-S-W/A-C treatments respectively (Figure 4A). While there were no significant differences in bulk density between any treatments after the three year transition period, all treatments showed a significant decrease in bulk density in 2006 as compared to 2004 (Figure 4A). We show similar results by treatment and year for soil water filled pore space (WFPS), where there were significant treatment differences in 2004 ($p < 0.001$) and no treatment differences in 2006 (Figure 4B). Since WFPS values are dependent on the soil moisture content at the time of sampling, we are not comparing differences of these values between 2004 (after the first year of the transition period) and 2006 (after the three year transition period).

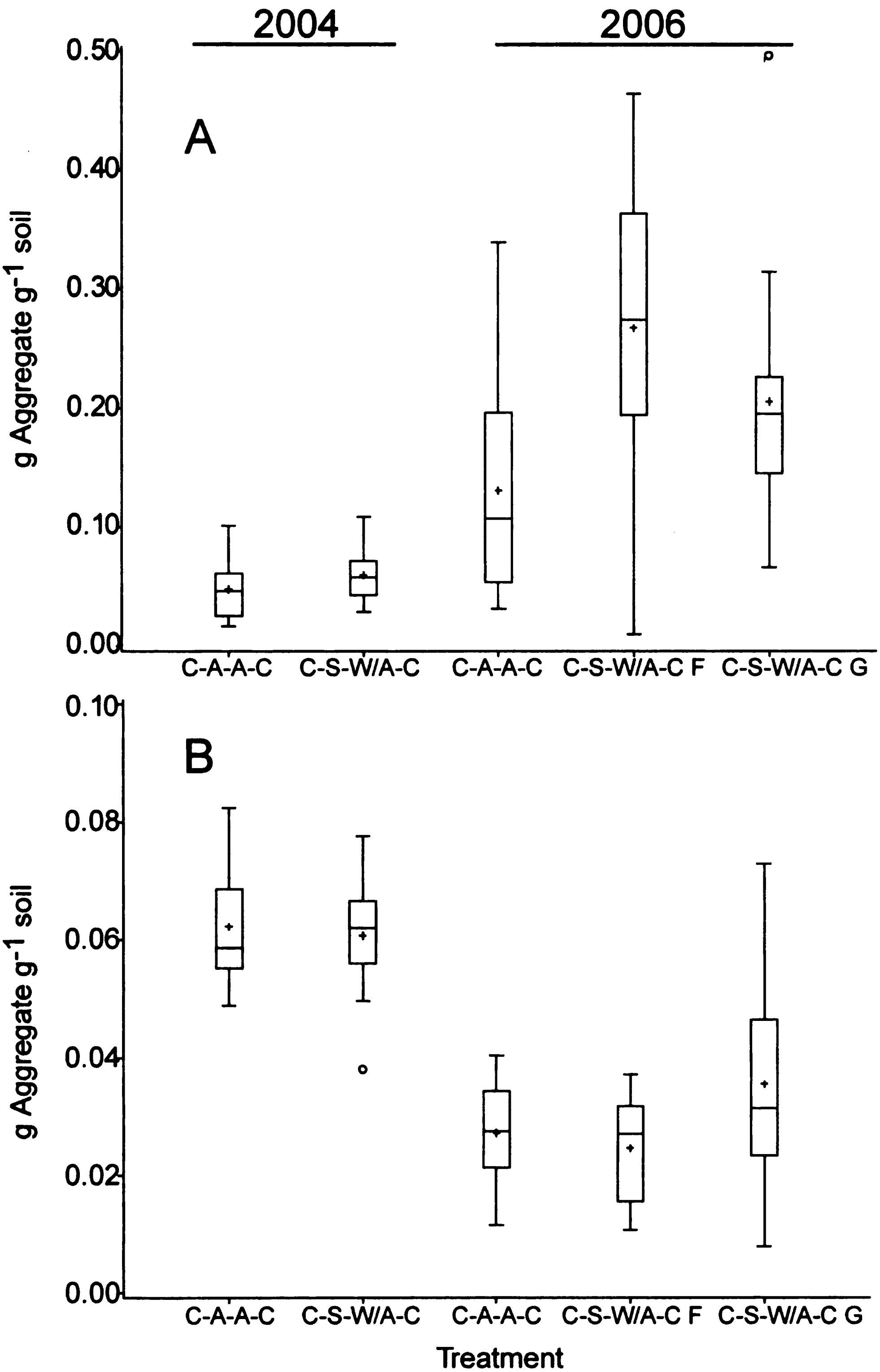


Figure 2. Schematic boxplots showing macroaggregate (0-7cm depth) variability between effects of transitional strategies and years for the > 2000 µm size class (A) and the 1000-2000 µm size class (B).

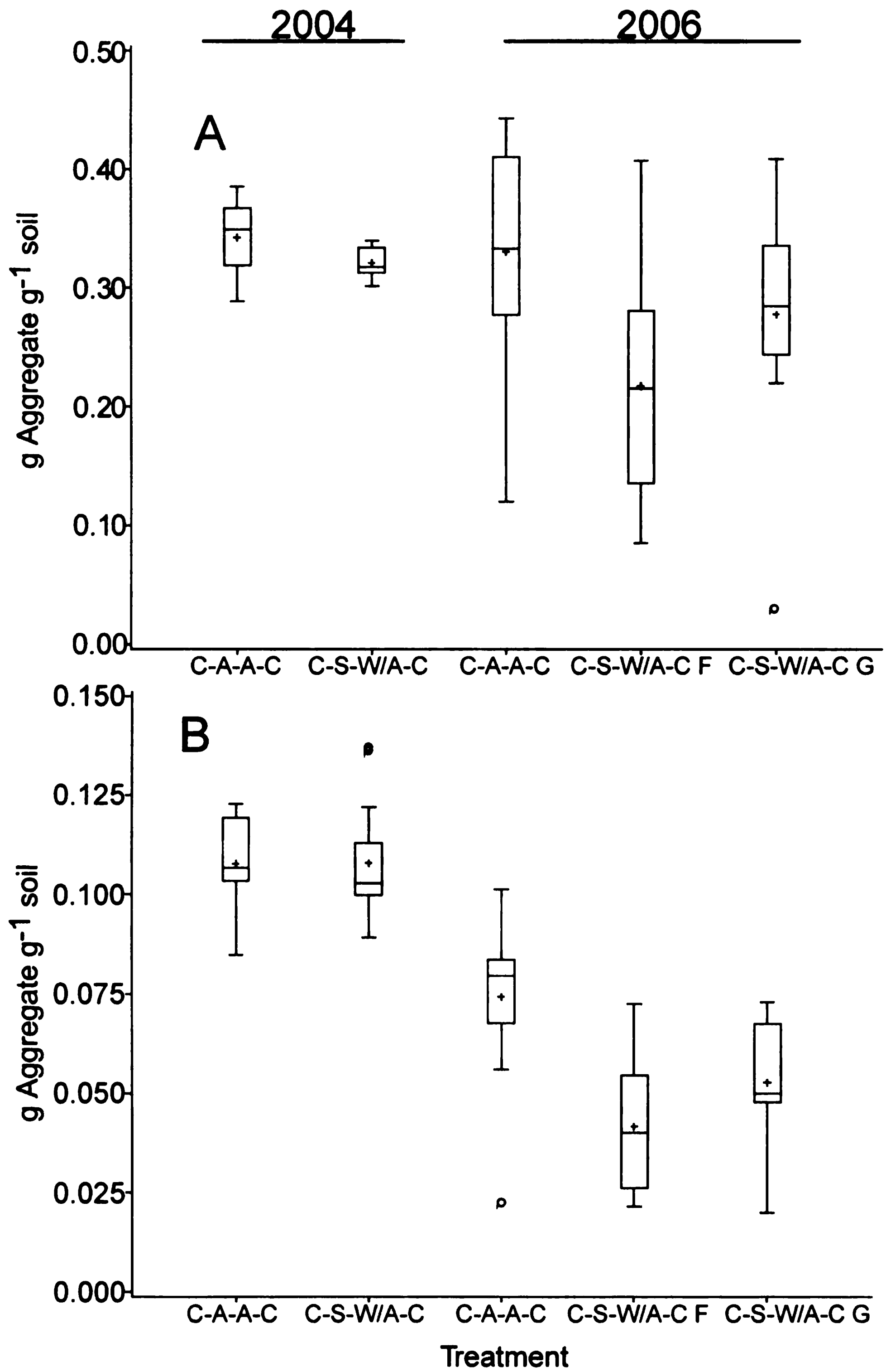


Figure 3. Schematic boxplots showing microaggregate (0-7cm depth) variability between effects of transitional strategies and years for the 530-1000 µm size class (A) and the < 530 µm size class (B).

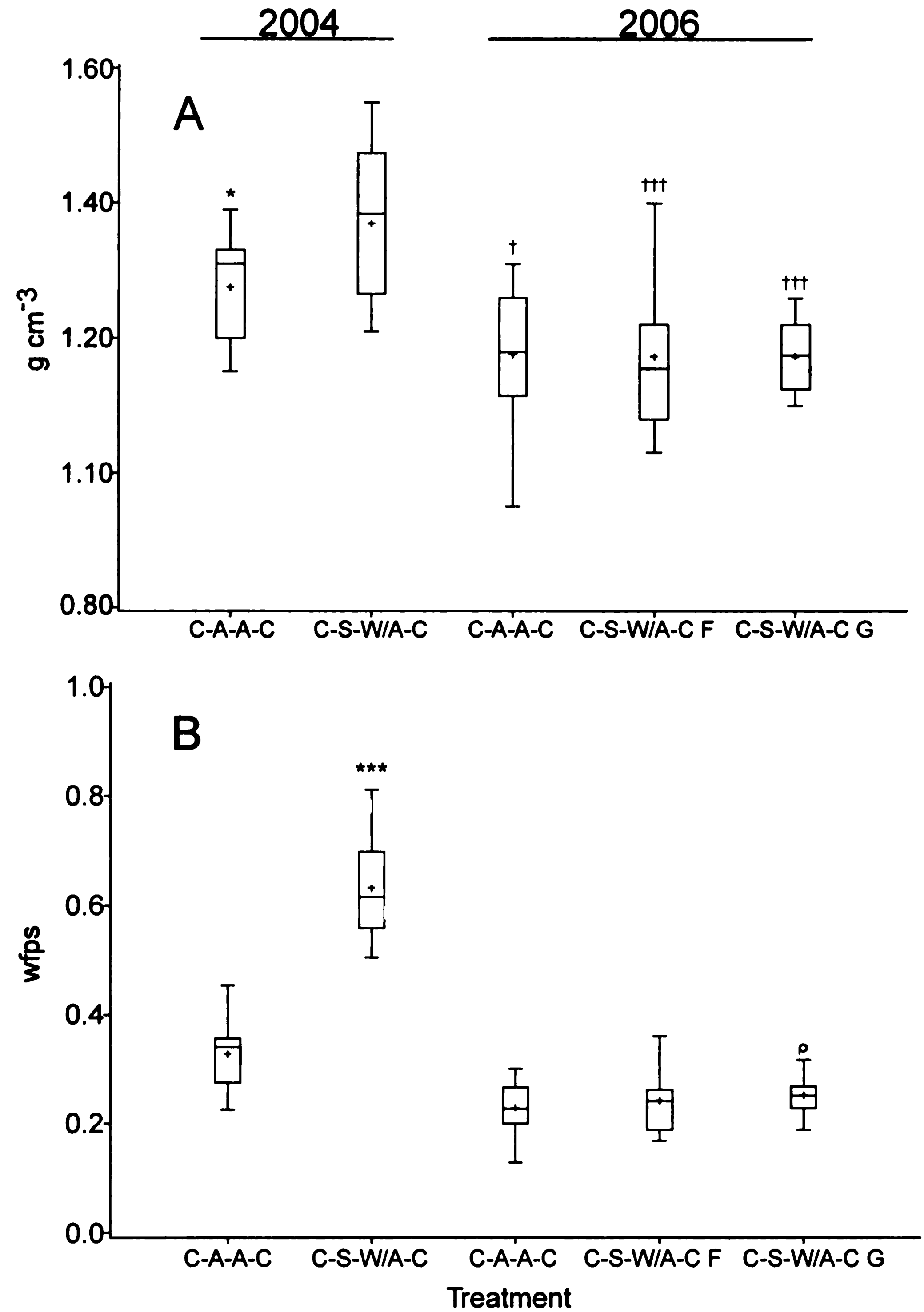


Figure 4. Boxplots showing differences (0-7cm depth) between treatments and years as indicated by bulk density (A) and between treatments as indicated by water filled pore space (B). *Significant treatment difference $p < 0.05$. ***Significant treatment difference $p < 0.001$. †Significant difference between years $p < 0.05$. †††Significant difference between years $p < 0.001$.

DISCUSSION and CONCLUSIONS

The results of this study indicate a substantial increase in the > 2000 μm macroaggregate size class at the 0-7 cm depth for the C-S-W/A-C treatments, which incorporated leguminous cover crops and solid dairy manure over a period of three years. There was a 2.7 and 3.4 fold increase in aggregates of this size class for the C-A-A-C, C-S-W/A-C treatments, respectively. The C-S-W/A-C system generated a 4.5 fold increase in aggregates of this class when wheat interseeded with alfalfa was harvested as forage.

While this effect on these systems may not be long lived, depending on future agronomic management practices, it may be important when transitioning to the first certified organic season. Both within season and inter-annual increases in macroaggregates have been demonstrated (Bipfubusa et al., 2008; Perfect et al., 1990; Tisdall et al., 1978), but results vary widely depending on sampling and analysis methods (Ashman et al., 2003; Douglas and Goss, 1982; Marquez et al., 2004; Niewczas and Witkowska-Walczak, 2005; Watts et al., 1996). Long term studies show results ranging from slight increases in macroaggregates with incorporated FYM (Blair et al., 2006; Holeplass et al., 2004; Rasool et al., 2007) to significant increases in aggregation with incorporated FYM but with no positive effect on crop yield and accompanying adverse effects on water quality (Edmeades, 2003) or higher soil sulfur concentrations (Yang et al., 2007).

This study also shows a 2.7 fold increase in macroaggregates at the 0-7 cm depth for the C-A-A-C treatment which did not incorporate FYM (or cover crops) during the three year transitional period. This may be attributable to the management practices performed before and during the transition. Both treatments were established after eight years of continuous alfalfa, however soil cores were sampled in the spring of year two (2004) after primary tillage had occurred the year before. Grandy and Robertson (2006) reported a substantial reduction in mean soil aggregate size and in the proportion of intraaggregate, physically protected organic matter after primary tillage of an untilled soil, and others have shown an increase in soil aggregation with reduced or no-till systems (Green et al., 2005; Mikha and Rice, 2004; Park and Smucker, 2005; Six et al., 1999; Taboada-Castro et al., 2006; Zotarelli et al., 2007). Therefore, although the C-A-A-C treatment did not incorporate FYM, the immediate decrease in aggregate size and distribution with primary tillage, may have been followed by the slight increase in these properties once the system returned to the perennial crop of alfalfa.

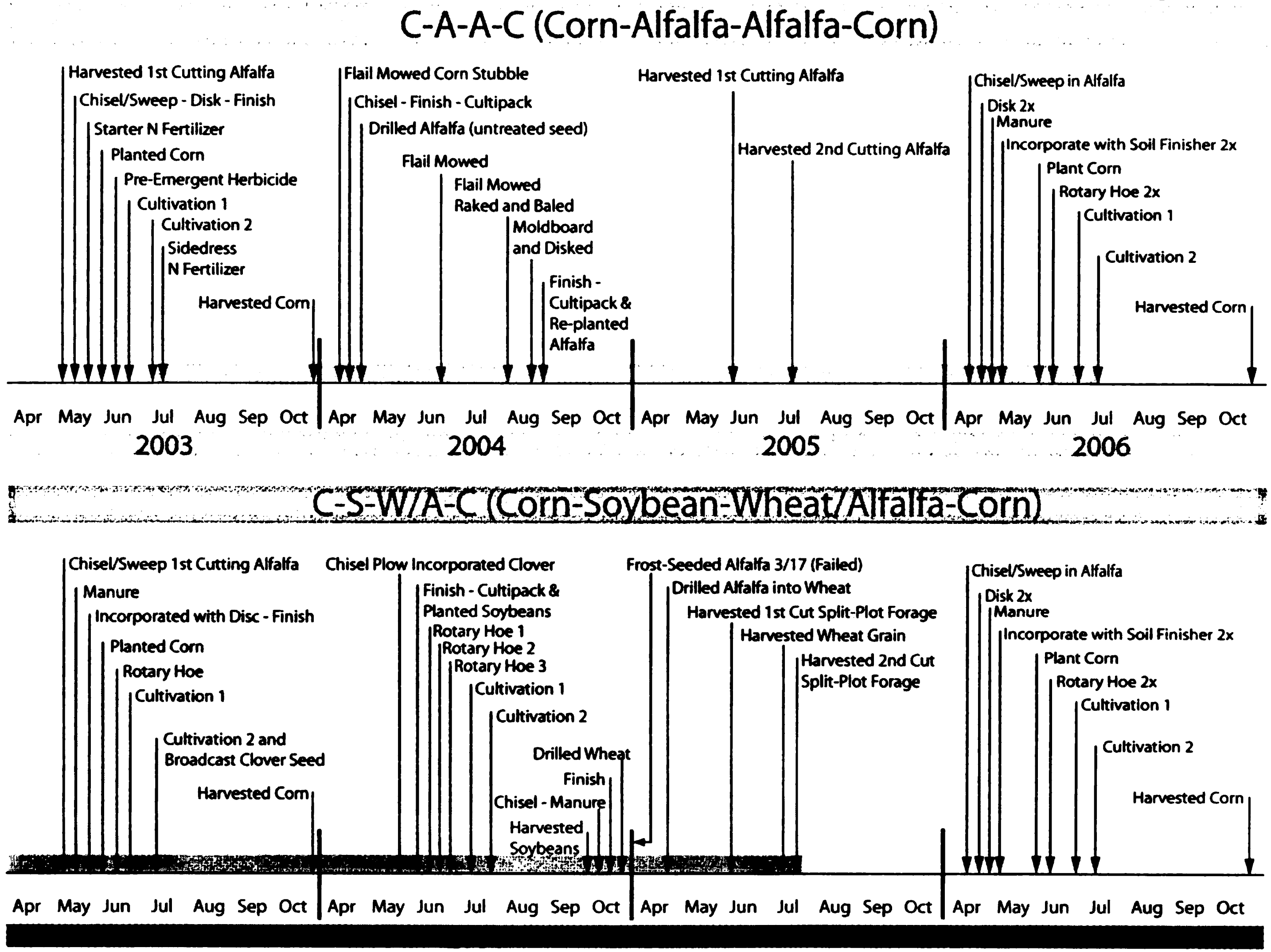
Increases in the > 2000 μm macroaggregate size class at the 0-7 cm depth for these systems were accompanied by a relative decrease in the 1000-2000 μm macroaggregate size class for both treatments. There was a significant decrease in the 53-1000 μm microaggregate size class over the course of the transition period for the C-S-W/A-C treatments, but this size class was relatively unchanged for the C-A-A-C treatment. Both treatments showed a significant decrease in the < 53 μm microaggregate size class, although the decrease was less significant for the C-A-A-C treatment. Six and colleagues (1999) suggested that the faster turnover rate of macroaggregates in a more conventionally tilled system compared with a no-till system lead to a slower rate of microaggregate formation within macroaggregates and less stabilization of new SOM in free microaggregates under such a system. The benefits of incorporating green manure and FYM may have been effaced by the higher rates of tillage in the C-S-W/A-C treatments for the lower diameter size classes which may explain these mechanisms.

Soil bulk density has been used as another indicator of soil quality (Werner, 1997) and has been shown to decrease with the incorporation of organic amendments such as plant residue and FYM (Latif et al., 1992; Sharma and Gupta, 1998). Attempts have been made to assess soil quality characteristics through an index that incorporates soil aggregate measurements, bulk density and water filled pore space, although these attributes tend to be highly variable both spatially and temporally (Karlen et al., 1994). In this study we observed a slightly lower soil bulk density from 0-7 cm in the C-A-A-C treatment compared to the C-S-W/A-C treatment after the first transitional year, which is likely attributable to the higher number of passes with farm machinery in the latter case with the annual crop rotation. Bulk density significantly declined for all treatments (0-7 cm) after the three year transition period which indicates an improvement associated with either strategy.

The significantly higher water filled pore space in the C-S-W/A-C treatment as compared to the C-A-A-C treatment after the first transitional year may be attributed to the higher rates of incorporated plant residue and FYM; however, this difference was not maintained over the entire rotation as there were no significant treatment differences at the end of the transition period. Since this variable is time specific - that is dependent on the soil moisture content at the time of sampling - the differences between years were not considered as indicative of principal transformations in soil quality.

In conclusion, at the end of the three-year organic transition period, the C-S-W/A-C rotation resulted in significantly more macroaggregates (> 2000 μm) than the C-A-A-C strategy. However, even though each rotation resulted in significantly lower bulk density at the end of the transition period relative to year one, overall there were no differences in soil bulk density observed between transitional rotations. Finally, after year one of the transition period, the C-S-W/A-C rotational strategy resulted in greater water filled pore space. However, by the end of the three year organic transitional period, there were no differences in water filled pore space between rotational strategies.

Appendix A. Agronomic management timeline for all treatments and years.



Appendix B. Custom machinery and application costs (U.S. $ per ha) by year, treatment

Year	2003		2004		2005			2006		
Cost	C-A-A-C	C-S-W/A-C	C-A-A-C	C-S-W/A-C	C-A-A-C	C-S-W/A-C F	C-S-W/A-C G	C-A-A-C	C-S-W/A-C F	C-S-W/A-C G
Crop Seed	95.93	95.93	362.96	69.63	0.00	45.19	45.19	100.25	100.25	100.25
Cover seed	0.00	46.02	0.00	0.00	0.00	345.68	345.68	0.00	0.00	0.00
Fertilizer	18.64	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Herbicide	54.79	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Planting	34.07	34.07	60.00	32.47	0.00	87.78	87.78	34.07	34.07	34.07
Tillage	30.86	30.86	30.86	30.86	0.00	0.00	0.00	30.86	30.86	30.86
Disk	25.06	25.06	25.06	25.06	0.00	0.00	0.00	50.12	50.12	50.12
Finish	27.78	27.78	27.78	27.78	0.00	0.00	0.00	55.56	55.56	55.56
Cultivation	36.30	36.30	0.00	36.30	0.00	0.00	0.00	38.89	38.89	38.89
Manure	0.00	44.44	0.00	44.44	0.00	0.00	0.00	44.44	44.44	44.44
Harvest	81.85	56.54	1.23	56.42	50.62	72.84	52.59	56.54	56.54	56.54
Rotary Hoe	0.00	12.47	0.00	12.47	0.00	0.00	0.00	24.94	24.94	24.94
Cultipack	0.00	0.00	12.47	12.47	0.00	0.00	0.00	0.00	0.00	0.00
Rake	11.11	0.00	11.11	0.00	22.22	0.00	0.00	0.00	0.00	0.00
Mow	25.31	0.00	50.62	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Moldboard	0.00	0.00	37.04	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Appendix C. Projected (2008) custom machinery and application costs (U.S. $ per ha) by year, treatment and operation.

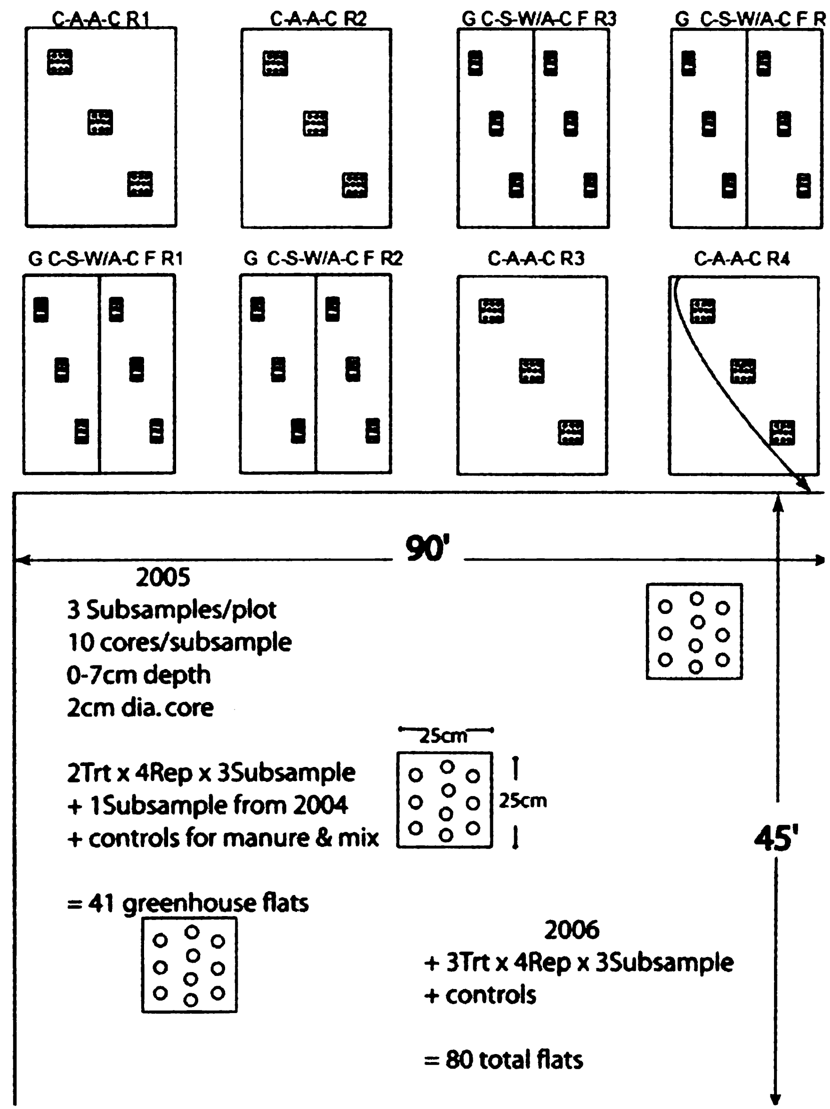
Year	2003		2004		2005			2006		
Cost	C-A-A-C	C-S-W/A-C	C-A-A-C	C-S-W/A-C	C-A-A-C	C-S-W/A-C F	C-S-W/A-C G	C-A-A-C	C-S-W/A-C F	C-S-W/A-C G
Crop Seed	121.85	121.85	362.96	97.53	0.00	80.00	80.00	103.70	103.70	103.70
Cover seed	0.00	55.56	0.00	0.00	0.00	345.68	345.68	0.00	0.00	0.00
Fertilizer	19.75	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Herbicide	60.20	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Planting	36.05	36.05	60.00	32.59	0.00	111.11	111.11	36.05	36.05	36.05
Tillage	33.83	33.83	33.83	33.83	0.00	0.00	0.00	33.83	33.83	33.83
Disk	27.16	27.16	27.16	27.16	0.00	0.00	0.00	54.32	54.32	54.32
Finish	27.78	27.78	27.78	27.78	0.00	0.00	0.00	55.56	55.56	55.56
Cultivation	42.47	42.47	0.00	42.47	0.00	0.00	0.00	42.47	42.47	42.47
Manure	0.00	47.16	0.00	47.16	0.00	0.00	0.00	47.16	47.16	47.16
Harvest	109.75	69.38	1.23	66.91	52.84	52.84	62.47	69.38	69.38	69.38
Rotary Hoe	0.00	16.54	0.00	44.44	0.00	0.00	0.00	29.63	29.63	29.63
Cultipack	0.00	0.00	14.81	14.81	0.00	0.00	0.00	0.00	0.00	0.00
Rake	11.11	0.00	14.81	0.00	27.90	27.90	0.00	0.00	0.00	0.00
Mow	25.31	0.00	52.84	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Moldboard	0.00	0.00	37.04	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Appendix D. Graphical depiction of methodology for seedbank germination

Greenhouse assay methodology

- 10 soil cores taken within a 25x25cm quadrat at 3 locations to a 7cm depth.
- Cores pooled and homogenized
- Soil spread on to 25x 25cm greenhouse flats and watered regularly
- Emerging seedlings were identified and counted
- After complete emergence, soil was dried, stirred and re-watered
- Last two steps were repeated

Adapted from Forcella 1992 and Menalled, Gross, and Hammond 2001.



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