Sustainable soils, sustainable communities: Promoting the environmental and social sustainability of human-soil interactions in Iowa

by

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CHAPTER 1. GENERAL INTRODUCTION

Few environmental factors play as significant a role in shaping ecological and social communities as soil. Soil is a dynamic amalgamation of living, dead, and abiotic components that literally form the foundation for terrestrial life. Soil performs a number of functions that are critical to humanity including supporting crop growth and regulating greenhouse gases (Morgan, 2005; USDA-NRCS, 2010). One of the defining characteristics of soil is its biotic components, which form some of the most biologically diverse and least understood ecosystems on Earth (Begon et al., 1996; Christensen et al., 1999). The incredible capacity of soil to support life, however, does not make it immune to anthropogenic abuse. Although agriculture is often cited as the primary culprit, the mismanagement of soils is by no means limited to farmers. Urban populations have also contributed to soil loss and degradation through ignorance, apathy, and tacit support of unsustainable soil management practices. The fundamental need for healthy, functional soils is shared by all; both rural and urban alike. Likewise, if unsustainable soil management practices are to be stopped, then both rural and urban populations must take action to better understand and interact with soil. If our society is to have healthy, sustainable communities, then measures must be taken to encourage sustainable human interactions with soil.

Definitions of “sustainability” can vary markedly depending on the source, which is why it is prudent to explain exactly what is meant by the term “sustainability” as it is used in this paper. For example, the Monsanto Corporation, a global leader in biotechnology and agri-business, envisions sustainability as achieving higher crop yields while using fewer resources; “Farmers need to get more from every acre of land, every drop of water and every unit of energy" (Monsanto, 2012). Farmer, philosopher, and author Fred Kirschenmann offers an alternative view of sustainability. Kirschenmann envisions sustainability as systems that use nature as a model for success. According to Kirschenmann, sustainable agriculture is "agriculture grounded more in perennials rather than annuals, closed nutrient cycles rather than inputs, diverse combinations of species organized so that the waste of one species becomes the food for another …and a gradual phasing out of specialized monocultures" (Kirschenmann, 2011). These are but two of the myriad interpretations that exist for agricultural sustainability.

The aforementioned examples are greatly simplified as they lack any mention of factors beyond the environmental aspects of sustainability, and serve only to illustrate the importance of relaying a clear definition to readers whenever using a term as open to interpretation as "sustainability". Sustainability, as used throughout this thesis, refers to practices that preserve, enhance and replenish natural resources; provide accessible, nutritious, and culturally appropriate food to everyone in the community; and offer non-exploitative economic opportunities to all of those whose labor keep the food system functioning.

Thesis Organization

Following this general introduction (Chapter 1) is a general review of literature (Chapter 2) that establishes the relevance and relationship of the following chapters. The literature review presented in Chapter 2 contains some of the same material as the literature reviews of the later chapters and is intended only as an overview of the topics that will be presented. The literature reviews of the individual chapters are more detailed, however they will likely be condensed prior to journal submission. Chapter 3 presents the findings of a field experiment designed to investigate the use of winter cover crops as a means to improve the sustainable management of agricultural soils in Iowa. Chapter 3 is written in manuscript style and will be submitted for publication in a scientific journal. E.B. Moore is the primary author and the other names listed are co-authors. Chapter 4 recaps the pilot season of an educational program designed to introduce Iowa's urban youth to the importance of sustainable agriculture and healthy soil, especially as it pertains to personal and environmental health. This chapter will be submitted as a paper to a science education journal. E.B. Moore is the primary author and the other names listed are co-authors. Lastly, Chapter 5 provides a general summary of the entire thesis project.

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CHAPTER 2. GENERAL LITERATURE REVIEW

Introduction

Iowa is one of the largest producers of agricultural commodities in the U.S. In addition to being the third largest producer of total agricultural products, Iowa is the nation's largest producer of several major commodities including corn, soybeans, eggs, and hogs (USDA NASS, 2007). The conventional corn/soybean cropping systems that dominate the Iowa landscape are among the most productive in the world and contribute to making the U.S. the world's largest producer of corn and soybeans (USDA FAS, 2012). However the success of conventional corn/soybean cropping systems in Iowa has not come without costs. Iowa's agricultural land has lost substantial amounts soil organic matter over the past century (Paustian et al., 1997), resulting in a decline in overall soil quality. The continued degradation of soil will undoubtedly have negative long-term consequences on agricultural productivity and quality of life among Iowa residents. If Iowa's corn/soybean cropping systems are to remain highly productive, then immediate action must be taken to reverse soil degradation and move towards sustainable management of soil resources. One of the best ways to promote soil health and improve soil quality is by increasing soil organic matter.

Soil Organic Matter

Soil organic matter is often considered the single most important factor contributing to overall soil quality (Larson and Pierce, 1991; Sikora et al., 1996). The influence of soil organic matter on overall soil quality stems from its effects on physical, chemical, and biological characteristics of soil (Doran and Parkin, 1994). Although the importance of organic matter to proper soil functioning is understood, quantifying changes in soil organic matter is challenging. Challenges include difficulty in detecting the relatively small changes in soil organic matter due to management practices (Kaspar et al., 2006) and difficulty in detecting changes amidst the variable climatic conditions that influence soil organic matter accumulation and decomposition (Sikora et al., 1996; Wilhelm et al., 2010).

Building Organic Matter: Reducing Soil Organic Matter Loss

One of the ways that soil organic matter loss can be reduced is by adopting no-tillage (Ismail et al., 1994; Triplett and Dick, 2008). No-tillage is defined as the practice of planting crops in undisturbed soil which retains at least 30% residue cover (Triplett and Dick, 2008). No-till has been touted as an effective means of reducing soil erosion and conserving soil water (Aase and Pikul, 1995; Liebig et al., 2004; Triplett and Dick, 2008). In general, research indicates that no-till enhances soil quality when compared to conventional tillage (Cambardella and Elliot, 1992; Beare et al., 1994; Ismail et al., 1994). With proper management, crop yield differences between no-till and conventional tillage are usually negligible (Triplett and Dick, 2008). Excessive tillage can result in accelerated soil organic matter oxidation, which can lead to a decline in soil quality (Tate, 1987; Ismail et al., 1994; Triplett and Dick, 2008). Managing crops under no-till is a viable means of improving soil quality by reducing soil organic loss.

Building Organic Matter: Increasing Soil Carbon Inputs

The benefits of no-tillage to soil organic matter accumulation are largely derived from reducing soil organic matter loss. Another viable strategy for increasing soil organic matter is to increase inputs of carbon into the soil by adding more plant biomass. In many agricultural systems, adding plant biomass can be accomplished through reducing the fallow periods in crop rotations. One approach is to incorporate cover crops into crop rotations. Cover crops are plants grown during the fallow period between main crops. Cover crops comprise a broad range of plant species which perform a wide range of ecosystem services including erosion mitigation (Kaspar et al., 2001; Wilhelm et al., 2010), nitrogen fixation (Reicosky and Forcella, 1998), nutrient scavenging (Kaspar et al., 2007), weed suppression (Liebman and Davis, 2000), and beneficial insect habitat (Tillman et al., 2004). Despite the functional diversity that exists among cover crops, they have at least one thing in common: they all add an additional crop to the rotation sequence, resulting in greater annual biomass production and potential increase in the amount of carbon deposited into the soil organic matter pool. Cover crops reduce fallow periods and extend the crop rotation sequence, both of which can increase soil carbon inputs and enhance soil quality (Wienhold et al., 2006).

Challenges of Implementing Cover Crops

Although the benefits of cover crops are understood, the perceived lack of short-term economic benefit to farmers has hindered widespread adoption of this practice (Singer et al., 2007; Faé et al., 2009). Other factors such as time required to manage cover crops, costs associated with cover crops, and lack of knowledge about cover crops also hinder widespread adoption (Singer et al., 2007). A survey conducted by Singer (2008) found that only 11% of Corn Belt farmers planted winter cover crops between the years 2001 to 2005. More information about the economic benefits of cover crops, particularly as it pertains to soil productivity and nutrient management, may encourage more widespread adoption of cover crops.

Rye Cover Crops

Cereal rye was the most planted cover crop in Illinois and Iowa in the period between 2001 and 2005 (Singer, 2008). There is a substantial body of research that has demonstrated the ability of rye to provide multiple ecosystem services; including mitigation of nutrient leaching (Logsdon et al., 2002; Kaspar et al., 2007), erosion control (Wendt and Burwell, 1985; Kaspar et al., 2001; Wilhelm et al., 2010) and weed suppression (Barnes et al., 1987; Liebman and Davis, 2000; Zotarelli et al., 2009). Rye also synthesizes an array of antifreeze proteins (Griffith and Xiao-Ming, 1999), giving it extraordinary cold-tolerance. In fact, rye is the most winter-hardy of all the small grains (Geiger and Miedaner, 2009), making it an ideal choice for overwintering in Iowa. There is also research supporting the plausibility of using cereal rye as a means to improve soil quality. Rye has been shown to increase several soil quality indicators including nitrogen mineralization (Malpassi et al., 2002), soil organic carbon (Wilhelm et al., 2010) and soil aggregation (Sainju et al., 2003; Jokela et al., 2009).

Enhancing Sustainable Soil Management with Rye Cover Crops

Farmers are faced with a number of challenges including demands to increase production to meet the needs of a growing population, adapting to an increasingly variable climate, and the rising costs of energy and inputs. These challenges can only be met through increasing on-farm sustainability, which includes the sustainable management of soil resources. Although a number of studies have demonstrated the ability of rye to perform ecosystem services, few have investigated how rye can be used to enhance soil quality in the corn-soybean cropping systems of the northern U.S Corn Belt. Rye cover crops have the potential to increase inputs of organic matter to soil by reducing fallow periods and extending the cropping sequence, and are one approach to improving soil quality.

Extending Soils and Agriculture beyond the Farm

The conversation thus far has been about how farmers' decisions affect soil quality and measures that can be taken by farmers to improve soil sustainability. However, farmers are not the only group whose decisions impact soil health and sustainability; the rest of society also plays an important role. Approximately 56% of Iowa's population is urban (USDA ERS, 2012), and this demographic distribution plays an important role in determining a person's exposure to agriculture in Iowa. Urban youth in particular are less likely to understand and have direct experiences with agriculture.

Gardens as an Education Tool for Urban Youth

Education is a powerful tool that can empower youth to learn more about how agriculture affects their everyday lives and be inspired to take an interest in how food is produced. Agricultural education for urban youth is a relevant issue because understanding agriculture is linked to understanding personal and environmental health (Trexler et al., 2000). Agricultural education can be enhanced through hands-on, or experiential, learning. One of the most common ways that agriculture is taught experientially is via school gardens (Brink and Yoast 2004). School gardens also provide ample opportunity for youth-initiated learning and inter-generational transfer of knowledge through prolonged youth contact with adult gardeners (Rahm, 2002). Additionally, school gardens have been shown to improve student test scores and behavior (Blair, 2009).

The Importance of Fostering Urban Youth's Connection to Food and Soil

Diet-related health epidemics are a critical problem in the U.S., especially amongst racial minority groups in urban populations. These segments of the population are disproportionately affected by type-2 diabetes, obesity, and hypertension; all of which are diet related and preventable (CDCP, 2007, 2009; USDHHS, 2011). Diet-related epidemics can be mitigated by teaching youth healthy food habits that will stay with them for life. Blair (2009) suggests that youth need to "broaden their perspective on what foods are edible and to re-personalize food" to combat diet related epidemics. Educational programs offer an effective means to broaden youth perspectives and provide a framework from which youth can begin to re-think issues pertaining to food choice and health. Knowledge about where food comes from, how food is grown, and how food production affects natural resources, such as soil, is needed in urban youth education. Providing urban youth with sustainable agriculture education will better prepare them to make conscious and informed decisions pertaining to food and the environment throughout their lives. The impacts of agriculture extend far beyond the farm, which is why it is important in Iowa, and elsewhere, to teach youth about the impacts that their choices play in personal and environmental health. This sentiment is echoed by the National Research Council (1988), which asserts that agriculture is "too important a topic to be taught to the relatively small percentage of students considering a career in agriculture".

Sustainable Soils, Sustainable Communities: A Collective Responsibility

Moving towards the long-term sustainability of soils in Iowa does not depend solely on the actions of farmers; the citizenry also plays an important role. People are more likely to support soil conservation measures and demand government conservation policies if they understand the role that healthy soils play in personal health and in creating sustainable communities. There are numerous actions that can empower farmers and the general public to move towards a more sustainable relationship with soil. The following chapters will highlight two approaches that can have a major impact; adding winter cover crops to corn and soybean cropping systems, and starting sustainable agriculture education programs for urban youth.

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CHAPTER 3. RYE COVER CROP EFFECTS ON SOIL PROPERTIES IN NO-TILL CORN SILAGE / SOYBEAN AGROECOSYSTEMS

A paper to be submitted to the Agronomy Journal

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Abstract

Farmers in the U.S. Corn Belt are showing increasing interest in winter cover crops. Known benefits of winter cover crops include reductions in nutrient leaching, erosion mitigation, and weed suppression, however little research has investigated the effects of winter cover crops on soil properties. Evidence of improvements in soil quality would provide further incentive for farmers to implement winter cover crops. This experiment investigated the effects of a rye (*Secale cereale* L.) winter cover crop on several soil quality indicators including particulate organic matter, potential nitrogen mineralization, and total soil organic matter. The objectives of this experiment were to determine whether a rye winter cover crop improves soil quality, if rye effects on soil quality vary depending on which crop it follows in the corn silage/soybean rotation sequence, and if the effects of a rye winter cover crop differ depending on soil depth. Soil properties were measured on four treatments and at two depths, 0-5cm and 5-10cm. Treatments included no rye winter cover crop (control), rye following soybean [*Glycine max* (L.) Merr.], rye following corn silage (*Zea mays* L.), and rye following both soybean and corn silage. All three of the soil quality indicators measured in this experiment responded positively to a rye cover crop. Data from this experiment suggests that

incorporation of a rye cover crop is a viable means for improving soil quality in corn silage/soybean rotations. The effects of the rye cover crop were most pronounced in the top 5cm of soil and when following corn silage.

Literature Review

Conventional corn/soybean cropping systems in the northern U.S Corn Belt are among the most productive in the world and contribute to making the U.S. the world's largest producer of corn and soybeans (USDA FAS, 2012). However the success of conventional corn/soybean cropping systems in this region has not come without costs. Agricultural land in this region has lost substantial amounts soil organic matter (SOM) over the past century (Paustian et al., 1997), resulting in a decline in overall soil quality. The continued degradation of soil quality will undoubtedly have negative long-term consequences on soil health and crop productivity. If corn/soybean cropping systems in the northern Corn Belt are to remain highly productive then action must be taken to reverse this trend in soil degradation and improve soil quality by increasing soil organic matter.

Soil quality is the physical, chemical, and biological properties of a soil that determine its suitability to support plant and animal growth (Larson and Pierce, 1991; Doran and Parkin, 1994). Soil quality can be assessed using soil quality indicators (Karlen et al., 2006), which include measurements such as potential nitrogen mineralization (POTMIN-N), total soil organic matter, particulate organic matter (POM), and bulk density. No uniform set of optimal soil quality indicators are used due to heterogeneity among environments and management goals (Karlen et al., 2006). Useful indicators for determining soil quality are often chosen based on processes that are most sensitive to changes in soil function (Karlen et al., 2006). The soil quality indicators chosen for this experiment were potential nitrogen mineralization, total soil organic matter, and particulate organic matter.

Soil organic matter is often considered the single most important factor contributing to overall soil quality (Larson and Pierce, 1991; Sikora et al., 1996). The influence of soil organic matter on overall soil quality stems from its effects on physical, chemical, and biological characteristics of soil (Doran and Parkin, 1994). One of the ways that soil organic matter and its associated microflora improve soil tilth is through enhancing soil aggregate formation (Tate, 1987). Soil aggregation serves to physically protect the organic matter within the aggregates from degradation, allowing the SOM within to serve as a slow release form of mineralized N, P, and S (Tate, 1987). Additionally, soil organic matter can hold up to 20 times its weight in water (Stevenson, 1994); significantly improving soil water holding capacity. The organic matter fraction also contains up to 99% of total nitrogen in soil (Sikora et al., 1996), serving as the primary source of mineralized N (Drinkwater et al., 1996). Lastly, the humic fraction of SOM serves to enhance soil cation exchange capacity (Magdoff, 1996).

Although the importance of organic matter to proper soil functioning is understood, quantifying changes in SOM is still challenging. A relatively large amount of background soil organic carbon (SOC) exists in northern Corn Belt soils, which makes it difficult to detect the relatively small changes in SOC due to management practices (Kaspar et al., 2006). Additionally, soil organic matter accumulation can be impacted by variable climatic conditions. Soil organic matter degradation is slower under cooler and drier conditions (Wilhelm et al., 2010), which retard microbial activity (Sikora et al., 1996). The measurement of soil organic carbon in agricultural fields is further complicated by spatial and temporal variability (Janzen et al., 2002). Soil organic matter also exists in both labile and recalcitrant pools, which vary substantially in their permanence in soil (Magdoff, 1992).

Nitrogen and carbon cycles are highly interdependent in soil ecosystems. Nitrogen cycling in soil is not possible in the absence of a functional carbon cycle, and vice versa (Tate, 1987). Soil microbes utilize the C in detritus to satisfy their energy needs, however, soil microbes, like all organisms, require more than energy; they also require nutrients to support physiological functions. The inorganic nutrient that has the most pronounced effect on the soil microbial community is nitrogen (Begon et al., 1996). Microbial biomass contains a relatively high percentage of N and has an average C/N ratio of approximately 8:1 (Myrold and Bottomly, 2008). Soil microbes will eventually release the N that they have incorporated through excretions, cell death, or when they are preyed upon by other soil organisms (Myrold and Bottomly, 2008). The biochemical composition of organic material entering the SOM pool influences the rate at which microbes are able to decompose it (Enriquez et al., 1993). Decomposition of low C/N residue will occur faster than decomposition of high C/N residue (Enriquez et al., 1993; Green et al., 1995). If residue with a high C/N ratio is added to the soil, then microbes will need to utilize N from their environment, effectively rendering the N unavailable for immediate plant uptake. If residue additions have a low C/N ratio, then microbes will be able to meet their N requirements from their food source and will not need to scavenge N from the environment.

Although microorganisms comprise less than 5% of total SOM (Myrold and Bottomly, 2008) they are indispensable to N cycling and are responsible for most of the mineralization of organic N compounds to inorganic N in soil (Tate, 1987; Drinkwater et al., 1996; Sikora et al., 1996). Nitrogen mineralization is critical for crop production because almost all of the N taken up by plant roots is in inorganic forms. Potential nitrogen mineralization (POTMIN-N) can be determined by measuring the change in inorganic N present in soil over time under optimal conditions for microbial activity (Drinkwater et al., 1996). Thus, potential nitrogen mineralization is a relative measure of the ability of the soil to supply N to plants and it is commonly used in soil quality assessments (Sainju et al., 2003; Liebig et al., 2004; Andraski and Bundy, 2008). Despite the utility of the procedure, several drawbacks limit its scope of inference. For example, a short-term aerobic incubation under optimal conditions, while useful for uniform and consistent handling of multiple samples, may not provide an accurate representation of N mineralization in the field under less than optimum conditions. Additionally, if soil samples are air-dried prior to re-hydration and measurement of POTMIN-N, then the soil microbe community that re-establishes itself after the soil rehydration may not be representative of the original microbial community (Drinkwater et al., 1996). Another problem is that sieving, drying, and mixing soil in preparation for this test can break apart soil aggregates and expose SOM to mineralization that would not occur if the soil were left undisturbed (Tate, 1987; Drinkwater et al., 1996). These factors work in concert to limit the scope of inference to laboratory conditions (Drinkwater et al., 1996). Despite the limitations, a short-term aerobic incubation to determine POTMIN-N remains a useful tool for comparing relative differences among management practices on the soil’s capacity to supply inorganic nitrogen.

Determination of soil organic matter is another useful soil quality indicator. The weight loss on ignition (WLOI) procedure can be used to measure SOM and involves burning a dry soil sample within a narrow temperature range for a pre-determined period of time to completely oxidize SOM and measure the resulting change in weight (Schulte and Hopkins, 1996). Soil samples are completely dried prior to WLOI to remove any water, which may otherwise be misinterpreted as SOM. Additionally, temperatures for the WLOI procedure must be high enough to ensure the complete oxidation of SOC, yet low enough (<500°C) to avoid the oxidation of inorganic C (Schulte and Hopkins, 1996). Studies conducted by Cambardella et al. (2001) and Kaspar et al. (2006) provide an overview on how WLOI is used to measure soil organic matter. Soil organic carbon comprises approximately 50% percent of SOM on average (Stevenson, 1994), however the percentage of SOC in SOM can vary widely (Cambardella et al., 2001; Wilhelm et al., 2010). Accurate estimates of soil organic carbon can be determined by weight loss on ignition of SOM if a calibration curve is developed based on a common set of samples using measurements of soil C determined using a method such as dry combustion (Kaspar et al., 2006).

Particulate organic matter also has properties that make it useful as a soil quality indicator. Particulate organic matter is defined as the organic fraction of soil less than 2mm and greater than 53 μm in size (Cambardella and Elliot, 1992) and is usually separated from soil by adding a chemical dispersant and shaking before passing the solution through a 53-μm sieve (Cambardella et al., 2001). The material retained on the sieve contains both POM and sand. Cambardella et al. (2001) assert that WLOI can be used to determine POM present in the sand-POM mixture and is a viable means to assess management-induced changes in

POM. In general, particulate organic matter is highly heterogeneous, containing both labile and recalcitrant elements, which range from root fragments to charcoal. Cambardella et al. (2001) describes the POM fraction as SOM, which is in the intermediate stages of transition between fresh plant residues and stable organic matter. Particulate organic matter is more sensitive to management-induced changes than total SOM (Cambardella and Elliot, 1992; Paustian et al., 1993; Bremer et al., 1994; Gregorich et al., 1995; Sikora et al., 1996; Liebig et al., 2004; Coulter et al., 2009), making POM a useful early indicator of long-term changes in SOM (Magdoff, 1996; Sikora et al., 1996). Particulate organic matter represents a substantial, yet variable, component of soil organic carbon. A study of Nebraska native grassland soils by Cambardella and Elliot (1992) discovered that as much as 39% of SOC is associated with the POM fraction. A study by Carter et al. (2003) on soils in eastern Canada found that POM in systems managed under continuous corn ranged from 18-29% of total SOC. The two previous studies suggest that positive changes in POM indicate improvement in soil quality.

Tillage influences soil quality and SOM in a number of ways including; disturbing microbial community dynamics, altering soil temperature, destroying soil aggregates, and increasing erosion. Excessive tillage can foster SOM decomposition by destroying physical barriers in soil that limit organic matter decomposition (Tate 1987). Accelerated organic matter oxidation and soil loss work in concert to reduce soil organic carbon stocks, leading to a decline in soil quality (Tate, 1987; Ismail et al., 1994; Triplett and Dick, 2008). Adopting a no-tillage system can reduce soil organic matter loss (Ismail et al., 1994; Triplett and Dick, 2008). Triplett and Dick (2008) define no-tillage as the practice of planting crops in undisturbed soil which retains at least 30% residue cover. As of 2008, no-till was practiced on approximately 24% of the total cropland in the United States, a dramatic rise from 5% of total U.S. cropland two decades earlier (CTIC, 2008). In general, research suggests that no-till enhances soil quality when compared to conventional tillage. In wheat cropping systems Cambardella and Elliot (1992) reported that POM levels in no-till soils were 50% higher compared to tilled soils. Beare et al. (1994) found that no-till increased POM and soil aggregation when compared to tillage. A 20-yr. tillage study conducted by Ismail et al. (1994) concluded that no-tillage can enhance cation exchange capacity and SOC in the top 5 cm of soil. No-till has also been identified as an effective means of reducing erosion and conserving soil water (Aase and Pikul, 1995; Liebig et al., 2004; Triplett and Dick, 2008).

No-till may also offer a means to sequester atmospheric carbon. Conservative estimates from a meta-analysis presented by West and Post (2002) suggests that transitioning to no-till from conventional tillage can sequester an average of 430 kg C ha^{-1} yr^{-1} over the first 10 years, after which SOC may approach a new equilibrium. A study of silt loams in Saskatchewan by Campbell et al. (1999) found that transitioning to no-till increased soil C storage in the top 15cm of soil by an average of 25 kg C ha^{-1} yr^{-1}. It is important to note that the C sequestration capacity of transitioning to no-till is a contentious issue in the scientific literature. Baker et al. (2007) suggests that most experiments examining the accrual of SOC as a result of adopting conservation tillage have biased sampling protocols because soil sampling was restricted to a depth of 30 cm or less. This bias in sampling fails to take into account the relatively higher concentrations of SOC that are present in deeper soil layers managed under conventional tillage. Baker et al. (2007), however, admit that the standard error of SOC measurements is usually so large that it is difficult to measure either positive or negative responses of SOC to tillage. A study conducted by Liebig et al. (2004) in the northern Great Plains suggests that management effects, including tillage, are mostly limited to the top 7.5 cm of the soil surface, reinforcing the Baker et al. (2007) claim that sampling too shallow can bias data.

No-tillage can have negative consequences on crop productivity as well. Surface residues can harbor pests, including insects and pathogens, which can make pest control more difficult on land managed under no-till (Triplett and Dick, 2008). Andraski and Bundy (2008) found that residue cover lowered soil temperatures early in the southern Wisconsin growing season, which led to decreased early season soil N mineralization. Nutrient stratification can also cause crop productivity issues under no-tillage. Phosphorous, due to its relative water insolubility, can become stratified in the upper layers of soil, leading to P deficiencies in the rhizosphere (Triplett and Dick, 2008).

Benefits of no-till to SOC accumulation are largely derived from slowing SOC loss. Another strategy for increasing SOC is to increase the input of biomass C to the soil. Adding greater biomass C can be accomplished through the implementation of cover crops. Cover crops are plants grown during the fallow period between main crops. Cover crops comprise a broad range of plant species, which perform a wide range of ecosystem services including erosion mitigation (Kaspar et al., 2001; Wilhelm et al., 2010), nitrogen fixation (Reicosky and Forcella, 1998), nutrient scavenging (Kaspar et al., 2007), weed suppression (Liebman and Davis, 2000), and beneficial insect habitat (Tillman et al., 2004). Despite the functional diversity that exists among cover crops, they have at least one thing in common: they all add an additional crop to the rotation sequence, resulting in greater annual biomass production and an increase in the amount of C deposited into the soil organic matter pool. Wilhelm et al. (2010) used modeling to predict that adding cover crops to a cropping system where some of the corn stover is removed would help maintain soil C by increasing total biomass production. Similarly, Wienhold et al. (2006) asserted that a reduction in fallow periods coupled with an extended crop rotation sequence, both of which can be accomplished with cover crops, can enhance soil quality. Karlen et al. (2006) determined that an extended crop rotation sequence increased total organic carbon. Cover crops can also be used to enhance the labile SOM pool. A study conducted by Faé et al. (2009) in Ohio found that intermediately labile organic matter was increased as a result of implementing winter cover crops. The same study found that particulate organic carbon responds rapidly to changes in management (Faé et al., 2009).

Despite the benefits conferred by cover crops, they have also been shown to negatively impact crop productivity under certain circumstances. Allelopathy has been observed in some cover crops, particularly among the *Poaceae*, or grass family (Sanchez-Moreiras and Reigosa-Roger, 2003). Allelopathy is the term given to plant chemical interactions that influence the growth and development of other plants (Barnes et al., 1987). Rye produces phytotoxic chemicals that have been shown to inhibit root growth in other plants by as much as 50% (Barnes et al., 1987). Rye shoot residue has been shown to contain twice as much allelochemical as rye root residue (Barnes et al., 1987). In no-till systems, rye shoot residue is concentrated near the seed germination zone, where it may have a greater impact on seedling growth (Barnes et al., 1987). Allelochemicals, however, are generally short-lived in soils. Dabney et al. (1996) found that legume allelochemical potency declined dramatically within three weeks of the legume kill date. Some research suggests that cover crops reduce main crop yields. Johnson et al. (1998) found that a rye cover crop reduced corn grain yield by as much as 1.6 Mg ha^{-1} when compared to a no cover crop treatment. The authors posit that the yield decline may have been due to reduced soil temperatures, less nutrient availability, or negative allelopathic interactions. Alternately, a meta-analysis performed by Miguez and Bollero (2005) found that although some experiments show a yield decrease in corn following a grass cover crop, there is on average a neutral corn yield response to grass cover crops. Faé et al. (2009) found that winter cover crops can be added to corn silage systems as a forage supplement without negative effects on corn silage productivity. Additionally, research by Singer et al. (2008) found that corn grain yield was unaffected by a rye cover crop. Although cover crops can harm main crop yields under certain circumstances, the benefits of implementing cover crops outweigh the negative impacts through providing multiple ecosystem services. Proper management and selection of cover crops is usually sufficient to prevent problems associated with yield decline.

Although the benefits of cover crops are understood, the lack of short-term economic benefit to farmers has hindered widespread adoption of this practice (Singer et al., 2007; Faé et al., 2009). Other factors such as time required to manage cover crops, costs associated with cover crops, and lack of knowledge about cover crops also hinder widespread adoption (Singer et al., 2007). A survey conducted by Singer (2008) found that only 11% of Corn Belt farmers planted winter cover crops between the years 2001 to 2005. Given the fact that crop nutrient supplements typically account for a significant percentage of crop production budgets, research demonstrating the potential of winter cover crops to enhance soil quality and increase the supply of plant nutrients may increase the adoption of cover crops in the northern Corn Belt.

Cereal rye was the most planted cover crop in Illinois and Iowa in the period between 2001 and 2005 (Singer, 2008). A substantial body of research has demonstrated the ability of rye to provide multiple ecosystem services; including mitigation of nutrient leaching (Logsdon et al., 2002; Kaspar et al., 2007), erosion control (Wendt and Burwell, 1985; Kaspar et al., 2001; Wilhelm et al., 2010) and weed suppression (Barnes et al., 1987; Liebman and Davis, 2000; Zotarelli et al., 2009). Rye is an effective scavenger of residual inorganic N that could otherwise be lost from the rhizosphere (Kaspar et al., 2007; Zotarelli et al., 2009). Research conducted by Kaspar et al. (2007) has demonstrated rye's ability to reduce nitrate concentrations in water by as much as 59% when compared to a no rye control. Nitrate leaching is a major water quality concern in the northern Corn Belt (Kaspar et al., 2007) and in large estuarine areas that receive water flow from this region. Hypoxic areas, also known as "dead zones", in the Gulf of Mexico are largely the result of leached nitrate from the Corn Belt (Rabalais et al., 1996). Nitrate concentrations exceeding 10 mg L^{-1} in drinking water pose a direct risk to human health and are known to cause methemoglobinemia, also known as blue baby syndrome (USEPA, 2012).

Cereal rye has also been shown to be effective at reducing soil erosion. Kaspar et al. (2001) found that rye following soybean reduced soil loss by 20 to 27 kg ha^{-1} when compared to no cover crop in no-till managed systems. Additionally, rye produces allelopathic phytochemicals, which inhibit weed growth (Barnes et al., 1987) and effectively outcompetes weeds for nutrients, water, and light (Liebman and Davis, 2000). Rye also synthesizes an array of antifreeze proteins (Griffith and Xiao-Ming, 1999), giving it extraordinary cold-tolerance. In fact, rye is the most winter-hardy of all the small grains (Geiger and Miedaner, 2009), making it an ideal choice for overwintering in the northern Corn Belt.

There is also research that supports the plausibility of using cereal rye as a means to improve soil quality. A study by Malpassi et al. (2002) investigating rye root decomposition suggests that rye plants were responsible for an increase in net N mineralization. The increase in N mineralization may have been due to increased microbial activity resulting from rye root exudates (Parkin et al., 2002). Villamil et al. (2006) found that winter cover crop sequences that included rye had lower bulk density and penetration resistance. A study conducted by Sequeira and Alley (2011) also found that rye cover crops positively influence light organic matter fractions. Rye adds a large amount of residue to the soil, which increases soil organic carbon (Wilhelm et al., 2010). Research by Jokela et al. (2009) suggests that rye may improve soil quality by increasing soil aggregation. Sainju et al. (2003) drew the same conclusion, particularly for aggregate formation in intermediate and small size classes.

In contrast to management practices that increase inputs of organic matter to the soil, harvesting corn for silage or energy biomass can have profound negative consequences on soil quality. Silage production is one the most soil resource intensive cropping systems in practice due to the drastic reduction in biomass and nutrients being returned to the soil (Jokela et al., 2009). Stalk removal during corn silage harvest can remove as much as twice the N, three times the amount of P, and 10 times the amount of K compared to corn harvested only for grain (Wheaton et al., 1993). Silage harvest greatly reduces the amount of soil residue cover, leaving soil more vulnerable to erosion (Wilhelm et al., 2010). Wendt and Burwell (1985) found that a combination of winter cover crops and no-till could significantly reduce erosion in corn silage systems. Silage harvesting also has negative impacts on soil by reducing the input of shoot residues, which results in a net loss of carbon (Wilhelm et al., 2010). Thus, this negative impact may be partly mitigated by promoting management practices, like cover crops, that increase organic matter inputs (Wilhelm et al., 2010).

Farmers are faced with a number of challenges including demands to increase production in an increasingly variable climate with the rising costs of energy and inputs. These challenges can only be met through increasing on-farm sustainability, which includes enhancing soil quality. Although a number of studies have supported the benefits of cover crops, few have investigated how cover crops can be used to enhance soil quality in a corn-soybean rotation in the northern U.S Corn Belt. A rye winter cover crop has the potential to increase inputs of organic matter to soil in this rotation and is one approach to improving overall soil quality. Measuring changes in soil organic matter, however, is often difficult in the high organic matter soils of the northern Corn Belt. We hypothesized that it would be easier to measure the positive benefits of a rye winter cover crop after nine years of a corn silage-soybean rotation because of the reduced main crop residue inputs and the greater growth of rye cover crop following corn silage. Therefore, the objectives of this experiment were to measure three indicators of soil quality; particulate organic matter, total soil organic matter, and potential nitrogen mineralization, in a no-till corn silage/soybean rotation managed with and without a rye cover crop. The results of this experiment will provide farmers with information on the extent to which rye cover crops can improve soil quality and whether the effects of rye vary depending on which crop it follows in the corn/soybean rotation.

Materials and Methods

This experiment was conducted at Iowa State University's Boyd Farm, located in Boone County, IA (42° 00' 26" N; -93° 47' 31" W) in 2009-2011. The two adjacent fields used in this experiment were established in 2001 and represent a combined area of approximately two hectares. The fields have a 2% slope with two predominant soil series: Clarion loam and Nicollet clay loam (Andrews and Diderikson, 1981). The Clarion loam series is fine-loamy, mixed, supreactive, mesic Typic Hapludolls, and the Nicollet clay loam series is fine-loamy, mixed, supreactive, mesic Aquic Hapludolls. The experiment site is located on the Des Moines Lobe, an area characterized by low slope (0-3%) and a relatively young (< 14,000 yr.) landscape (Prior, 1991).

A corn silage/soybean rotation was established in 2001 and the corn silage and soybean phases of the rotation were grown alternately in the two adjacent fields. As a result, the main crop preceding soil sampling each year, that is the previous crop, depended on the year and the field being sampled. For each of the two fields individually the two factors, previous crop and year, are synonymous, but for the combined analysis across fields and years the effect of previous crop was of more interest. The experimental layout for each field was a randomized complete block design with six treatments randomly assigned to the five blocks in each field. Only four of the six treatments were examined in this study. The four cropping system treatments compared in this experiment: (1) rye cover crop after corn silage:

soybean with no rye; (2) rye after both corn silage and soybean; (3) corn silage and soybean with no rye (control); (4) rye after soybean: corn silage with no rye. Each plot was 54.9 m long and 3.8 m wide and consisted of five rows spaced 0.76 m apart. Dates for winter cover crop planting and termination are listed in Table 3.1.

The site was managed with no-tillage. Weeds were suppressed using pre-emergence herbicides in corn and glyphosate [N-(phosphonomethyl) glycine] in soybean. A glyphosate-resistant cultivar of soybean (Pioneer 92M11) and a modern corn hybrid (Pioneer 36V75) were used throughout this experiment. Both corn and soybeans were planted with a five-row, 0.76 m row width no-till planter. Soybeans were planted at 395,000 seeds ha^{-1} in mid-May (Table 3.1). Corn was planted at 79,000 seeds ha^{-1} in late Apr. to early May (Table 3.1). Nitrogen fertilizer was applied before corn at a rate of 208 kg N ha^{-1} as sidedress applications at planting and in late May. Phosphorus and potassium fertilizer were applied as a subsurface band at rates of 117 kg P ha^{-1} and 74 kg K ha^{-1} in the fall before corn silage years as indicated by soil tests and corn silage nutrient removal rates.

A winter hardy variety of cereal rye (cv. Rymin) was used for the rye winter cover crop treatments. Rye was seeded using a no-till grain drill following soybean harvest in late Sept. to mid Oct. (Table 3.1) at a rate of 3.0×10^6 seeds ha^{-1}. Rye was drilled at the same seeding rate following corn silage harvest in late Aug. to mid Sept. (Table 3.1). Rye was drilled in the crop inter-row in three rows spaced 0.19 m apart, leaving the old crop row in the center of an unplanted 0.19 m gap. The main crop was planted into this gap the following spring. Rye was killed with glyphosate [*N*-(phosphonomethyl) glycine] applied at 1.12 kg of active ingredient ha^{-1} 4-21 days prior to planting the main crop (Table 3.1). The variable field conditions that are common to central Iowa during spring were responsible for the wide termination interval.

Average monthly air temperatures and precipitation were calculated using information collected at the Iowa State University research farm located approximately 2 km from experiment field site and is listed in Table 3.2 (Iowa Environ. Mesonet, 2012).

Soil Sampling and Analysis

Soil sampling took place on 9 June 2010 and 13 June 2011. All soil samples were taken from un-trafficked inter-rows at five separate locations starting 9.14 m from the end of each plot and then sampling every 9.14 m. Three soil cores were taken at each of the five locations within the plot. Three soil cores were taken at each location within a plot; one in the center rye row and the other two at evenly spaced distances relative to the center of the rye cover crop inter-row. A total of 15 soil cores were taken per plot at a depth of greater than 10 cm using a 32-mm diameter soil probe. After each sample extraction, soil cores were immediately measured and divided into 0-5 cm and 5-10 cm depth samples. The samples taken in each plot were combined based on depth; yielding two plastic storage bags of soil per plot.

After the samples were collected, they were transported to the laboratory in insulated coolers and then refrigerated at 4°C until processing. When removed from refrigerated storage, the bags were weighed and the soil was pushed through sieves with 8mm and 4mm openings and mixed. A subsample of approximately 100 g was then taken and oven-dried at 105º C for 48 hr to determine soil water content. Soil water content, along with the original soil weights and volumes of the soil samples were then used to calculate bulk density. Bulk density data was expressed as g soil cm^{-3}. Two approximately 50-g subsamples of the oven-dried soil were later analyzed for weight loss-on-ignition by weighing samples before and after burning in a programmable muffle furnace (Fisher-Scientific Isotemp® 650-126) at 460º C for 16 hr. Weight loss-on-ignition was considered to be the ash-free change in weight during burning per 50 g of air-dry soil. Data will be expressed as change in g SOM g dry $soil^{-1}$. The remainder of the original soil sample was partially air-dried and then pushed through a 2mm mesh sieve. Samples were then completely air-dried and returned to refrigerated storage until analysis for potential nitrogen mineralization and particulate organic matter.

The POM fraction was isolated by adding 240 ml of 5 g L^{-1} sodium hexametaphosphate to two 80-g soil sub-samples, shaking for no less than 18 hr., and then wet sieving the soil slurry through a 53-μm sieve (Cambardella and Elliot, 1992; Cambardella et al., 2001). Sand particles and POM remaining on the sieve were oven-dried at 105º C for 48 hr., weighed, burned in a muffle furnace at 460°C for 16 hr., and weighed again in a manner consistent with the aforementioned WLOI procedure. Particulate organic matter was considered to be the ash-free change in weight during burning per 80 g of air-dry soil. Data will be expressed as g POM g dry $soil^{-1}$.

Potential nitrogen mineralization was determined by re-hydrating two 40 g sub-samples of air-dried soil with 14.95 g of water, which was calculated to provide 60% water-filled pore space, and aerobically incubating at 30º C for 28 days, which is similar to the procedure described by Drinkwater et al. (1996). After incubation, 200 ml of 2 M potassium chloride solution was added to each sub-sample. Afterwards, sub-samples were shaken for 30 minutes and filtered using ashless 185 mm filter paper. The filtered solution was then frozen until analysis. After thawing the filtrate was immediately analyzed for nitrate (NO_3 +NO_2) and ammonia using a colorimetric method (Keeney and Nelson, 1982) and flow injection technology (Zellweger Analytics, Lachat Instrument Division, Milwaukee, WI). Data will be expressed as mg N kg soil^{-1}.

Statistical Analysis

Data sets for individual combinations of field, previous crop, and depth initially were analyzed separately for block and treatment effects as a randomized complete block design using the PROC GLM procedure. The two subsamples from each plot for each measurement and sampling year (previous crop) were averaged before any statistical analyses. For the combined analysis, data from both fields and previous crops were combined, but depths were kept separate. Because soil samples were taken early in the growing season, it was assumed that effect of the previous crop was more important than the current crop and that any year effects would be confounded by the previous crop. Therefore, the combined year and previous crop effect will be referred to as previous crop. Additionally, because soil samples were taken at the same locations in each plot in both years, the previous crop effect is treated as a repeated measure. For the combined analysis the experiment could be considered a split plot treatment structure arranged in a completely randomized complete block design combined over fields (McIntosh, 1983). The cover crop treatments were the main-plot factors and previous crop was the repeated-measure split-plot factor. The combined data were analyzed as a mixed model ANOVA with repeated measures using PROC MIXED. When the analysis of variance indicated significant effects at the 0.05 probability level, the LSD test at the 0.05 probability level was used to compare treatment means.

Results and Discussion

Weather

Average monthly air temperatures and total monthly precipitation for 2009-2011 are shown in Table 3.2. Weather data for 2009 are included because the rye winter cover crop treatments that were sampled in summer 2010 were planted in fall 2009. Air temperatures during the fall 2009 cover crop establishment season varied from the 60-yr average, with temperatures 3.6°C cooler in October and 3.8°C warmer in November. Total precipitation in 2009 was 89 mm higher than the 60-yr average, however it is worth noting that the cover crop establishment season varied from the average with September being drier than normal (58 mm below average) and October being wetter than normal (124 mm above average). Average air temperatures in 2010 did not show much variation from the 60-yr average; however total precipitation was significantly higher than normal. Total precipitation for 2010 was 431 mm higher than the long-term average, with precipitation from June-August being 68-174 mm higher than average for each month during that period. Average air temperatures in 2011 did not show much variation from the long-term average with the exception of a cooler than average (-3.3°C) December. Total precipitation in 2011 was 30 mm lower than the 60-yr average, with the period between July-October being 30-39 mm less than average.

Rye Cover Crop Shoot Biomass

Over the course of the experiment rye biomass was consistently lower when following soybean compared with following corn silage. Average rye shoot biomass following soybean was similar to rye biomass yield data presented by Johnson et al. (1998), who reported an average rye biomass of 0.41 Mg ha^{-1}. Approximately 5 times more rye shoot growth was present when rye followed corn silage compared to rye following soybean. This difference is most likely attributable to an extended rye growing season when following silage. Silage was harvested earlier than soybean, giving the rye following corn silage an extra 14-41 days of growth when compared with rye following soybean (Table 3.1).

Corn Silage and Soybean Yields

Corn silage and soybean grain yields are shown in Table 3.4. Corn silage is reported as dry weight of silage and soybean is reported as grain yield at 130 g kg^{-1} water content. Soybean yields were slightly higher when soybean was preceded by a rye cover crop in 2009 and 2010, and were not different in 2011. Corn silage yields were numerically higher for the treatment that had a rye cover crop following both corn silage and soybean; however this was not a statistically significant difference. The lower yields in 2010 for both main crops may be attributable to abnormally wet conditions during summer 2010 (Table 3.2). Although there is some concern that rye reduces corn productivity (Johnson et al., 1998), our yield data indicate that rye did not reduce corn silage yield. Miguez and Bollero (2005) drew the same conclusion and found that there is a neutral corn grain yield response to grass cover crops. Faé et al. (2009) also drew the same conclusion after they determined that a rye cover crop can be added to corn silage systems without negative effects to silage productivity.

Bulk Density

Bulk density showed no significant differences among cover crop treatments in the 0-5cm or 5-10cm depths, and the only significant effect was for previous crop for the 5-10 cm soil layer (Table 3.5). Bulk density means are shown in Tables 3.6 and 3.7 and were on average 1.26 and 1.45 g cm^{-3} for the 0-5 and 5-10 cm layers, respectively. Calculations of equivalent soil mass help eliminate bias derived from comparing management practices that have different bulk densities (Ellert and Bettany, 1995). Cambardella et al. (2001) recommended measuring bulk density in order to calculate SOM on a volumetric basis, which allows for comparisons of SOM across management systems. In our experiment the cover crop treatments did not affect bulk density; therefore, values for SOM and POM were calculated on a concentration basis instead of an area or volumetric basis.

Total Soil Organic Matter

Total soil organic matter was significantly higher in the ‘rye following silage’ and the ‘rye following both main crops’ treatments than in the ‘no cover crop’ and ‘rye following soybean’ treatments at the 0-5cm soil depth (Tables 3.5 and 3.8). In fact, the average SOM weight loss was 15% greater in the ‘rye following both main crops’ treatment than the ‘no cover crop’ treatment at the 0-5 cm soil depth. Total SOM in the ‘rye following both main crops’ treatment was also higher in the 5-10 cm soil depth (Table 3.9), suggesting that rye’s effect on total SOM has begun to move deeper into the soil profile. There was also a previous crop effect for both depth layers. Data indicate that total SOM was significantly higher when the previous crop was soybean. For the most part, this was probably because all of the soybean stover was returned to the soil surface, whereas nearly all the corn stover was removed during silage harvest. There was a significant field x previous crop interaction for both depth layers. In Field 42 SOM was greater when soybean was the previous crop and in Field 44 SOM was greater or equal when corn was the previous crop. Year determined which main crop was planted in each field, and because main crops alternated between fields from year to year, previous crop effects were confounded with year. We suspect that the field x previous crop interaction was largely due to higher main crop yields, and most likely, greater shoot and root growth in 2009 compared to 2010 (Table 3.4). Measuring changes in SOM resulting from the implementation of cover crops, however, can be difficult. Jokela et al. (2009) were not able to detect a cover crop induced change to total SOM; even though they were able to detect a change in POM. Kaspar et al. (2006) were also unable to detect a change to soil organic carbon resulting from the addition of a rye cover crop. The probable reason that our experiment has been able to detect changes in total SOM is the length of time our treatments have been in place, which was 10 years in 2011. While we were able to detect relative differences in total SOM between treatments, our experiment was not designed to quantify changes in net SOM over time. Thus, adding a rye cover crop to a no-till corn silage/soybean cropping system may or may not have increased net SOM, but at a minimum the rye cover crop mitigated the loss of SOM compared to the treatment without a rye cover crop.

Particulate Organic Matter

Particulate organic matter was significantly higher in the ‘rye following silage’ and the ‘rye following both main crops’ treatments compared to the ‘no cover crop’ and ‘rye following soybean’ treatments at the 0-5 cm soil depth (Tables 3.5 and 3.10). Particulate organic matter averaged over both years was 44% greater in the ‘rye following both main crops’ treatment than the ‘no cover crop’ treatment. Both Jokela et al. (2009) and Sequeira and Alley (2011) also observed greater POM in a corn silage system with cover crops. A significant field x previous crop interaction was also measured for the 0-5 cm depth and this was identical to the significant interaction observed for SOM. There was no significant difference among treatments at the 5-10 cm depth (Table 3.11), although the probability of a greater F value from the ANOVA came close to being significant ($Pr > F = 0.07$; Table 3.5). Although previous research asserts that POM is more sensitive to management-induced changes than total SOM (Cambardella and Elliot, 1992), our experiment was not able to discern a treatment effect in POM at the 5-10 cm depth, despite the fact that we were able discern a treatment effect in SOM at the 5-10 cm depth. Our experiment used the weight loss-on-ignition technique to measure both SOM and POM. The POM measurement, however, had the additional steps of soil dispersal and sieving, both of which could have added some additional variability to the measurement, which may explain why we detected a treatment effect at the 5-10 cm depth for SOM but not POM. In general, greater POM in treatments with a rye cover crop may indicate that even greater differences in total SOM between treatments with and without cover crops may occur over time (Cambardella and Elliot 1992; Sikora et al., 1996).

Potential Nitrogen Mineralization

Potential nitrogen mineralization was significantly higher in the ‘rye following silage’ and the ‘rye following both main crops’ treatments compared to the ‘no cover crop’ and ‘rye following soybean’ treatments at the 0-5cm soil depth (Tables 3.5 and 3.12), however there was no significant difference among treatments at the 5-10cm depth (Table 3.13). Data from the 0-5cm soil layer show that N mineralization was 38% less in the 'no cover crop' treatment than in the 'rye following both main crops' treatment. There were also significant previous crop effects for both depth layers, with POTMIN-N being higher when the previous crop was soybean. The previous crop effect was likely due in part to differences in mineralization rates between corn and soybean stover, and the amount of stover added to the surface. The interaction effect of field x previous crop was also significant at the 0-5cm depth layer, as it was for SOM and POM. Similarly, the significant interaction may have been caused by the differences observed between 2009 and 2010 main crop yields (Table 3.4). Research by Biederbeck et al. (1994) suggests there is a positive correlation between POM and POTMIN-N. While our experiment did not investigate this correlation, our data did show a similar treatment effect pattern for both POM and POTMIN-N at both depth layers. The greater POTMIN-N observed when the main crops were followed by a rye cover crop could mean the potential for greater long-term N availability (Drinkwater et al., 1996) in cropping systems that have a rye cover crop, which could reduce the need for synthetic N fertilizers.

Summary

Adding a rye winter cover crop to no-till corn silage/soybean cropping systems can improve or maintain soil quality. Our data show that rye cover crops had higher total soil organic matter, particulate organic matter, and nitrogen mineralization relative to the treatment without cover crops, resulting in overall better soil quality. All of the soil quality indicators measured in this experiment responded positively when a rye cover crop was present following both main crops. Each of the soil quality indicators also responded positively when rye followed corn silage, which is most likely the result of the rye having an extra 2-4 weeks of growth in the fall when compared to the rye following soybean treatment. Our data also indicate that the effects of a rye cover crop are most pronounced in the uppermost layer of the soil profile. Although our experiment has demonstrated the ability of a rye cover crop to improve or maintain soil quality, it is worth noting that this improvement is not immediate and may take several years before the benefits to soil quality begin to show. This time lag should not, however, deter farmers from adopting a rye cover crop since rye performs a number of other valuable ecosystems services including; reductions in nutrient leaching, erosion control, and weed suppression, without harming main crop productivity. Some additional obstacles may hinder the adoption of rye cover crops, including knowledge about successfully managing cover crops, and costs associated with cover crops, however these obstacles are likely to diminish over time as rye cover crops gain more widespread use in the Corn Belt.

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Table 3.1: Management dates.

	Field 42			Field 44		
	2009	2010	2011	2009	2010	2011
Main Crop	Soybean	Corn	Soybean	Corn	Soybean	Corn
Main Crop Planting date	12-May	28-Apr	19-May	5-May	19-May	4-May
Main Crop Harvest date	30-Sept	24-Aug	7-Oct	16-Sept	4-Oct	31-Aug
Rye Cover Crop Planting date	1-Oct	25-Aug	7-Oct	17-Sept	5-Oct	1-Sept
Rye Cover Crop Kill date	8-May	19-Apr	6-May	22-Apr	28-Apr	25-Apr

Table 3.2: Average monthly air temperature and total precipitation 2009-2011.

Month	Average Air Temperature (ºC)				Total Precipitation (mm)			
	2009	2010	2011	1951-2011 Avg.	2009	2010	2011	1951-2011 Avg.
Jan.	-10.0	-10.0	-8.9	-7.4	25	28	18	19
Feb.	-2.2	-8.9	-4.4	-4.2	7	19	33	22
Mar.	3.3	3.3	2.8	2.1	103	55	20	53
Apr.	8.9	13.3	8.9	10.0	116	93	101	90
May	15.6	16.7	15.6	16.2	102	92	142	115
June	21.1	22.2	21.1	21.3	104	284	160	128
July	20.6	23.9	25.6	23.3	70	173	75	105
Aug.	21.1	24.4	22.2	22.0	123	285	76	111
Sep.	17.8	18.9	15.6	17.8	24	167	43	82
Oct.	7.8	13.3	12.2	11.4	186	12	25	62
Nov.	6.7	3.3	4.4	2.9	34	60	78	43
Dec.	-6.7	-6.7	-1.1	-4.4	50	18	54	26
Jan.-Dec.†	8.9	9.4	9.4	9.3	945	1287	826	856

† Values for the Jan. through Dec. periods are averages for the period for air temperature and totals for the period for precipitation.

Table 3.3: Rye cover crop dry weight for the corn silage-soybean rotation over two years and two adjacent fields.

Field (F)		Field 42			Field 44			Avg. of Both Fields		
Previous Crop (P)[1]		Corn	Soybean	Avg.	Corn	Soybean	Avg.	Corn	Soybean	Avg.
		-- Mg ha^{-1} --								
Treatment (T)[2]										
	1	3.40	-----	3.40	1.99	-----	1.99	2.69	-----	2.69
	2	3.23	0.69	1.96	2.50	0.21	1.35	2.86	0.45	1.66
	3	-----	-----	-----	-----	-----	-----	-----	-----	-----
	4		0.87	0.87	-----	0.28	0.28	-----	0.57	0.57
F * P Avg.		3.31	0.78		2.24	0.25				
F Avg.				2.08			1.21			
P Avg.								2.78	0.51	

[1] Previous crop refers to main crop that was present in a field the year before soil samples were taken. This effect is confounded with years because main crops were rotated between the two fields. Field 42 had soybean in 2009 and corn silage in 2010. Field 44 had corn silage in 2009 and soybean in 2010.

[2] There were four cover crop treatments: 1 = rye cover following corn silage and no cover crop following soybean; 2 = rye cover crop following both corn silage and soybean; 3 = no cover crop; 4 = rye cover following soybean and no cover crop following corn silage.

Table 3.4: Corn silage and soybean yields for treatments with a rye cover crop in a corn silage-soybean rotation over three years and two adjacent fields. Corn silage is reported as dry weight of silage and soybean is reported as grain yield at 130 g kg-1 water content.

Field		Field 42		Field 44	
Main Crop[1]		Corn	Soybean	Corn	Soybean
		Mg ha^{-1}			
Treatment[2]	Year				
	2009				
1		-----	4.00 a[3]	19.21 a	-----
2		-----	3.95 ab	19.60 a	-----
3		-----	3.90 ab	19.21 a	-----
4		-----	3.77 b	19.61 a	-----
Avg.		-----	3.91	19.40	-----
	2010				
1		16.72 b	-----	-----	2.92 ab
2		19.58 a	-----	-----	2.99 a
3		18.57 ab	-----	-----	2.66 b
4		17.26 ab	-----	-----	2.81 ab
Avg.		18.03	-----	-----	2.84
	2011				
1		-----	3.51 a	18.21 b	-----
2		-----	3.51 a	19.30 a	-----
3		-----	3.41 a	18.87 ab	-----
4		-----	3.29 a	18.50 ab	-----
Avg.		-----	3.43	18.72	-----

[1] Main crop that was present in a field in the year indicated. Main crops were rotated between the two fields: Field 42 had soybean in 2009, corn silage in 2010, and soybean in 2011; Field 44 had corn silage in 2009, soybean in 2010, and corn silage in 2011.

[2] There were four cover crop treatments: 1 = rye cover following corn silage and no cover crop following soybean; 2 = rye cover crop following both corn silage and soybean; 3 = no cover crop; 4 = rye cover following soybean and no cover crop following corn silage.

[3] Numbers within a column and year followed by the same lowercase letter are not significantly different as indicated by LSD test at the 0.05 probability level.

Table 3.5: Probabilities of a greater F value for main effects and interactions from the analysis of variance for bulk density, total soil organic matter, particulate organic matter, and potential N mineralization for the 0-5 and 5-10 cm soil layers.

Soil Layer		0 - 5 cm soil layer				5-10 cm soil layer			
Measurement		Bulk Density	Total Soil Organic Matter	Particulate Organic Matter	Potential N Mineraliza-tion	Bulk Density	Total Soil Organic Matter	Particulate Organic Matter	Potential N Mineraliza-tion
ANOVA Effect	df	----------	----------	----------	Pr > F	----------	----------	----------	----------
Field (F)	1	0.2566	0.2260	0.9601	0.2350	0.3119	0.3904	0.1051	0.3276
Treatment (T)	3	0.3031	0.0001 **	0.0001 **	0.0001 **	0.4537	0.0435 *	0.0681	0.1414
T×F	3	0.5145	0.3878	0.7425	0.7051	0.1800	0.6139	0.2204	0.0613
Previous Crop (P)	1	0.1782	0.0445 *	0.9492	0.0082 **	0.0394 *	0.0001 **	0.5710	0.0538 *
F×P	1	0.8138	0.0001 **	0.0015 **	0.0009 **	0.2804	0.0001 **	0.9338	0.3861
T×P	3	0.0947	0.0875	0.1071	0.0249 *	0.7190	0.1906	0.3800	0.7224
T×F×P	3	0.6965	0.1638	0.3304	0.2897	0.1493	0.5532	0.3777	0.5673

*, ** Indicates the probabilities of a greater F are less than the 0.05 and 0.01 significance levels, respectively.

Table 3.6: Bulk density for the 0-5 cm depth layer for treatments with and without a rye cover crop in a corn silage-soybean rotation over two years.

Field (F)		Field 42			Field 44			Avg. of Both Fields		
Previous Crop (P)[1]		Corn	Soybean	Avg.	Corn	Soybean	Avg.	Corn	Soybean	Avg.
		g soil cm^{-3}								
Treatment (T)[2]										
	1	1.22	1.26	1.24	1.27	1.25	1.26	1.25	1.25	1.25
	2	1.30	1.20	1.25	1.21	1.19	1.20	1.25	1.19	1.22
	3	1.31	1.35	1.33	1.22	1.26	1.24	1.27	1.31	1.29
	4	1.32	1.23	1.28	1.33	1.18	1.25	1.32	1.21	1.27
F * P Avg.		1.29	1.26		1.26	1.22				
F Avg.				1.27			1.24			
P Avg.								1.27	1.24	

[1] Previous crop refers to main crop that was present in a field the year before soil samples were taken. This effect is confounded with years because main crops were rotated between the two fields. Field 42 had soybean in 2009 and corn silage in 2010. Field 44 had corn silage in 2009 and soybean in 2010.

[2] There were four cover crop treatments: 1 = rye cover following corn silage and no cover crop following soybean; 2 = rye cover crop following both corn silage and soybean; 3 = no cover crop; 4 = rye cover following soybean and no cover crop following corn silage.

Table 3.7: Bulk density for the 5-10 cm depth layer for treatments with and without a rye cover crop in a corn silage-soybean rotation over two years.

Field (F)		Field 42			Field 44			Avg. of Both Fields		
Previous Crop (P)[1]		Corn	Soybean	Avg.	Corn	Soybean	Avg.	Corn	Soybean	Avg.
		g soil cm^{-3}								
Treatment (T)[2]										
	1	1.43	1.43	1.43	1.47	1.46	1.46	1.45	1.44	1.45
	2	1.50	1.43	1.47	1.43	1.39	1.41	1.47	1.41	1.44
	3	1.57	1.42	1.49	1.44	1.47	1.45	1.50	1.44	1.47
	4	1.48	1.47	1.47	1.47	1.41	1.44	1.47	1.44	1.46
F * P Avg.		1.50	1.44		1.45	1.43				
F Avg.				1.47			1.44			
P Avg.								1.47 B	1.43 A	

[1] Previous crop refers to main crop that was present in a field the year before soil samples were taken. This effect is confounded with years because main crops were rotated between the two fields. Field 42 had soybean in 2009 and corn silage in 2010. Field 44 had corn silage in 2009 and soybean in 2010.

[2] There were four cover crop treatments: 1 = rye cover following corn silage and no cover crop following soybean; 2 = rye cover crop following both corn silage and soybean; 3 = no cover crop; 4 = rye cover following soybean and no cover crop following corn silage.

[3] Numbers within a column followed by the same lowercase letter and numbers within a row followed by the same uppercase letter are not significantly different as indicated by LSD test at the 0.05 probability level.

Table 3.8: Total soil organic matter (SOM) for the 0-5 cm depth layer determined by weight loss on ignition for treatments with and without a rye cover crop in a corn silage-soybean rotation over two years and two adjacent fields.

Field (F)	Field 42			Field 44			Avg. of Both Fields		
Previous Crop (P)[1]	Corn	Soybean	Avg.	Corn	Soybean	Avg.	Corn	Soybean	Avg.
	------------ g SOM g soil^{-1} ------------								
Treatment (T)[2]									
1	0.0552	0.0574	0.0563	0.0538	0.0514	0.0526	0.0545	0.0544	0.0544 a[3]
2	0.5680	0.0602	0.0585	0.0558	0.0532	0.0545	0.0563	0.0567	0.0565 a
3	0.0520	0.0535	0.0528	0.0464	0.0453	0.0459	0.0492	0.0494	0.0493 b
4	0.0500	0.0537	0.0519	0.0473	0.0470	0.0472	0.0487	0.0504	0.0495 b
F * P Avg.	0.0535	0.0562		0.0508	0.0492				
F Avg.			0.0548 A			0.0500 A			
P Avg.							0.0522 B	0.0527 A	

[1] Previous crop refers to main crop that was present in a field the year before soil samples were taken. This effect is confounded with years because main crops were rotated between the two fields. Field 42 had soybean in 2009 and corn silage in 2010. Field 44 had corn silage in 2009 and soybean in 2010.

[2] There were four cover crop treatments: 1 = rye cover following corn silage and no cover crop following soybean; 2 = rye cover crop following both corn silage and soybean; 3 = no cover crop; 4 = rye cover following soybean and no cover crop following corn silage.

[3] Numbers within a column followed by the same lowercase letter and numbers within a row followed by the same uppercase letter are not significantly different as indicated by LSD test at the 0.05 probability level.

Table 3.9: Total soil organic matter (SOM) for the 5-10 cm depth layer determined by weight loss on ignition for treatments with and without a rye cover crop in a corn silage-soybean rotation over two years and two adjacent fields.

Field (F)	Field 42			Field 44			Avg. of Both Fields		
Previous Crop (P)[1]	Corn	Soybean	Avg.	Corn	Soybean	Avg.	Corn	Soybean	Avg.
	g SOM g $soil^{-1}$								
Treatment (T)[2]									
1	0.0482	0.0511	0.0496	0.0475	0.0472	0.0473	0.0479	0.0491	0.0485 ab[3]
2	0.0491	0.0528	0.0509	0.0484	0.0505	0.0495	0.0487	0.0516	0.0502 a
3	0.0477	0.0516	0.0497	0.0455	0.0456	0.0455	0.0466	0.0486	0.0476 b
4	0.0473	0.0504	0.0489	0.0458	0.0455	0.0457	0.0466	0.0480	0.0473 b
F * P Avg.	0.0481	0.0515		0.0468	0.0472				
F Avg.			0.0498 A			0.0470 A			
P Avg.							0.0474 B	0.0493 A	

[1] Previous crop refers to main crop that was present in a field the year before soil samples were taken. This effect is confounded with years because main crops were rotated between the two fields. Field 42 had soybean in 2009 and corn silage in 2010. Field 44 had corn silage in 2009 and soybean in 2010.

[2] There were four cover crop treatments: 1 = rye cover following corn silage and no cover crop following soybean; 2 = rye cover crop following both corn silage and soybean; 3 = no cover crop; 4 = rye cover following soybean and no cover crop following corn silage.

[3] Numbers within a column followed by the same lowercase letter and numbers within a row followed by the same uppercase letter are not significantly different as indicated by LSD test at the 0.05 probability level.

Table 3.10: Particulate organic matter (POM) for the 0-5 cm depth layer determined by weight loss on ignition for treatments with and without a rye cover crop in a corn silage-soybean rotation over two years and two adjacent fields.

Field (F)	Field 42			Field 44			Avg. of Both Fields		
Previous Crop (P)[1]	Corn	Soybean	Avg.	Corn	Soybean	Avg.	Corn	Soybean	Avg.
	---------- g POM g soil^{-1} ----------								
Treatment (T)[2]									
1	0.0085	0.0087	0.0086	0.0090	0.0076	0.0083	0.0088	0.0081	0.0084 a[3]
2	0.0078	0.0093	0.0086	0.0098	0.0084	0.0090	0.0088	0.0089	0.0088 a
3	0.0060	0.0059	0.0060	0.0066	0.0060	0.0063	0.0063	0.0059	0.0061 b
4	0.0055	0.0073	0.0065	0.0060	0.0062	0.0061	0.0058	0.0067	0.0063 b
F * P Avg.	0.0070	0.0078		0.0080	0.0070				
F Avg.			0.0074 A			0.0074 A			
P Avg.							0.0074	0.0074	

[1] Previous crop refers to main crop that was present in a field the year before soil samples were taken. This effect is confounded with years because main crops were rotated between the two fields. Field 42 had soybean in 2009 and corn silage in 2010. Field 44 had corn silage in 2009 and soybean in 2010.

[2] There were four cover crop treatments: 1 = rye cover following corn silage and no cover crop following soybean; 2 = rye cover crop following both corn silage and soybean; 3 = no cover crop; 4 = rye cover following soybean and no cover crop following corn silage.

[3] Numbers within a column followed by the same lowercase letter and numbers within a row followed by the same uppercase letter are not significantly different as indicated by LSD test at the 0.05 probability level.

Table 3.11: Particulate organic matter (POM) for the 5-10 cm depth layer determined by weight loss on ignition for treatments with and without a rye cover crop in a corn silage-soybean rotation over two years and two adjacent fields.

Field (F)	Field 42			Field 44			Avg. of Both Fields		
Previous Crop (P)[1]	Corn	Soybean	Avg.	Corn	Soybean	Avg.	Corn	Soybean	Avg.
	-------------------	g POM g $soil^{-1}$	-------------------						
Treatment (T)[2]									
1	0.0040	0.0038	0.0039	0.0033	0.0030	0.0032	0.0037	0.0034	0.0035 a[3]
2	0.0038	0.0039	0.0038	0.0038	0.0047	0.0042	0.0038	0.0043	0.0040 a
3	0.0031	0.0038	0.0035	0.0030	0.0028	0.0029	0.0030	0.0033	0.0032 a
4	0.0038	0.0036	0.0037	0.0030	0.0029	0.0029	0.0034	0.0032	0.0033 a
F * P Avg.	0.0037	0.0038		0.0033	0.0034				
F Avg.			0.0037 A			0.0033 A			
P Avg.							0.0035	0.0036	

[1] Previous crop refers to main crop that was present in a field the year before soil samples were taken. This effect is confounded with years because main crops were rotated between the two fields. Field 42 had soybean in 2009 and corn silage in 2010. Field 44 had corn silage in 2009 and soybean in 2010.

[2] There were four cover crop treatments: 1 = rye cover following corn silage and no cover crop following soybean; 2 = rye cover crop following both corn silage and soybean; 3 = no cover crop; 4 = rye cover following soybean and no cover crop following corn silage.

Table 3.12: Potential nitrogen mineralization for the 0-5 cm depth layer for treatments with and without a rye cover crop in a corn silage-soybean rotation over two years and two adjacent fields.

Field (F)	Field 42				Field 44				Avg. of Both Fields					
Previous Crop (P)[1]	Corn	Soybean	Avg.		Corn	Soybean	Avg.		Corn		Soybean		Avg.	
	mg N kg soil^{-1}													
Treatment (T)[2]														
1	37.40	45.25	41.35		51.75	48.20	50.00		44.60		46.75		45.65	a[3]
2	45.25	49.20	47.20		54.40	49.25	51.85		49.85		49.20		49.55	a
3	31.40	36.85	34.10		36.85	37.85	37.35		34.15		37.35		35.75	b
4	24.60	48.45	36.55		37.80	40.15	39.00		31.20		44.30		37.75	b
F * P Avg.	34.65	44.95			45.20	43.90								
F Avg.			39.80	A			44.55	A						
P Avg.									39.95	B	44.20	A		

[1] Previous crop refers to main crop that was present in a field the year before soil samples were taken. This effect is confounded with years because main crops were rotated between the two fields. Field 42 had soybean in 2009 and corn silage in 2010. Field 44 had corn silage in 2009 and soybean in 2010.

[2] There were four cover crop treatments: 1 = rye cover following corn silage and no cover crop following soybean; 2 = rye cover crop following both corn silage and soybean; 3 = no cover crop; 4 = rye cover following soybean and no cover crop following corn silage.

[3] Numbers within a column followed by the same lowercase letter and numbers within a row followed by the same uppercase letter are not significantly different as indicated by LSD test at the 0.05 probability level.

Table 3.13: Potential nitrogen mineralization for the 5-10 cm depth layer for treatments with and without a rye cover crop in a corn silage-soybean rotation over two years and two adjacent fields.

Field (F)		Field 42				Field 44				Avg. of Both Fields					
Previous Crop (P)[1]		Corn	Soybean	Avg.		Corn	Soybean	Avg.		Corn		Soybean		Avg.	
		---------- mg N kg soil^{-1} ----------													
Treatment (T)[2]															
	1	23.25	23.40	23.20		19.65	19.80	19.75		21.45		21.60		21.50	a[3]
	2	20.25	24.55	22.40		23.55	29.90	26.70		21.90		27.20		24.55	a
	3	15.90	22.15	19.05		16.50	19.45	18.00		16.20		20.80		18.50	a
	4	21.45	34.65	28.05		17.85	17.65	17.75		19.65		26.15		22.90	a
F * P Avg.		20.20	26.20			19.40	21.70								
F Avg.				23.20	A			20.55	A						
P Avg.										19.80	B	23.95	A		

[1] Previous crop refers to main crop that was present in a field the year before soil samples were taken. This effect is confounded with years because main crops were rotated between the two fields. Field 42 had soybean in 2009 and corn silage in 2010. Field 44 had corn silage in 2009 and soybean in 2010.

[2] There were four cover crop treatments: 1 = rye cover following corn silage and no cover crop following soybean; 2 = rye cover crop following both corn silage and soybean; 3 = no cover crop; 4 = rye cover following soybean and no cover crop following corn silage.

[3] Numbers within a column followed by the same lowercase letter and numbers within a row followed by the same uppercase letter are not significantly different as indicated by LSD test at the 0.05 probability level.

CHAPTER 4. AGCULTURE: ENGAGING IOWA'S URBAN YOUTH IN HANDS-ON SUSTAINABLE AGRICULTURE EDUCATION

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Abstract

AgCulture was created to address the lack of practical agricultural education offered to urban secondary students in Central Iowa. Current trends in youth gardening programs target elementary and middle school students, however, few have been designed with secondary school students in mind. Programs that build the skills and knowledge needed to develop healthy eating habits and to grow and cook fresh foods, while typically not geared towards secondary students, have the potential to create lasting positive impacts in the lives of high school students. This impact extends further for urban youth, because they are less likely than rural youth to understand food's journey from farm to fork. The primary objective of AgCulture was to increase food knowledge among high school youth by providing hands-on experiences growing, cooking, and eating fresh foods. The goals designed to meet this objective were: increasing the youth's consumption of fresh fruit and vegetables, increasing knowledge pertaining to growing and cooking fresh foods, and developing an interest in agriculture among the youth. This paper recaps the pilot season of AgCulture in Ames, IA, complete with discussions of the successes and short-comings of our nascent program, as well as the benefits and challenges associated with using this program model in other locations. Overall, youth in the program increased their consumption of fresh fruits and

vegetables, increased their confidence in cooking with fresh foods, and increased their confidence in growing their own food. Youth also used the skills gained in this program to start a student-managed garden at the Ames High School.

Introduction

Iowa is one of the largest producers of agricultural commodities in the U.S. In addition to being the third largest producer of total agricultural products, Iowa is the nation's largest producer of several key commodities including corn, soybeans, eggs, and hogs (USDA NASS, 2007). Despite the importance of agriculture to Iowa's economy, many Iowa youth often have few direct experiences with agriculture. Approximately 56% of Iowa's population is urban (USDA ERS, 2012); and this demographic distribution may play an important role in determining youth exposure to agriculture in Iowa. Urban youth are often less likely to understand and have direct experiences with agriculture. Agricultural education for urban youth is a relevant issue because understanding agriculture is linked to understanding personal and environmental health. A focus group study in Michigan on teacher's perceptions found that educators noticed links between their students' understanding of agriculture and their understanding of nutrition and environmental issues (Trexler et al., 2000). This same study also observed that teachers often perceived that their students were both apathetic and uninformed about where food comes from. Education is a powerful tool that can empower youth to learn more about how agriculture affects their everyday lives and be inspired to take an interest in how food is produced.

Agricultural education can be enhanced through hands-on, or experiential learning. One of the most common ways that agriculture is taught experientially is via school gardens. Brink and Yoast (2004) describe school gardens as a means to promote experiential learning through the creation of outdoor learning landscapes. School gardens can also provide ample opportunity for youth-initiated learning and inter-generational transfer of knowledge through prolonged youth contact with adult gardeners (Rahm, 2002). A meta-analysis by Blair (2009) suggests that school gardens are also a viable means to "improve students' test scores and school behavior".

Despite the known benefits of experiential agricultural education, few programs are targeted towards secondary students (Blair, 2009). For many urban secondary students, knowledge of where food comes from doesn't extend beyond the supermarket. In the U.S. an estimated 83% of the population is non-rural (USDA ERS, 2009). The demographic trend of increasing urbanization is expected to continue well into the future; highlighting the need for agricultural education geared towards urban secondary students. Familiarizing secondary students with the importance of fresh food and an understanding of where food comes from is an issue that demands immediate attention.

Diet-related health epidemics are a critical problem in the U.S., especially amongst racial minority groups in urban populations. Racial minorities are disproportionately affected by type-2 diabetes, obesity, and hypertension, all of which are diet related and preventable (CDCP, 2007, 2009; USDHHS, 2011). Blair (2009) suggests that youth need to "broaden their perspective on what foods are edible and to re-personalize food" to combat diet related epidemics. Educational programs can be an effective means to broaden youth perspectives and provide a framework from which youth can re-think issues pertaining to food choice and health.

Given the fact that many of society's most pressing concerns are heavily influenced by our food system; including diet-related health problems, biodiversity preservation, and non-renewable energy consumption, knowledge about where food comes from and how food is grown is desperately needed in youth education programs. This sentiment is echoed by the National Research Council (1988), which asserts that agriculture is "too important a topic to be taught to the relatively small percentage of students considering a career in agriculture".

In February 2011, Urban Dreams, a non-profit organization based in Des Moines, IA, initiated a program called *AgCulture* to help address the lack of experiential agriculture programs offered to urban secondary students in Iowa. AgCulture was designed to increase food knowledge among high school youth by providing hands-on experiences growing, cooking, and eating fresh foods. The core goals of the program were: increasing the youth's consumption of fresh fruit and vegetables, increasing knowledge pertaining to growing and cooking fresh foods, and developing an interest in agriculture among the youth. The program also placed strong emphasis on fostering participation among racial minorities.

The pilot season of AgCulture began in spring 2011 and focused primarily on cooking and gardening principles. AgCulture youth applied the skills and knowledge gained from the spring program to create a student-led garden at the local high school in fall 2011. Examples of lessons and activities will be presented along with the results of surveys and questionnaires used to assess youth attitude changes towards cooking and gardening. An assessment of how well program objectives were met and suggestions for improving the program will also be presented.

Spring Program Overview

The spring program began on 4 April 2011 and ended 2 June 2011. Eight youth, ages 14-16, and two instructors participated in the program. AgCulture met twice a week at the United Church of Christ facility in Ames, IA. Although meetings took place in a church, the AgCulture program contained no religious aspects. Each Tuesday was devoted to cooking lessons and assisting with Farm to Folk, which is one of the farmer's markets that service the Ames community. Cooking lessons were taught by the instructors and guests from the community. Each Tuesday the youth cooked a meal using fresh ingredients from the Farm to Folk farmer's market, which was also located at the United Church of Christ facility. Tuesdays also provided youth with an opportunity talk with the farmers that sold at Farm to Folk. Each youth was asked to profile one of the farmers that serviced Farm to Folk. These one-on-one interviews allowed the youth to get to know the farmers on a more personal level and also gave the youth the opportunity to learn more about the business aspects of farming. Each of the youth gave a synopsis of their interview to their peers and the instructors.

Thursdays were devoted to gardening and agricultural education. Gardening lessons focused primarily on garden design, plant seasonality, crop rotation, and soil health principles. Over the course of the program youth also learned about food plant origins, identification of plant families, sustainable agriculture principles, soil and water conservation, and Iowa agriculture. The Thursday gardening section culminated in students successfully designing a garden plan, which was implemented at the Iowa State University Student Organic Farm in May 2011. Youth participation in planning and creating a garden was deemed essential to the success of the program. Thorp and Townsend (2001) observed a transitional stage in which youth up to age 14 bond closely to natural spaces outside of the home. One of the ways that this bond, which, according to Thorp and Townsend (2001), is “essential for healthy maturation”, can be developed is through youth being active participants in planning and creating a garden (Blair, 2009).

Spring Program Learning Activities

At the beginning of the program students were asked to work together to create a group mission statement for the program. They agreed upon:

"We strive to learn more about our food, how it’s grown, and how to prepare it. We commit to use this knowledge to help educate the community about local foods, and to have fun doing it!"

The strategy for reaching this group goal revolved around incorporating hands-on learning activities. Agricultural education activities used in this program employed a learner-centered approach, which is the cornerstone of many successful non-formal education programs (Seevers et al., 2007). The learner-centered approach differs markedly from a teacher-centered approach, which is used in most formal secondary school courses. The learner-centered approach is characterized by the learners being actively engaged in determining the program content, whereas the teacher-centered approach is characterized by the educator assuming all control over program content (Seevers et al., 2007).

AgCulture is a completely voluntary program; youth received no pay or academic credit for participating. Non-formal, voluntary programs such as AgCulture can only be successful if participants perceive that their interests are being addressed. According to Seevers et al. (2007), non-formal education should be “practical, flexible, and based on the needs of the participants”. Cooking and gardening activities revolved around crops that were of interest to the group. The garden planted by the youth at the end of the spring program at the Iowa State University Student Organic Farm was composed entirely of plants that the youth expressed an interest in growing.

All activities employed during the program were designed to educate as well as engage youth in learning about food. The following example is an activity from Week 2 of the spring program:

The goal of this activity was to encourage the youth to begin thinking about which crops would be successful in an Iowa garden. Achieving this learning goal required several steps. First, the youth needed to be made aware that different plants evolved in different environments, which has a major influence on where those plants can be grown successfully. Secondly, the youth needed to understand the environmental factors that influence where certain plants can grow. Lastly, the youth needed to apply the knowledge gained from the previous step to create a list of plants that would be likely to do well in an Iowa garden. The activity began with a game adapted from the book “French Fries and the Food System” (Coblyn, 2002):

“Pair off in teams of two and take 10 minutes to help me work on a story that I’m writing. The story takes place 600 years ago in London, and it is about a fancy birthday party for the main character, and at this party the main courses are French fries and ketchup, corn on the cob, and chocolate pudding. I want my story to be as historically accurate as possible so tell me if there is anything I can change to make it better.”

The students provided a wide range of responses; some said that people didn’t fry food in those days, so no one ate French fries; some said that people in London have always preferred mashed potatoes instead of French fries; some even said that people didn’t celebrate birthdays back then. The youth were surprised to learn that this meal was impossible in London in the year 1411 because all the plants that these foods are made from (potatoes, tomatoes, maize, and cacao) are native to the New World and thus were not available to Europeans until after Christopher Columbus sailed to the Americas in 1492.

The youth were then challenged to think about the reasons that plants are able to be grown in areas other than where they were first domesticated, and how this has influenced their own cultures. We gathered around a world map and played food origins “Jeopardy” (Coblyn, 2002). Clues about different food plants were given, and the youth eagerly competed to be the first with the correct answer. An example of one of the questions is: “It stood taller than a man and had ears as thick as a human arm”: the answer of course is maize. Another example is “Some are sweet, but some make you cry”: the correct answer being onions. After giving the correct answer the group worked together to guess the place on the map where the crop originated and, with the assistance of the instructors, successfully mapped over 20 crops. We also used the map to find where our family origins are and what types of crops are native to those places. Students reacted very positively to this part of the exercise and were often surprised when learning where some of their favorite foods originated. A Mexican-American youth responded to this activity with pride, noting that "a lot of the really tasty foods (avocado, cacao, and maize) come from Mexico". Afterwards, the youth were tasked with using this information to think about which plants were likely to be successful in an Iowa garden. The youth worked together to construct a list of plants that would do well in Iowa's temperate climate. This list was used in later lessons about plant families, crop rotation, and garden design.

Another example of youth activities is from Week 5 of the spring program:

The objective of this activity was to encourage youth to view gardening as an activity that can be adapted to indoor scenarios. This learning objective was deemed especially important for urban youth since many of them may not have access to outdoor space for growing food. Achieving this objective required youth to learn which foods plants are adapted to thrive in small spaces. Herbs fit in with our learning goal excellently. In addition to their suitability for growing in small spaces, herbs allowed the youth to explore edible plants other than fruits and vegetables. Youth grew a variety of herbs from seed and later transplanted the herbs to pots, which each of the youth took home. Creating indoor herb pots served as a way to provide the youth with a constant reminder that growing fresh food is an option for everyone; even those that live in urban spaces. Starting potted herb gardens had the added benefit of providing the youth with experience in transplanting, which proved valuable when work began at the Iowa State University Student Organic Farm. Anecdotal evidence shared by the youth suggests that the indoor herb pots also provided the youth with opportunities to share their enthusiasm about edible plants with others, including their parents and friends.

Youth Peer Outreach

In addition to teaching youth practical skills such as healthy eating, proper food preparation, and home gardening; the youth were also encouraged to become active community members by sharing their food knowledge with others. An informational event for the On-Farm Summer AgCulture Program, a paid internship which offered youth an opportunity to gain valuable work experience while learning about agriculture, was held in April 2011.

The goals of this event were to disseminate information about the summer AgCulture program to youth in the community, foster a sense of community by sharing a meal that used locally grown ingredients, and spark interest in gardening among the youth. The latter was accomplished through hosting a “seed bomb” workshop (Fig.1). Seed bombs consist of clay, water, composted manure, and seed mixed together and shaped like a ball. Seed bombs are popular because they provide an easy means of facilitating the successful establishment of plants and can be used with a wide variety of seeds. AgCulture youth were responsible for all cooking at the event and for teaching their peers how to make seed bombs. This event enabled AgCulture youth to meet part of their original mission statement: “to help educate the community about local foods, and to have fun doing it!”. This event also succeeded in encouraging several youth from the community to apply for the On-Farm Summer Program.

Spring AgCulture Program Results

Each of the youth was given a pre-survey on the first day of the program and a post-survey on the last day of the program (Fig. 2). These surveys were designed to assess the youth's food knowledge and eating habits. The surveys included questions pertaining to the youth's knowledge about how agriculture affects the environment, which foods are healthy, fruit and vegetable consumption habits, and confidence in cooking, gardening, and making healthy food choices. Youth were asked to rate the degree to which they agreed with statements such as "I know what foods are grown around here", "I want to be a farmer", and "It is important to eat local foods". Most of the questions required a response that ranged from 1-5, with "1" being the lowest (never, or strongly disagree) and "5" being the highest (always, or strongly agree). The survey also included questions that required a written response, allowing the instructors to better understand the perspectives of each youth participant. The pre survey and post survey were identical with the exception of one question being changed from "What are the main things you *want to learn*" in the pre-survey to "What are the main things you *learned*" in the post-survey.

Overall, the youth showed a more positive attitude towards fresh local foods, increased confidence in growing their own food, better understanding of food seasonality, and more confidence in their ability to cook with raw ingredients (Fig. 3). It is also worth noting that fruit and vegetable consumption among the group increased by an average of 29%. There was also a 21% average increase amongst the group in confidence cooking with fresh/raw ingredients. Youth agreement with the statements "I help people in my community find fresh food" and "I am a leader in my community" both declined by 4%. These were the only progress indicators that showed a decline over the period of the program. It is possible that this decline was due to the youth having a more realistic understanding of what each of those questions means as a result of the program. It is also worth noting that the number of participants was relatively small (n=8), allowing the responses of one participant to heavily skew the group average in either direction.

Comparison of the pre-survey question “What are the main things you want *to learn* in this program” and the post-survey question “What are the main things you *have learned* in this program” revealed that the youth learned a great deal of what they hoped to learn in the program (Fig. 2). For example, in the pre-survey one of the youth wrote that they would like to “learn how to cook with fruits and vegetable and learn about gardening”. In the post-survey the same youth wrote they had “learned how to cook and grow fruits and vegetables”. Another youth hoped to learn “how to make fresh food!, how to make a very neat garden” in the pre-survey and noted they had learned “gardening, cooking, establishing a farmer’s market” in the post-survey. Additional survey results can be found in Figure 3.

Youth were also asked to provide feedback about the program as a whole (Fig. 4). As a group, the youth were asked about the parts of the program they enjoyed most, and which aspects they would like to see changed. In general, the youth enjoyed having guest chefs, visiting gardens, and learning how to cook without recipes. Many youth also said they would have liked to have more educational games, plant more unconventional crop varieties (e.g. yellow-fleshed watermelon, purple carrots) and have more workshops centered on their interests.

Survey results indicate that AgCulture was successful in meeting all of its main objectives. Consumption of fresh fruit and vegetables was increased; however fresh fruits and vegetables were provided to the youth during the Tuesday cooking lessons and it remains unclear whether the increase was solely a result of consumption at AgCulture lessons, or the result of increased consumption at home and at school. The program was also successful at increasing knowledge about growing and cooking fresh foods.

The final objective, developing an interest in agriculture among the youth, was more difficult to assess. For example, youth response to the statement “I want to be a farmer” showed no net change. Youth could become more interested in agriculture without necessarily wanting to become farmers; however some may interpret these results as indicating that the youth did not develop an interest in agriculture. A negligible increase in students’ desire to study agriculture in college presents the same issues as the previous example. Likewise, students showed increased agreement with the statement “It is important to eat local food”; however this does provide direct evidence that they have developed a greater interest in agriculture. Youth were asked to provide a written response to the survey question “Is eating food from local, sustainable farms important to you? Why or why not”; however some of the youth didn’t exactly answer the question being asked of them, and one youth did not provide a response. These factors make it difficult to definitively state that AgCulture youth developed an interest in agriculture; however anecdotal evidence such as some of the youth opting to participate in the On-Farm Summer program and some deciding to volunteer at local farmer’s markets, seem to suggest at least a modest increase in their interest in agriculture. Re-wording of the survey questions could help the instructors gain a better understanding of the extent to which youth have developed an interest in agriculture.

Responses from the pre-survey also made it clear that the youth did not have a firm understanding of what is considered a vegetable. One youth counted a fast-food baked potato as a fresh vegetable, and several youth counted tomatoes, which should have been placed in the fruit category. While this point is moot, establishing definitions for certain terms, such as fresh vegetables, local foods, and leadership, prior to the survey may have yielded more accurate results.

Although still in its infancy, AgCulture seems to show promise as a vehicle for providing experiential agriculture education to urban secondary students. No major factors prohibit the implementation of similar programs in other parts of the country; however, having access to farmer's markets and farm land did make it easier to provide the youth with a more well-rounded agricultural education experience. Agricultural education is important for all students, not just those who live in rural areas. Youth will be less capable of making conscious, informed food and environmental choices throughout their lives, if they are not exposed to sustainable agricultural education. Increasing the number of programs similar to AgCulture could help address the agricultural knowledge gap among urban youth and move our society towards a future where the public is informed enough to make conscious food and environmental choices and support farmers and landowners in using sustainable soil management practices.

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Figure 1. This is the informational flyer for the On-Farm Summer Program. Flyers were posted at Ames High School and circulated by AgCulture youth.

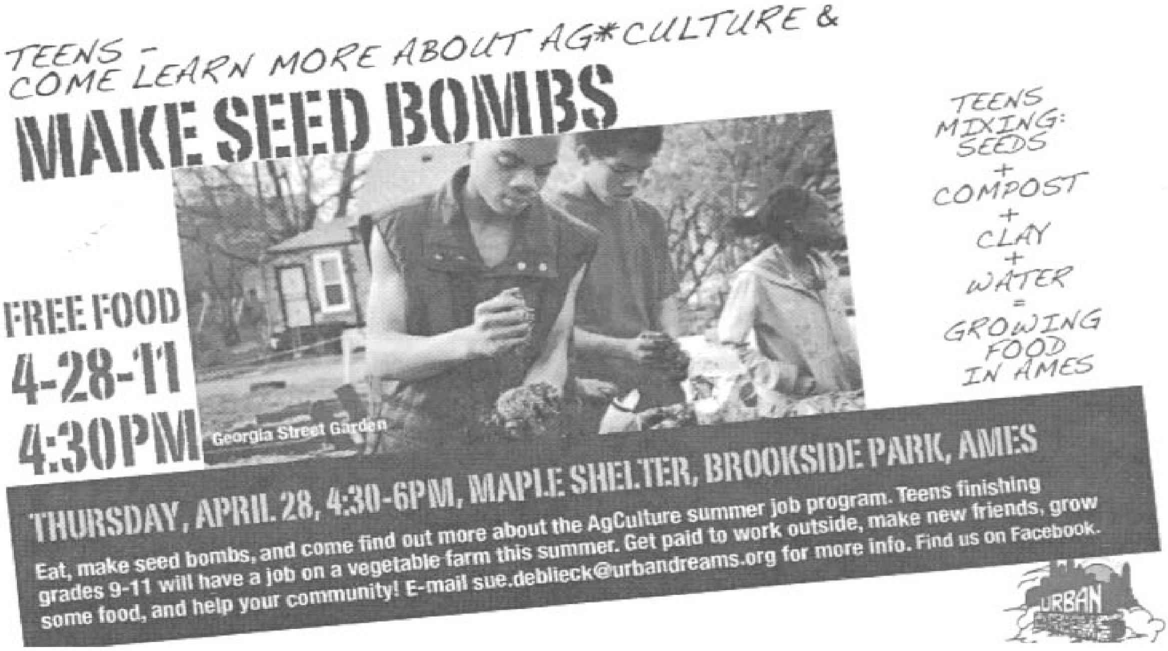

Figure 2. A survey given to each of the youth on the first day of the spring program. The same survey was given to each of the youth on the last day of the spring program.

SURVEY FOR AGCULTURE PARTICIPANTS SPRING 2011

Name	
School/ Home School	What grade are you in? 9 / 10 / 11

1. How often do you know about each of the following items?

I know...	All of the time	Most of the time	Some of the time	Rarely	Never
a. Where the food I eat comes from.	☐	☐	☐	☐	☐
b. What foods are grown around here.	☐	☐	☐	☐	☐
c. What kinds of foods grow in each season.	☐	☐	☐	☐	☐
d. What distance foods travel before they get to me.	☐	☐	☐	☐	☐
e. Which foods are healthy and which foods are not healthy.	☐	☐	☐	☐	☐
f. Why farms and gardens are important.	☐	☐	☐	☐	☐
g. How agriculture affects the environment.	☐	☐	☐	☐	☐
h. The food traditions of my friends	☐	☐	☐	☐	☐

2. Is eating food from local, sustainable farms important to you? Why or why not?

3. Name the fruits you ate yesterday: ____

4. Name the vegetables you ate yesterday:____

5. How many servings of fruits and vegetables did you eat yesterday? ____ A serving is defined as a half cup of a fruit or vegetable.

6. How confident are you in your ability to do each of the following activities?

	Very Confident	Somewhat Confident	Not Confident	Don't know
a. Make healthy food choices	☐	☐	☐	☐
b. Plant a vegetable garden	☐	☐	☐	☐
c. Maintain an established vegetable garden	☐	☐	☐	☐
d. Improve the soil health and fertility of a garden	☐	☐	☐	☐
e. Identify weeds in a garden	☐	☐	☐	☐
f. Cook with fresh/raw ingredients	☐	☐	☐	☐

Figure 2 cont.

g.	Harvest (pick) fruits and vegetables	☐	☐	☐	☐
h.	Establish a local food market for customers	☐	☐	☐	☐

7.If you needed help with the activities listed on the previous page (garden, cooking, etc...), who are the people and organizations you would turn to for help?

8.What are the main things you would like to learn about in this program?

9.Rate the extent to which you agree or disagree with the following statements (mark the box with an x)

	Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree
I can cook a healthy meal for myself.	☐	☐	☐	☐	☐
It is important to eat local food.	☐	☐	☐	☐	☐
I want to be a farmer.	☐	☐	☐	☐	☐
I care about the environment.	☐	☐	☐	☐	☐
I know how to grow my own food.	☐	☐	☐	☐	☐
I feel comfortable speaking in front of groups.	☐	☐	☐	☐	☐
I am a leader in my community.	☐	☐	☐	☐	☐
People in my community can easily get fresh food.	☐	☐	☐	☐	☐
I plan on studying agriculture in college	☐	☐	☐	☐	☐
It is important to participate in activities with diverse groups of people.	☐	☐	☐	☐	☐
I help people in my community find fresh food	☐	☐	☐	☐	☐

Figure 3. These tables are the original data from the pre survey and post survey. Responses range from 1-5, and from 1-3 in some questions. Lower numbers are associated with the youth having less confidence with an action or disagreeing with a statement, whereas higher numbers are associated with the youth having more confidence or agreeing with a statement.

1= never, not confident, strongly disagree
2= rarely, somewhat confident, disagree
3= some of the time, very confindent, neutral
4= most of the time, agreee
5= all of the time, strongly agree

∆- Denotes the difference in response values from the pre survey and post survey.

How often do you know about each of the following items?	Where the food I eat comes from	What foods are grown around here	What foods grow in each season	What distance foods travel before they get to me	Which foods are healthy	Why farms and gardens are important	How agriculture affects the environment	The food traditions of my friends	Is eating food from local, sustainable farms important to you?
	a. from	b. grown	c. season	d. distance	e. healthy	f. important	g. environment	h. traditions	
AF - pre	5	3	3	3	4	4	3	5	0.5
AF - post	3	4	4	3	5	4	3	5	1
FP - pre	1	1	2	1	3	4	3	1	1
FP - post	3	2	4	2	3	4	4	2	1
RL - pre	3	4	3	3	4	4	3	3	0
RL - post	4	4	3	3	4	3	3	3	1
CH - pre	3	3	5	2	5	4	5	3	1
CH - post	4	5	5	3	5	5	5	4	1
CB - pre	3	3	2	3	4	4	4	4	0.5
CB - post	2	3	4	2	4	5	5	4	1
EE - pre	3	4	2	3	4	2	2	2	1
EE - post	4	4	3	4	4	3	4	5	1
IB - pre	4	4	4	3	4	5	5	4	1
IB - post	4	5	5	4	5	5	5	4	1
SH - pre	4	4	3	3	4	4	5	4	
SH - post	4	4	4	3	3	5	5	4	1
Pre Mean	3.25	3.25	3	2.625	4	3.875	3.75	3.25	0.71428571
Post Mean	3.5	3.875	4	3	4.125	4.25	4.25	3.875	1
∆	0.07	0.19	0.33	0.14	0.03	0.1	0.13	0.19	0.4

Figure 3 cont.

Rate the extent to which you agree or disagree the the following	I can cook a healthy meal for myself	It is important to eat local food	I want to be a farmer	I care about the environment	I know how to grow my own food	I feel comfortable speaking in front of groups	I am a leader in my community	People in my community can easily get fresh food	I plan on studying agriculture in college	It is important to participate in activities with diverse groups of people	I help people in my community find fresh food
	a. cook	b. local	c. farmer	d. environment	e. grow	f. speaking	g. leader	h. get fresh	i. studying	j. diverse	k. find fresh
AF - pre	5	3	3	3	5	2	4	3	1	2	3
AF - post	5	4	3	3	5	3	3	4	1	3	3
FP - pre	3	4	3	5	3	2	1	4	3	4	3
FP - post	4	5	3	5	4	3	2	4	3	5	3
RL - pre	3	2	3	4	2	3	4	4	3	4	2
RL - post	5	4	2	5	3	3	3	5	2	4	2
CH - pre	4	5	2	5	3	4	3	3	2	5	3
CH - post	5	5	3	5	5	4	3	4	3	5	3
CB - pre	4	4	2	4	4	5	3	4	2	5	3
CB - post	4	3	2	4	3	4	3	4	3	4	3
EE - pre	5	4	3	4	4	3	4	3	3	4	5
EE - post	5	4	4	5	5	3	4	4	4	5	4
IB - pre	5	5	4	4	4	4	4	3	3	5	3
IB - post	4	5	3	4	4	4	4	2	3	5	3
SH - pre	4	4	5	5	3	3	3	5	4	5	3
SH - post	4	5	5	4	4	3	3	4	3	5	3
Pre Mean	4.125	3.875	3.125	4.25	3.5	3.25	3.25	3.625	2.625	4.25	3.125
Post Mean	4.5	4.375	3.125	4.375	4.125	3.375	3.125	3.875	2.75	4.5	3
Δ	0.09	0.13	0	0.03	0.18	0.04	-0.04	0.07	0.04	0.06	-0.04

Figure 4. The youth provided feedback about things they liked and disliked about the spring program. Positives are the things the youth enjoyed and deltas are things that they would have changed.

AgCulture SpringProgram Feedback May 24, 2011

	Positives	Deltas
Cooking	guest chefs cook without recipes	more guest chefs youth plan recipes
Gardening	visiting gardens got to plant our garden visiting Ethy & Steve's garden	go to gardens more often planning was so specific want more diverse plants (funky varieties)
Farm to Folk	got to learn about foods and cook with them pass out samples	not enough work for all of us
Community Involvement	seed bomb activity was fun	needed to do more outreach donate food to MICA cook for Food at First
Workshops	good when informational and fun (i.e. No Tomato Sauce til 1492)	base them on our interests
Farm Assignment	got to learn about farmers	difficult to get ahold of farmers
Other		visit Des Moines farmers market
Games	fun ones include pictionary, veggie off, and party host	less get to know you games & discussions, let's jump in! more games that get us to think/ informational

CHAPTER 6. GENERAL CONCLUSION

Healthy soil, healthy people, and healthy communities are inextricably linked. The long-term sustainability of communities in Iowa, and elsewhere, depend upon the sustainable management of soil resources. Moving our society towards a sustainable relationship with soil requires concerted action on the part of both farmers and urbanites. Farmers need to understand the importance and benefits of implementing sustainable soil management practices. Urbanites need to support farmers both socially and economically in their efforts to sustainably manage soil. This thesis examined two strategies that have the potential to dramatically improve the sustainability of human interactions with soil in Iowa. One of these strategies is implementing rye winter cover crops in corn and soybean cropping systems. The field experiment presented in this thesis shows that rye winter cover crops can improve soil quality. Other scientific work has demonstrated the ability of rye cover crops to provide multiple ecosystem services, however these services have generally been viewed by farmers as lacking economic incentive. Results from our experiment show that rye cover crops can enhance the ability of soil to provide plant nutrients, which may encourage more farmers to adopt cover crops. The other strategy for improving sustainable human relationships with soil involved teaching urban teenagers about the role that soils and agriculture play in their personal health and the health of the environment. The first season of AgCulture introduced urban youth to fresh foods, gardening, soils and sustainable agriculture. After completing the AgCulture program, youth expressed more interest in gardening and eating fresh, healthy foods. It remains to be seen whether this display of interest will translate into a life-long appreciation of agriculture and soil, however preliminary results indicate that the youth have at least begun to re-assess their relationship with soil. The strategies investigated in this thesis are but two of myriad actions that can be taken to improve the sustainability of human-soil interactions. More research is needed in both the natural and social sciences to help further move our society towards a sustainable relationship with the soil that forms the very foundation of our livelihoods and communities.

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