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Production, perceptions and limitations of organic small grains in Iowa

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Production, perceptions, and limitations of organic small grains in Iowa

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The student author and the program of study committee are solely responsible for the content of this thesis. The Graduate College will ensure this thesis is globally accessible and will not permit alterations after a degree is conferred.

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ABSTRACT

Small grains, such as, barley (*Hordeum vulgare* L.), oat (*Avena sativa* L.), rye (*Secale cereale* L.), triticale (*X Triticosecale* Wittmack) and wheat (*Triticum aestivum* L.) contribute to the proper functioning of organic row crop systems in Iowa and the upper Midwest. Besides producing grain and straw, which have value either as sold products or on-farm inputs, they are commonly used rotation crops that contribute functions such as forage legume establishment and weed suppression. Additionally, they may contribute to a suite of below ground functions that included soil quality improvement and disease suppression. However, small grains themselves are less profitable than corn (*Zea mays* L.) and soybean (*Glycine max* (L.) Merr.). Some of this has to do with production challenges to grain yield and grain quality, the latter being often more important than the former. Some of this may be dependent on economic considerations such as market options or a lack thereof. Additionally, these challenges and considerations are also intertwined with farmer perceptions, which can shape and be shaped by these different factors. The goal of this research was to use a variety of methodologies, specific to agronomy, sociology, and economics, to explore the present status of organic small grains in Iowa. This was achieved via a large-scale, mixed-methods study involving 41 farmers across the state, a set of three on-farm trials at seven farms, and an agronomic small-plot experiment at the Iowa State University Agricultural Engineering and Agronomy Farm. The mixed-methods study helped to highlight a range of production, economic and farmer perception-based factors and was useful in generating hypotheses for on-farm and on-station research. The latter two studies focused on oat. On-farm trials consisted of testing low-cost tactics such as oat density manipulations, physical weed control and planting oat as a monoculture followed by a mid-season cover crop vs. oat planting

with a forage legume underseeding. On-station research further examined the effects of oat population density and delayed planting.

CHAPTER 1. GENERAL INTRODUCTION

Cropping system diversity is an essential part of organic agriculture; it is ingrained in the bylaws of its certification and the ecological foundations of its practices (Reganold and Wachter, 2016, Seufert et al., 2017). With respect to organic systems in particular, as of 2014, Iowa was tenth in the nation for farm gate sales of organic crops and livestock (Economic Research Service, 2014). This is primarily driven by the sale of corn and soybean, as animal feed, which has increased steadily with consumer demand for organic milk, eggs and meat (Cavigelli et al., 2008, Winkler et al., 2017). However, corn and soybean are planted and harvested in similar windows each season. Continuous planting of just these two crops in a sequence can lead to both pest and labor challenges. Additionally, the corn and soybean years of a rotation offer little opportunity for establishing forage legumes, such as alfalfa and clover, which are essential for contributing to soil fertility and quality within organic and low external input (LEI) row crop systems in the Midwest (Liebman and Davis, 2000; Liebman et al., 2008).

In Iowa, long-term research and observation, stemming from both farmers and researchers, has shown that diversifying crops over time and space helps control pests, cycle nutrients, and distribute labor requirements more evenly over a growing season (Liebman et al., 2008; Thompson, 2009). In organic and LEI cropping systems in Iowa, small grains, which are planted and harvested at different times of the year relative to corn and soybean, are added to rotations to aid in pest suppression, to distribute farm labor more evenly over a season, and to establish forage legumes or provide a larger window for mid-season planted cover crops . Small grains that are grown in Iowa consist of barley, oat, triticale, rye and wheat (both spring and winter).

While small grains can contribute important functions to cropping systems, they are often less profitable relative to corn and soybean in Iowa. (Chase, 2016). Whether as cause or consequence of this, small grains have been planted on fewer acres over time and received less attention relative to corn and soybean, from both farmers and researchers alike. To provide some specific context to one small grain in particular, the harvested area of oat in Iowa peaked at approximately 2.6 million hectares in 1950 (National Agriculture Statistics Service, 2016). From that point onwards, the area planted to oat decreased. As of 2016, oat was planted on approximately 17,500 ha in Iowa, 99.9% reduction in a 66-year period (National Agriculture Statistics Service, 2016). This change in production area has altered the opportunities for research and development and may have changed farmers' perceptions of small grains, their utility and management (Blesh and Wolf, 2014; Larsen, 2015; DeLonge et al., 2016). Iowa was once a prominent location for small grain breeding, physiology and management research, for oat in particular, but its principle investigator in the public sector in Iowa passed away in the early 2000s, and the breeding program, which had been diminishing for decades, was shuttered shortly after, and has not been active since, representing a considerable loss of knowledge, both applied and fundamental (Thro, 2011; J.L. Jannick, personal communication, April 14, 2017). Similarly, official Iowa State University extension guidelines for small grains management have not been released or updated since the early 1990s (Hansen, 1992, 1994).

Given this context, the goal of the research described in this thesis was to evaluate factors important to small grains production and value; doing so entailed examinations of agronomic management practices, such as planting date and seeding rate, economic determinants, such as input costs and market prices, institutional factors, such as the presence or absence of extension services and materials, and sociological elements such as farmer perceptions of these different

parameters. A conceptual model below provides a general framework for explicating these relationships (Fig. 1.1). Simply understood, net returns (gold box) represent revenue (green box) minus input cost(s) (red box). However, while basic conceptions of net returns consider factors such as grain yield weight (W) and quality (Q) (sources of revenue), in addition to management costs associated with seed and labor (sources of input costs), a more nuanced system would also take into account interactions among farmer perceptions, markets, and institutional factors, in addition to geographic and environmental determinants. Synergies and antognisms among these may support or limit farmer perception and management as they relate to organic small grains production and value. While the work in this thesis considers many of these relationships, it focuses primarily on factors within dashed-line boxes (i.e. the complex of farmer perceptions and management and their influence on desirable agronomic and economic outcomes).

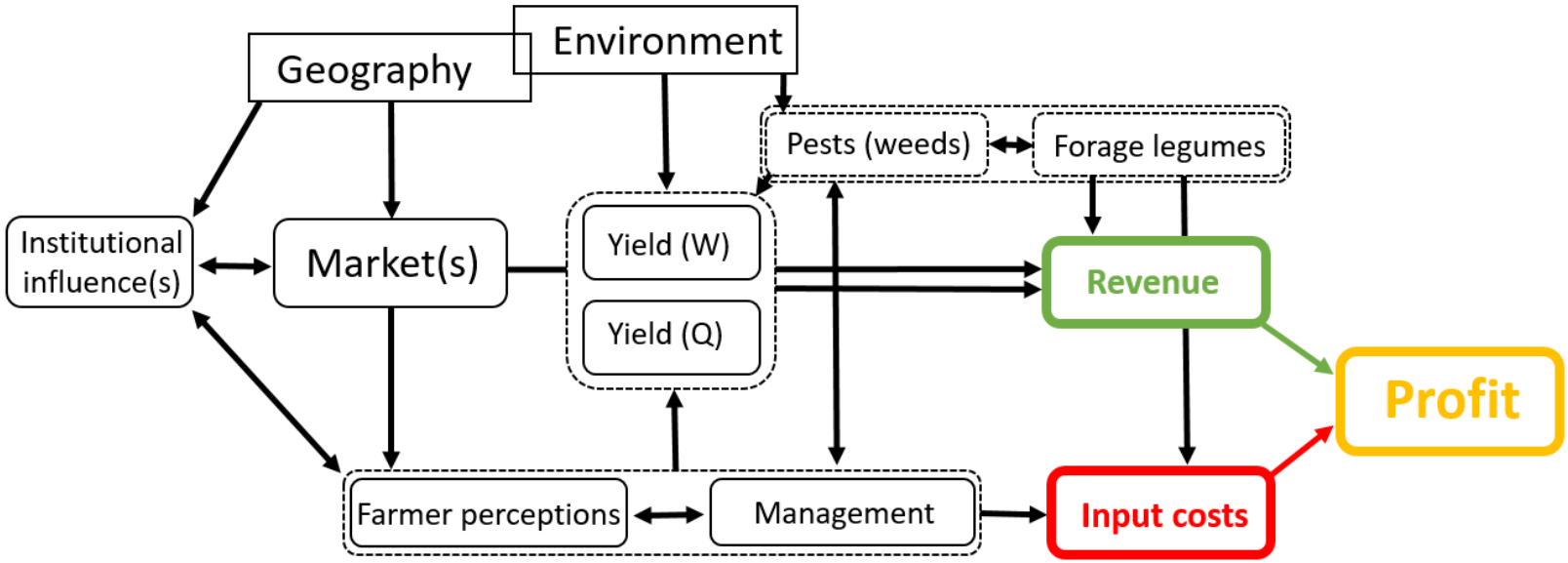

Figure 1.1 Conceptual model of factors (boxes) and their relationships (arrows) that influence organic small grain profitability (gold box). The amalgam of geography (e.g. latitude) and environment (e.g. the effects of latitude – photoperiod, heat unit accumulation) are in boxes with acute shapes indicating that they cannot be altered. Agronomic production goals of a given small grain (yield weight [W] and quality [Q], middle, dashed-line box) are one determinant of revenue (green box), another being market(s). The amalgam of farmer perceptions and management (lower left, dashed-line box) is a key determinant of input costs (red box).

Thesis Organization

This thesis is organized into five chapters. Chapter 1 is the general introduction. Chapter 2 presents works from a large-scale, mixed-methods study that highlights agronomic, socio-economic and institutional factors in organic small grain production and farmer perceptions of these. Chapter 3 describes three on-farm trials, focusing on management tactics to improve both grain yield and quality in oat, in addition to other common functions of a small grain rotation year including forage legume establishment and/or weed suppression. Chapter 4 is a paper to be submitted to Agronomy Journal. It details a two-year study analyzing the effects of both planting date and oat plant density on yield components, grain yield and test weight, alfalfa and weed biomass, and net returns. Chapter 5 entails an overarching discussion of the work, synthesizing its outcomes, as well as providing suggestions for further steps that could be implemented to improve the prospect of organic small grains in Iowa.

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CHAPTER 2. ACROSS THE GRAIN: USING A MIXED-METHODS APPROACH TO ASSESS ORGANIC SMALL GRAIN PRODUCTION AND ECONOMIC CHALLENGES

Abstract

Small grains such as barley (*Hordeum vulgare* L.), oat (*Avena sativa* L.), rye (*Secale cereale* L.), triticale (*X Triticosecale* Wittmack) and wheat (*Triticum aestivum* L.) are an important component of organic row crop operations in the Upper Midwest. Beyond providing goods for either on-farm use or sale, like grain and straw, they help disrupt above and below ground pest and disease life cycles, provide opportunities for establishing legumes for either forage or green manure purposes, and promote more even distribution of farm labor over the cropping season. Aside from these functions, the economic value of small grains themselves is usually less than other crops within the rotation, primarily corn (*Zea mays* L.) and soybean (*Glycine max* (L.) Merr.). This is due to a complex amalgam of biophysical and socioeconomic factors including agronomic management, yield potential, economic decisions and their interactions with farmer perceptions. Our goal was to determine key limitations to organic small grains by highlighting the variance around eleven factors thought to be vital to both the production and economic considerations of these crops. These factors were related to agronomic, socioeconomic and institutional dimensions of organic small grains. To do this, we implemented a mixed-methods approach, centered on a two-year study involving 41 organic farmers and their farms across the state of Iowa. This included agronomic field measurements, surveys and focus group participation. Measurements around these eleven factors displayed a high degree of heterogeneity in field measurements, survey responses and focus group participation. Factors relevant to agronomic management, the weather and their concomitant effects on grain yield and quality were major determinants in the economic viability of small grains. Farm operations varied greatly and often had built in features, such as livetock integration, to deal with potential

economic variability. A general recognition of the agroecological functionality of small grains within organic rotations was an important feature of keeping farmers engaged with small grains production.

Introduction and Background

Small grains such as barley (*Hordeum vulgare* L.), oat (*Avena sativa* L.), rye (*Secale cereal* L.), triticale (*X Triticosecale* Wittmack) and wheat (*Triticum aestivum* L.), are an important component of organic row-crop systems in the upper Midwest (Porter, 2009). Both grain and straw can contribute to value of small grains via sale or on-farm use. However, small grains serve several functions beyond producing grain and straw. They can contribute to weed suppression and forage legume establishment; which are vital objectives for multi-year rotations in which weed control and nitrogen additions must be managed using biological and mechanical methods (Liebman et al., 2008; Liebman and Davis, 2009; Porter, 2009). In addition to these benefits, the planting and harvest schedule of small grains differs from that of corn and soybean, helping spread the workload for farmers (Thompson, 2009). Small grains themselves, are often the least profitable crop within diversified crop rotations in Iowa (Chase et al., 2016). This is due to a combination of price, grain yield, and grain quality, which includes metrics such as test weight (kg m^{-3}) and protein concentration. Grain quality, in particular, is often insufficient for food-grade markets.

Small grains have also received diminished agronomic attention from both farming and research communities over the last two decades. This has come about as a result of larger trends in regional crop-preference, which in turn, have altered both spatial and institutional opportunities for alternative crops in the upper Midwest (Olmstead, 2008; Fausti, 2015; DeLonge et al., 2016). These changes in cropping system diversity have also generated a set of

socioeconomic repercussions. These include a decrease in the diversity of economic enterprises, and the erosion of both physical and knowledge infrastructures (Bell, 2004; Carolan, 2012). These infrastructures consist of tangible entities such as seed cleaning equipment, regional mills, and harvest machinery, as well as intangible ones such as generational knowledge and experience with alternative crops and systems (Sharp et al., 2002; Anderson, 2009; Brown and Schulte, 2011; Blesh and Wolf, 2014).

Understanding both biophysical and socioeconomic dimensions that effect the productivity and profitability of small grains presents a challenging realm of study. The perceptions of Iowan farmers with respect to cropping system diversity and socio-economic changes has been examined over time via the Iowa Farm and Rural Life Poll (IFRLP). The IFRLP is the longest running longitudinal survey on agricultural and rural life. Research completed using data from the IFRLP has examined the perceptions a group of Iowa farmers on subjects ranging from climate change to cover-cropping (Arbuckle et al., 2013; Arbuckle and Roesch-McNally, 2015). Other studies, focused on Iowa farmer practices and perceptions, have examined socioecological aspects of the use of alternative crops and systems, including attention to small grain production and its associated challenges (McGuire, 2013; Blesh and Wolf, 2014). Pertaining to organic systems specifically, survey and focus group-based research in Iowa and the greater US, has focused on using respondent answers in order to examine both farm/farmer characteristics and/or perceptions of management practices (Delate and DeWitt, 2004; Walz, 2004; Baker and Mohler, 2014, O'Connell et al., 2015). However, to date, no research has examined both the biophysical and socioeconomic factors that may be limiting the agronomic productivity and economic profitability of organic small grains production in the Upper Midwest. Moreover, none have examined farmers' perceptions of these factors.

Our goal was to determine which factors may be most limiting organic small grain production in Iowa. In order to do this, we examined the variance around a set of biophysical, socioeconomic and institutional factors related to the production and profitability of organic small grain crops, and farmer perspectives on each of these factors. The factors investigated were deemed important to both the production and the economic viability of organic small grains. They included grain yield and quality, soil and crop management, weather and pest-related issues, in addition to economic considerations, such as market(s), and institutional limitations, such as the presence or absence of extension support and publicly-funded crop varietal development. The complete list of these factors is presented in Table 2.1. To examine these categories, we used a transdisciplinary, mixed-methods research approach drawing on insights and tools from agronomic and sociological disciplines, and deploying qualitative and quantitative data collection methodologies, specifically in-field agronomic measurements, surveys and focus groups. Analysis relied upon both quantitative and qualitative approaches. The methods and materials used to select farmers and collect data related to each factor, a results and discussion section that delves into each in greater depth, and a conclusion are presented below.

Methods and Materials

In this study, the population of interest was organic row crop farmers growing small grains as a part of his/her rotation. A sample frame was assembled from lists of certified organic growers acquired from the Iowa Departmental of Agriculture and Land Stewardships (IDALS) and the Iowa Organic Association (IOA). The total number of growers certified by or accounted for under both agencies was 154. The list was filtered to exclude those potentially not involved in small grains production such as specialty crop and livestock-only farmers. The remaining list of 114 farmers was segregated by using two interstate highways to create four quadrants of the

state (Fig. 1). Each year, these lists were randomly ordered within a quadrant. The minimum number of farmers in a given quadrant, after randomization, was 20. As such, invitation letters were sent out to 20 from each quadrant, so as to have equal sample sizes from which to draw. This letter explained the goals of the research, the extent of farmer involvement and the honorarium amount for those able to participate. Follow up phone calls were made to farmers that listed phone numbers on the IDALS/IOA aggregated data base. In 2014, 19 farmers agreed to participate and in 2015, 22 agreed to participate, resulting in a sample of 41 discrete farmers/farms over two years. While this sample size may seem small, it represents approximately 70% of organic farmers growing small grains over 2014 and 2015 (Agriculture Marketing Service, 2016). Our research protocol was approved by the Institutional Review Board through Iowa State University.

Three distinct types of research activities were conducted with the selected farmers. During the actual growing season, **field research** consisted of periodic visits to the farmers and their farms to collect biophysical data related to small grains production. Additionally, **surveys** were given to farmers during the growing season to collect information on historical and in-season management of small grains. At the end of each season, **focus groups** were held to discuss in-season observations and elicit feedback from participating farmers.

Field research

The purpose of in-field measurements was 1.) to collect data related to agronomic factors such as crop density soil fertility, and scout for pest pressures 2.) to collect grain samples and 3.) to receive in-season feedback from farmers about specific observations and/or production challenges. In each season, three visits were made at each farm.

The first visit entailed taking crop density measurements using PVC quadrats (0.25-m^2) at eight randomly chosen points in each sampled field, making sure to stay at least 5 m from field borders. Mean field size was approximately 13 ha (SD = 9). Quadrats were placed on the ground so that two crop rows were captured. Quadrat widths varied to account for different widths in grain drills. When farmers indicated that grain had been broadcast seeded instead of drilled (n=2), the quadrat used to measure a 15-cm row spacing was used. Small grain plants were removed from the soil within quadrats and counted. Soil samples were taken at each of these same eight points by walking in a circle (radius = 2.5 m) around each point and extracting six cores at a depth of approximately 15 cm. These six cores were mixed together to form one sample. These samples were submitted to the Iowa State University Soil and Plant Analysis Laboratory center in order to test for phosphorus (P) and potassium (K) (Mehlich 3), organic matter concentration (OM%) (combustion) and pH levels (1:1 gravimetric method). The sampling period in both years extended from the end of May to early July for the first visit. The second visit was used primarily to scout fields for pests and receive mid-season feedback from the farmers. These visits occurred from July into mid-August in both years. A third and final visit to each site was made to collect a one-quart sample of grain produced from the sampled field and receive any feedback from the cooperating farmers. These visits occurred from late September to late-October in both years. Grain samples were analyzed for factors most highly related to small grain marketability; test weight, and ß-glucan and protein concentration. Test weight measurements were conducted using a DICKEY-john Grain Analysis Computer model number 2500 (Auburn, IL, USA), and ß-glucans and protein grain concentrations were determined using the AACC method 32-23.01 (mixed-linkage ß-glucan) and the AACCI method 46-30.01 (Dumas

combustion method) respectively. The third visit also served as an opportunity to remind cooperating farms about focus groups that would occur after the conclusion of grain harvest.

Surveys

Surveys were given to farmers in order to obtain information about farmers' past and in-season management practices as they related to small grains. Question types included open-ended, as well as different types of multiple choice (e.g. "select all that apply" and "select one"). Surveys supplemented field research by asking questions that helped to clarify agronomic practices and collect data on farmer perceptions.

The first survey (S1) contained questions about small grain management and marketing/end-use history (i.e. prior to the year in which we took measurements). This included, but was not limited to, details on what small grains were grown, where small grains fit into crop rotations and fertilization practices (Appendix 1). We also included two open-ended questions about what challenges farmers had faced with respect to the growing and marketing of small grains (Appendix 1, questions 14 and 18).

The second survey (S2) was similar to the first, but specific to the cropping year in which we sampled (2014 or 2015) (Appendix 2). Additionally, the second survey included a "select all that apply" multiple choice question about yield constraints and two open-ended questions, which asked farmers how both yield and profitability might be improved with respect to small grains (Table 2.2).

Surveys were given to each cooperating farmer over the course of the farming season. S1 was delivered either to the cooperating farmer personally or placed in his/her mailbox for completion. Follow-up calls were placed (within one week) to all farmer cooperators as a

reminder to complete the survey. We collected S1 from farmers during our second field research visit and either handed or placed S2 in his/her mailbox again. Similarly, follow up calls were placed (within one week) in order to remind farmer cooperators to complete the survey. S2 was collected from farmers during our third field research visit (during which grain samples we collected). Because grain sales can take place months after grain is harvested and stored, we did not ask for economic data on our surveys. We informed farmers that we would make reminder calls, during the winter after the specific cropping season, to determine if/when a grain sale had been made and the value of the grain at that point.

Both surveys were constructed in Google forms, printed out, handed/delivered to farmers and were then completed as hard copies. Data was manually entered from the hand-written surveys into the electronic version. In order to minimize measurement error, all surveys were entered manually by three separate individuals. Any processing errors were rectified via a comparison of the three distinct sets using practices recommended in Biemer, 2010. Summary statistics from the survey data (mean, standard deviation, and percentage values) were all calculated using the R statistical software version 3.2.1 (R Core Team, 2015). Open-ended answers to survey questions were coded to correspond to our preconceived categories of interest (Table 1). Coding was performed manually, drawing on insights gained from Cho and Lee (2014), and using ideas and methodologies taken from both grounded theory and qualitative content analysis approaches in order to organize survey data into conceptual categories.

Focus Groups

Focus groups (FG) were used to collect additional qualitative data on farmer perceptions about small grain production and economic viability by providing a space in which farmers would feel comfortable sharing their reflections on the past growing season, in addition to

general thoughts on challenges related to small grains production and marketing. The themes explored and questions asked in the focus groups were structured around our preconceived categories of interest (Table 2.1).

During the focus groups meetings, data, related to our preconceived categories, were shared using a presentation that consisted of information explaining the general structure of the study and details specific to the particular cropping season in which the meeting was held (either 2014 or 2015). The presentations were fairly short (approximately 25 slides), allowing ample time for farmer responses and discussion. Our preconceived categories were each discussed using two to three slides to present data from the study in addition to relevant literature and extension materials when necessary. Additionally, at the beginning of each meeting, participants were encouraged to ask questions and/or add comments as/when they saw fit. Our objective was to use the presented materials as a catalyst for participant feedback. Focus group meetings were all approximately ninety minutes in length.

Focus groups were held, in both years, the winter after the cropping season in which samples were taken. Cooperating farmers were notified about the focus groups during the third site visit. Follow up phone calls were made to all cooperating farmers with specific time and site details. Cooperating farmers were encouraged to invite other farmers and farming partners to the focus group meetings. In each year, we held four focus group meetings in each quadrant of the state at a location within reasonable distance of cooperating farmers. Over two years, we held eight focus group meetings with a total of twenty-six farmer cooperators and five farmers not involved in the observational study (n=31). Participation in focus groups ranged from three to eight individuals per session. Focus group meetings were recorded, transcribed, and coded at a

later date. The same methodology and categories used to code survey data was used to code focus group transcriptions.

Results and Discussion

The results and discussion section is ordered by factor (as presented in Table 2.1). Data from field measurements, where applicable, are presented first, followed by survey results and quotations taken from surveys and focus groups. Quotations from survey responses and focus group transcriptions are annotated so as to identify the farmer who responded with a number and its corresponding data source; for example, **F1/S1**, would represent a quotation from farmer 1 taken from the first survey.

Soils

Soils and their management represent a fundamental contributor to the productivity of agricultural systems (Karlen et al., 1994; Ball et al., 2005; Bennett et al., 2012). Organic certification guidelines prevent the use of synthetically derived nutrient sources (USDA AMS, 2002). As such, soil fertility management in organic systems can often be a limiting factor in crop production (Stockdale et al., 2006; Watson et al., 2013). Our field measurements aimed to characterize the range of soil fertility levels and farmers' perceptions on the management of soil fertility with respect to small grains.

Mean and standard deviation values based on analyses conducted on soil samples taken from farmer cooperators' fields are presented in Table 2.3. Fertility thresholds used for the purposes of this study represent Iowa State University Extension guidelines that are most applicable and readily accessible in this instance (Mallarino et al., 2013). Based on these fertility level recommendations, we found that 18% and 42% of sampled fields were within the low range of P and K soil nutrient concentrations respectively (Mallarino et al., 2013). Other edaphic

factors, such as pH and organic matter concentration, are also presented in Table 2.1. The degree to which pH and organic matter levels may be affecting small grains production would be difficult to determine, given the myriad confounding factors in our study. In general, the small grain crops in this study are tolerant to a fairly wide range of pH, similarly organic matter levels are not sufficiently low to warrant concern with respect to production constraints (Wiersma et al., 2005).

Only 46% of farmers reported the use of an organic amendment. Of this group, 20% used an amendment with defined quantities of P and/or K, while 80% applied a low analysis amendment such as manure with bedding. Growers were also aware of the fact that excess fertilization, pertaining primarily to nitrogen (N), of many small grains can result in lodging, a phenomenon in which a crop stand is flattened by a combination of the excess fertilization, weak stalks, heavy grain and strong rain and/or winds. Practically speaking, lodging makes combine harvesting challenging and usually results in greater yield losses as well (Berry et al. 2004).

In response to the open-ended question about ways to improve small grain production, 14% of sampled farmers mentioned fertilization, while only 2% mentioned this in the open-ended question asking about ways to increase profitability. Similarly, only 12.5% of farmers selected low fertility as a major constraint to yields, but 41% did select lodging as major constraint to crop yield making it one of the top two factors chosen from the list of yield-constraints (Fig. 2.2). A slightly higher percentage selected poor seedbed preparation as a major constraint to crop yield (Fig. 2.2). Focus group participation helped to highlight issues related to both over-fertilization and lodging, in addition to economic considerations:

F1/FG ***You can get the fertility too high. You sneeze and they'll fall over.***

F2/FG ***I used to put chicken litter on, I couldn't pencil it out. It was costing $150 an acre and you don't get the yields.***

Small grain choice

Choice of small grain species (i.e. oat vs. barley) and type (spring vs. winter wheat) is important feature of production and potential profitability. Small grains vary in their yield potential, market value and level of farmer preference and growing experience. The combination of these factors is what determines what small grains are grown by a given farmer in a given area.

Just over two-thirds of the farmers in this study were growing oat, followed by wheat (both spring and winter) and then barley, triticale and rye (Fig. 2.3). One question on S1 asked farmers, "What small grains have you grown?" to which all respondents (100%) answered that they had grown oats. This was followed by rye (approximately 53%), barley (51%), winter wheat (44%), spring wheat (34%), and finally triticale (24%).

A variety of reasons have led Iowa farmers to raise one small grain over another and our results are certainly influenced by these. For example, historically speaking, oat was a major crop in Iowa, due to its use as feed for horses prior to wide-scale tractor adoption. Additionally, before the mass fabrication and use of synthetic N fertilizer, small grains were grown as a nurse crop to establish forage legume stands both for animal feed and nitrogen (Anderson, 2005). Presently, a large mill in the NE part of the state processes, primarily, food-grade oat processing. While the mill also deals with other food grade small grains, the bulk of their business is in oat processing. This provides a substantial incentive for farmers to focus on oat production,

especially if they are interested in more profitable food grade markets. One farmer in the focus group reinforced this in describing his switch from barley to oat:

> **F3/FG** ***I got away from oats for quite a few years and went to barley. When the mill started raising the prices on contracts it looked attractive to try it again. It worked out this year, I hope it does next year. My small grain production, I've been doing half oats, half barley. I would have been $100 an acre better off doing just oats these past few years.***

Crop rotation

Crop rotation has considerable effect on crop, soil and pest dynamics (Karlen et al., 1994; Ball et al., 2005; Bennet et al., 2012). Within organic systems, crop rotation is both an essential tool for managing these three factors as well as a "codified" tenet within USDA organic certification guidelines (USDA AMS, 2002; Seufert et al., 2017). Small grains both impact and are impacted by the crops precding and succeeding them in a rotation. Surveys and focus groups were used to determine crop rotations, and to assess farmers' reasoning around where small grains are/should be placed within a crop rotation.

Both surveys showed that, within our sample of farmers, small grains were preceded (in a rotation) about half the time by corn, and the other half by soybean. A small percentage of small grains were preceded by another small grain (Fig. 2.4). Most regional extension recommendations for small grains advise against planting after corn within a rotation. Corn is an alternate host for different species of a fungal pathogen known as head blight or scab (*Fusarium* spp.), which can be severely detrimental to barley and wheat but less so to oat (Wiersma and Bennett, 2001; Wiersma et al., 2005). A corn crop can also produce a large amount of light colored residue with a relatively high carbon to nitrogen ration. This can mean that soil conditions after corn can be slower to warm and to mineralize organic sources of nitrogen, both

of which can pose challenges to cool-season planting windows and the fertility considerations of an organic small grain crop (Wiersma and Bennett, 2001; Wiersma et al., 2005; Chen et al., 2014). After presenting survey results about crop rotation in focus group meetings and supplemented with some of the afore-mention agronomic information, we explicitly asked farmers why they chose to plant a small grains after a given crop. We found cases in which economics was the driving factor in designing a crop rotation. One farmer shared the reasoning for his rotation:

> **F4/FG** ***We've tried growing soybeans and we can grow soybeans, but I've moved away from it, purely from an economic standpoint. What I do is take the net profit of my corn crop and my net income on oats. That's not a lot here but it's a two year average. If I'm going to introduce a third, it better bring that average up or there's no motivation to do it, purely from an economic standpoint. So that's what's probably guided us more so to a shorter rotation with corn-oats.***

We also found that the general practice of diversifying rotations with small grains was seen as a way to balance and manage crop yield, pests, and labor requirements. This was the case for many farmers, some of which are presented below:

> **F5/FG** ***You have to have certain things that aren't going to give you the income, to get the income from the high value crops.***
>
> **F6/FG** ***You have to have a long rotation in organics, to control weeds.***
>
> **F7/FG** ***You have to stay with your rotation. You have to be diversified, one year one thing goes well, another year, another thing.***
>
> **F4/FG** ***You get all your oats in early, you're done with a lot of acres. Then you plant your corn, cultivate it, you harvest it…from a work load standpoint, it's beautiful too.***

Seeding rates/crop density

Crop density, the amount of crop plants in a given surface area, can affect grain yield and quality, as well as the success of the underseeded forage legumes and the production of weed

biomass (Willey and Heath, 1969; Mohler, 2001). Crop density is manipulated by farmers via seeding rate, the quantity of grain planted over a given surface area. We collected data related to both seeding rates (via surveys) and crop densities (via field research).

Our field research results from crop density counts are presented in Table 2.1. Optimal crop densities have been explored via experimentation and are shared in extension guidelines within the region (Wiersma and Bennett, 2001; Wiersma et al., 2005). To use oat and winter wheat as examples, optimal densities per extension recommendations in Minnesota are approximately 312 and 237 plants m^{-2}, respectively. Field measured densities for oat a wheat, respectively, were 263 and 138 plants m^{-2}. Additionally, standard deviation around these two densities were 105 and 44, respectively, demonstrating a sizeable variance. Accordingly, surveys showed a wide range of seeding rates (Table 1). Using oat, specifically as an example, seeding rates ranged from 63 to 179 kg ha^{-1}.

In the US, it is common practice to plant small grains by the bushel, a volumetric standard, which is approximately 0.035 m^{-3}. In both S1 and S2, questions asking about seeding rates were done so using a bushel standard (Appendices 1 and 2, questions 6 and 7, respectively). All of the farmers growing oats (n=28) referenced this bushel standard on S1 and S2, but none of the farmers growing either spring or winter wheat (n=8) and one farmer growing rye did. In these cases, farmers specified use of a mass-based seeding rate (kg ha^{-1}) on the survey itself. In either instance, small grains were planted without a consideration of the variance in actual seed quantity per volume/weight. This can create sizeable differences in plant population densities from year to year, as the same bushel or even kg ha^{-1} seeding rate may result in distinct quantities of individual seeds. Some focus group responses spoke to the lack of fine-tuning around determining a small grain seeding rate:

F10/FG ***There's not a lot of objective perspective on this. It's all passed down from the generation above us. It's all just go out and try.***

F2/FG ***I raise seed oats and the house called me asking for a recommendation, they were always saying two bushel to the acre was enough. I said, 'I really think you need to go heavier', they weren't sure either.***

F9/FG ***We used to just dump the oats in the back of an end gate seeder and take off. Well, once we started using the drill it was recommended using three and a half, four bushels an acre.***

Low planting rate was one of the answer options on our "select all that apply" multiple choice question on S2 (What do you consider the biggest factors were constraining your organic small grain yield this year?). 12.5% of the farmers selected this answer option (Fig. 2.2). Approximately 15% mentioned crop density or seeding rate manipulation as a potential area of improvement in S2. One farmer, during the focus group meeting, mentioned the potential need to alter seeding rates based on test weight (density) of oat.

F8/FG ***I guess when the test weight is higher, I should be planting more seed.***

While another expressed his belief that seeding rate was not a major determinant in grain yield:

F9/FG ***It's like beans, you can have good yields with beans even if you don't have a good stand. I would say the stand count isn't that important as long as you've got a minimum there.***

Other farmers shared experiences on how altering crop density can have both positive and negative repercussions.

F2/FG ***Whenever I do my oats, I double drill them. I left a single strip when I first did it. I started doubling drilling it, the yields weren't any different but the weed yields were.***

F11/FG ***The thicker your stand the harder it is on the (alfalfa) seeding.***

F12/S2 ***Seeding at a higher rate may increase oat production, but maybe at a detriment to the nurse crop below.***

Underseeding(s)

Small grains are often grown to generate some value during the establishment year of a forage legume crop. Planting small grains with an underseeding, however, may present challenges to both crops. Competition for resources such as light, water and nutrients can limit both grain yield and quality, and forage plant density, growth and subsequent biomass (Sheaffer, 2005).

The topic of intercropping or underseeding came up in surveys and focus groups and was highlighted in the selected focus group quotations above (**F11/FG** and **F12/S2**). Among farmers in our study, 89% reported that they presently grown small grains as an intercrop with a forage grasses and/or legume or green manures including legumes, such as alfalfa (*Medicago sativa*) and clover species (*Trifolium* spp.), and grass species, such as bromegrass (*Bromus intermis* L.), fescues (*Festuca* spp.), orchardgrass (*Dactylis glomerata* L.), and timothy (*Phleum pretense* L.). The economic importance of the forage crop was a theme among the farmers with whom we spoke:

F1/FG ***One of the main reasons I grow oat is to establish a new seeding [of alfalfa], the hay crop can be a very valuable organic crop. Several years ago I sold bales at over $300 a ton. 5 and a half ton per acre. That's better gross than conventional corn and soybean, not quite as good as organic corn.***

F13/FG ***I would rather have a seeding cutting of alfalfa than another oat or two.***

However, we also found farmers were interested in knowing more about potential antagonisms between the small grain crop and the underseeding of choice. The following are

responses to the question, “How do you think that you could increase your organic small grain yields?”.

> **F14/S2** ***I sometimes question if it would be better to not underseed or inter-seed legumes into the small grain. Then seed the legumes in the fall after the small grain were harvested***.
>
> **F15/S2** ***A heavier planting and no intercrop could work.***
>
> **F16/S2** *I* ***plant barley for a cover crop for my new seeding - alfalfa, clover etc. If I put too much barley or oat seed down it can kill the new seeding! But I would like bigger yields!!***

Planting date

Planting date is of great importance to small grains production. Small grains, whether they are fall or spring sown, have optimal temperature ranges that are lower than corn and soybean (Wiersma and Bennett, 2001; Wiersma et al., 2005). Both small grain yield and quality can be compromised by high temperatures that come with mid-summer conditions, as such planting during an optimal window is an important management practice (Wiersma et al., 2005).

Farmers involved with this study were located on a latitudinal gradient that ran from almost the Minnesota border (to the North) and Missouri (to the South) (Fig. 2.1). Sowing dates, accordingly, were earlier at southern latitudes and later at northern latitudes. Our main goal in collecting information about planting dates was not to determine the causal effects of this factor on small grain yield and quality, but rather to understand what informed this practice and farmers’ perceptions of it. Our “select all that apply” multiple-choice question from S2 found that 12.5% of surveyed farmers selected delayed sowing as a major constraint to yield (Fig. 2.2). A quarter of responses within the open-ended question from S2 (*“In what other ways could you*

increase your organic small grain profitability?") identified planting date as an important tactic to improve small grains profitability.

Some of the focus group responses mentioned sowing date and some of its associated challenges and trade-offs.

> **F17/FG** ***Planting dates have been later. We try and get in as early as possible but it's not always possible.***
>
> **F9/FG** ***We had neighbors who used to mud, and I mean mud, the oats in. But I don't like to work the soil any earlier than I have to. It's probably not the earliest possible day, but it's the one I'm comfortable with. We're ready with the seed when we need to be ready.***
>
> **F18/S2** ***Earlier planting would have helped, it's dependent on soybean harvest.***

While farmers were aware of the general negative effects of delayed planting, only one farmer from either survey responses or focus group participation, mentioned a quantifiable metric for measuring yield reduction over time. More so, this was an anecdotal account that had been passed down through social interaction with a fellow community member:

> **F19/FG** ***The old-timers used to say, for every day you couldn't plant oats, you'd lose a bushel.***

Weather

That weather is a major factor in crop production has been recognized with certainty for some time now (Smith, 1920). Prevailing weather conditions (the climate) are a major factor in determining what crops are grown and when field operations can take place, in addition to factors related to the quantity and quality of light and moisture, and their effects on soils and crops. The farmers from our study related this in both the surveys and focus groups.

Our “select all that apply” multiple-choice question in the survey was used to address sampled farmers’ perceptions of some of these moisture and temperature factors. Farmers were asked to select if rain events were too frequent/infrequent at time periods within the season, and if temperatures were either too warm or too cold (Table 2.2). The general pattern of response shows that an excess of precipitation, at different times in the season, was selected as a major constraint more than a lack of adequate precipitation (Fig. 2.2). Temperatures being too cool were more selected than temperatures being too warm (Fig. 2.2).

Focus groups discussions also demonstrated farmers’ acute awareness of climate as key determinant, and the perceived weather-related challenges specific to small grain crops.

> **F20/S1** ***The weather seems to determine the quality more than anything.***
>
> **F21/S2** ***I'm convinced weather is the main contributing factor. If oats can be seeded in a timely manner and appropriate amounts of moisture are present and temperatures do not climb too quickly, the potential for good oat crop is there.***
>
> **F22/S2** ***Being a short season crop, oat yields are very dependent on the weather. Oat yields were extremely good this year because of near perfect weather.***
>
> **F9/FG** ***I was a little disappointed with the variety we had, they went down. We had two wind storms, they did come up, some of them. But, if you looked into the sun in the afternoon, looked to me like there was a lot of empty kernels. I was upset with them for most of the year, it came out fine for the weather we had. I think a lot of years the problem we have is heat during grain fill. Oats are more sensitive than corn and beans are to the weather, for sure.***

Pests

Pests include insects, pathogens and weeds. Organic systems, in which use of synthetic pesticides is restricted, can be greatly affected by these three pest categories (Lotter, 2003; Liebman and Davis, 2009; Zehnder et al., 2007). We did not directly measure pest incidence and/or severity with our field research but did make general field observations and receive in-season feedback from the participating farmers, which were sometimes referenced in focus group

meetings. Surveys and focus group discussions were used to more clearly identify farmer perceptions on pest issues.

Weeds were a major feature of survey and focus group responses. That this topic is of constant concern to organic producers has been commented on both generally and with respect to small grains (Taylor et al., 2001; Walz, 2004; Liebman and Davis, 2009). Both surveys and focus groups provided insight into farmer perspectives on this theme. Weeds were selected as a major constraint in our "select all that apply" multiple choice question, with annual weeds being the most selected constraint tied with lodging (Fig. 2). Open-ended questions at the end of S2 mentioned weed control as a potential source of productivity improvement in approximately 12% of all responses.

Disease can also affect oat production in Iowa, particularly under organic constraints, which do not allow the use of synthetic fungicides (USDA Agricultural Marketing Service, 2002). In general, growers were aware of disease pressures but were clear that disease was not a problem for all farmers in each cropping year. During our second round of site visits, in both years of the study, we did scout fields and saw incidences of oat rust. Diseases were also mentioned in the focus groups. Farmers did not mention disease in open-ended questions in either survey and disease was only selected by 12.5% of the farmers in our multiple-choice question. Insects were not mentioned as a possible constraint to production. Insect pests were not mentioned in any of the open-ended questions in either S1 or S2, and were not selected in our "select all that apply" multiple-choice question (Fig. 2).

Focus groups further emphasized the gravity of weed management as a fundamental concern of the farmers with which we worked:

F23/S2 ***We had some other oat and succotash fields that were weedy due almost entirely to giant ragweed. We could increase our yields in these fields if we had better weed control in previous years.***

F16/S2 ***It would have helped to have better weed control in our corn crop prior to barley.***

F25/S2 ***We are going to start to leave alfalfa in longer to help control weeds in the crops that come after.***

Grain yield and quality

Grain yield and its associated quality are the primary determinants of the economic viability of a small grain crop. We asked farmers to report yields and collected grain samples to analyze grain quality so as to have an idea of the variance around those two metrics.

Grain quality differs by small grain. One metric, test weight (kg m^{-3}), is the most commonly used parameter by the milling industry because it is related to the efficiency with which grain can be milled (Seibel et al., 2006). Other grain quality metrics, such as ß-glucan and protein concentration, are related to human health and baking objectives for oat and wheat, respectively (Wieser, 2007; Daou and Zhang, 2012). We chose to measure and highlight these grain quality metrics because they have sizeable impacts on market class and profitability for the two small grains mentioned, which also happen to be the most widely grown within our sample of farmers/farms. Standard US bushel weights for these two crops are approximately 364 and 682 kg m^{-3} for oat and wheat, respectively. For wheat, this test weight standard is adequate for sale into a food grade market; however, for oats, millers desire a test weight of ≥ 432 kg m^{-3} and will purchase grain at a discounted price until a lower threshold of 409 kg m-3. With respect to ß-glucan and protein concentration millers prefer ≥ 4% and 14%, for oat and wheat respectively.

Mean values and standard deviations for grain yield and grain quality are presented in Table 3 for each crop we sampled over the two years of the study. Based on the harvested samples we collected from farmers, mean test weight for oat was 375 kg m^{-3} (SD = 51) and 584 kg m^{-3} (SD = 51) for wheat. Mean values for oat ß-glucan and protein concentration were 4.9% for oat, and 9.3% for wheat. Mean values of samples for oat grain quality, with respect to food grade production, were below the lower threshold for test weight and above the threshold for ß-glucan. Mean values of samples for wheat, with respect to food grade production, were both suboptimal for both test weight and protein concentration.

Surveys also showed that the farmers in the study were acutely aware of both grain yield and grain quality challenges. The following represent answers to the question, "What challenges do you have marketing oats" from S1:

> **F/S1** ***Oats need to be at least 36 pound test weight (409 kg m^{-3}). If not no one wants them - very hard to sell light oats.***
>
> **F/S1** ***Market for light test weight.***
>
> **F/S1** ***I do not market oats because of low test weight issues.***

Economics

Small grains are either sold, as food, feed and/or seed or they are used on-farm for the latter two options. The profitability of small grains themselves is almost always highest when selling into a food-grade market. However, this may or may not be the goal of a farming operation. Surveys and focus groups were used to ascertain how farmers determine the economic value of a small grain crop.

Over the two years of the study, a little over 40% of cooperating farmers actually sold grain. Of this group, 17% sold their crop to be marketed the following year as organic seed via

two regional seed houses. The other 83% sold their crop into a feed or food grade market. A little over a quarter of this latter group (the 83%) was unable to sell into organic markets and ended up selling their crop into conventional feed grade markets. Of all farmers who presented either receipt of sale or responded to having made a sale, most were oat (67%), followed by wheat (22%), and rye and triticale (both 5.5%), somewhat mirroring the breakdown of small grain use by farmers (Fig. 2.3). Average prices received for the small grain crops sold into organic markets were \$0.40, 0.45, 0.47 and 0.25 kg^{-1} for oat, wheat, rye and triticale, respectively, compared with conventional prices (for oat and wheat), which were \$ 0.25 and \$0.13 kg^{-1} (Economic Research Service, 2017).

Food-grade small grains offer the highest price premiums to farmers, but that not all farmers sold into this specific market. In fact, survey results concerning farmers' intended end-use showed that 57% of all those surveyed planned to use the small grain on-farm as either seed or feed, while 43% had the intention to sell to either a seed house or grain-processor as a food grade product (Fig. 5). That such a large percentage of our sampled group chose to use grain as feed may be related to the high level of livestock integration seen in this group (Fig. 6). Having a livestock enterprise serves as a considerable contingency plan if/when a food grade small grain cannot be produced. This is especially true as limited organic feed-grade markets exist for small grains in Iowa forcing many to sell into conventional markets, where possible (e.g. F27/S2 above).

Opinions and perceptions around market limitations ran the gamut within our sample group. Some were positive about their economic situation with respect to small grains.

F25/FG ***Marketing is not an issue, we have good local markets and neighbors.***

F4/S2 ***Things are going well.***

F9/FG ***If you get over six bucks for oats, yea, it works.***

While others were more negative about the situation.

F26/S2 ***We don't have a lot of options.***

F27/S2 ***We end up having to sell them on the livestock market - conventionally.***

One farmer iterated the importance of having livestock as a backup market for low-quality grain.

Q39 ***We have a good use for our rained on oats and hay, with the feed lot.***

While another mentioned looking to other alternative local markets in order to improve the profitability of small grains but also mentioned the associated challenge related to this.

Q41 ***If you could get in with the livestock operations, the organic layers, but that's a lot of legwork to get involved with those guys.***

Another expressed some of the challenges of having to deal with the uncertainty of moving a lower quality product to grain-processing facilities in often distant parts of the state.

Q40 ***Well, it's two hours up there. I took my transition oats in, and they were right around that thirty-two pound mark (364 kg m^{-3}). And usually you go up to the facility and you pick up a pound or two (11-23 kg m^{-3}). I was just auguring them, if I vac' them, maybe better. They say if you can make thirty-five (398 kg m^{-3}), they can squeeze you in otherwise, they're going to have to sell it as a feed. I'm thinking about doing something to make it work and maybe I need to screen them, that's what I may need to do. They told me at the time, they don't have a place for feed oats, and I'm going to have to take them back. I don't want to haul back. I say wait at least until they have a bin or a spot so I don't have to come back with them.***

Institutional limitations

The historical trajectory of both research and harvested area extent for crops and cropping systems is often shaped by research and development trends, which are themselves subject to the interests and goals institutions, such as land-grant universities and private agricultural businesses (Vanloqueren and Baret, 2009; Jacobsen et al., 2015; DeLonge et al., 2016). Within these institutions, research funding for alternative crops (e.g. small grains and forages) has dwindled over the past 40 years (Olmstead, 2008; Blesh, 2014). How and why institutional limitations may affect farmer perceptions and management of crops like small grains, is complex and difficult to measure.

Over the two years of the study, small grains were harvested for grain on approximately 24,000 ha in the state of Iowa. Certified organic small grain production during that same period was approximately 2300 ha. Respectively, these account for approximately 0.2 and 0.02% of the total row-cropped area of Iowa. Iowa State University extension materials on small grain production were last released in the early 1990s (Hansen 1992, 1994) and the last official small grain cultivar developed in Iowa, Baker oat, was released in 2006, but was grown by none of the farmers in the study.

Many of the farmers with which we spoke, expressed an interest in greater support for small grains research and development within Iowa. The bulk of the comments, from surveys and focus groups, on the role, or lack thereof, of institutional support focused on potential improvements and modifications to small grain cultivars. Some comments provided specific recommendations for potential improvements:

> **F9/FG** ***If you could shorten the maturity of oats that would help. Also breed the shorter plant, lodging is an issue.***

F10/S2 ***Shorter faster-maturing varieties.***

F30/S2 ***Varieties with better plant vigor.***

Other comments were more general and expressed frustrations with certain crops:

F14/S2 ***Improve varieties.***

F15/S2 ***I hate growing oats, find some good genetics.***

Lastly, one farmer, clearly and directly, expressed a sentiment that was hinted at by many in our focus group sessions. The farmer's comment helps frame one of the fundamental dilemmas with respect to small grains research and development and a considerable hurdle with respect to farmer perspectives as well:

> **F9/FG** ***You're not going to get funding to develop oats like you will corn and soybean because it's a low value crop. It doesn't have the uses that corn and soybean do. A hundred bushel (3.5 m^{-3}) oats is 3200 pounds (1.45 Mg), 200 bushel corn (7 m^{-3}) is 11,200 pounds (4.98 Mg). Don't waste money on it, leave that to states like Minnesota and South Dakota.***

Conclusions

Our goal was to determine which factors may be most limiting organic small grain production in Iowa. In order to do this, we examined the variance around a set of biophysical, socioeconomic and institutional factors related to the production and profitability of organic small grain crops, and farmer perspectives on each of these factors. We used tools and insights from both biophysical and social science research approaches to highlight these factors. Key agronomic factors such as adequate soil fertility and pest management were measured via field research, and observation, as well as reports from farmers via surveys and focus groups. In both instances, we found situations in which values (for soil nutrients) were suboptimal, and pest problems, primarily weeds, were recognized as major production challenges. Crop

density/seeding rates varied highly, and we are unable to draw any conclusions from this data. However, the range of values coupled with relevant cited literature indicate that while this may be a possible area of improvement gains may be marginal.

There was a fundamental recognition, from farmers in the study, of the necessity of having a small grain within an organic rotation irrespective of potential, in-season, economic challenges. Over half of the farmers dealt with this economic challenge by having a diverse farm organizational structure including livestock and/or by using grain as seed for subsequent production years. Those without these options shared their frustrations with the associated marketing challenges, especially when grain did not meet adequate quality for entry into a food grade market. Very few farmers expressed direct frustration about the role that institutions can/cannot play in the improvement of small grains. However, the excerpted quotation above (F9/FG) plus those from the crop rotation section (F4-7/FG) about the role of, and tradeoffs associated with, small grains portray a general acceptance of small grains' current status as low input crop; one that may less profitable relative to others in a rotation, but is vital to the long-term functioning and profitability of organic row crop systems.

Lastly, coming to clearly understand the complex web of causality among biophysical, socioeconomic and institutional factors is a distinct challenge; one which eclipses the purview of this study. However, our examination of diverse and complementary data sources, pertaining to the different dimensions mentioned above, does create a clearer picture of production systems for organic small grains than existed before. The benefit of this is in the formulation of subsequent hypotheses and research, which, instead of providing descriptive analyses (like our study did), can provide explanatory or even predictive analyses. Further research, be it agronomic, economic or sociological in nature, based on this work would have an a priori understanding of concrete

production limitations, as well as farmer perspectives and inclinations. Having a clearer idea of what limitations exist, from the field management- to the individual perception-level of organization, may go some way towards addressing challenges in a way that considers the myriad actors and structural elements required to improve the prospect for organic small grains in Iowa.

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Table 2.1 Summary of preconceived categories selected for the study, which we considered to be important determinants of both the production and economic potential of organic small grains. These categories shaped the structure of field research, survey questions and focus group sessions.

- Soils
- Small grain choice
- Crop rotation
- Seeding rates / crop densities
- Planting date
- Underseeding(s)
- Weather
- Pests
- Grain yield and quality
- Markets / end-use
- Institutional limitations

Table 2.2 Question themes and check-box options for "select all that apply" multiple choice as well as open-ended questions from Survey 2 of the study given to farmers in 2014 and 2015. The specific questions asked for the multiple choice questions was, “What do you consider your biggest factors constraining your organic small grain yield this year?

Question theme (S2)	Check box options
Weather	• too much early season rain • too much mid-season rain • too much late season rain • too much rain during harvest • to little rain early • too little rain mid-season • too little rain late season • temperatures too cool • temperatures too warm
Pests	• weed pressure (perennials) • weed pressure (annuals) • disease • insect issues
Other management challenges	• delayed planting date • poor seedbed • poor stand • planting rate too low • lodging • low fertility
Open-end questions (S2)	

- How do you think you could increase organic small grain yields?
- In what other ways could you increase your organic small grain profitability?

Table 2.3 Agronomic data on soil, grain and crop management metrics collected from field visits and surveys from farmer cooperators in 2014-2015.

	Small grain crop											
	Barley (n=2)		Oats (n=28)		Rye (n=2)		Spring Wheat (n=2)		Triticale (n=2)		Winter Wheat (n=6)	
Agronomic category	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Soil fertility metrics												
P (ppm)	39	17	34	29	n.a.[1]	n.a.	43	47	60	3	74	34
K (ppm)	199	81	175	56	n.a.	n.a.	246	118	252	42	193	37
OM%	4.8	0.03	4.8	1.2	n.a.	n.a.	4.2	0.5	5.4	0.4	3.5	1
pH	6.9	0.7	6.8	0.5	n.a.	n.a.	5.8	0.6	6.6	0.1	6.9	0.4
Crop metrics												
Seeding rate (kg ha^{-1})	121	18	108	23	112	12	137	18	105	5	121	15
Crop density (plants m^{-2})	108	79	263	105	n.a.	n.a.	311	145	59	0	138	44
Yield (Mg ha^{-1})	1.9	0.49	2.6	0.95	0.97	0.40	1.3	0.19	0.94	0	2.3	1.07
Test Weight (kg m^{-3})	418	52	375	51	517	79	491	51	455	16	584	51
Protein (%)[2]	n.a.	n.a.	13.7	0.6	n.a.	n.a.	n.a.	n.a.	14.5	3	9.3	3
ß-glucans %[3]	n.a.	n.a.	4.9	0.5	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.

[1] Data not available (n.a.). Not all samples were able to be taken at each farm due to the logistics challenges associated with working around farmer schedules.
[2]Protein concentration analysis was only performed on oat, triticale and winter wheat.
[3] ß-glucan concentration analysis was only performed on oat.

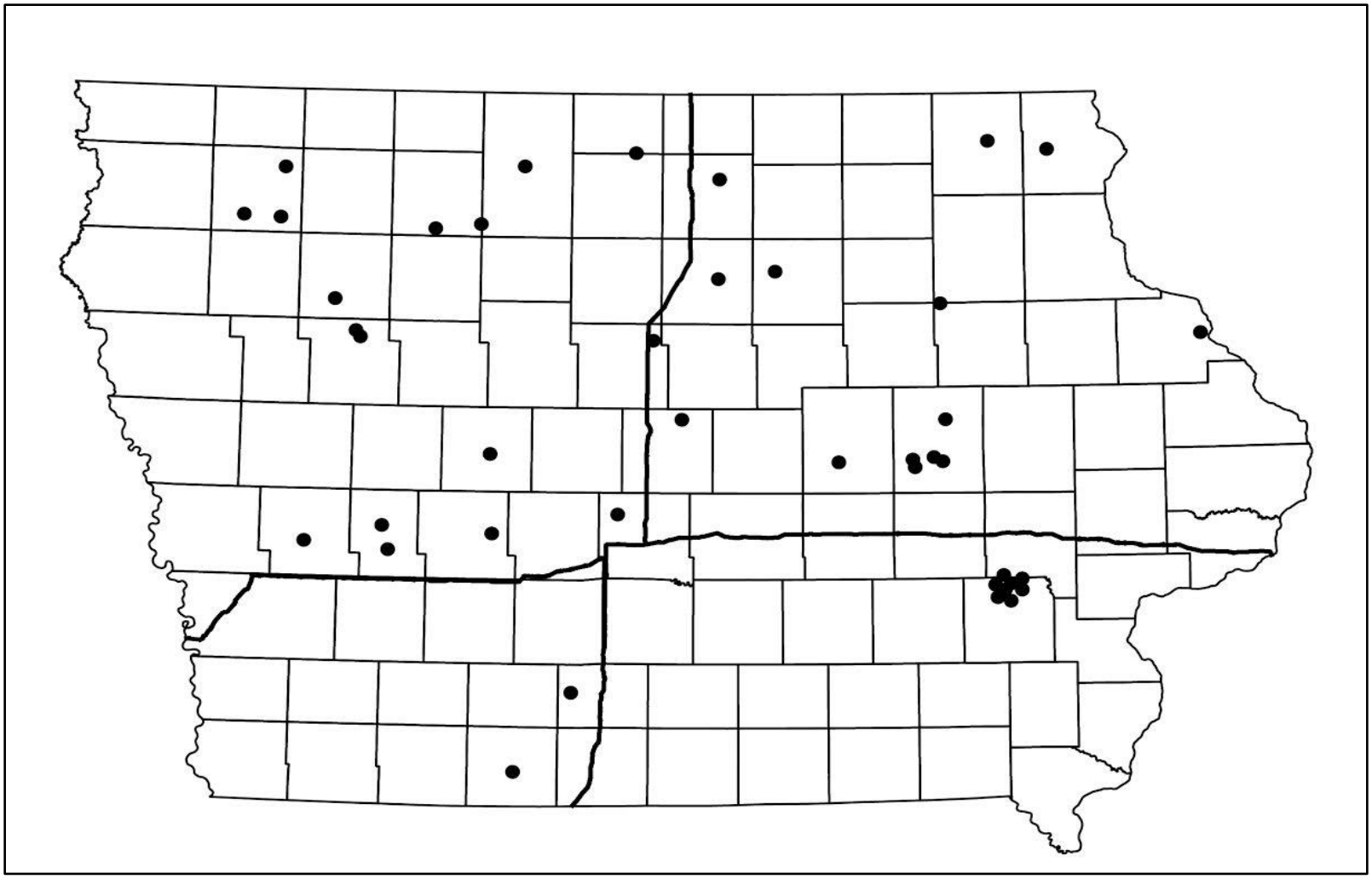

Fig. 2.1 Map of farmers/farm sites in Iowa from 2014-2015 study. Black lines are major N/S and W/E highways used to create quadrants of the state, from which farmers were selected for the study. Black dots represent farms sites visited over the two year study.

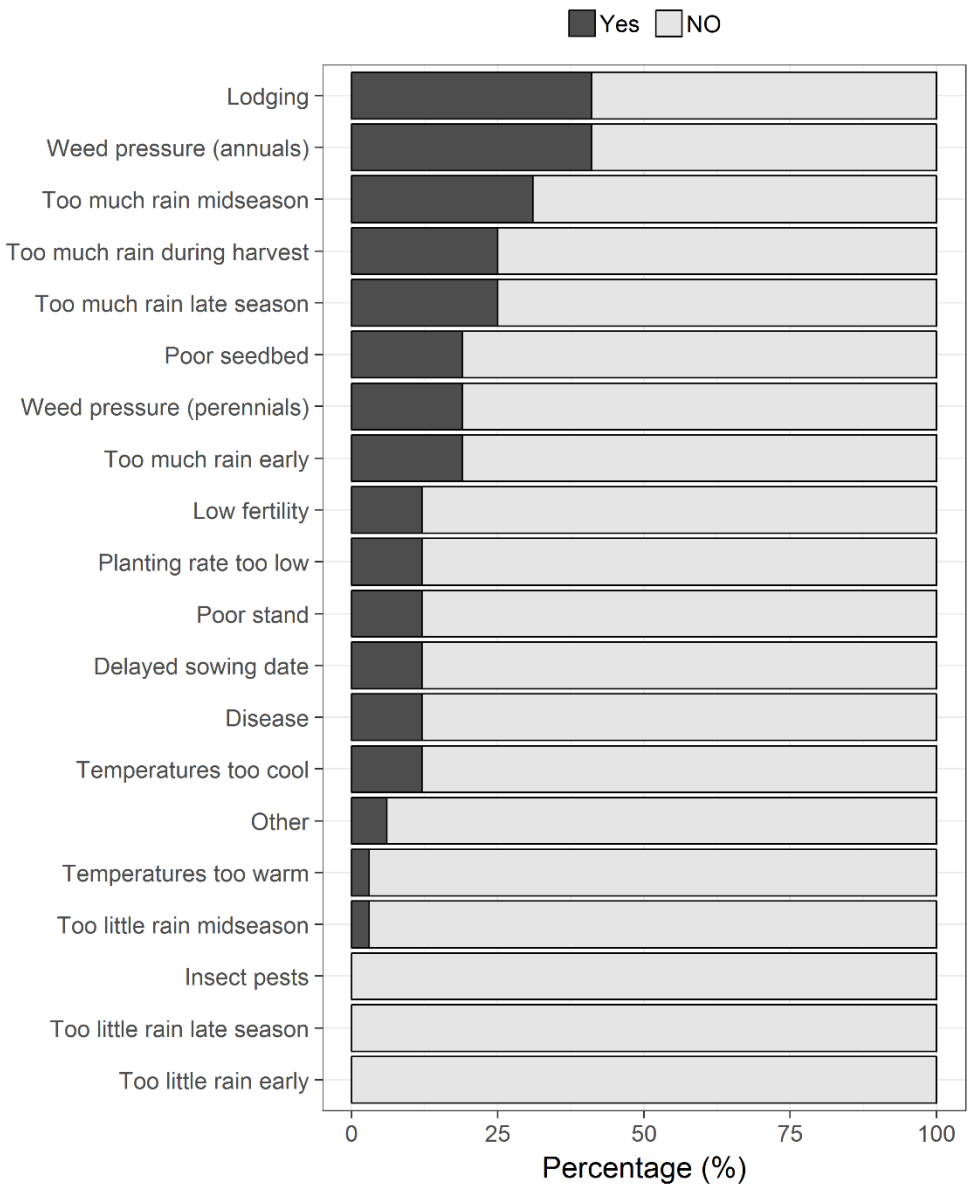

Fig. 2.2 Summary of responses for "select all that apply" multiple-choice question on Survey 2 (2014 and 2015). The survey question asked, "What do you consider your biggest factors constraining your organic small grain yield this year?", and provided a set of nineteen options (above) from which to choose. The figure displays the answer choices on the y-axis and percentage (%) on the x-axis. Dark grey bars represent the percentage of sampled farmers who selected one (or more) of the 20 answer options, light grey bars represent the percentage that did not select a given answer option.

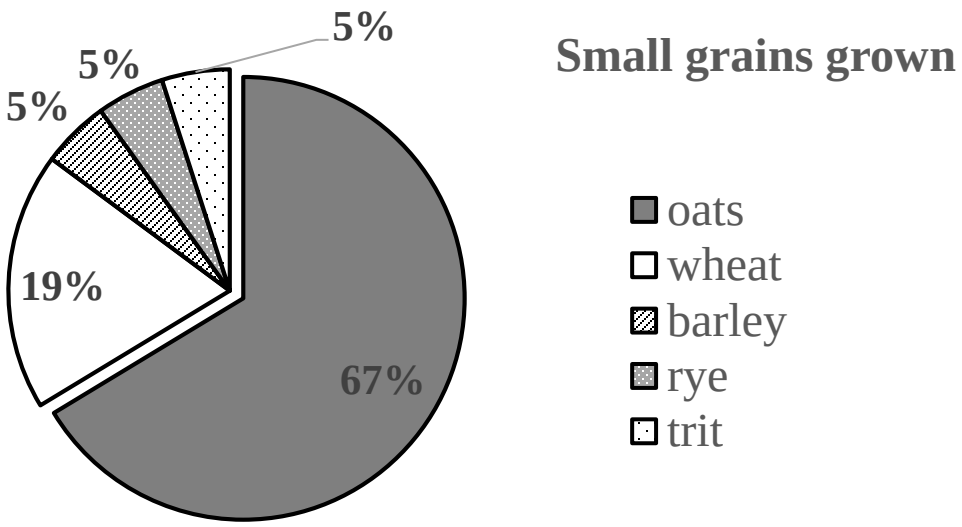

Fig. 2.3 Percentage of small grains grown by organic farmers participating in the study over 2014 and 2015 growing seasons.

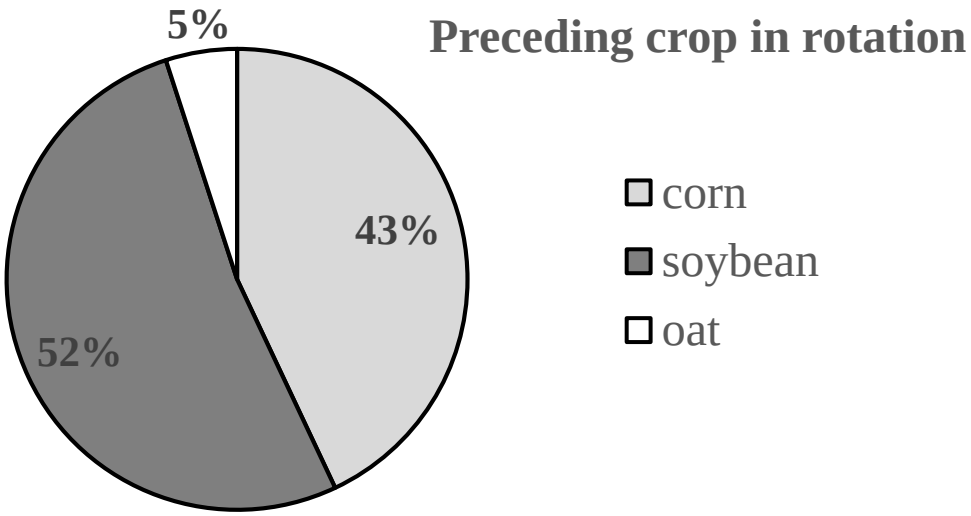

Fig. 2.4 Percentage of crop preceding a small grain within farmer rotations. Data reflect both historical and current practices of crop rotation sequence.

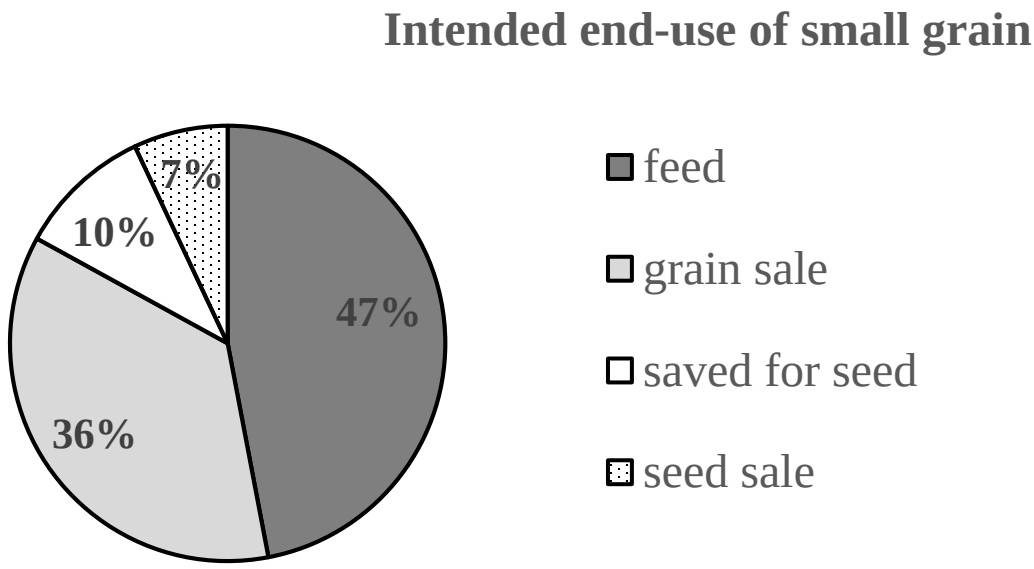

Fig. 2.5 Intended options for market/end-use for small grains for 2014 and 2015 growing seasons.

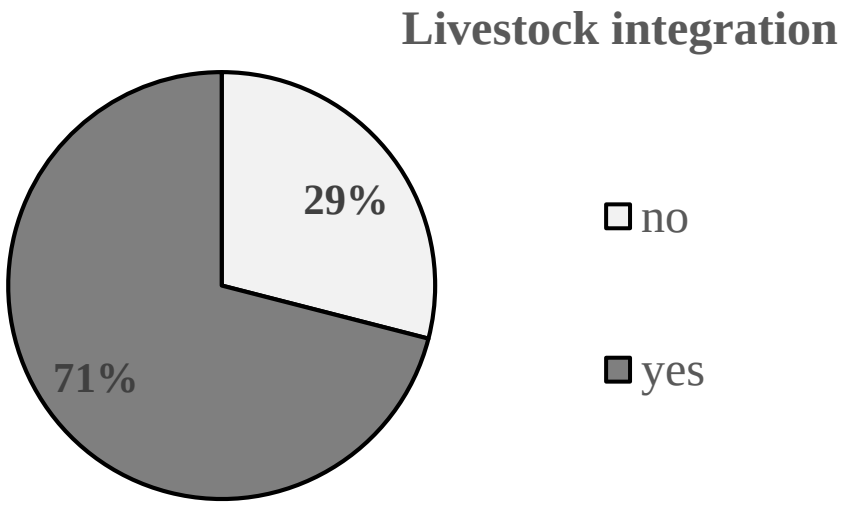

Fig. 2.6 Percentage of farmers from the study with an integrated livestock enterprise in addition to a crop enterprise in 2014 and 2015.

CHAPTER 3. USING ON-FARM TRIALS TO EXPLORE MANAGEMENT IMPROVEMENTS TO ORGANIC OAT PRODUCTION

Abstract

Small grains, such as oat, are an important part of organic row-crop systems in Iowa and the upper Midwest. They contribute value to operations from grain and straw, which can be sold and/or used on-farm. Oat is often used as a companion crop with which to establish forage legumes and is effective in suppressing summer annual weeds. Because the planting and harvest schedule of oat differs relative to corn and soybean, it also helps to distribute labor requirements more evenly across the growing season. However oat is a less profitable crop than corn or soybean. This is often because of limitations to both grain yield and grain quality (i.e. test weight). The goal of this study was to test three distinct management tactics that could improve oat grain yield and test weight while maintaining or improving other functions such as weed suppression and forage establishment. In order to test these tactics, seven farmers agreed to participate in a series of on farm trials. These examined the effects of oat population density (the population trial), physical weed control (PWC) of oat with a rotary hoe to control weeds (the PWC trial) and oat sown with and without an underseeding (the underseeding trial). The underseeding trial also compared an underseeded legume with a mid-season planted cover crop mixture. Results of the first trial showed no difference in yield, test weight, and weed and forage legume biomass across all three participating farms. However, differences in seed cost suggest that the lowest target oat population would have been the most profitable. The second and third trials both demonstrated significant farm x treatment interactions. Rotary hoeing was an effective tool in reducing weed populations relative to untreated controls at both participating farms but was only effective in controlling certain broadleaf weed species at one of the two farms. Furthermore, no yield or test weight differences were observed at either farm. In the

underseeding trial, yield differences were observed at one farm, where an oat monoculture yielded higher than oat sown with red clover. Test weight did not differ between underseeding treatments at either farm.

Introduction

Small grains such as spring oat (*Avena sativa* L.) are an important part of organic row-crop systems in Iowa and the upper Midwest. Within extended rotations, they provide income or value from grain and straw, as food, feed, bedding or seed. Oat is often sown with underseeded legumes, primarily alfalfa (*Medicago sativa*) and clovers (*Trifolium* spp.). A rotation year including a small grain underseeded with forage legumes provides some of the goods listed above, but also essential services like weed control, nitrogen fixation and soil quality improvement (Liebman and Davis, 2000; Anderson, 2010). In addition to these benefits, the planting and harvest schedule of oat differs from that of corn and soybean, helping spread the workload for farmers (Thompson, 2009). Unfortunately, oat is often the financial weak link in diversified crop rotations (Chase et al., 2016). This is due to a combination of market factors in addition to low yields (kg ha^{-1}) and substandard test weight of grain (kg m^{-3}), the latter being an important metric in determining oat quality for access to more profitable food-grade milling markets (Forsberg and Reeves, 1995; Doehlert et al., 2006).

Over the past three decades, oat production and breeding efforts have received increasingly limited attention from farmers and researchers alike in Iowa. Both a lack of institutional support and a loss of generational agronomic knowledge around small grains agronomy may constrain possible decision-making skills (Blesh and Wolf, 2014; Larsen, 2015). The most recent Iowa State University extension publication providing basic information on oat agronomy was released over two decades ago (Hansen, 1992). However, a limited number of

yearly variety trials still take place using cultivars developed in other Midwest states, and management tactics related to pathogen control have been explored by both Iowa State University Extension and Outreach and Practical Farmers of Iowa (PFI), an Iowa-based, farmer-focused, non-profit organization (Gailans et al., 2015; Exner, 2007).

Given this context, our goal was to establish a series of on-farm trials over the 2015 and 2016 growing seasons in order to answer questions related to possible improvements in the management of an oat rotation year. Our trials were both inspired and informed by the work of PFI. The organization and its founding members helped to establish a protocol for designing and implementing on-farm trials. They also developed an epistemological viewpoint that considers both local, place-based knowledge derived from farmer experience, and scientific expertise generated from research institutions and their affiliated staff, as complementary rather than competing sources of good ideas and novel insights (Thompson, 2009; Bell, 2004). In this vein, addressing concrete questions of agronomic interest were essential, but we also aimed to actively implement the PFI research "philosophy" so that trials would contribute to farmer-knowledge and agency in addition to providing insights on oat production practices.

Research topics related to crop management were conceived of via a two-year study (2014 and 2015), which involved taking both field measurements and gauging farmers' perceptions via surveys and focus groups with 41 organic farmers across Iowa. This observational study was essential to both the elucidation of potential research questions and the identification of a group of farmers interested in and willing to use part of their farms for research. Six of the 41 farmers from the observational study agreed to assist in the development, implementation and data collection related to three distinct trials. Overall, there were seven on-farm sites over two years (one farmer participated in different trials, in both 2015 and 2016). The

initial ideas for the trials were developed during the focus group portion of the observational study. During their conception, information sharing occurred via phone and electronic mail between farmers and researchers. This included a variety of insights ranging from practical logistical considerations, raised by farmers, to relevant research uncovered in the literature, by researchers.

Overall, cooperating farmers were interested in testing practices that could potentially improve **grain yield** and/or **test weight** while maintaining or improving **legume establishment** and/or **weed** control, variables important to profitability and systems-level productivity. Our trials were developed to address the following three questions **with respect to the variables in bold above:**

- What are the effects of a targeted oat plant population density (the population trial)?
- What are the effects of physical weed control using a rotary hoe (the PWC trial)?
- What are the effects of planting oat with an underseeding vs. in a monoculture followed by a mid-season planted cover crop (the underseeding trial)?

The subsequent sections will briefly provide some background information related to each trial, describe the specific methods employed and statistical procedures used, present and discuss results, and provide a general conclusion.

Background

The Population Trial

Based on our mixed-methods study results, there was limited consensus among our sampled population of farmers concerning what optimal seeding rates should be used. Seeding rates, reported by the farmers, ranged from approximately 63 to 179 kg ha^{-1}. While this wide range of seeding rates reflected a diversity of end-goals from solely forage establishment to food-

grade grain production, most of the farmers involved with the study admitted that their choice of seeding rate often lacked the objectivity and meticulous planning that would go into corn and soybean management.

In 1992, an Iowa State University extension publication examined the effects of different seeding rates, expressed as seeds sown per m^2 (Hansen, 1992). Four seeding rates were tested: 161, 323, 484 and 646 seeds m^{-2}. Mean yields for those four treatments were 1308, 1434, 1430 and 1394 kg ha^{-1}, respectively, and indicated a yield plateau at approximately 323 seeds m^{-2}. Another study, from the University of Illinois, tested the effects of three sowing rates (67, 101 and 134 kg ha^{-1}) on two oat cultivars (Marshall et al., 1987). Significant genotype x environment interactions were present, and grain yields as a function of seeding rate were either linear, quadratic or non-significant across environments and treatments. Grain test weight increased linearly with seeding rate, across genotypes and environments (Marshall et al., 1987). More recent data from Wisconsin tested the effects of low (296 seeds m^{-2}) and high (370 seeds m^{-2}) seeding rates on grain yield and quality, and observed no difference with regard to either yield or test weight between the two treatments (Mourtzinis et al., 2015). A University of Minnesota organic management guide suggested that optimal crop densities should be 301-323 plants m^{-2} and advocated the use of a targeted population density in place of seeding by bushel or seeds per acre (Wiersma et al., 2005).

While methods of seeding oat differ in these examples, the general goal of determining an economically optimal oat population density could increase production, improve profitability and contribute to greater precision in oat management.

The PWC Trial

Weed management is a primary research concern of organic producers (Walz, 2004). While much effort in Iowa is centered on organic weed management in corn (*Zea mays* L.) and soybean [*Glycine max* (L.) Merr.], little research addresses the possibilities for weed management in the small grain year of an organic rotation (Delate and Hartzler, 2003). Extended crop rotations that include small grains have been shown to help control weed populations due to life cycles that differ from that of corn and soybean and are able to completely suppress weed species that would thrive in both corn and soybean (Teasdale et al., 2004; Blaser et al., 2007). However, the possibility for further suppression of weed density and biomass using physical weed control (PWC) in a small grain crop has not been the subject of much research in the Midwest, USA. PWC includes hoeing, harrowing and/or flaming using tractor mounted machinery (Bàrberi, 2002). A commonly used tool in PWC in Iowa is the rotary hoe. The rotary hoe is a fairly common implement among organic farmers in the state and has some historical precedence regarding use and study as well (Hull, 1956). The rotary hoe is commonly used at both pre-emergent and/or early developmental stages of crop development for weed control (Bowman, 1997).

To date, limited research on the efficacy of rotary hoeing in small grains has been conducted. Reseachers in New York compared multiple weed control tactics in oat including rotary hoeing, tine harrowing, herbicide application and an untreated (non-weeded) control (Mohler and Frisch., 1997). There were no differences on yield among any of the treatments over the three years of the study. Results indicated that PWC (rotary hoe and tine-weeding) reduced oat plant populations relative to both the untreated control and to the herbicide treatment. Additionally, the response of weed biomass to the treatments differed in each year of the study;

with rotary hoeing and tine weeded being equally as effective as each other and the untreated control (Mohler and Frisch., 1997). A group in Finland examined differences among inter-row hoeing, tine harrowing, chemical control, rotary hoeing and an untreated control in spring barley (*Hordeum vulgare* L.) (Lötjönen and Mikkola, 2000). Rotary hoeing was the least effective of those tactics, and rotary hoed treatments had 6% lower yield than untreated controls. In the New York study, two passes of the rotary hoe were made, one prior to crop emergence and one at the two to three leaf stage; in the Finnish study only one pass was made when all crop plants were between 5-15 cm in height (Mohler and Frisch., 1997; Lötjönen and Mikkola, 2000).

Because PWC utlizing the rotary hoe is already part of "the toolbox" of weed management tactics among many organic farmers in Iowa, our objective was to evaluate its efficacy as a weed management tactic in oat at the one to two-leaf stage of development.

The Underseeding Trial

Underseeding a forage legume, primarily alfalfa or clover species, for use as a green manure and/or as livestock feed, is a common practice in oat production in Iowa and the upper Midwest. However, some farmers may prefer to sow oat as a monoculture in the early spring and then plant a single or multiple-species mid-season cover crop (MSCC) after oat has been harvested in mid-summer. A MSCC may provide a similar suite of benefits to underseeded legumes (Blanco-Canqui et al., 2015). The use of a MSCC instead of an undersown legume also provides a window of opportunity for mechanical weed cultivation in addition to supplying in-season weed suppression via competition (Teasdale et al., 2007).

Competition between the small grain and forage legume is also a factor that may limit both oat yield and test weight as well as the establishment of the forage legume. When a small grain crop is sown with an underseeded legume, competition for resources of water, light and

nutrients can limit productivity for both crops (Sheaffer, 2005). Competitive relationships can depend on the species involved and environmental conditions such as rainfall and temperature. For example, in a long-term study conducted in central Iowa, oat yield when underseeded with medium red clover was significantly lower (4%) than when underseeded with alfalfa. (Liebman, unpublished data).

When using an underseeded legume versus a MSCC, clearly understanding potential tradeoffs to subsequent crops in a rotation is also important. An on-farm trial conducted, on three farms, by the Practical Farmers of Iowa from 2012 to 2014 assessed differences in biomass quantity and quality (nitrogen content) between a MSCC mixture (including legumes, grasses and brassicas) planted after a small grain crop was harvested (mid-July to early August) versus frost-seeded red clover (*Trifolium pretense* L.), which had been broadcast seeded into a small grain during early to mid-spring (early March to mid-April) (Gailans, 2014). Results showed that on one of the three farms, frost-seeded red clover produced more biomass and contained more nitrogen than the MSCC mixture, while no differences were observed between treatments for either biomass or N content at the other two farms. Corn yields were measured in treatment plots the year after the trial; no differences occurred as a result of the frost-seeded vs. MSCC mixture treatments (Gailans, 2014). On-farm trials of this type often confound treatments with environmental and management factors as treatments are not planted at the same time. Nonetheless, they serve to provide system-level comparisons in real-world settings.

Our aim was to further explore some of the trade-offs in sowing oat as a monoculture vs. with an underseeded legume; and to ascertain end of season differences in biomass quantities between the underseeded species and the MSCC mixture.

Methods and Materials

The following paragraphs describe methods and materials that were shared across all three studies. Sections after that detail methods and materials specific to each study and are labelled accordingly. A summary of oat cultivars used, their associated planting and harvest dates along with underseeding species and seeding rates (where applicable) is presented in Table 1. All other operations specific to a given trial are described in their associated sections below.

Farmers were responsible for assigning treatments to given plots using a randomized complete block design. Plot sizes varied due to both field and equipment size. Plot lengths were approximately 150 m. Plot widths were always two times the width of a given grain drill, and ranging from 4 to 12 m. Seeding rates for all experiments were calculated using the following calibration equation adapted from Wiersma et al., 2005:

$$\textbf{Planting Rate } \left(\frac{\textbf{kg}}{\textbf{ha}}\right) = \frac{\textbf{Target Oat Population } \left(\frac{\textbf{plants}}{\textbf{ha}}\right) \div (\textbf{1} - \textbf{expected loss}(\%))}{\frac{\textbf{Seeds}}{\textbf{kg}} \textbf{ x Pure Live Seed } (\boldsymbol{PLS})}$$

Farmers were responsible for determining seeds kg^{-1} by counting out a small lot of 1000 seeds and ascertaining their weight via a scale. Target oat populations and expected loss percentages used in the experiments are commented on within specific methods sections below. Pure live seed (PLS) was calculated by each farmer by multiplying the number of viable seeds times the germination percentage, both of which were found on seed bag tags.

In-season field samples were measured using 0.5 m^2 frames. In all instances, five randomly assessed subsamples were taken at each sampling event by walking in a ‘W’ pattern across plots. Sampling frames were placed on the ground so that four crop rows were straddled

by the frame. Frames of varying widths and lengths were used to account for different grain-drill row widths whilst maintaining the 0.5 m^2 surface area measurement.

Grain yield measurements were recorded by cooperating farmers using their own equipment. Mean yield values for each treatment consisted of strips of one combine-width down the middle of each plot. The seed mass harvested from this area was determined using a weigh wagon and converted to a kg ha^{-1} basis. Subsamples of approximately 1 L were taken from each harvested strip to estimate grain moisture concentration and test weight with a DICKEY-john 2000-AGRI Grain Analysis Computer. Reported yields were normalized to 13% moisture and grain yields were converted to a 364 kg m^{-3} standard.

The Population Trial

Research was conducted on Doug Alert's farm near Hampton, IA in Franklin County and Aaron Lehman's farm near Polk City in Polk County in 2015, and Ortrude Dial's Farm near Williams, IA in 2016. On each farm, spring oat was sown at three target oat populations: 236, 311 and 386 plants m^{-2}, which will be referred to as low, medium and high, respectively. Expected loss for oat populations was 15%. Each of the three cooperating farmers established five replicates of the three treatments, totaling 45 plots across three farms (site-years).

Hand-harvested measurements were taken 6 weeks post-harvest to determine the effects of the treatments on underseeded legumes and weed biomass. These measurements at the Lehman and Alert farms on 30 August and 15 September 2015, respectively. Underseeding and weed biomass samples were not taken on the Dial farm due to a major disturbance of the stand from a liquid manure application. All vegetative biomass was removed at the soil surface with garden shears and placed into paper bags. The samples were then sorted into underseeding and weed biomass. Samples were then dried at 60 °C to a constant weight and weighed.

The PWC Trial

Research was conducted on Darren Fehr's farm near Rolfe, IA in Pochahontas County and on Dan Wilson's farm near Paullina, IA in O'Brien County in 2015. On both farms experimental treatments consisted of a rotary hoeing and a control (non-rotary hoed) treatment. On both farms, oat was sown at a target population density of 311 plants m^{-2}. Expected loss in this case was set at 25% due to anticipated damage to seedlings during the rotary hoeing. Both farms established five replicates of the treatments, totaling 20 plots across the two farms.

Rotary hoeing events were performed at the 1-2 leaf stage of oat crop development. This took place on 5 and 6 May 2016, and 6 and 7 May 2016 at Fehr and Wilson's farms, respectively. Both farmers made one pass per day over a two-day period with the rotary hoe. These passes were made parallel to the crop row. Driving speed was approximately 16 km hr^{-1} and soil conditions on all days of cultivation were windy and dry, which are optimal for rotary hoeing. Weed and oat density counts were made before rotary hoeing on 3 May at Wilson's farm and on 5 May at Fehr's farm; and after rotary hoeing on 19 May at both farms.

When oat plants were in the early dough (ZGS 8.0) stage of development all vegetative material was removed at the soil surface using garden shears (Zadoks et al., 1974). Oat plant biomass was discarded and weed biomass was sorted into grasses and broadleaves, dried at 60°C to a constant weight and weighed.

The Underseeding Trial

Research was conducted on Doug Alert's farm near Hampton, IA in Franklin County and on Vic Madsen's farm in Audobon, IA in Audobon County. On both farms treatments consisted of oat planted with an underseeded legume and oat planted in a monoculture. In plots sown without an underseeding, both farmers planted a MSCC after oat harvest. On both farms, oat was

sown at a specified population density of 312 plants m^{-2}. Expected loss in this case was set at 15%. Underseeded legume species were chosen by the farmers based on normal rotation and management practices. The same mid-season cover crop (MSCC) mixture was used on both farms and was chosen via phone and email discussions. Species included in the MSCC mixture were medium red clover (*Trifolium pratense* L.), sunn hemp, tillage radish (*Raphanus sativus* L. var. *longipinnatus*) and yellow sweet clover (*Melilotus officinalis* L.). A summary of species and their seeding rates is presented in Table 3.1. Both farms established five replicates of the two treatments, totaling 20 plots on two farms.

The first set of measurements were taken when oat plants were in the early dough (Zadoks growth stage [ZGS 80]) stage of development (Zadoks et al., 1974). This occurred at Alert's farm on 22 July and at Madsen's farm on 15 July. All vegetative material was removed at the soil surface using garden shears. This included oat plants, legume underseeding and weed biomass. Underseeding and weed biomass were separated and dried at 60°C to a constant weight and then weighed. A second set of measurements was made in mid-fall, just before the first frost date, to determine biomass quantities of the underseeded legume and the MSCC. The prior sampling protocol was used and samples were taken at Alert's farm on 14 October and on at Madsen's farm on 16 October.

Statistical Analyses

Much of the same statistical methodology was used across all three trials. Data were all analyzed using the GLIMMIX procedure in SAS 9.4 (SAS Institute, 2013) to evaluate the effect of the specific treatment (oat plant population density, rotary hoeing, and underseeding) in addition to farm (site-year) on grain yield, test weight, underseeding biomass, weed biomass, and end of season cover crop biomass, where applicable. Combined analysis was performed for each

trial considering farm as a random factor, unless significant farm x treatment interactions suggested an exploration of residual error. Where residual error was significantly different between farms (Hartley's f-max test, $P < 0.05$), data was analyzed by farm. Combined analyses were performed with respect to the population trial. Both PWC and underseeding trials were analyzed by farm. Means were separated using Tukey's Honestly Significant Difference (HSD) at the $P \leq 0.05$ significance level. With respect to the PWC trial, weed count data were $\log_e$ transformed in order to stabilize variance. Back-transformed values are presented in Figure 3.2.

Results and Discussion

The Population Trial

Grain yield and test weight

Grain yield did not differ among population treatments ($P = 0.82$). Mean yield over the three populations was 3476 kg ha^{-1}. Test weight was similarly unaffected by the population treatment ($P = 0.37$); mean test weight was 409 kg m^{-3} (Table 2).

Underseeding and weed biomass

Neither underseeded legume nor weed biomass differed among the oat populations tested ($P = 0.58$ and $P = 0.75$, respectively) (Table 2). Mean underseeding and weed biomass were 405 and 1486 kg ha^{-1}, respectively. At both Alert and Lehman's farms, yellow foxtail (*Setaria pumila* (Poir.) Roem & Schultgiant), giant foxtail (*Setaria faberi* L.) and Canada thistle (*Cirsium arvense* (L.) Scop.) were the weed species of greatest abundance in the legume/forage samples.

These data support both older and more recent research on yield and test weight response to a range of seeding rates and populations for Midwest growing conditions (Hansen, 1992, Mourtzinis et al., 2015). In our study, there were no significant effects of oat plant population on grain yield or test weight indicating the potential for using lower seeding rates, while

maintaining productivity and profitability. Likewise, there was little to no population effect on weed and legume biomass, suggesting that weed suppression and legume establishment may be maintained with the economically optimal oat population.

These results indicate that within the range of populations tested on these farms (site-years combinations), equivalent yields were attained at lower populations and at a lower cost. Average seed costs over all farms were approximately $67, $89 and $108 ha^{-1} for the low, medium and high populations respectively. Net returns would have been greatest at the lowest oat plant population tested and savings between the low and high populations in these particular situations would have amounted to an average of $42 ha^{-1}.

While savings on seed costs are possible with a lower population, it is important to calculate seeds per pound and recalibrate grain drills acordingly on a yearly basis. Says cooperator Aaron Lehman, “There’s quite a bit of variance in seed size in oats. Knowing that, I found that I would probably save some money if I made a practice of figuring out how many seeds there are per pound and using that, rather than bushels per acre as my basis for planting. It will vary your planting rate quite a bit if you don’t know exactly how many seeds per pound you have.” Irrespective of the results of the trial, Aaron’s insight also highlights the benefits of calibrating a grain drill to achieve a desired population, and his future plans to adopt this practice: “It’s something I’ll put into practice in the coming years, it’s definitely worthwhile”.

The Rotary Hoeing Trial

Grain yield and test weight

Grain yield and test weight did not differ between rotary hoed and control treatments at either Fehr ($P = 0.08$ and $P = 0.62$, respectively) or Wilson’s farm ($P = 0.06$ and $P = 0.65$, respectively). Mean oat yield was 3997 and 4014 kg ha^{-1}, respectively. Mean test weight was 364

kg m^3 at both farms. Specific results relating to both yield and test weight for both farms can be viewed in Table 3.3.

Oat and weed plant density

Oat plant densities did not differ due to the rotary hoeing treatment at either farm ($P = 0.10$), but did differ due to measurement timing (before and after rotary hoeing) ($P < 0.0001$). Simply put, our measurements indicate that oat densities were reduced equally, due to the passage of time, at both farms regardless of the rotary hoeing treatment (Fig. 1). This type of population density reduction can occur in plant populations as a result of intraspecific competition (self-thinning), losses due to abiotic factors or a combination of the two (Westoby, 1984).

The effects of rotary hoeing on weed density were different at each farm. At Fehr's farm, weed densities did not differ when measured before the rotary hoeing ($P = 0.83$), but did differ between treatments when measured after the rotary hoeing ($P < 0.0001$) (Fig. 3.2). Weed density decreased by 60% in the rotary hoed plots and increased almost three-fold in control plots. Weed density was approximately six times lower in rotary hoed plots than in control plots, when measured after rotary hoeing (Fig. 3.2). At Wilson' farm, weed densities also did not differ between treatments when measured before the rotary hoeing ($P = 0.82$) but did differ when measured after the rotary hoeing ($P = 0.0009$) (Fig. 3.2). However, weed density counts increased in rotary hoed plots by 78%, and were almost nine-fold greater in control plots. While weed density did increase in rotary hoed plots, it was still three and a half times lower than control plots, when measured after rotary hoeing, (Fig. 3.2).

Weed Biomass and Composition

Similarly, effects of the rotary hoeing treatment on weed biomass, when sampled at ZGS 80, were different at each farm. At Fehr's farm, total weed biomass differed between treatments ($P = 0.002$). Weed biomass was one and a half times greater in the control treatment than the rotary hoed treatment (Fig. 3.3). Examination of the reduction of weed type (broadleaf vs. grass) as a fraction of total biomass indicates that the biomass of broadleaf weeds was reduced in the rotary hoed plots (Fig. 3.3). At Wilson's farm, weed biomass did not differ ($P = 0.06$) between rotary hoed and control treatments. Rotary hoeing had no effect on broadleaf weed biomass but did reduce grass weed biomass relative to the control.

At Fehr's farm, the weed species of greatest abundance were Pennsylvania smartweed (*Polygynum pennsylvanicum* L.), giant foxtail (*Setaria faberi*) and yellow foxtail (*Setaria pumila*). At Wilson's farm, common cocklebur (*Xanthium strumarium* L.), lamb's quarters (*Chenopodium album* L.) and crab grass (*Digitaria sanguinalis* L.) were the species of greatest abundance.

Rotary hoeing was effective in reducing broadleaf weed biomass at Fehr's farm. This may be due to the fact that the weed species of greatest abundance was Pennsylvania smartweed. Pennsylvania smartweed is a shallow-rooted, early-emerging annual that was more readily uprooted at cotyledon and two-leaf stages when plants were approximately 0.6 cm in height. In comparison, the lack of efficacy in reducing broadleaf weeds at Wilson's farm may have been due to the fact that the majority of the broadleaf weed biomass was composed of common cocklebur, another early-emerging weed species. Cocklebur, unlike Pennsylvania smartweed, is noted for emerging from deeper in the soil profile and having a strong taproot and thick leaves, making it challenging species when using PWC (Buhler et al., 1993).

Differences in rotary hoeing efficacy between farms point to the complex relationship between weed seedbanks and management practices such as crop rotation and other forms of PWC. Because of this complexity and site-specificity, farmers' awareness of problematic weeds and their basic biology is a requisite for effective management (Delate and Hartzler, 2003; Liebman and Davis, 2009). While the farmers in this study were instructed to perform rotary hoeing passes based on crop stage, truly effective weed management involving mechanical cultivation necessitates a careful examination of weed stage as much, if not more so, than crop stage (Mohler, 2001). In a spring cereal such as oat, this may present a challenge as PWC even earlier in crop development might be as or more detrimental to yield potential as the weed pressure. Delaying cultivation further might risk even greater ineffectiveness with respect to the rotary hoe creating challenging timing issues with respect to the use of rotary hoeing in oat (Rasmussen et al., 2009).

The rotary hoe may have helped with reductions in potential additions to the weed seedbank (pertaining to broadleaves at Fehr's farm and grasses at Wilson's). However, because this tactic did not provide clear benefits to crop productivity, and had mixed results in different environments and with different weeds, farmers should consider the use of a rotary hoe with caution. Farmers not using an underseeding with oat may have better mid-season weed control after harvest (using other forms of tillage). Additionally, farmers that underseeded clover or alfalfa may be uninterested using PWC in oat to begin with. Dan Wilson summed up his experience with this research trial saying, "Based on these results, we probably won't rotary hoe in the future, mainly because we typically grow our oats with an underseeding. But any research we can get on how to grow a third crop is beneficial".

The Underseeding Trial

Grain Yield and Test Weight

Grain yield differed between treatments at Alert's farm ($p = 0.02$); oats underseeded with red clover yielded 13% less than when planted as a monoculture (Table 3.4). There was no difference between treatments at Madsen's farm where alfalfa was used an underseeding ($p = 0.69$); mean yield was 3190 kg ha^{-1} averaged over both treatments (Table 3.4). Test weight did not differ across treatments at either farm. Mean test weight at Alert's and Madsen's farms, respectively, was 375 and 409 kg m^{-3} (Table 3.4).

Weed Biomass

Treatment effects on weed biomass at both Alert and Madsen's farms did not differ ($P = 0.34$ and $P = 0.92$, respectively). Mean weed biomass at Alert's and Madsen's farms was 174 and 344 kg ha^{-1}, respectively (Table 3.4). Dominant weeds at Alert's farm consisted almost exclusively of yellow foxtail (*Setaria pumila* (Poir.) Roem & Schultgiant) while Madsen's farm included annuals yellow and giant foxtail (*Setaria faberi* Herrm.), in addition to sunflower (*Helianthus annuus* L.) and the perennial weed Canada thistle (*Cirsium arvense* (L.) Scop.).

End of Season Legume and MSCC Biomass

There were differences in end of season biomass between the underseeded legumes and the MSCC at both farms ($P < 0.001$). At Alert's farm there was approximately six times more biomass where red clover had been underseeded with oat in the spring versus the MSCC (Fig. 3.4). At Madsen's farm the opposite was true albeit to a lesser degree. Plots that had been seeded to the MSCC contained approximately two and half times more biomass those that had been undersown with alfalfa (Fig. 3.4).

Lower mean weed biomass at Alert's farm (Table 3.4) may be attributable to the fact the field used in this trial was recently transitioned to organic production compared to the Madsen site, which had been under certified organic production for the past 15 years. A longer period of time under organic management would strongly suggest a greater and more diverse weed seed bank and its associated challenges (Hald, 1999; Albrecht, 2005). The large variation in these results may also be attributable to environmental, management and legume species differences at each site. Differences in MSCC biomass were probably most attributable to differences in planting date as Madsen's planted the MSCC almost a month prior to Alert (9 Aug. vs. 5 Sept.).

While direct comparisons cannot be made as to the effects of a given underseeding species on oat grain yield, these two trials coupled with information from an aforementioned long-term study here in Iowa allude to the competitive nature of a red clover underseeding and its possible impact on grain yield (Liebman, unpublished). Farmers who use red clover, looking for multiple agronomic and economic goals in a given season, may have to carefully consider tradeoffs between crop yield and establishment of a green manure. Also, while we didn't explicitly measure MSCC biomass composition, it was clear from our field observations at sampling, that the majority of Madsen's MSCC biomass was tillage radish and volunteer oat. While these species have been shown to provide benefits, such as alleviation of soil compaction and erosion control, they do not provide atmospherically fixed nitrogen like clover or alfalfa (Chen and Weil, 2010, De Baets et al., 2011).

Results were highly site specific and differences in planting date between undersown and MSCC treatments become confounded with environmental and management factors. However, our goal was to analyze differences between underseeded legumes and a MSCC in light of real-world production challenges, including delayed seedbed preparation and planting. While these

trials do not provide exact comparisons, they do offer insights into differences that can, and often do, occur when trialing different tactics in on-farm settings.

Those seeking to maximize oat yield and are thinking of using a MSCC should aim to plant the MSCC as early as is possible after oat harvest. Results from this trial point to that conclusion (see Table 3 and Figure 2, MSCC biomass values). Similarly, if neither red clover nor a MSCC is of interest, those using an alfalfa underseeding may be satisfied with the results of this trial as Vic Madsen was, “The legume does good things for soil conservation and making nitrogen for the next year’s crop so we’re happy it doesn’t hurt the oats.”

Conclusion

Our goal with these studies was to vet management practices related to an organic oat production year using on-farm trials. Research questions were conceived of and implemented using both farmer and researcher knowledge and skill sets. The results of the three trials were highly varied and often site-specific. Significant farm x treatment interactions in two of the three trials, led us to analyze these data by farm. This limits the scope of inference around using these results. Irrespective of this, we would like to re-emphasize some of our findings.

In one case, rotary hoeing in oat was an effective tool for reducing both weed density and broadleaf biomass, worthwhile goals in organic production systems. That this tactic was only effective on an early-emerging, shallow-rooted, weed species limits its broad applicability but also suggest PWC with a rotary hoe as another management option for certain production scenarios. In another case using red clover as an underseeding was superior to using a diverse mixture of cover crops planted after oat harvest, providing equivalent weed control and a greater potential for nitrogen fixation as well. We also found that slight modifications to current

practices demonstrated an ability to save on seed costs with respect to oat production without negatively impacting grain production, forage legume establishment or weed suppression. This trend held over three distinct sites over a two-year period.

Overall, we should be clear that none of the questions explored through these on-farm trials resulted in major improvements to either oat grain yield or test weight, the two factors most tied to the in-season profitability of this crop. While this may be unfortunate in some respects, it helps to clarify future research directions and assists in sorting out practices that are, or are not, worth trying again. The on-farm trials helped generate useful data and findings. Additionally, their formulation, design, and implementation served not just as a litmus test for effective oat management practices, but also as an opportunity for researchers to understand limitations to agronomic management tactics and for farmers to learn more about their own farming systems and management skills, worthwhile objectives even in light of mixed results.

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Table 3.1 Oat cultivar choice, forage species and seeding rate quantities, in addition to MSCC species and seeding rate quantities and operation timing specifications for all 2015 and 2016 on-farm trials.

Trial	Farmer Cooperator	Oat Cultivar	Underseeding/MSCC species (kg ha^{-1})[1]	Planting date for oat + underseeding/ (MSCC)	Harvest date of oat crop
Population	Alert	Saber	Alfalfa (13.4), orchard grass (5.6)	4/14/2015	8/15/2015
	Dial	Shelby 427	Mammoth red clover (13.4)	3/31/2015	7/19/2015
	Lehman	Saber	Crimson clover (11.8), medium red clover (1.7)	4/15/2016	7/26/2016
PWC	Fehr	Deon	n.a.[2]	4/13/2016	7/25/2016
	Wilson	Shelby 427	n.a.	4/8/2016	7/22/2016
Underseeding	Alert	Saber	Medium red clover (13.4)	4/16/2016	8/17/2016
			Medium red clover (3.4)/ sunn hemp (3.4)/ tillage radish (2.2)/ yellow sweet clover (3.4)	(9/6/2016)	
	Madsen	Shelby 427	Alfalfa (13.4)	4/2/2016	7/26/2016
			Medium red clover (3.4)/ sunn hemp (3.4)/ tillage radish (2.2)/ yellow sweet clover (3.4)	(8/9/2016)	

[1]Underseeding species and rates are listed for both population and underseeding trials. MSCC species and rates are listed after underseeding species and rates with respect to the underseeding trial

[2]The use of an underseeding did not occur with respect to the PWC trial.

Table 3.2 Population trial: Target oat population effects on grain yield, test weight, forage legume and weed biomass across all three farms in 2015 and 2016.

	Oat population (plants m^2)		
Variable	236	311	386
Grain yield (Mg ha^{-1})	3.51a[1]	3.45a	3.55a
Test weight (kg m^{-3})	414a	409a	407a
Forage biomass (kg ha^{-1})	376a	426a	413a
Weed biomass (kg ha^{-1})	1510a	1448a	1500a

[1] By variable, values not followed by the same lowercase letter are significantly different, HSD ($P < 0.05$).

Table 3.3 PWC trial: rotary hoeing effects on oat grain yield, test weight and weed biomass at each farm in 2016.

	Farm			
	Fehr		Wilson	
	Treatment			
Variable	Rotary hoed	Control	Rotary hoed	Control
Grain yield (Mg ha^{-1})	3.87a[1]	4.12a	4.11a	3.91a
Test weight (kg m^{-3})	365a	368a	360a	363a
Weed biomass (kg ha^{-1})	264b	413a	129a	200a

[1] By variable, values not followed by the same lowercase letter are significantly different, HSD ($P < 0.05$).

Table 3.4 Underseeding trial: underseeding effects on grain yield, test weight, mid-season sampled weed biomass, and mid-fall (end of season, EOS) differences between underseeding and MSCC biomass at both farms in 2016.

	Farm			
	Alert		Madsen	
	Treatment			
Variable	Oat + underseeding	Oat monoculture	Oat + underseeding	Oat monoculture
Grain yield (Mg ha^{-1})	3.82a[1]	3.55b	3.23a	3.15a
Test weight (kg m^{-3})	372a	376a	410a	411a
Weed biomass (kg ha^{-1})	220a	127a	348a	339a
EOS biomass (kg ha^{-1})[2]	1294a	218b	1459a	571b

[1]By variable and farm, values not followed by the same lowercase letter are significantly different, HSD ($P < 0.05$).

[2]End of season biomass values are a comparison of the underseeded legume and the MSCC.

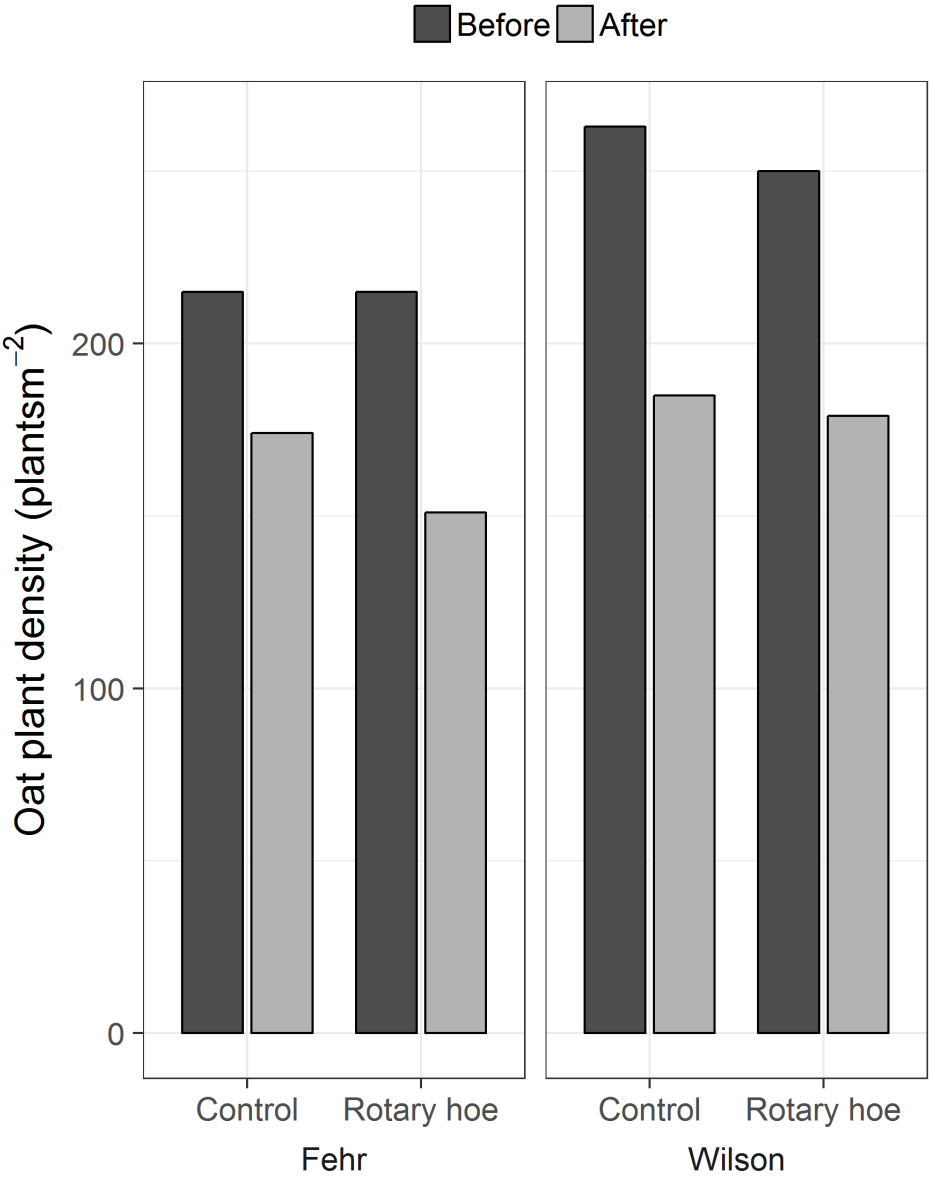

Fig. 3.1 PWC Trial: Effects of rotary hoeing on oat plant density at Fehr and Wilson's farms in 2016. Oat plant density counts were made immediately or one day before (dark gray bars) rotary hoeing in both control and treatment (rotary hoed) plots and again approximately a week and a half after (light grey bars) the rotary hoeing treatment. By farm and treatment, bars not followed by the same lowercase letter are significantly different, HSD ($P < 0.05$)

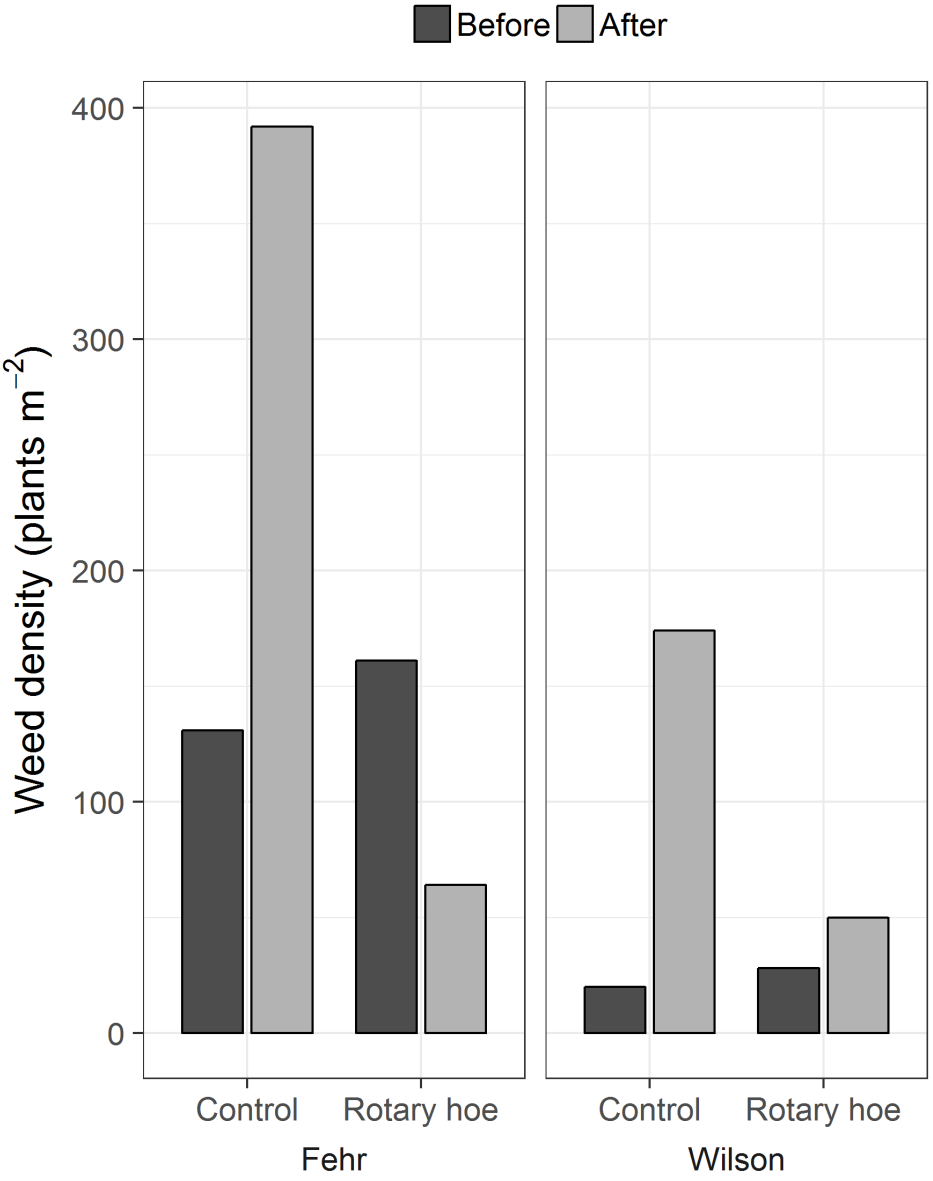

Figure 3.2 PWC Trial: Effects of rotary hoeing on weed density at Fehr and Wilson's farms in 2016. Weed density counts were made immediately or one day before (dark gray bars) rotary hoeing in both control and treatment (rotary hoed) plots and again approximately a week and a half after (light grey bars) the rotary hoeing treatment. By farm and treatment, bars not followed by the same lowercase letter are significantly different, HSD ($P < 0.05$).

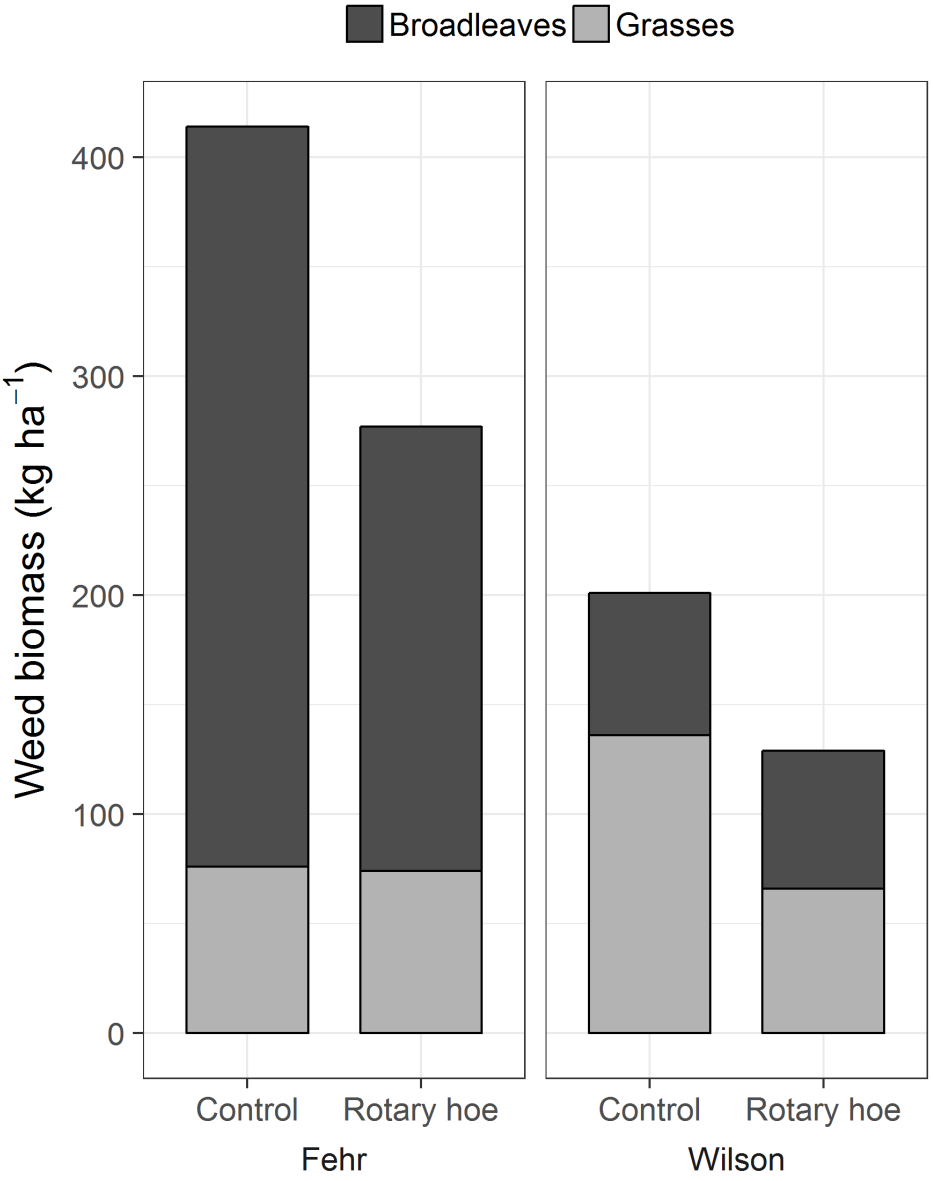

Figure 3.3 PWC Trial: Effects of rotary hoeing on mid-season sampled weed biomass at Fehr and Wilson's farms in 2016. Bars representing rotary hoed treatments that have an asterisk above them are significantly different, HSD ($P < 0.05$). By farm, treatment and weed type, bars not followed by the same lowercase letter are significantly different, HSD ($P < 0.05$).

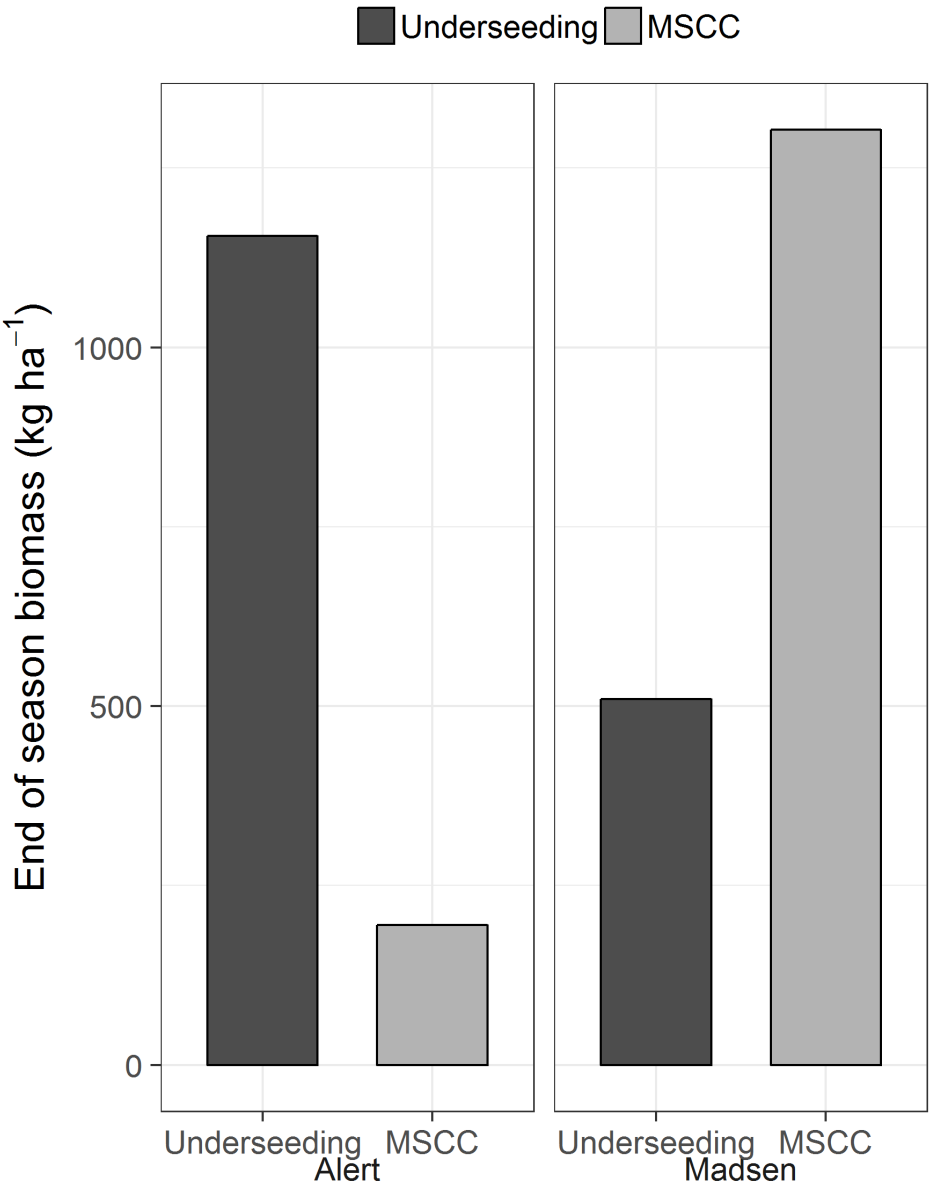

Figure 3.4 Underseeding trial: Differences in end of season biomass (taken six weeks after oat harvest) between underseeded legumes and MSCC at Alert and Madsen's farms in 2016. By farm, bars not followed by the same lowercase letter are significantly different, HSD ($P < 0.05$).

CHAPTER 4. BALANCING OBJECTIVES IN A SMALL GRAIN ROTATION YEAR: IMPLICATIONS OF PLANTING DATE AND TARGET CROP DENSITY

Abstract

Small grains, such as oat (*Avena sativa* L.), are an important component of organic row crop rotations in the Upper Midwest. They aid in disrupting pest cycles, establishing forage legume stands, and helping distribute farm labor requirements more evenly across the growing season. However, limited agronomic research has explored the potential for optimizing oat crop density and planting date to balance grain production and profit objectives, in addition to forage establishment and weed suppression. Our goal was to determine effects of planting date and crop density on oat grain yield and yield components, test weight, straw yield, alfalfa and weed biomass, and net returns. The study was conducted on certified organic farmland on an agricultural experiment station in Boone, IA, USA, over two years. A split-plot design was used to test effects of planting date (whole plot) and target oat density (subplot). Planting date and target oat density were both significant with respect to either all or some of the dependent variables above. A planting date x target oat density interaction only occurred in one year (2016) with respect to panicle density. The clearest effect resulted from planting date. Plant density, grain yield, test weight, and net returns all decreased as a result of delayed planting in both years. Losses of approximately 53 kg ha^{-1} day^{-1} were equated with an economic loss of approximately \$22 ha^{-1} day^{-1}. Target oat density did affect yield components in both years but only had an effect on grain yield in 2015, and test weight and weed biomass in 2016. Net returns did not differ due to target crop density when the crop was intended for a livestock feed. Our results suggest potential no-cost improvements can be made to oat management to improve the multiple objectives of a small grain rotation year, but also suggest limitations to the precision of oat crop management.

Introduction

As of 2015, Iowa was the leading producer of organic field corn (*Zea mays* L.) and soybean (*Glycine max* (L.) Merr.) in the United States. The combined value of these crops was over $35 million (National Agricultural Statistics Service, 2015). These two crops are essential to the economic well-being of many farmers and the organic industry in the state. However, the sustained production and profitability of these two crops relies on practices like crop rotation (Porter et al., 2003; Cavigelli et al., 2008). USDA National Organic Program (NOP) bylaws require producers implement rotations that achieve agronomic and environmental goals of soil organic matter maintenance or improvement, pest and nutrient management and erosion control (Agriculture Marketing Service, 2002). In the Upper Midwest, organic farmers using rotations of corn and soybean also include small grains such as barley (*Hordeum vulgare* L.), oat (*Avena sativa* L.), rye (*Secale cereal* L.), triticale (*X Triticosecale* Wittmack) and wheat (*Triticum aestivum* L.). These are often underseeded with forage legumes such as alfalfa (*Medicago sativa* L.*)* and green manure crops including clovers (*Trifolium* spp.).

The most commonly grown small grain in Iowa is spring-seeded oat (National Agricultural Statistics Service, 2016). Oat, a cool-season C3 crop, is usually planted in the spring and harvested in mid-summer. From a farm-management perspective, the crop's lifecycle allows for labor to be distributed more evenly across the farming year relative to corn and soybean production. Phenological differences in crop growth and development and its associated management schedule also allow for greater summer annual weed suppression via crop competition early in the season, and provide an opportunity for mechanical termination of weeds via combine harvesting and mowing of stubble later (Mohler, 2001; Liebman et al., 2008). After small grain harvest, a larger window is available for forage legume growth and development,

which is more favorable for both biomass accumulation and nitrogen fixation potential than later seeded cover crops. This combination of factors including exploitation of crop competitive ability (CA), mechanical intervention, and intercropping with a forage legume or green manure is essential to the management of weeds in organic systems (Mohler, 2001; Melander et al., 2005; Liebman and Davis, 2009). The small grain rotation year also contributes to soil-aggregation and tilth in a way that the corn and soybean rotation years do not (Monroe and Kladivko, 1987; Karlen et al., 1994; Aziz et al., 2011).

These multiple benefits are essential to the long-term productivity and profitability of organic and low external input (LEI) systems, but are difficult to monetize in single-season enterprise budgets. To provide some indication of relative economic differences among organic row crops, average corn, soybean and oat/alfalfa net profits generated via Iowa State University organic enterprise budgets for 2016 were approximately \$2840, \$1402, and \$368 ha^{-1}, respectively (Chase et al., 2016). While these budgets do not account for nitrogen savings (via alfalfa), soil improvements and/or potential subsequent crop yield increases, they do highlight the fact that small grains, such as oat, are less profitable relative to corn and soybean. This economic reality is unfortunate because oat and other small grains are integral to the durability and resilience of extended crop rotations in the Upper Midwest (Karlen et al., 1994; Liebman and Davis, 2000; Porter et al., 2003; Blaser et al., 2007)

The economic viability of an oat rotation year itself is often determined by the quantity of the grain produced (kg ha^{-1}), but also its quality, measured as test weight (kg m^{-3}). Test weight is a commonly used indicator of milling quality and is a vital determinant for farmers seeking to access more profitable food as opposed to feed grade markets (Doehlert et al., 2001, 2006). Both yield and test weight can vary based on synergies and antagonisms between environmental

factors and cultural practices such as planting date and/or crop density. Improvements to either of these cultural practices may help to improve the productivity and profitability of oat (Peltonen-Sainio, 1999; Doehlert et al., 2001).

Planting date studies have been conducted in Iowa, with respect to grain yield and test weight; general guidelines for optimal dates are mentioned in extension literature (Frey, 1959; Coffman and Frey, 1961; Colville and Frey, 1986, Hansen, 1992). Similarly, research from Washington state, as well as eastern Canada, has investigated the effects of delayed planting on a variety of spring-sown cereals including oat (Nass et al., 1975; Ciha, 1983; Humphreys et al., 1994; May et al., 2004a; 2004b). General trends of yield and test weight reduction were observed with delayed planting in all these experiments. However, specifics differences related to genotype-, environment, and management-based factors were significant in all instances.

Crop density/seeding rate research has been conducted in conventional oat systems in the Midwest for the purposes of optimizing grain yield and test weight, but with a focus on oat planted without a forage legume (Marshall et al., 1987; Mourtzinis et al., 2015). Marshall et al. (1987) planted oat on a weight ha^{-1} basis (67, 101, and 134 kg ha^{-1}) and Mourtzinis et al. (2015) did so based on seeds ha^{-1} (2.96 and 3.70 million seeds). An extension publication from Iowa examined the effects of four planting densities ranging 1.6 to 6.4 million seeds ha^{-1} (Hansen, 1992) and more recent extension guidelines from the University of Minnesota suggested planting oat with a target oat density of 300 to 323 plants m^{-2} (3.00-3.23 million plants ha^{-1}) (Wiersma et al., 2005). A target oat density can be understood as the desired oat plant population ha^{-1}, which differs somewhat from volumetric and seeds ha^{-1} based seeding rate methods in that it considers factors such as pure live seed (PLS), seed germination percentage, 1000-kernel weight, and estimated crop mortality (Wiersma et al., 2005).

In organic systems specifically, there has been research on interspecific competition between small-grain crops and weeds. In the US and Canada, much of this has explored the roles that mechanical cultivation and cultural manipulation can play in weed management (Kolb et al., 2010, 2012; Benaragama and Shirtliffe, 2013). Crops used in these studies included oat sown at densities of 250 and 500 plants m^{-2} (Benaragama and Shirtliffe, 2013), spring wheat at densities of 400 and 600 plants m^{-2} (Kolb et al., 2012), and spring barley sown at a density of 200 plants m^{-2} (Kolb et al., 2010).

Although some picture of organic production may be pieced together from the available literature, there is a lack of clear, contemporary guidelines focusing on the effects of oat management on both agronomic and economic objectives of the rotation year (oat/forage legume). For example, we were not able to find recent research in either organic or conventional oat production that examined any possible interaction between planting date and crop density. The paucity of current research on basic agronomic practices related to the production of crops that often occupy ≥ 30% of the cropping area of organic row crop operations exposes limitations in organic crop and cropping systems research in the upper Midwest.

Our goal was to determine the effects of planting date, target oat density (plants m^{-2}) and any possible interactions on factors that effect in-season economic returns and/or use (e.g. grain yield, test weight and straw yield), while maintaining benefits of weed suppression and alfalfa forage establishment that are important to systems-level functioning. We hypothesized that target oat densities for oat would adequately balance these objectives (grain yield, its associated test weight and straw yield vs. forage establishment and weed suppression) at approximately 312 plants m^{-2} (3.1 million plants ha^{-1}) and when sown at the earliest possible date. We also

hypothesized that target oat density would have to be increased as planting date is delayed (i.e. planting date x target oat density interactions would be significant).

Materials and Methods

Experimental Design and Location

This study was conducted at the Iowa State University Agronomy Farm, located in Boone County, Iowa, USA (42°0'N; 93°6'W) for 2 yr. An oat-alfalfa intercrop was used as a model system for the experiment. Sites in 2015 and 2016 were adjacent to one another in order to maintain a system of crop rotation for organic certification per NOP guidelines. In both years, the oat/alfalfa intercrop followed corn in a rotation sequence. The plot areas had both been under organic management for 9 yr. Soil types at the site are Clarion loam (fine-loamy, mixed, superactive, mesic, Typic Hapludolls), Nicollet loam (fine-loamy, mixed, superactive, mesic, Aquic Hapludolls), and Webster silty clay loam (fine-loamy, mixed, superactive, mesic, Typic Endoaquolls).

The experimental design was a split plot with five replicates. Planting date was the whole plot (three treatments in each year) and target oat density the subplot (four treatments in each year). The oat cultivar used in both years was Shelby 427. The alfalfa genotype used in both years was Viking® 3200.

Experimental Procedure

Before planting, primary and secondary cultivation were performed. Primary cultivation included two passes with a tandem disk over consecutive days. In 2015, this operation was completed on 31 March and 1 April and in 2016, on 10 March and 11 March. Planting dates began in each year as early as field operations could occur without causing undue damage to soil structure. Planting date delays were spaced at an interval of approximately 11 d. In 2015, our

Early planting date treatment was 6 April, followed with *Mid* on 17 April and *Late* on 28 April. In 2016, the *Early* planting date treatment was 22 March, followed by *Mid* on 4 April and *Late* on 15 April (a summary of planting dates and associated Julian days is presented in the footnotes of Table 2). Secondary cultivation was performed on each planting date with a 3.6 m field cultivator. After this secondary cultivation pass, alfalfa seed was planted using a 1.5 m Brillion grass seeder (Marysville, KS, USA). Oat was then planted using a 1.5 m Almaco Light Duty Grain Drill with an inter-row spacing of approximately 15 cm (Nevada, IA, USA).

For oat, target oat densities in this experiment were 161, 236, 311 and 386 plants m^{-2}. Seeding rates used to plant these target oat densities were calculated with an equation from Wiersma et al. (2005), which considered PLS, seed germination percentage, 1000-kernel weight, and estimated mortality, which was set at 15% in both years. The associated seed weight and cost of each target oat density is presented in Table 1. Alfalfa was seeded at a constant rate of 12.3 kg ha^{-1} in both years. Subplot (planting date x target oat density) size was approximately 3 m x 18 m.

Oat plant density measurements were made in the late-milk/early soft dough stage of development (Zadoks Growth Stage [ZGS] 83-85) (Zadoks et al., 1974). A quadrat (0.25-m^2) was used to take three subsamples in each subplot (planting date x target oat density. Plant counts were performed by placing the quadrat parallel to two crop rows. Each individual row of oat plants was removed from the ground, counted, and the average of both rows was used in our analyses.

All plots were hand-harvested at maturity (ZGS 90) over a 2 d period from 22 July to 23 July in 2015, and over a two day period from 11 July to 12 July in 2016. Oat physiological maturity was visually determined using phenological guidelines provided by Lee et al. (1979).

Frames (0.5-m^2) were used to harvest mature plants in both 1-m^2 weeded control and non-weeded areas. Mature oat plants were cut at a height of approximately 15 cm from the soil surface. All aboveground biomass was placed in paper bags and dried at room temperature for 5 d until a constant moisture was obtained. Aboveground biomass was weighed and the number of panicles counted. Grain was then threshed using an Almaco Small Bundle Thresher (Nevada, IA, USA). Grain was further cleaned by manually removing larger pieces of chaff and debris and by using a small (30-cm diameter) set of two circular sieves with a screen mesh size of 4.7 mm. Straw yields were determined by subtracting the weight of the grain from the total aboveground biomass and are reported at 20% moisture content. Grain test weight and moisture concentration were estimated with a Dickey-john 2000-AGRI Grain Analysis Computer (Dickey-john, Auburn, IL). Reported grain yields were normalized to 13% moisture.

Forage and weed biomass measurements were made approximately 6 wks after the entire surface area of the experiment was cleared of grain and straw. In 2015, due to a combination of poor weather and excessive lodging, all plots were cleared using a forage harvester on 3 August instead of being combined and having straw baled. In 2016, plots were combined and straw was raked and baled on 14 and 15 July. Forage and weed biomass samples were taken over a 2 d period on 14 and 15 September in 2015 and 26 and 27 August in 2016. The same 0.5-m^2 frames were used to harvest forage/weeds by removing all above ground biomass from the soil surface with garden shears, and placing it in a paper bag. All samples were sorted into alfalfa biomass and weed biomass. Dominant weed species were noted. All biomass samples were then dried at 60°C for 24 h for 5 to 7 d. Dried biomass was then weighed and recorded.

Data Analysis

Preliminary analyses were conducted using the GLIMMIX procedure in SAS 9.4 (SAS Institute, 2010) using year and block as a random effect. These analyses indicated significant year x treatment interactions for all dependent variables of interest. Therefore, treatment effects were analyzed separately by year. Based on visual inspection of residuals, alfalfa biomass and plant density data were both $\log_e$ transformed for analysis. Back-transformed values are presented in Table 4.2. Slice statements were used to parse significant interaction effects and all treatment means were separated using Tukey's Honestly Significant Difference (HSD) at $P < 0.05$. Second order polynomial equations were also used to model the response of grain yield and test weight to observed crop density. Analysis of variance procedures and F-tests were used to determine if quadratic and linear components of the second-order polynomial equations were significant in each environment. Simple linear regression was also used to model the relationship of grain yield and net profit as a function of Julian day (Fig. 6).

Partial Budget Analysis

A partial budget analysis was performed to ascertain effects delayed planting, target oat density (plants m^{-2}) and its associated seeding rate (kg ha^{-1}). An economically optimal seeding rate was that which generated the greatest net return; this can be understood as the difference between gross returns ha^{-1} (grain yield x market price) and seed cost ha^{-1}. Oat seed cost over the two years of the experiment averaged \$0.86 kg^{-1}. The 2015 average oat market value of \$0.42 kg^{-1} was used for both years of analysis (USDA Economic Research Service, 2016). Markets for oat exist in the form of food and feed, the Economic Research Service data used did not specify. For the purposes of this paper, we consider them to be feed-grade prices.

Results and Discussion

Weather

Precipitation in the three-month period of March through May of 2015 (93.2 mm) was lower than that of 2016 (142.3 mm). The most drastic difference occurred in March 2015 when precipitation was only 15% of that in 2016 (Fig. 4.1). Precipitation in June through August was reversed as totals for 2015 (536 mm) were greater than those in 2016 (382 mm). The most marked difference within this three-month period occurred in June 2016 when precipitation was only 13% of that in 2015 (Fig 4.1). March and June also marked the greatest temperature differences between the two years. Average temperatures in March of 2015 were 4.4°C compared with 7.7°C in 2016 (Fig. 4.1). In June average temperatures in 2015 were cooler (21.7°C) than those in 2016 (23.9°C) (Fig. 4.1).

Plant and panicle density

One of the goals of this study was to use a target oat density approach to seeding oat. Our results indicated that while there was almost no variance between years with respect to oat plant densities, densities in both years were 25 to 43% lower than our targets (Fig. 4.2). This variance may have occurred due to the greater potential to observe the effects of density dependent mortality (self-thinning) when we took measurements at the soft-dough stage of development (ZGS 85) rather than at the one- to two-leaf stage (ZGS 11-12). Similarly, we may have underestimated oat plant mortality in both years of the study with a value of 15% in our seeding rate calculation.

Yield components measured in this study were limited to oat plant density (measured prior to harvest) and oat panicle density (measured at harvest). In 2015, oat plant densities differed as a result of planting date and target oat density (both $p < .0001$). Oat plant density

decreased by 50% over the three-week planting period and increased approximately 83% from the lowest to the highest target oat density treatment (Table 4.2). In 2016, differences in oat plant density were observed for planting date ($p = 0.0004$) and target oat density ($p < .0001$). In 2016, oat plant density actually increased by approximately 9% over the planting period and doubled going from the lowest to the highest target oat density (Table 4.2).

In 2015, oat panicle density only differed as a result of the target oat density treatment ($p < .0001$). Oat panicle density increased by approximately 40% going from the lowest to the highest target oat density (Table 4.2). In 2016, oat panicle density differed as a result of planting date ($p < .0001$), and target oat density ($p < .0001$). Oat panicle density increased 13% over the planting period and 84% as target oat densities increased (Table 4.2). A planting date x target oat density interaction was significant at densities of 312 and 387 plants m^{-2} (both $p < .0001$). Oat panicle density for these two target oat densities was 15% greater at the *Mid* and *Late* (not different) planting dates than the *Early* date.

While oat plant density did not differ greatly between years, oat panicle density did. Mean oat panicle density in 2015 was almost 50% lower than that of 2016 (229 vs. 342 m^{-2}). We attribute these differences to the fact that mean daily temperatures and precipitation in the period before and during early planting in 2016 were considerably higher than in 2015 (Fig. 4.1). These favorable early-season conditions allowed for faster germination, emergence, and early development including tillering and panicle formation (Wiggans and Frey, 1957; Colville and Frey, 1986; Peltonen-Sainio, 1999; Peltonen-Sainio and Rajala, 2007).

While both plant and panicle density increased linearly with target oat density in both years, planting date effects on these yield components were less straight forward. Results from 2015 showed a decrease in plant density as planting date was delayed but no difference in

panicle density (Table 4.2). This would suggest that tillering had actually increased as a function of delayed planting (i.e. the ratio of panicles to plants increases over the planting period). Results from 2016 showed an increase in both plant and panicle density as a function of delayed planting (Table 4.2). The idea that tillering and the density of yield components may increase as planting date is delayed has been documented in the literature and is a function of the highly plastic nature of this crop (Frey and Wiggans, 1957; Wiggans and Frey, 1957; Colville and Frey, 1986; Peltonen-Sanion, 1999). In those and this study, this phenomenon can probably be explained by the above average ambient temperatures and precipitation in March prior to 2016 planting dates (Fig. 4.1). Both would suggest optimal soil moisture and temperature conditions and the potential for accelerated seedling development, tillering and subsequent panicle formation.

Grain yield

Yield itself, in 2015, differed among target-crop densities ($p = 0.03$) and planting date ($p = 0.001$) treatments. There were no significant interactions. Yield reductions were correlated with delayed plantings; yield decreased by 37% over the planting period. Yield was maximal at the target oat density of 237 plants m^{-2}. The lowest yield occurred at the target oat density of 161 plants m^{-2}; grain yields for target oat densities of 312 and 387 plants m^{-2} were not different from each other or the other target oat densities. In 2016, there were yield differences in planting date treatments ($p = 0.02$), but not for main effects of target oat density or any interactions therein. In 2016, only planting date was significant ($p = 0.02$), but yield only decreased by 9% over the planting period (Table 4.2). Considering data from both years together, the relationship between planting date (Julian day) and grain yield showed a linear decrease in grain yield of approximately 53 kg ha^{-1} day^{-1} (Fig. 4.5).

The relationship between oat grain yield reduction and delayed planting has been documented in past agronomic experiments (Nass et al., 1975; Ciha, 1983; Humphreys et al., 1994; May et al., 2004a; b). Yield in oat and other cereals can be understood as a direct function of the vegetative growth rate (VGR), duration of this VGR and harvest index (HI) (Colville and Frey, 1986; Peltonen-Sainio and Jarvinen, 1994). Results from those previous studies and this study suggest that shortening the duration of VGR will result in a decreased yield potential. Later plantings are almost always coupled with a decrease in gross photosynthesis, a major factor or constraint in oat yield potential (Doehlert et al., 2001). Delayed planting can also affect VGR and the formation of yield components as planting delays increase the probability of exposure to both higher day and night time temperatures, both of which are detrimental to panicle development, floret fertility, and the subsequent period of grain filling (Kilnck, 1977; Frey, 1998; Doehlert et al., 2001).

Yield response to crop density differed between years. Our findings suggest that yield response as a function of crop density may be quadratic, or non-existent, for the observed range of crop densities (Fig. 4.2). Other investigators have also found a quadratic response or no response in grain yield (Hansen, 1992; Ciha, 1983; Peltonen-Sainio and Jarvinen, 1994; Mourtzinis et al., 2015; Marcos et al., 2017) and are different than those in which yields increased linearly (Marshall et al., 1987; Peltonen-Sainio and Jarvinen, 1994; Benaragama and Shirtliffe, 2013).

Lastly, mean yield in 2016 was almost double that of 2015 (3220 vs. 1732 kg ha^{-1}). Aside from weather-based differences between years, part of this may be explained by the high by two additional factors being out of our control. One was the high incidence and severity of oat crown rust (*Puccinia coronata* Corda var. *avenae* W.P. Fraser and Ledingham). Rust incidence was

evenly distributed across the entire experimental area. Rust severity was visually estimated using guidelines from Peterson et al., 1948, determining the level of leaf coverage to be, on average, approximately 50%. The other was grain lodging, which affected approximately 60% of the experimental area. Visual lodging estimates were made using a 1-5 scale; 1 being fully erect to 5 being flat. We determined the field average to be 3.5. Both of these phenomena can cause serious reductions to grain yield potential and present considerable challenges to actual grain harvest as well (Chong, 2003; Berry et al., 2004).

Test weight

In 2015, test weight differed among planting date treatments ($p < 0.0001$). Test weight decreased by approximately 32% over the planting period (Table 2).Test weight did not differ due to main effects of target oat density ($p = 0.07$) or any interactions. However, the second-order term was significant when modelling test weight as a function of observed oat density, demonstrating an increase in test weight for the observed range (Fig. 4.4). In 2016, test weight differed among planting date and target oat density treatments (both $p < 0.0001$). There were no significant interactions in 2016. Test weight decreased over the planting period, but only by 2%, and increased as target oat density increased, but also by only 3% (Table 4.2). The linear relationship between test weight and crop density is graphically presented in Fig 4.4. There were no significant interactions among main effects in either year of the study.

Delayed planting can reduce test weight for many of the same reasons that it does yield. Studies have found that the critical period of yield and test weight formation seems to extend from stem elongation (ZGS 31) until about a week after anthesis (Mahadevan et al., 2016). Temperatures above 21°C for extended periods of time, and inadequate precipitation during this period are detrimental to grain fill, which determines both yield and test weight potential (Ehlers,

1989; Humphreys et al., 1994; Peltonen-Sainio, 1999; Doehlert et al., 2001). Conditions in 2016 during June were not only well above the temperature threshold requisite for optimal filling, but precipitation values also were low (Fig. 4.1). Adequate grain filling may have also been inhibited by the higher panicle density (larger sink size) in 2016 relative to 2015 (Peltonen-Sainio, 1999).

Though differences were minor in test weight as a function of crop density in our study, the phenomena of greater test weight occurring at higher crop densities has been documented (Marshall et al., 1987; Peltonen-Sainio and Jarvinen, 1994). Increasing oat plant density will usually inhibit tillering because of intraspecific competition (crowding), and plants are often less taxed by the added physiological burden of additional vegetative material. Consequently, they may be able to add more carbohydrate to individual seed sinks (Peltonen-Sainio and Jarvinen, 1994; Peltonen-Sainio, 1999).

Straw Yield

In 2015, straw yield did not differ due to planting date, target oat density, weed control or any interactions (Table 2). Mean straw yield in 2015 was 2642 kg ha^{-1}. In 2016, straw yield did differ as a result of planting date ($p < .0001$), but not as a result of target oat density or any of their interactions. The greatest quantity of biomass was produced at the *Early* date, followed by the *Mid* and *Late* dates, which were not different from each other (Table 2). Mean straw yield in 2016 was 3043 kg ha^{-1}.

A lack of strong response in straw yield to increased density and/or seeding rates has been described in small grains forage production guidelines as well as agronomic experiments (Derscheid, 1978; Watson, 1993; Maloney et al., 1999; Shaffer, 2007). Also, planting-date effects on forage yields have been documented for other small-grain crops and are verified by the same physiology used to describe delated planting date effects on grain yield (i.e. a reduced

period of growth will result in reduced biomass) (Epplin et al., 2000; Hossain et al., 2003; Coblentz et al., 2012).

Alfalfa Biomass

In 2015, alfalfa biomass was not affected by target oat density, planting date, weed control, or any interactions. In 2016, alfalfa biomass was affected by planting date ($p = 0.002$), but no other individual or interaction effects occurred. Biomass was greatest at the *Early* planting date followed by *Mid* and *Late*, which were not different from one another (Table 4.2). Mean biomass in 2016 was almost double that in 2015 (706 vs. 362 kg ha^{-1}).

While limited research exploring the effect of nurse-crop planting density on an underseeding forage legume exists, studies using triticale and winter wheat with undersown alfalfa and red clover, suggested that increasing the density of those cereal species had no effect on forage legume biomass (Blaser et al., 2007; Gibson et al., 2008). This would support our results if not our initial hypothesis of achieving optimal forage production at a lower density (312 plants m^{-2}). Additionally, studies examining alfalfa planting dates have suggested that delayed planting may decrease first season alfalfa biomass or have no effect at all, which would also support our results from these two years (Van Keuren, 1973; Thies et al., 1992).

Weed Biomass

In 2015, there was no effect of target oat density, planting date, nor any interactions. In 2016, there were differences in weed biomass observed as a result of planting date ($p = 0.05$) and target oat density ($p = 0.002$). No interactions were significant. Weed biomass was lowest at the *Early* planting date and greatest at the *Mid* planting date. Weed biomass from the *Late* planting date was not different from the other two (Table 4.2). The highest quantities of weed biomass were observed at the lowest target oat densities (161 and 237 plants m^{-2}). The lowest quantities

of weed biomass were observed at target oat densities of 312 plants m^{-2} and 387 plants m^{-2} (not different), but biomass associated with the latter was also not different from the lower two densities tested (Table 4.2). In both years, weed species of greatest abundance were yellow foxtail (*Setaria glauca* [L.] Beauv.), giant foxtail (*Setaria faberi* L.), Pennsylvania smartweed (*Polygonum pensylvanicum* L.), large crabgrass (*Digitaria sanguinalis* L.) and lambsquarters (*Chenopodium album* L.).

Research on the effects of planting date and crop density on weed biomass has been reviewed by Mohler (2001), who highlighted advantages to crop competitive ability (CA) that are gained via cultural practices. Specific research in organic oat and spring wheat has shown that increasing crop density can reduce weed biomass, as was observed in 2016 (Weiner et al., 2001; Kolb et al., 2012; Benaragama and Shirtliffe, 2013). However, the lack of difference in weed biomass in 2015 and the relatively unclear trend in 2016 may also be attributed to the target oat densities that we tested, which were approximately 30 – 55% less than those used in the cited literature. While greater gains in CA and weed biomass reduction may have been observed with even higher crop densities, the range that we tested was within that of common management practices in the region. While differences in weed-biomass were not observed as a function of planting date in 2015, the general principles of exploiting asymmetric seed size and phenology to increase a crop's ability to compete effectively with weeds substantiate the importance of early planting (Mohler, 2001). That these gains may be concomitant to the beneficial effects of early planting on grain yield and test weight is a positive finding.

Net Profit

Using our price assumptions, target oat densities and their associated seed inputs, had no effect on net returns in 2015 or 2016. Net returns differed as a result of planting date in both

2015 ($p = 0.0014$) and 2016 ($p = 0.02$). Though not different from each another in 2015, net returns were greater at *Early* and *Mid* planting dates than at the *Late* planting date (Table 2). In 2016, net returns were greatest at the *Early* planting date and lowest at the *Late* planting date, the *Mid* planting date did not differ from either of those treatments. Net returns as a function of planting date (Julian day), over both years of the study, determined losses to be approximately $ 22 ha^{-1} day^{-1} (Fig. 4.5).

Markets for oat exists in the form of food and feed grades. Organic commodity prices, with which we ran our analyses, were retrieved from an Economic Research Service data set. These reports did not specify grade but were, on average, approximately \$0.06 kg^{-1} less than food-grade prices advertised by a large regional food grade mill (E. DeBlieck, personal communication, 16 March, 2017). Regional millers set the test weight threshold for food grade oat at 432 kg m^{-3}, with price discounts applied until the minimum entry point of 409 kg m^{-3}. Under this set of circumstances, test weight at the earliest planting dates in both years (444 and 414 kg m^{-3} in 2015 and 2016 respectively) and at the highest target oat density (387 plants m^{-2}) in 2016 (419 kg m^{-3}) would have contributed to the profitability of those treatments relative to the rest. While the target oat density of 312 plants m^{-2} did have a test weight of 411 kg m^{-3}, that it was not statistically different than the next lowest target oat density's (237 plants m^{-2}) test weight (406 kg m^{-3}) suggests that it may or may not have met the adequate standard to be sold as a good grade product. We also made a conscious decision not to include straw sales in our economic analyses as limited data are available for organic markets and the range of potential prices varied greatly within Iowa and the region.

Conclusion

One goal of this research was to determine if a target oat density of 312 plants m^{-2} would result in an optimal balance among grain yield and quality, forage legume production and weed suppression. Additionally, we hypothesized that target oat density would have to be increased as a function of delayed planting to maintain those same objectives. The diversity of findings in the literature, coupled with our own, highlight both the difficulty and flexibility of determining an optimal target plant density with respect to a highly plastic cereal crop like oat, where genotypic and environmental factors can create variable quantities of vegetative and reproductive structures.

The experiment highlighted the importance of planting oat as early as possible. Not only were net profits maximized by early planting, but alfalfa biomass was greater and weed biomass lesser in one of the two years, indicating that early planting may actually improve objectives other than grain yield and quality. Climate-change scenarios for the Midwest, USA predict earlier accumulation of heat units in the spring in addition to more stochastic precipitation and drought events throughout the growing season (Pryor et al., 2014). Earlier planting dates may become requisite for oat and other spring cereal crops to maintain or improve productivity and profitability. We suggest that further studies be implemented to revisit the scarce amount of research that explores the effects of very early or frost seeding of spring cereals (Grafius, and Wolfe, 1960; Stute et al., 1998). Identifying an optimal target oat density was less precise, in this experiment, than we hypothesized and there was little support for increasing target oat density as a result of delayed planting. Under our feed-grade partial budget scenario, target oat density did not have a significant effect in either year of the study. Test weight and crop density increases were positively correlated in one year, enough so that the highest target oat density resulted in

the production of a food-grade crop. This suggests the potential economic significance of using a higher seeding rate and would be worth testing with different oat genotypes under different environmental conditions.

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Table 4.1 Summary of seeding rate (kg ha^{-1}) and cost ($ ha^{-1}) for target oat density treatments in 2015 and 2016.

		Treatment			
		Target oat density (plants m^{-2})			
Year	Value	161	237	312	387
2015	Seeding rate (kg ha^{-1})	49	73	96	119
	Seed cost ($ ha^{-1})	56	82	108	134
2016	Seeding rate (kg ha^{-1})	60	88	116	144
	Seed cost ($ ha^{-1})	49	72	95	118

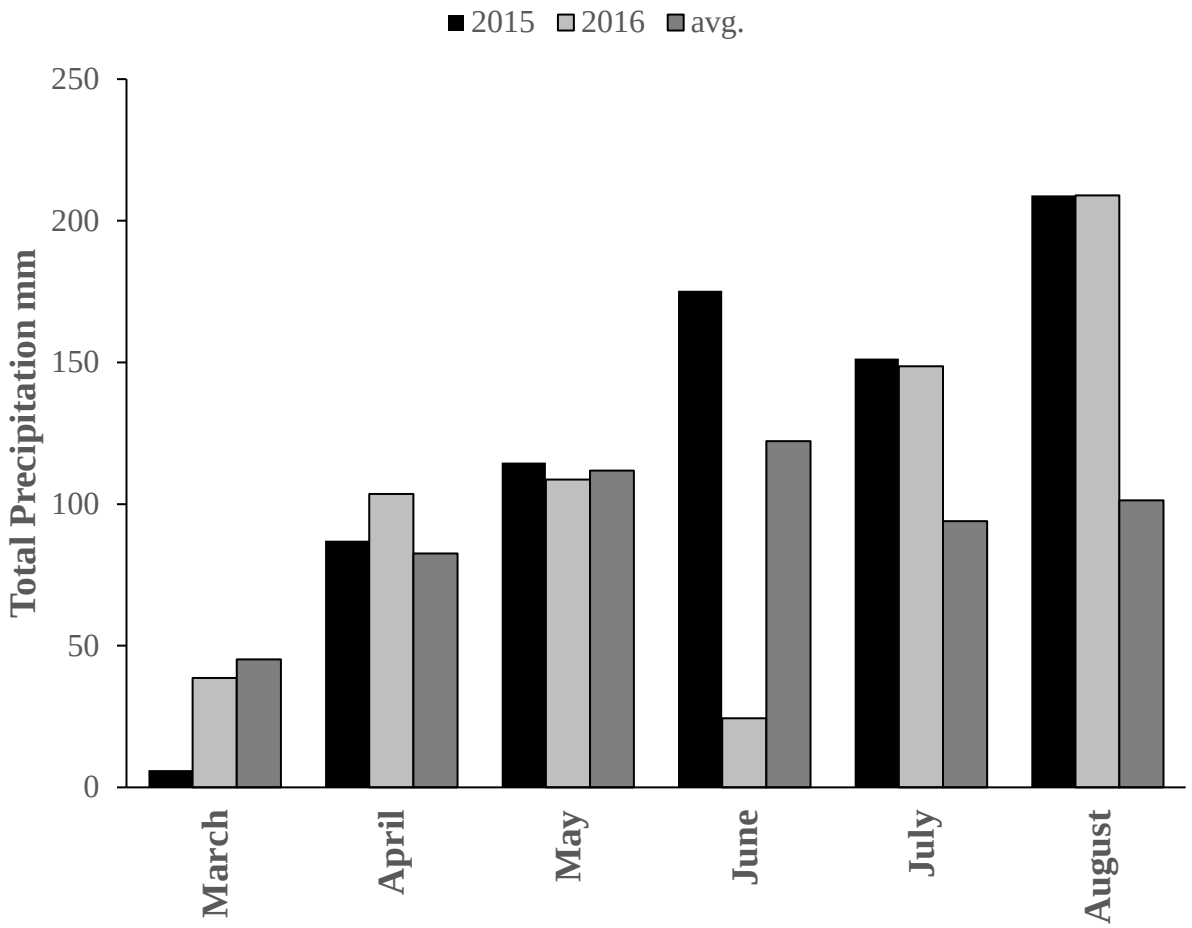
Table 4.2 Summary of grain yield, test weight, straw yield, alfalfa yield, and weed biomass as a function of target oat density, and planting date in 2015 and 2016.

	2015						
	Target oat density (plants m^{-2})				Planting date[1]		
Dependent Variable	161	237	312	387	Early	Mid	Late
Plant density (no. m^{-2})[2]	120a3	156b	197c	219c	244a	153b	122b
Panicle density (no. m^{-2})	186a	230b	240bc	262c	219a	232a	237a
Grain yield (kg ha^{-1})	1521a	1869b	1791ab	1745ab	2085a	1791a	1319b
Test weight (kg m^{-3})	373a	394a	397a	400a	444a	425a	304b
Straw yield (kg ha^{-1})	2482a	2651a	2655a	2780a	2673a	2561a	2693a
Alfalfa biomass (kg ha^{-1})	353a	377a	358a	363a	452a	358a	279a
Weed biomass (kg ha^{-1})	2037a	1997a	2914a	2053a	1987a	1905a	2183a
Net profit ($ ha^{-1})	589a	712a	657a	614a	791a	668a	470b
	2016						
	Target oat density (plants m^{-2})				Planting date[1]		
	161	237	312	387	Early	Mid	Late
Plant density (no. m^{-2})[2]	121a	155b	191c	224d	169a	164a	185b
Panicle density (no. m^{-2})	255a	311b	366c	435d	316a	352b	357b
Grain yield (kg ha^{-1})	3193a	3209a	3183a	3296a	3417a	3139ab	3106b
Test weight (kg m^{-3})	397a	406b	411b	419c	414a	406b	405b
Straw yield (kg ha^{-1})	2935a	3015a	3057a	3163a	3582a	2784b	2762b
Alfalfa biomass (kg ha^{-1})	671a	696a	685a	771a	924a	643b	550b
Weed biomass (kg ha^{-1})	2253a	2249a	1876b	1980ab	1947a	2260b	2061ab
Net profit ($ ha^{-1})	1292a	1276a	1267a	1242a	1352a	1235ab	1221b

[1]Planting dates in 2015 were 4/6, 4/17 and 4/28. Planting dates in 2016 were 3/22, 4/4, and 4/14.

[2]Data were $\log_e$ transformed for analysis.

[3]Within rows, by year and treatment, values not followed by the same lowercase letter are significantly different ($P < 0.05$).



	Month					
	March	April	May	June	July	August
	Temperature °C					
2015	4.4	11.7	16.7	21.7	22.8	21.1
2016	7.2	11.1	16.1	23.9	23.3	22.8
Avg.†	2.2	10.1	16.1	21.1	23.3	22.2

†Avg. represents the 65 year mean temperature via Iowa Environmental Mesonet.

Figure 4.1 Mean monthly precipitation and temperature for Agricultural Engineering and Agronomy Research Farms in Boone, IA, USA from March to August of 2015 and 2016. Avg. represents the 65-year average. Data were obtained from Iowa Environmental Mesonet (2016).

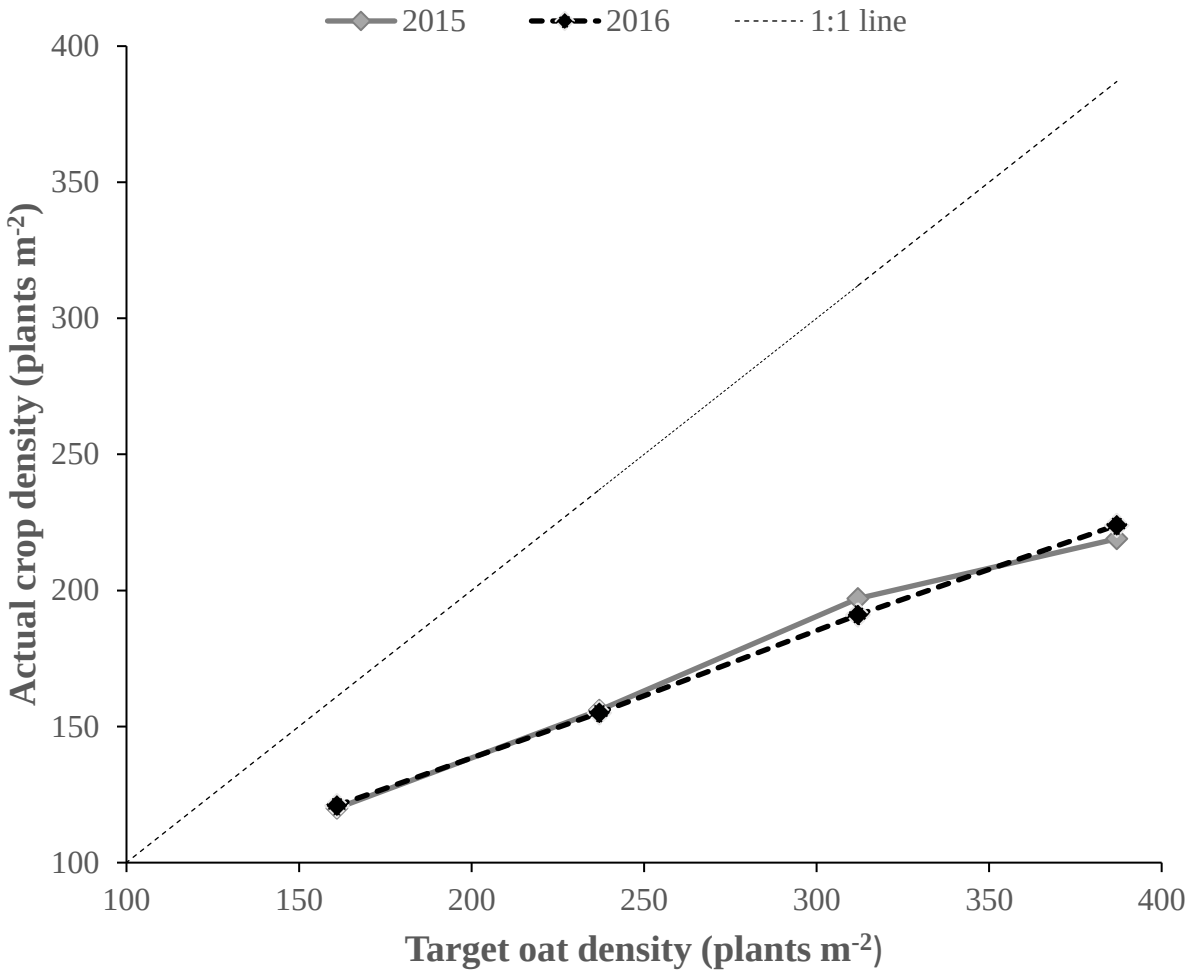


Figure 4.2 Actual vs. target oat density, across all planting dates, in 2015 and 2016 with a 1:1 line as a reference.

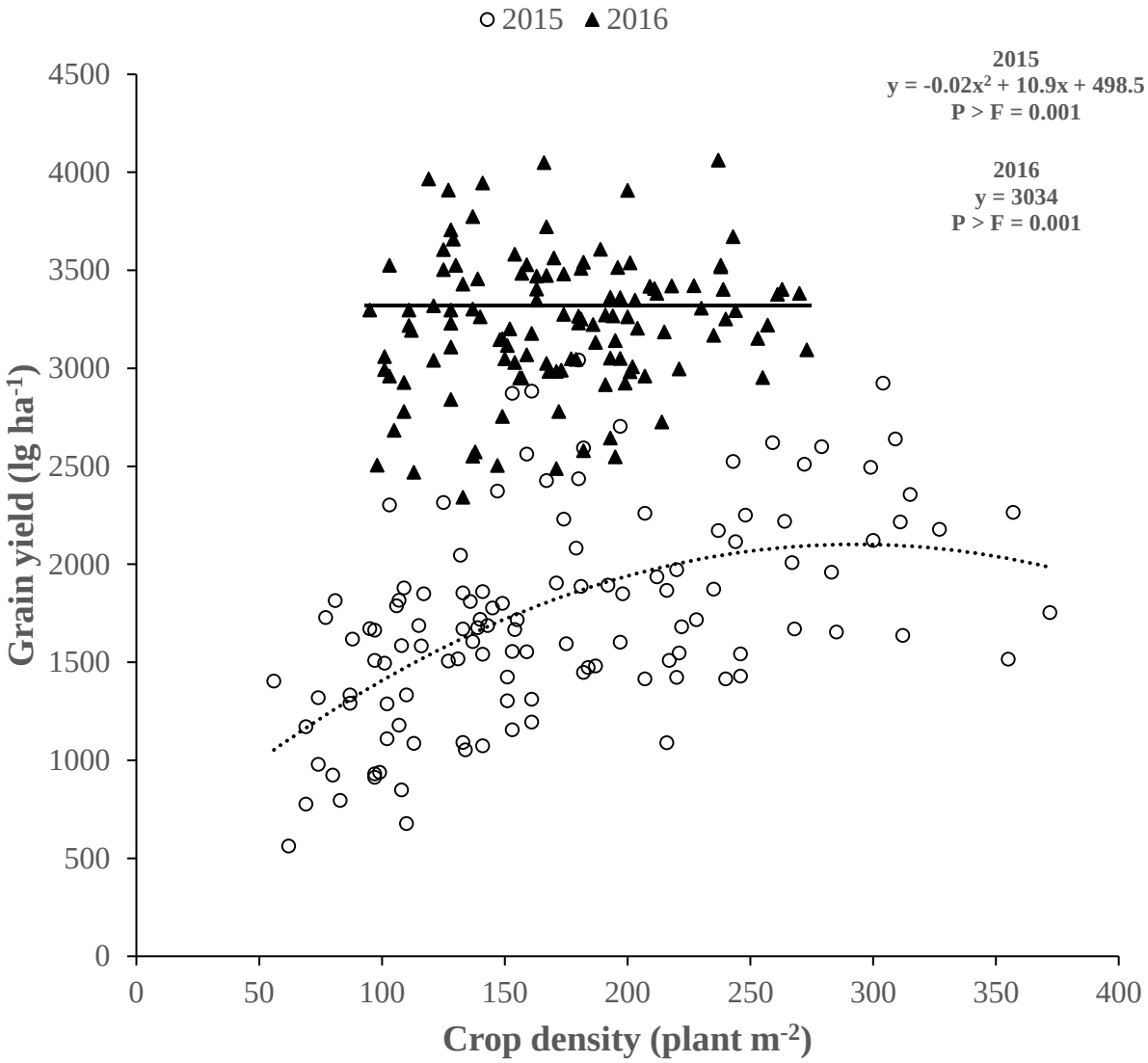


Figure 4.3 Grain yield as a function of crop density in 2015 (white circles) and 2016 (black triangles). A quadratic model was fit to the data in 2015 whose equation and statistical significance is presented. Data from 2016 showed no relationship between the two variables.

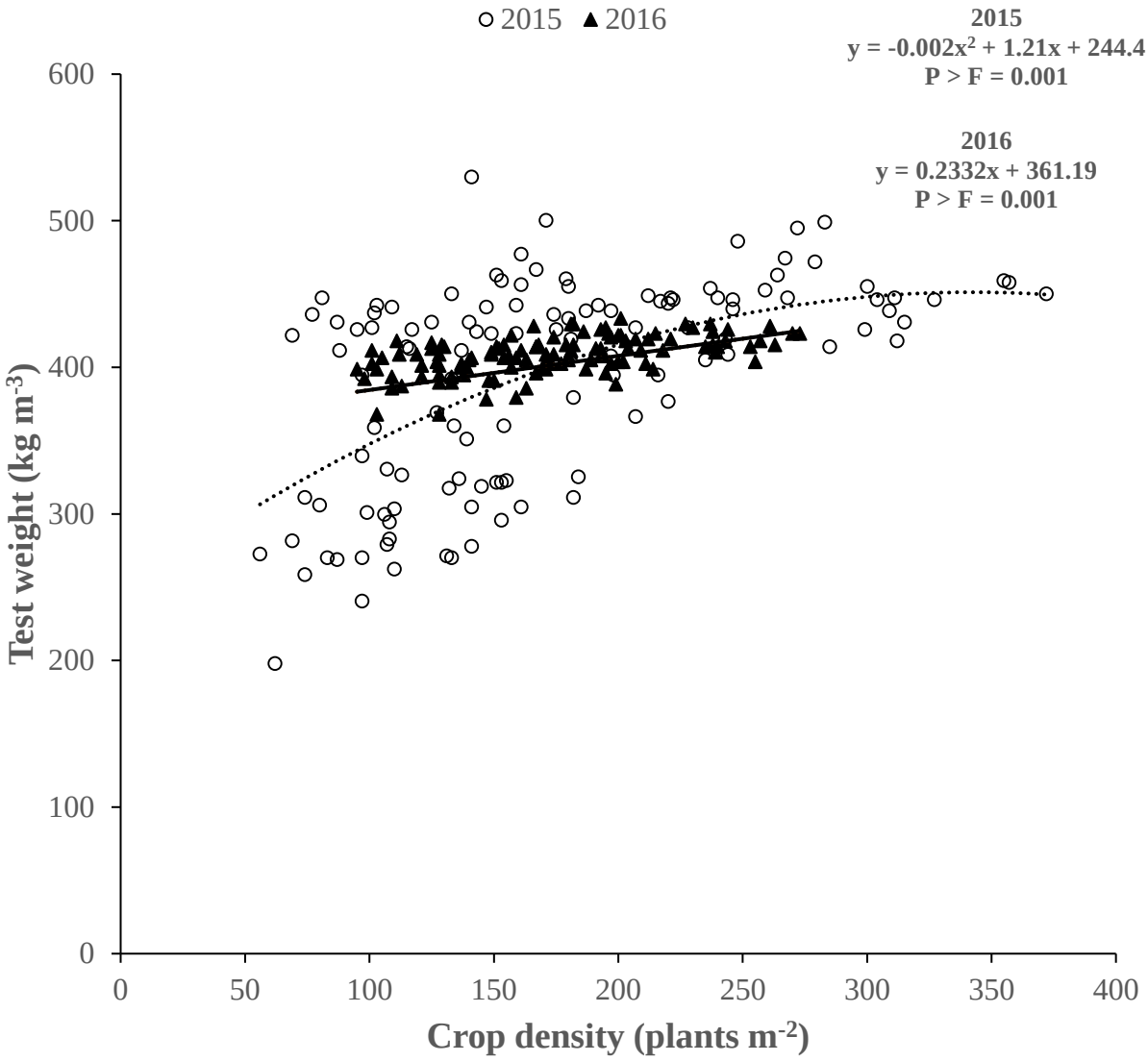


Figure 4.4 Test weight as a function of crop density in 2015 (white circles) and 2016 (black triangles). A linear model was fit to the data in 2015, and a quadratic model was to the data in 2016. Equations and the statistical significance of each is presented in the top right corner of the figure.

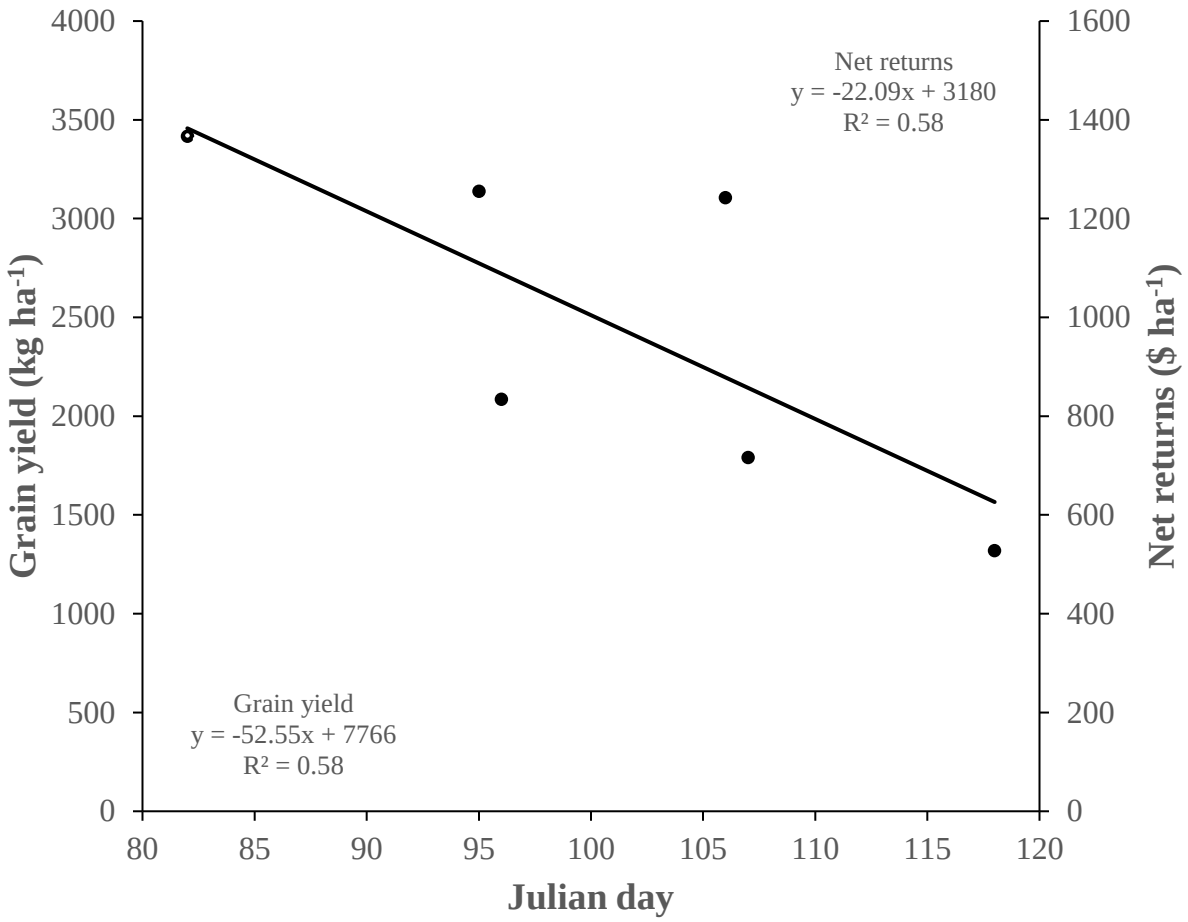


Figure 4.5 The linear regression of grain yield and net profit, across all target oat densities, as a function of planting date (Julian day). Equations for the linear models and associated R^2 values are presented in the top right (net returns) and bottom left (grain yield) of the graph.

CHAPTER 5. CONCLUSION

The results of these studies highlight some important features of organic small grains in Iowa. Our mixed-methods research showed considerable variance around agronomic production factors, economic considerations, as well as farmer perceptions of these two parameters. Many of the farmers were often aware of both the limitations and tradeoffs involved with small grains production within an organic system context, and found ways to use small grains on-farm as either feed or seed, to buffer themselves economically if selling into a more profitable food-grade market was not possible. Those unable to sell food-grade grain were open in sharing their challenges with us. Additionally, the study helped guide many of the research questions that have been presented in the body of this thesis. These included testing cultural practices and physical weed control (PWC) in both on-farm and on-station settings with respect to oat and/or forage legumes. Findings from these sources also demonstrated variance around results and the influences (sometimes confounding) of environmental and management factors.

On-farm trials examining target oat density showed no treatment effects on grain yield and test weight, or forage legume and weed biomass, but suggested savings could be made via seed and associated cost reductions. PWC with a rotary hoe was effective in reducing broadleaf weed biomass at one farm, but was ineffective at another, and had no effect on grain yield or test weight relative to the control. Sowing oat with red clover at one farm reduced oat grain yield relative to the monoculture control, but not test weight. Oat undersown with alfalfa, at another farm, had no impact on yield or test weight. Underseeded red clover outperformed a mid-season cover crop mixture at one site, while the opposite was true where alfalfa was the undersown forage legume. Differences in underseeded legumes versus mid-season planted cover crop

mixtures were drastic but may have been influenced by farm management and prevailing weather conditions as much as any species-based differences.

Our on-station experiment emphasized the importance of planting date, the effects of which were observed in grain yield, test weight and net returns in both years (decreases), in addition to alfalfa (increase), and weed biomass (increase) in one year. Yield showed a quadratic response with respect to oat density in one year, and no response in the other. Target oat density had no effect on net returns in either year of the study. However, observed oat crop densities suggested that increased test weight may be associated with seeding rate increases up to a certain point, which would improve the economic prospects of oat density manipulations. That food-grade quality oats may be produced at higher crop densities is certainly worth re-examining under different environments, using different cultivars, and management systems.

While oat has fallen from favor, from both a surface area and research standpoint both regionally and globally, it remains an important crop in temperate climate cropping systems, in which external synthetic inputs are minimized or eliminated. Our findings suggest that, while agronomic management has an important role to play, it may be limited. Beyond planting date, which is often outside the control of farmers, many of the management practices we tested demonstrated mixed or minimal effects with respect to grain yield and test weight in oat, across the varied environments in which they were tested. Research must also continue to explore areas of oat-crop physiology and breeding, as important insights and gains from these fields have severely lagged behind those achieved in other crops, especially over the last thirty years. While breeding efforts and physiological insights are not miraculous cure-alls for crop improvement, potential gains in these two areas can certainly contribute more to both tangible crop advances related to productivity and quality, in addition to a greater understanding of the negative effects

of abiotic factors and management. These will all be essential to both the ongoing success of this crop and its function within a diverse rotation. As importantly, a greater quantity and diversity of in-state and regional markets, for food and feed-grade organic oats, would contribute immensely to the potential success of organic small grains in Iowa. Fully developed organic feed-grade markets would positively alter the economic potential for farmers, creating a truly viable market place for small grains that are unable to meet rigorous food-grade standards. Additionally, regional food-grade small grain markets for barley, rye and wheat are developing at a steady rate, on both coasts, as the demand for local beer, spirits and baked goods continues to rise. A few local mills in Iowa point the way toward this same potential in this state.

Lastly, activities related to all three chapters of this thesis generated a plethora of outreach events and materials. Research-related activities were strongly allied with two local farmer-led non-profit organizations, the Iowa Organic Association and Practical Famers of Iowa, both of which help to support field days, and to generate print and web-based materials on small grains production and its associated challenges. The research also helped generate ideas for a series of questions that have been added to the Iowa Farm and Rural Life poll for future inquiry into small grains and farmers' perceptions of them. The goals of this research were to explore limitations to organic small grain production, develop agronomic strategies to help improve

APPENDIX A: SURVEY 1

Historical survey (S1) asking about relevant small grains management and marketing experience prior to specific year of the study from 2014 and 2015.

1.) How many years have you been farming (as an adult)?

2.) How many years have you been growing small grains?

3.) How many years have you been certified organic?

4.) What crop rotations do you use? (Please list all rotations that you use)

5.) What small-grain crops have you grown?

6.) What seeding rate do you use for small grain?

7.) Do you use an underseeding with your small grain?

8.) What forage species do you seed with your small grain?

9.) What are your typical field operations for small grain production?

10.) What planting method do you use for small grain?

11.) What harvest method do you use for small grain?

12.) What has been your average small grain yield?

13.) What has been the average test weight of your small grain?

14.) What challenges do you have growing small grain?

15.) What type of storage facility do you use for your small grain?

16.) What percentage of your small grain do you use on-farm?

17.) To whom do you sell your small grain?

18.) What challenges do you have marketing small grain?

APPENDIX B: SURVEY 2

Growing-season specific survey (S2) given to farmers during either the 2014 or 2015 season.

1.) Which of your organic small grains were part of the project for 2014/2015?

2.) Number of acres in your 2014-2015 project organic small grain field that you PLANTED FOR GRAIN HARVEST?

3.) What is the crop rotation you used in this 2014-2015 project organic small grain field? (Please list all crops that preceded this crop of small grains in the order they were grown.)

4.) Did you apply any soil amendments or fertility prior to this organic small grain crop?

5.) If soil amendments were applied before (either fall or spring) this small grain crop, please list them and the rate applied per acre.

6.) What variety of small grains did you plant in this field?

7.) What was your seeding RATE for organic small grains in this field?

8.) What was your seeding DATE for this organic small grain field?

9.) Do you use an underseeding in this organic small grain field?

10.) What forage species did you seed with your organic small grains this year?

11.) What were your field operations for organic small grains in this field this year?

12.) What planting method do you use for your organic small grains in this 2014-2015 project field?

13.) Number of acres HARVESTED FOR GRAIN in your organic small grain project field in 2014-2015?

14.) What did you do on the acres that were NOT HARVESTED FOR GRAIN?

15.) How did you harvest your organic small grains?

16.) If you windrowed this organic small grain field, what was the date of windrowing?

17.) Date of combining (either with pick up head or for the standing crop)?

18.) What were the TOTAL BUSHELS HARVESTED from your 2014-2015 project organic small grain field?

19.) What do you consider the biggest factors were constraining your organic small grain yield this year? (Multiple choice answer options presented in Table 2 and Fig. 2.)

20.) How do you think that you could increase your organic small grain yields?

21.) In what other ways could you increase your organic small grain profitability?