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DEPARTMENT OF PLANT SCIENCE

EVALUATING THE AGRONOMIC POTENTIAL AND NUTRIENT PRODUCTION EFFICIENCY OF PULSE CROP PRODUCTION IN CENTRAL PENNSYLVANIA

KAITLYN RIMOL
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Reviewed and approved* by the following:

Mark Dempsey
Laboratory Technician-Department of Plant Science
Thesis Supervisor

Heather Karsten
Professor of Agroecology
Honors Adviser

* Signatures are on file in the Schreyer Honors College.

ABSTRACT

Pulse crop production is currently of marginal importance in the Northeast, especially in Pennsylvania. The purpose of this study was to determine the potential for pulse crop production in Central Pennsylvania as well as the relative nutrient production compared to other agricultural systems, should market forces make this economically viable. A one-year variety trial was conducted to determine the yield potential for multiple varieties of lentil, dry pea, and dry edible bean in Central Pennsylvania. Pea produced the highest yield, followed by dry bean and lentil. These yield results were used to conduct preliminary findings about the food production potential for Central Pennsylvania, and to compare pulse crop production to other agricultural systems, including grain and animal systems. These systems were compared on the basis of land use, calorie and protein production, and economics, and provided multiple platforms for comparison of each of the production systems in terms of future viability and practicality of feeding a growing global population.

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Chapter 1

Introduction

Worldwide, the human population is growing at an exponential rate, with the United States population following a similar trend. With this increase in population comes an increased demand for food, which puts pressure on the already limited resources such as land, water, and energy. People around the world are also spending more money on food due to an increasing gross domestic product in many developing countries, causing the worldwide demand for meat to rise in addition to total food consumption. In 2006, 267 million tons of meat were consumed worldwide, and by 2016, global consumption is projected to reach 320 million tons annually (FAO, 2015). These needs will be largely met by converting pastoral animal production systems to intensive ones in order to maximize the total output from the land already in production (Heinz and Hautzinger, 2008).

Currently, two thirds of all agricultural land is used to grow crops for livestock feed. Only 8% is used to grow crops for direct human consumption, and with the increasing global demand for meat, these ratios will continue to diverge from each other (Brooks, Stanford Woods). Agriculture takes up 38.6% of the earth's land. The rest is either urban, developed land, or undeveloped land that is either unsuitable or undesirable for conversion to agriculture, such as forests, mountains, tundra, and deserts. Further agricultural land expansion is either not possible in these areas, or extremely unsustainable, as in the case of converting tropical forests to farm or pasture land. In order to meet the growing global demand for food, the solution lies in improving efficiency on the land that is already in production, a reduction in the global demand for animal products, or a combination of the two (Foley *et al.*, 2011).

In order to anticipate the future demands of a global market with limited resources, it is wise to evaluate sustainable alternatives in local markets that may provide solutions. Plant-based protein production through pulse crop cultivation is one such system that may improve land use efficiency compared to protein from animal production systems. Currently, pulse crops contribute 33% of the dietary protein needs to humans worldwide, so the room for growth and adoption of this system may exist, especially in the United States. The most frequently consumed pulse crops are dry edible bean (*Phaseolus vulgaris)*, dry edible pea (*Pisum sativum*), chickpea (*Cicer arietinum*), broad bean (*Vicia faba*), pigeon pea (*Cajanus cajan*), cowpea (*Vigna unguiculata*), and lentil (*Lens culinaris)* (Grahm and Vance, 2003).

Current and Future Legume Markets: A Closer Look

Lentil

Domestic lentil production has increased in the last decade despite domestic demand remaining relatively stagnant. In the global market, increased demand in developing countries is being met through increased imports, so the increased production in the U.S. has and will continue to be absorbed by world export markets unless consumption in the American population increases (Akibode & Mywish, 2011). Over half of all lentils produced in the United States are exported. Domestic production has trended towards producing a high quality, food grade product, a significant portion of which is purchased by the government for food aid, which makes up 70% of U.S. lentil exports. Globally, Canada is the leading supplier, but export demand is trending upward, with the biggest demand from Europe and Africa (USDA Economic Research Service, 2005).

Pea

Dry edible peas rank fourth in the world production of pulse crops, falling short only to soybean, peanut, and dry bean. They can be used for both human and animal consumption as a supplemental protein source, although in the United States, the high quality of peas generally makes them more suited for food and processing markets. Over 70% of domestic production is exported to India, China, and Spain (Knopf, 2012). However, a strong dependence on the export market makes prices very volatile. Therefore, when growing peas in the United States, crop insurance, where available, is highly recommended, as well as marketing through a livestock enterprise (Krall and Miller, 2005).

Bean

Dry bean consumption remains stagnant in the United States today. Annual consumption by Americans peaked back in 1942 at 11 pounds per capita. In 2013, per capita annual consumption totaled 5.7 pounds and has remained relatively constant over the decade. In the future, further efforts to publicize dietary benefits of dry bean consumption will be of integral importance to further market growth as well as combatting dietary challenges such as obesity (Zahniser and Wells, 2014). The 2010 Dietary Guidelines for Americans recommended eating one and a half cups of beans and/or peas per week (USDA, 2010). For all Americans to meet this recommendation would double domestic dry bean consumption, and would be historical for the market, allowing for many more acres of dry beans to be planted (Zahniser and Wells, 2014).

The future of growth in the domestic dry bean industry largely depends on dietary changes in the American population. In 2013, the United States produced 1.1 million metric tons of dry beans, totaling $977 million and utilizing 1.3 million acres of farmland. Unlike many grain and oilseed crop markets, the dry edible bean industry has experienced little overall growth in the past decade. Although output remains relatively stable, crop commitments fluctuate from year to year according to expected market conditions, certified seed supply, and variable weather conditions affecting yields. Despite the appearance of a relatively stable market output, production in the dry bean industry has changed in the past decade, and is masked by two factors. The first is the rise in garbanzo production over the past decade, due to garbanzo beans being included as a market class of dry beans in reports. From 1998-2003, garbanzos made up 4% of all market classes of dry beans. However, from 2008-2013, their share increased to 9%. This is mainly due to the increased popularity of vegetarian and vegan diets among Americans. Additionally, black bean production rose from 7% to 13% over those same time periods due to increased export demand from Mexico. However, shares of other market classes of dry beans have been decreasing in the past decade. These two factors make it appear as if production has remained relatively constant in the United States, which is largely untrue. In market classes where domestic demand is met or exceeded by production, the export market has become increasingly streamlined and important due to acts such as NAFTA and CAFTA-DR, especially as consumption in the American diet remains at stagnant levels (Zahniser and Wells, 2014). Unless domestic demand rises, production will likely remain relatively constant, or will be forced to be absorbed by the export market and be subjected to often volatile prices (Jerado, 2012).

Future Outlook on Pulse Crops

The Agricultural Act of 2014 granted $125 million towards researching the nutritional benefits of food legumes and their potential to decrease rates of obesity and chronic disease in the American population. These funds will be spread over five years, and will also include $10 million for the development of a pilot program aimed at increasing the use of food legumes in school meals. Also covered under this act are expanded pulse crop insurance programs to support domestic farmers, as consumption and therefore production is expected to increase. Once the nutritional benefits are researched, health claims can be made and promoted (Lind, 2014). Historically, the use of health claims on products has increased consumer demand. Quaker Oats are one such example of this phenomenon; the use of health claims on their products increased the market share of Quaker Oats by more than five points in a declining market (Childs and Childs, 2001). It is expected that food legumes will also experience this trend over the next few years as research is conducted and health benefits are promoted.

The Growing Importance and Potential for a Local Market

A growing body of evidence suggests that the demand for pulse crops will be rising in the near future, both domestically and internationally. At this same point in time, the global food supply is being increasingly affected by population growth, climate change, rising energy costs, and biofuel production. Each of these variables has been attributed to the rising cost of food, and shows no signs of letting up in the near future. The solution to these challenges will come from a summation of many different solutions, each with their own local adaptation to make the best possible use of available resources, but all working to answer the question of how to feed a growing world population with an equivalent, if not declining, amount of natural resources. Pulse crop production in Pennsylvania is one possible solution, as both a platform from which to contribute to the global food supply, as well as a land base for ensuring regional food security.

The recent popularity of the local food movement has raised questions about the extent to which the world can continue to rely on long-distance food transport, given that these challenges are becoming increasingly relevant to the state of global food security (Peters *et al.*, 2008). The term "foodshed" is used to understand the flow of food in the food system, and refers to the geographic area that is responsible for feeding a certain location. Foodsheds today often rely on long-distance transportation, usually to much more of an extent than the public they serve is aware. However, given the challenges faced by the global food supply today, there is riskiness in taking this system for granted until it is in danger, rather than adapting to meet those challenges. Although the overall impact of creating more localized foodsheds is still being debated, some examples of proposed benefits include a reduction in energy used to transport goods, shorter supply chains that improve relations between producers and consumers, and greater public control of the food system and issues related to it. Given these anticipated challenges, it makes sense to evaluate the potential for regional food crop production in Pennsylvania, including pulse crops, due to their forecasted increase in demand (Peters *et al.*, 2008).

In determining the overall costs and benefits to locally produced food, researchers have concluded that *how* something is produced is just as important as *where* it is produced.

Producing a product in a region that is unsuitable can outweigh the benefits of producing it locally because increased need for inputs pushes production costs higher than the combined production and transportation costs when grown in a suitable area. Therefore, proximity to markets alone is not enough of a justification for local food production. There are three factors that prompt the exploration of Pennsylvania as a pulse crop production region; climate and growing conditions, proximity to major food processing hubs, and the current importance of animal agriculture in the state.

Climate

Central Pennsylvania is characterized by a humid continental climate, meaning that it has large seasonal temperature differences. This climate designation has warm and somewhat humid summers, and very cold winters. The humidity in the summer is generally not excessive, but not low enough to be characterized as arid or semi-arid. The temperature averages 68.8°F in May-August, which is the general growing season for cool season crops, and 69.2°F in June-September, the growing season for warm season crops. Precipitation totals average 18.4 inches for May-August, and 17.6 for June-September, which during the growing season comes mostly in the form of thunderstorms.

Given these climatic conditions, some pulse crops may succeed in this growing environment and fit into established crop rotations more than others. Lentil is hypothesized to have moderate chances of success in this region. Although a cool season crop, lentil is moderately resistant to high temperatures, so may be able to tolerate the slightly higher than ideal summer temperatures in Central Pennsylvania. Traditionally, lentils have been grown in the

Palouse region of eastern Washington and western Idaho, which is a high quality, although high cost growing region for this crop. Production in this area results in a top quality product that commands a premium price, although acres dedicated to lentil production in this area have remained constant despite increased demand. Recently, acreage has increased in the upper Midwest area encompassing North Dakota and Montana. This region is a lower cost production area, and creates a relatively lower quality crop that is more suited for exports to be used as both human and animal food.

Lentil is a cool season crop that is frost-tolerant. Semi-arid conditions will slightly reduce yields, but lead to a very high quality crop. Lentil grows best in sandy-loam soils that are high in phosphorous and potassium, and must be planted in well-drained ground as they are very intolerant of wet conditions. Even short periods of flooding can completely kill plants. High humidity or excessive rain will promote vegetative growth and reduce quality and yields. Since lentils are grown in dry areas, diseases are not typically a major problem, however, in years of excessive moisture, the most significant diseases are usually Ascochyta blight, white mold, and *Fusarium* root rot. Insects are not typically economically damaging (Oplinger *et al.,* 2015)

Pea is hypothesized to have low to moderate levels of success in this region. Traditionally, peas were grown in the Palouse region, but more recently, the Northern Plains, which includes Montana, North Dakota, and South Dakota, has become the primary region for pea production. Peas fit well into the already established crop rotations of the Northern Plains, especially when following a cereal crop such as winter wheat or barley, which are also common in crop rotations in Pennsylvania (US Dry Pea and Lentil Council, 2008). Peas are a cool season crop, and grow best in semi-arid climates with an average growing season temperature between 55 and 65°F. Young plants are very tolerant to frost, and generally do worse if temperatures exceed this range because of increased disease and aphid pressure, as well as reduced seed set (Sell, 2010). Due to higher than ideal average summer temperatures, which may lead to reduced seed set during periods of hot weather while flowering, yields are expected to be below average when grown in Central Pennsylvania (University of Wisconsin, 1991).

In the United States, the top five dry edible bean producing states are North Dakota, Michigan, Nebraska, Minnesota, and Idaho (Jerado, 2012). Many farmers who produce beans in these areas integrate them into a cereal grain or oilseed crop rotation and make the decision to grow them based on the current market situation (Zahniser and Wells, 2014). Most of the dry edible beans produced in North Dakota are grown in the eastern half of the state because of the ideal climate and soil conditions in the area. Dry bean is a warm season crop and grow best in temperatures averaging 65-75°F, and don't do well in cool, humid, or rainy weather. Legumes are very sensitive to wet conditions which also make them very susceptible to a wide range of diseases that can cause significant reductions in quality and yield (North Dakota State University, 2000). Eastern North Dakota is characterized by a continental climate, meaning it has warm summers and cold winters. The average summer temperature is 68.5°F and annual precipitation averages 21.2 inches. The climate conditions make areas such as these ideal for dry bean production. Dry bean is likely to be the most successful pulse crop in Central Pennsylvania, given that their growing requirements align well with the climate of Centre County.

Table 1: Summary of growing requirements for each variety trial species. Growing season is defined as the duration of crop growth from planting to harvest, and the temperature range for each crop will ideally encompass the average temperature during this time.

Growing Season Climate	Centre County, PA	Lentil	Dry Pea	Dry Bean
Temperature	68.8°F (May-August) 69.2°F (June-Sept.)	55-65°F	55-65°F	65-75°F
Precipitation	18.45” (May-August) 17.59” (June-Sept.)	Negatively impacted by excess precipitation, especially standing water		

All legumes generally do not tolerate excessive moisture well, and do not compete well with weeds due to their growth habits and physiology. The precipitation received in this region may be a limiting factor for pulse crop production unless disease can be controlled or moisture is below average. Therefore, it is hypothesized that if disease and weed pressure can be controlled, these pulse crops may be successful in Central Pennsylvania and will experience competitive yields with those grown in the western states where they are currently produced.

A Major Food Processing State

Nationwide, Pennsylvania ranks fourth in food processing and manufacturing states. Food manufacturing, which is mostly concentrated in the south central portion of the state, is the number one source of employment in the commonwealth. According to the Pennsylvania Global Competitiveness Initiative Report (2010), the food processing industry was ranked as a strength within the state because of the overall quality of goods produced, a large cluster of food processing companies, good access to raw materials, a large labor pool, and excellent access to its customer base. Nine counties in South Central Pennsylvania are home to over 170 processing companies, and this region also has ideal access and proximity to suppliers, purchasers, distribution centers, and manufacturers of equipment and supplies. Finally, this region is close to many major domestic and international markets; 40% of the United States' population, and 60% of Canada's population is located within 500 miles (Smart Market, 2006).

With the expected increase in demand for food legumes in the coming years growing them in proximity to food processors may provide an incentive, as raw materials can be sourced through a shorter supply chain, allowing growers to contract with processors instead of distributors, leading to more stable prices. This may also help to stabilize or even reduce food costs at the consumer level, and will reduce reliance on the global market to provide inputs for these Pennsylvania companies.

Animal Agriculture in Pennsylvania

In Pennsylvania, livestock operations account for 68% of all commonwealth farm income. The state ranks fifth nationwide in dairy production, which is the largest agricultural industry in Pennsylvania. Other livestock industries of importance vary by region, but include hogs, horses, and poultry production (National Agricultural Statistics Service, 2013). Many experts suggest that the future of regional pulse crop production depends on identifying alternative uses in order to gain entry into the market and allow for price stability, and due to the available protein of these crops that is high in both quality and quantity, many are suitable for protein supplementation in animal feeding rations. Additionally, crops that do not make food grade in years of bad weather can still be marketed as animal feed. Having these markets so close to each other provides an advantage to both growers and buyers, as growers have multiple options for marketing their crop, and feed buyers have alternatives to typical rations should prices their usual feed rations increase.

The Value of Producing Pulse Crops in Central Pennsylvania

The climatic conditions and growing requirements for each crop, and the availability of marketing through animal operations and food processors and large markets all provide a justification for the exploration of pulse crop success in Central Pennsylvania. This is best evaluated by conducting a variety trial to determine the likelihood for success on both a species and varietal level. In this experiment, multiple varieties of pea, dry bean, and lentil were grown and their performance evaluated over the course of one growing season.

In order to determine how pulse crop production may fit into the larger solution of global and regional food security, land use efficiency of each species was evaluated and compared against crop and livestock systems. To meet the future needs of a growing population, land use must be re-evaluated to maximize the amount of food produced per acre since further land expansion is either not possible or unsustainable. Land use efficiency, as measured in pounds of food produced per acre per year, can help assign relative values to each system to determine its future viability in a world that demands more from each acre.

Chapter 2

Materials and Methods

Variety Trial

The pulse crop variety trial was conducted during the 2014 growing season at the Penn State University Russell E. Larson Agricultural Research Center, Rock Springs (Centre County), Pennsylvania. Pulse crops selected for the study included lentil, pea, and dry bean. Market classes and varieties are shown in Table 2, along with seeding rates. Treatments and replications were assigned according to a randomized complete block design. Each lentil and pea variety had 3 replications (limited seed quantities) and each bean variety had 4 replications, and each replication measured 50’ x 7’ (lentil and pea), or 50’ x 10’ (dry bean). The predominant soil type is a Hagerstown silt loam and the trial was non-irrigated.

Table 2: Variety trial design and management. This table shows the crop species, market class, variety, and the target planting rate for the variety trial portion of this study.

Crop	Market Class	Variety	Target planting rate (plants/a)
Dry bean	Black	Zorro	105k
		Eclipse	105k
	Great Northern	Coyne	75k
	Navy	T-9905	105k
		Vista	105k
	Pink	Rosetta	75k
	Pinto	Medicine Hat	75k
		Santa Fe	75k
	Small red	Merlot	75k
	Heirlooms	Yelloweye	75k
		Calypso	75k
	Unclassified	Carioca	105k
Field pea	Yellow	Spider	325k
		Bridger	325k
		Navarro	325k
		Salamanca	325k
		DS Admiral	325k
		Korando	325k
		Mystique	325k
		Nette	325k
Lentil	Red	Maxim CL	650k
		Impala CL	615k
Chickpea	Kabuli	Orion	130k
		Alma	130k

Soil test results indicated adequate nitrogen and phosphorous based on expected crop yields of 1500 lb/A for lentil, 2000 lb/A for pea, and 2000 lb/A for dry bean. Potassium was slightly below adequate levels and it was recommended that 20-30 lb K_2O/A be added, although it was not. No pH adjustment was needed based on a soil test result of 7.2. Because field availability was limited the trial was carried out in a field where the previous crop was soybean.

Due to concerns of foliar pathogens the field was disked prior to planting to incorporate soybean residue, and worked to a seedbed April 21-24, 2014. Pea and lentil were planted with a 15-row Esch no-till drill on 5.5” rows. Dry bean was planted with a 4 row Monosem corn planter (using soybean plates) on 30” rows. All crops were planted according to guidelines established for common growing regions, but adapted to Central Pennsylvania’s climate. Weed control in pea and lentil was the application of the herbicide imazamox (trade name Raptor, 0.023 lb ai/A), applied approximately 4 weeks after planting. The pea and lentil varieties in this trial are tolerant of this herbicide. Weed control in dry bean consisted of frequent cultivation with an inter-row cultivator (approximately 3, 4, 5, and 6 weeks after planting), instead of herbicide application, due to concerns about reducing bean yield, as bean plants were not as vigorous as expected in the early season (foliar yellowing and overall slow growth) and showed signs of herbicide damage (deformed leaves and slow to mature) in plots adjacent to pea and lentil plots, where Raptor was applied. Weed pressure, evaluated visually, was high in dry bean – owing mostly to in-row weeds not controlled by cultivation – but was low in lentil and pea. Nutrient limitation and disease pressure were evaluated by visual assessment in the field and using photographs: one photograph was taken of each plot down its length, and two taken randomly along their length. Visual assessment of diseases is not adequate for positive identification – which requires infected and non-infected controls – and thus this information was used only to evaluate potential disease limitations to yields, post-hoc. Whole plots were harvested for yield: pea and lentil were harvested by hand and threshed using a gas-powered thresher, and dry beans were harvested using a Massey 550 combine. Grains were weighed soon after harvest, and grain moisture was calculated by drying a subsample; grain yields were corrected to 13% moisture.

Crop and variety yields were analyzed using the Minitab statistical software to perform ANOVA and a multiple comparison test. Normality was evaluated with Q-Q plots and equal variance was evaluated with HOV plots, and data was transformed as needed to meet these assumptions.

Nutrient Production Efficiency

Calculations to determine nutrient production efficiency of various production systems were performed using the most local data, when available (Appendix A). The animal systems selected for analysis were beef, swine, and broiler production, as these are the three most consumed meats in the United States. Sample diets for each animal production system were created using extension publications and reviewed by Penn State Extension specialists for accuracy. Extension recommendations were based on average input costs, availability of feedstuffs, and animal nutrition requirements. Sample diets for each animal system were determined for the entire lifespan of the animal from birth to slaughter, and specific requirements and information for each growth phase were based on average local production and average local slaughter weights. Each diet was broken down into its individual feed components, and the total acreage required to grow feed components for one animal was calculated using local yield data. Feed inputs that were byproducts of other industries, such as dried whey, fish meal, etc., were not included as part of the final land use requirement because these inputs were very small, and the acreage required to produce inputs such as fish meal is difficult to quantify.

For the purpose of comparing nutrient production per acre among crops, the 3 highest-yielding bean and pea varieties from the variety trial were averaged to represent yields in Central

Pennsylvania. This was done for two reasons: first, it is assumed that a grower would not knowingly choose a low-yielding variety, and second, higher yielding varieties likely better represent dry bean yield potential in Central Pennsylvania, as bean yields were limited by intense weed pressure and potassium limitation. Both lentil varieties were included in the lentil average yield, despite concern that yields were depressed by insect pressure. Due to the likelihood that dry bean and lentil yields could be improved with better nutrient and pest management the target yields for dry bean and lentil (2000 lb/A and 1500 lb/A, respectively) were also included in this analysis for comparison. Yield data obtained by the trial are referred to as "observed" yields, while target yields are referred to as "potential" (see Figure 5).

Nutrient production data are converted to a dry weight basis to account for the dramatically different moisture contents of different foods. Nutrient production data were not analyzed statistically as these data were replicated only for crops included in the variety trial. The caloric and protein contents of each food were determined using the USDA National Nutrient Database for Standard Reference (2014).

The final component of the nutrient production efficiency comparison was an economic analysis of each production system. Enterprise budgets for each grain and animal system were completed using local data when available. Yields of grain crops were obtained from the most recent Penn State agronomic trials. In determining market prices to calculate economic returns, the 5-year national average was used, calculated from data provided by the USDA's National Agricultural Statistics Service. National averages were used instead of Pennsylvania averages because the pulse crops evaluated in the variety trial are not commonly grown in Pennsylvania and therefore local data do not exist. Breakeven yields and profitability for each crop and animal product were then calculated and compared.

Chapter 3

Results

Variety Trial

Pea yielded substantially higher than both dry bean and lentil (Table 3, Figure 1) Crop yields were different than expected, with pea yields averaging 32% higher than the expected 2000 lb/A (2632 lb/A), but with lentil yields averaging only 40% of the expected 1500 lb/A (603 lb/A), and with bean yields averaging only 30% of the expected 2000 lb/A (603 lb/A). Within each crop, there were no differences among pea varieties or between lentil varieties (Figures 2 and 3), however there were several differences among dry bean varieties (Table 3). The navy bean "Vista" yielded significantly higher than "T-9905", the other navy variety, the pinto variety "Santa Fe", the red variety "Merlot", and the two heirloom varieties "Calypso" and "Yelloweye" (Figure 4). Additionally, "Calypso" yields (120 lb/A) were lower than most other varieties (650-750 lb/A;

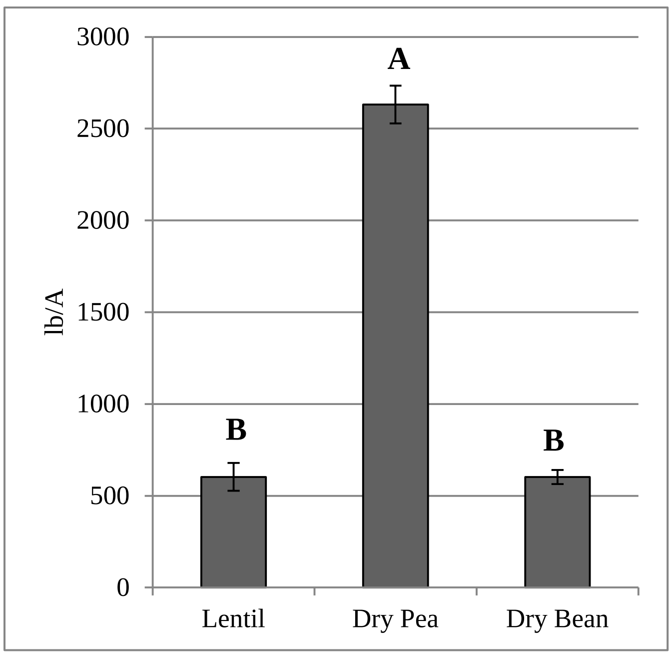

Figure 1: Average yields (lb/A) of each variety trial species. Error bars are standard error of the mean. n = 3 for pea and lentil, and n = 4 for dry bean. Letters above the bars indicate statistical groupings; groups that do not share a letter are significantly different from each other.

Figure 4). In evaluating the difference among bean market classes, heirloom beans (230 lb/A) yielded less than all other classes (640-750 lb/A) except for red beans (540 lb/A; Table 3).

Table 3: ANOVA results from analysis of crop yields (lb/A).

Test	DF	F-value	P-value
Differences among crops	2	267.65	0.000
Lentil	1	0.50	0.519
Pea	7	1.83	0.150
Dry Bean	11	3.31	0.004
Bean by market class	7	4.09	0.002

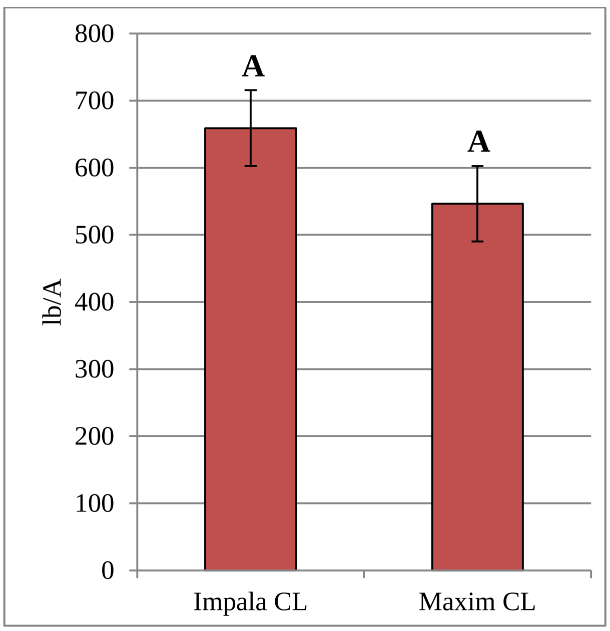

Figure 2: Average lentil yields (lb/A) for each variety included in the trial. Error bars are standard error of the mean. Letters above bars indicate statistical groupings, but letters should not be compared across different graphs.

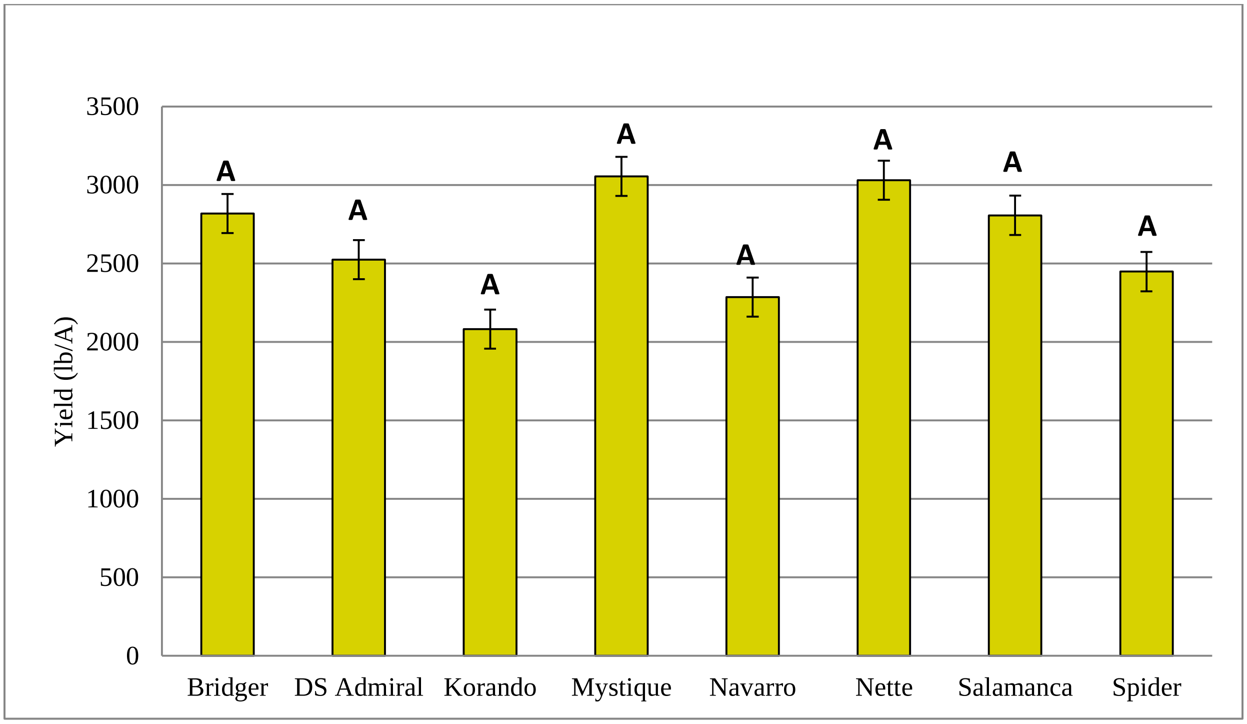

Figure 3: Pea yields, in pounds per acre, for each variety included in the trial. Error bars are standard error of the mean. Yield is displayed as an average of all replications. Letters above the bars indicate statistical groupings.

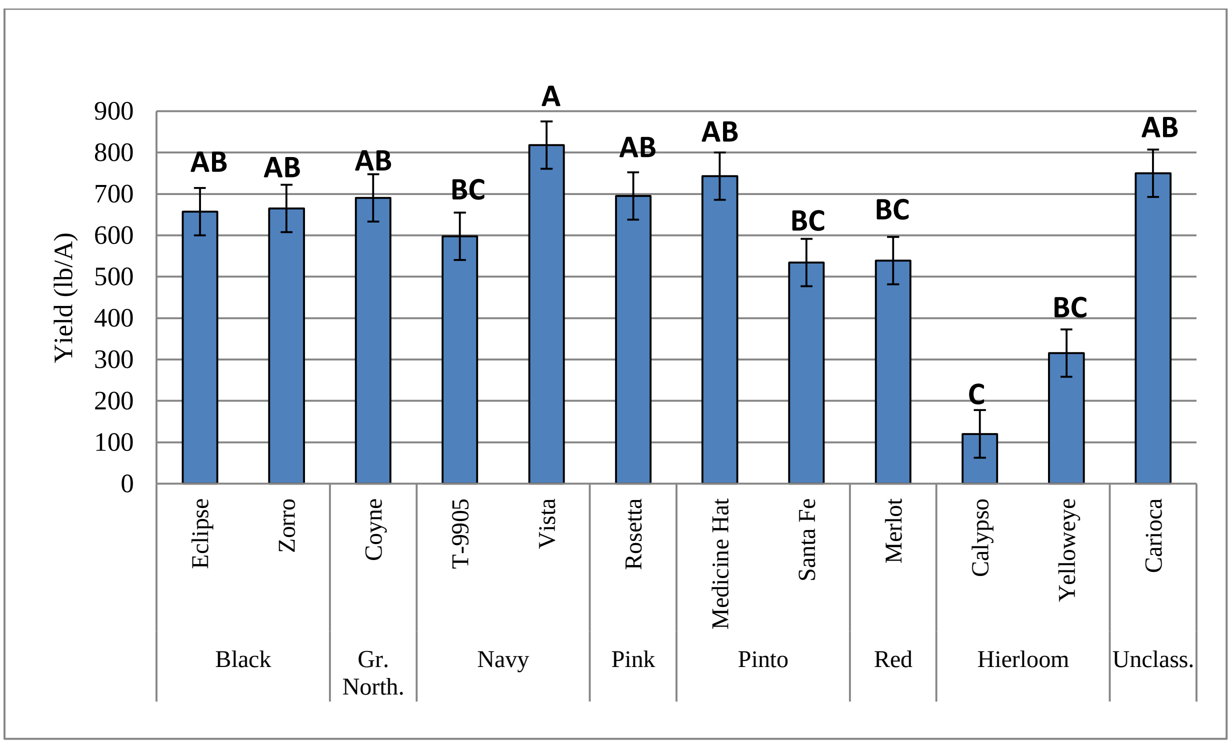

Figure 4: Dry bean yields, in pounds per acre, for each variety included in the trial. Error bars are standard error of the mean. Yield is displayed as an average of all replications. Letters above the bars indicate statistical groupings.

Qualitative evaluation of disease and nutrient limitation (via in-field assessment and via photograph) indicated that certain dry bean varieties were more sensitive to potassium limitation than other varieties, for example Calypso was very sensitive, while Vista was less sensitive, based on the extent of marginal leaf yellowing, and this evaluation also revealed information about potential diseases of lentil based on foliar symptoms. Possible foliar pathogens include Mastrevirus, which is characterized by foliar reddening/yellowing, and Stemphylium blight (*Stemphylium botryosum*), which is characterized by necrosis at the leaf tip that progresses back toward the stem, and closely resembles leafhopper damage. However, these diseases cannot be identified by symptoms alone, and positive identification requires infected controls, which were lacking in this study. Soil and root samples tested for the root rot diseases Pythium (*Pythium spp*.) and Phytophthora (*Phytophthora spp*.) tested positive for both diseases, although infection was patchy, relatively sparse, and limited to wet, low-lying areas.

Nutrient Production Efficiency

Total grain crop yield (dry lb/A) was highest for corn and wheat, lowest for dry bean and lentil, and intermediate for oat, pea and soybean (Figure 5). Animal product yields (dry lb/A) were generally lower than grain crops, with beef at only 20% of the lowest-yielding grain crop (lentil), and pork 34% of lentil; however, chicken yield was comparable to low-yielding grain crops (Figure 5). Caloric yields (Mcal/acre) mirrored crop yields: highest among corn and wheat, lowest among bean, lentil and animal products, and intermediate in oat, pea and soybean (Figure 5). Because both dry bean and lentil under-yielded substantially in the variety trial, their hypothetical potential yields – if crop management improved – are also included to evaluate yields among crops and animal products. These are included for comparison purposes only, and are not intended to substitute for under-yielding crops in the variety trial.

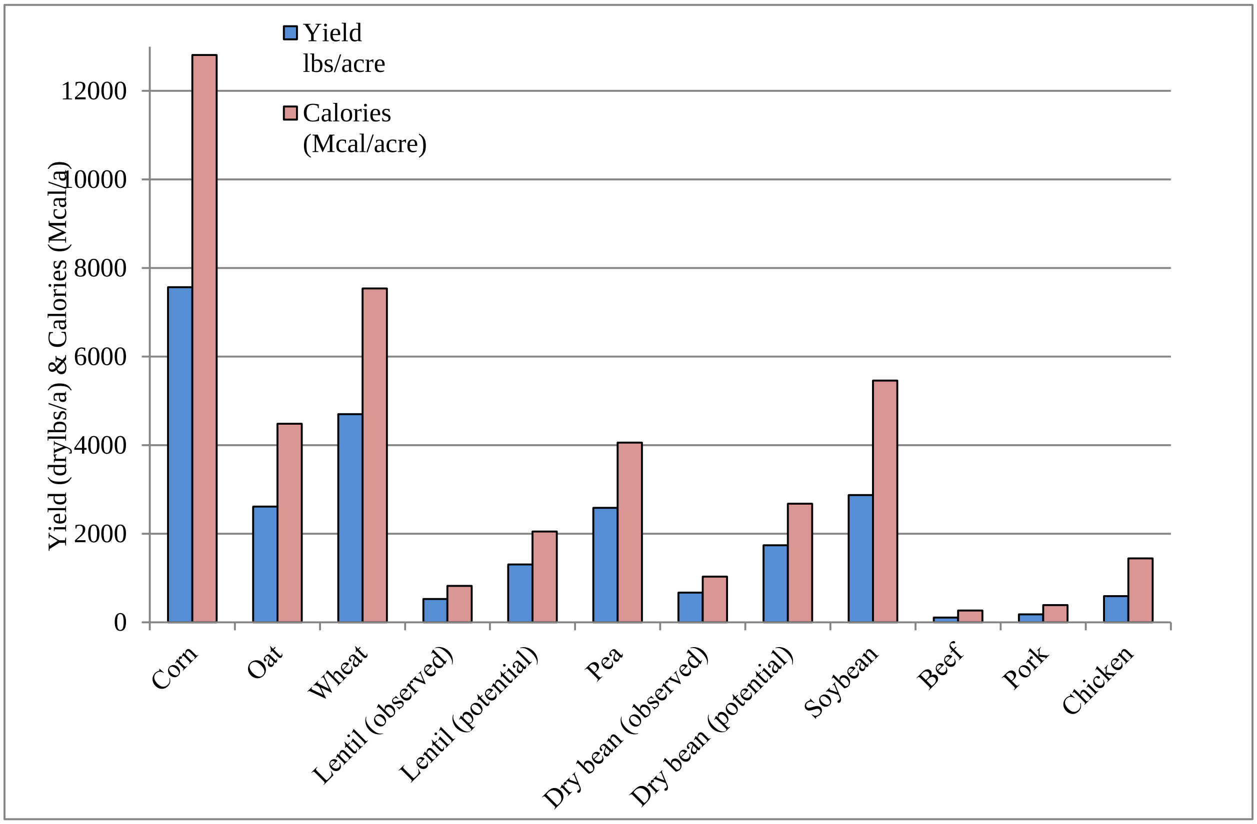

Figure 5: Dry weight yield (lbs/a) and caloric yield (Mcal/A) of grain crops and animal products. Observed and potential yields are shown for dry bean and lentil, where potential yield is a hypothetical value that may be attainable given better crop management

Protein production (dry lbs/acre) was quite different from total crop and caloric yields, with protein yields relatively lower among cereals versus legumes compared to caloric yields (Figure 6). This is a result of the very high overall yield of cereals, but the higher protein concentration of legumes. Protein production from animal products was relatively low, however, despite having the highest protein concentration (Figure 6).

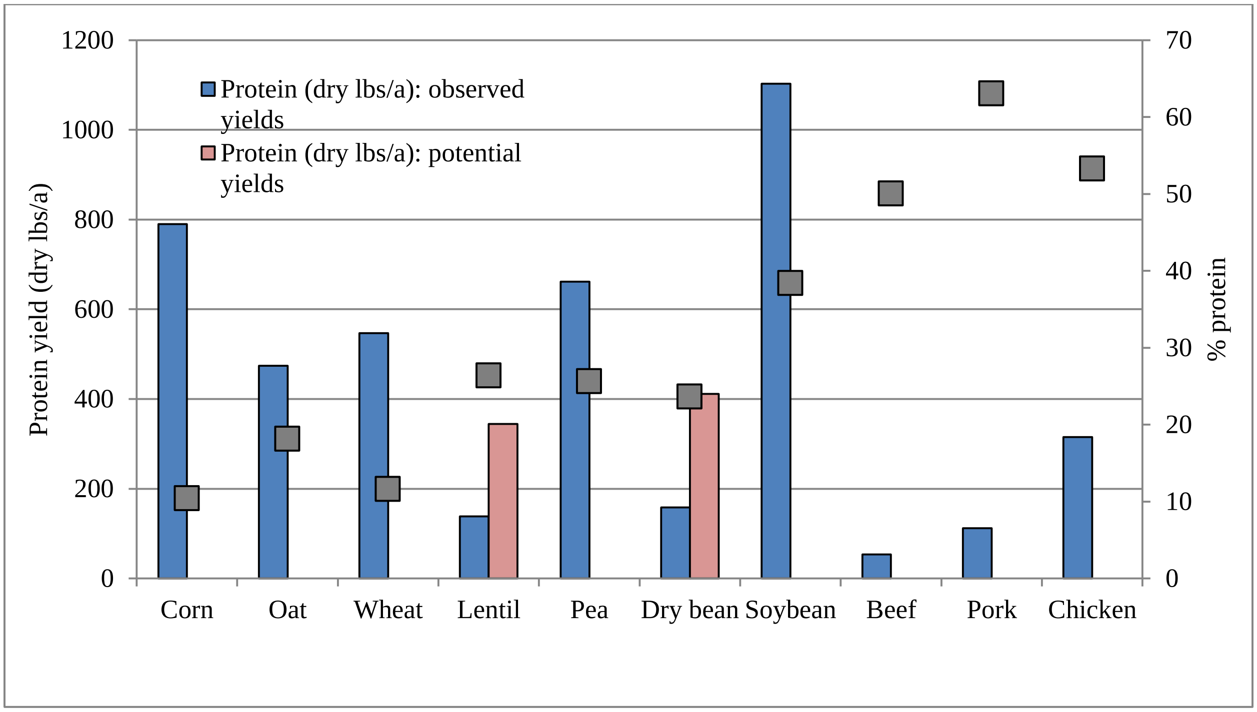

Figure 6: Protein dry weight yield (left axis, lbs/A) and percent protein (right axis) among grain crops and animal products. Potential yields of dry bean and lentil, shown as pink bars, are hypothetical values that may be attainable given better crop management. Grey squares indicate protein content of each food (% protein).

To address meeting dietary protein requirements of 60 g (2.11 oz) per day, given a 2000 calorie diet (Food and Nutrition Board), protein and calorie contents of each crop and animal product were considered. Total food required to meet protein requirements was highest among cereals, lower among legumes, and lowest among animal products, with corn and wheat exceeding 2000 calories to meet the daily requirement (Figure 7).

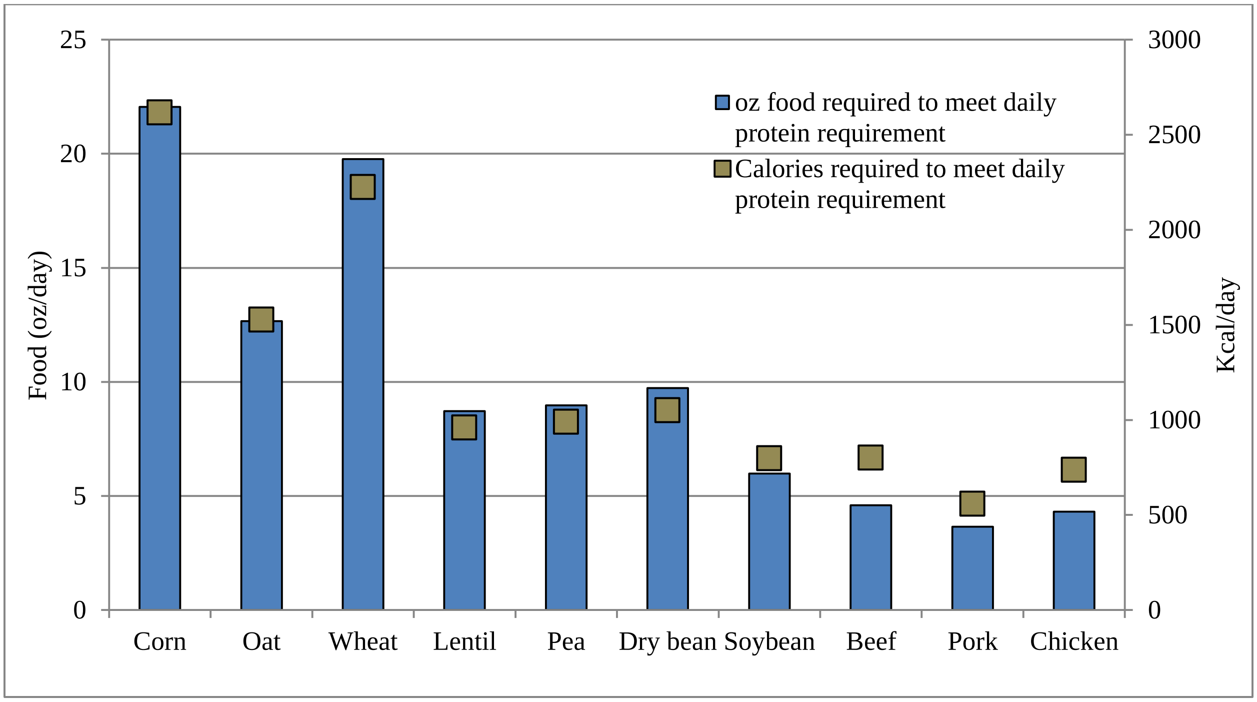

Figure 7: Food (dry oz/day) and corresponding caloric intake required to meet dietary protein requirement (60g/day for a 2000 calorie diet) for each grain crop and animal product.

Economic Returns

Corn, soybean, and wheat operations as well as broiler production were the most profitable enterprises (Figure 8). Profits for these operations were more than twice as much per acre than pea; and dry bean and lentil were not profitable given the yields obtained with the variety trial, nor was swine production (Figure 8). In order to reach comparable levels of profitability with grain crops, either yields or prices, or both would need to increase substantially. If prices remained relatively stable, yields would need to increase for lentil by about 75%, pea by 35%, and bean by 70% to meet average profitability of a cropping system consisting of corn, oat, wheat, and soybean. Yield increases for pea, lentil and dry bean needed to achieve comparable profitability to individual grain crops commonly grown in Central Pennsylvania are shown in Figure 9.

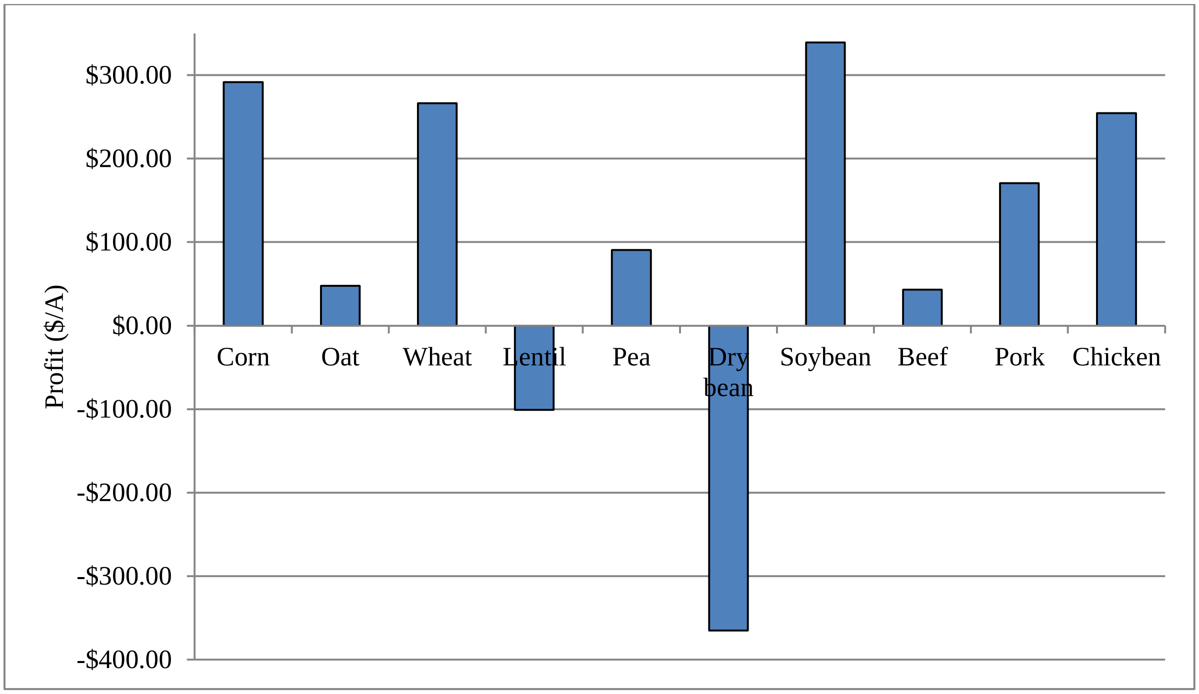

Figure 8: Relative profitability, $/A, of each crop and livestock system.

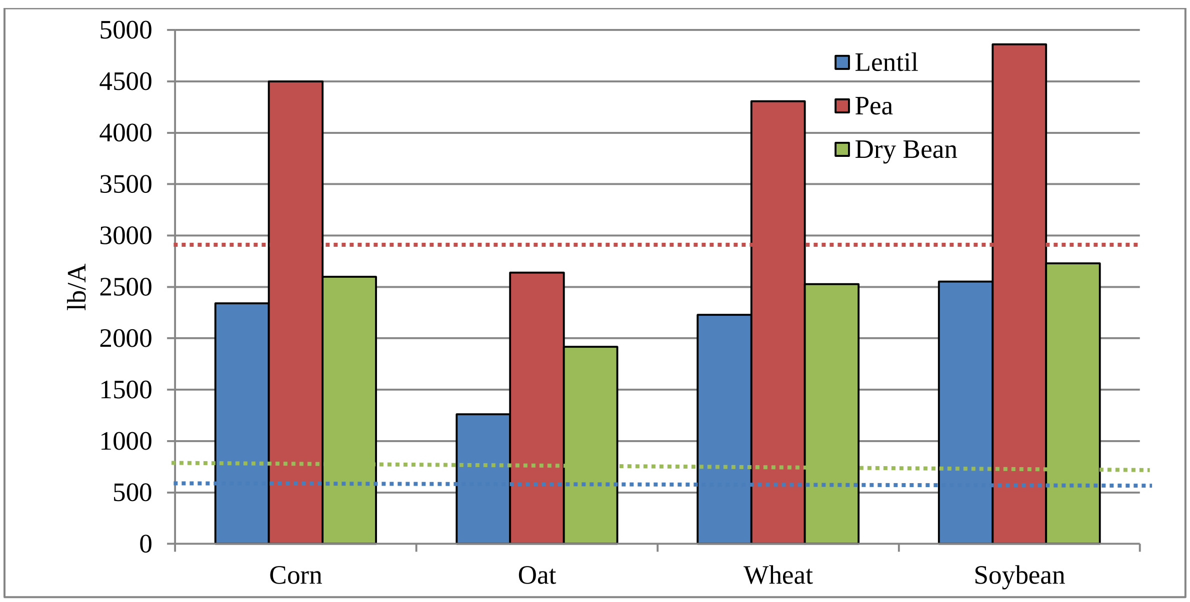

Figure 9: Yield increases needed from variety trial crops to reach comparable levels of profitability, $/A, with grain crops. Dashed lines indicate current yields, as observed in the variety trial.

Chapter 4

Discussion

Variety Trial: Agronomic Performance and Economics

Pea was overall the most successful crop in this variety trial, yielding significantly higher than dry bean, and lentil. The agronomic success of pea compared to dry bean and lentil can most likely be attributed to the its high yield potential, good weed control, low insect pressure, and its relatively low potassium requirements. Pea may have also been more successful than predicted because of the cooler than average summer temperatures that were experienced over the growing season (average May - August 2014 temperature: 65.0°F; compared with long-term average: 68.8°F), which is more suitable weather for pea than any other crop in the variety trial.

Dry bean and lentil performed poorly to moderately in this field trial. The success of dry bean was heavily influenced by two factors: inadequate soil potassium, evidenced by marginal leaf yellowing mid to late-season, and strong weed pressure that came about shortly after emergence, and continued through the growing season despite frequent cultivation. The persistence of weeds (primarily Large crabgrass, *Digitaria sanguinalis*) in dry bean is likely due to season-long wet conditions and a high weed seedbank, as seedlings continued to emerge throughout the season (especially in low lying spots), and competition with the potassium-limited bean crop. It may be that if potassium was not limiting and weed pressure was lower, dry bean yields could have been at or approaching the target yield of 2000 lbs/acre, which is a moderate yield for commercial dry beans. For example, in the plots with yields exceeding 1000 lbs/a, marginal leaf yellowing was minimal compared to other plots of the same variety, but weed pressure was higher in these plots due to their location in the field (low-lying and wet), while there were many lower-yielding plots where weed pressure was somewhat lower (higher in field and drier), but marginal leaf yellowing was more pronounced. This suggests two things: that potassium limitation might have been more limiting than weed pressure, and that all plots were affected by at least one of these problems and often both; and dry bean yields could have been greatly improved with better management.

The lower than expected lentil yields was most likely due to infestation by leafhoppers (Order: Hemiptera; Family: Cicadellidae) and tarnished plant bugs (Order: Hemiptera; Family: Miridae). These insects have piercing/sucking mouthparts, feeding on the sap of the plant, and may inject a digestive enzyme into the plant's vascular tissue, resulting in necrosis proximal to feeding, leaf yellowing, aborted seed-set, and overall weakening of the plant. The reduction in plant vigor by these insects is likely the primary cause of the low lentil yields observed in this trial, although it's possible diseases transmitted by insects and wet soil conditions also depressed yields. Leafhoppers are known to transmit diseases, including viruses, and several bacterial and fungal pathogens. There were signs of the foliar diseases Mastrevirus and Stemphylium blight, although symptoms of Stemphylium blight are very similar to that of leafhopper damage, and therefore difficult to distinguish, and there is no documentation of Mastrevirus in Central Pennsylvania. There were also isolated areas, especially within wet areas, that tested positive for the root rots *Pythium spp*. and *Phytophthora spp*. (as tested by Penn State's Plant Pathology lab). The effect of root rot pathogens on lentil yield is not clear in this trial, and, while infestations were patchy, may have reduced yield more than expected. Thus, it's possible that diseases spread by insect vectors, and the wet conditions in 2014 contributed to low lentil yields, in addition to intense insect pest pressure.

Yields obtained in this study indicate that pea has the highest potential for success and adoption in the region, based on yields that exceed those where the crop is already widely grown with success. However, these results should be interpreted with caution: the pea growing season temperature was on average? 3.8°F cooler than is typically experienced in Centre County, which is a condition that would favor pea production. Additionally, rainfall totals were much higher than the 5-year historical average, 6 inches more than expected through the duration of pea and lentil production, and 4 inches more than expected through the duration of bean production (Table 4). These significantly higher totals most likely had a negative effect on the yield of all crops because legumes perform poorly in excessively wet conditions (Grahm and Vance, 2013). To more accurately determine the local yield potential of the crops in this study, multiple replications over time and across locations should be performed. With better weed control and adequate soil potassium, dry bean performance could be improved, and with better insect pest management and typical rainfall, lentil performance could be improved. These changes have the potential to improve crop yields and allow them to be closer to their expected yields.

Table 4: Observed 2014 average temperature and total precipitation data, as calculated from Centre County hourly records. May-August data is representative of the growing season for pea and lentil, and June-September data is representative of the growing season.

	Temperature (°F)	Precipitation (in)
May-August	65.0	24.23
June-September	65.5	21.53

Greater, and probably more accurate yield estimations would significantly affect the economic returns from lentil, pea, and bean production. Low prices and/or low yields of each crop will limit earning potential and profitability. Lentil and bean yields could possibly be improved by the 70-75% needed to reach profit levels of corn, oat, wheat, and soybean, however, it is unlikely that pea yields will improve by the 35% needed. Therefore, in order to achieve comparable profitability, the price would have to increase in order to improve returns.

In the future, price supports, improved crop insurance programs, and increased domestic and foreign demand may all play a role in stabilizing and improving pulse crop prices. Price volatility and uncertainty are common reasons why American farmers choose to plant crops such as soybeans in place of pulse crops in years of uncertain markets. Price supports and improved crop insurance programs such as those included in the Agricultural Act of 2014 could help to stabilize prices. In conjunction, increased demand may help to raise prices. Nearly all of the domestic lentil, pea, and bean demand is supplied by U.S. grown crops. As demand is forecasted to increase in the near future, this would mean higher prices and greater returns for U.S. growers. The rising global demand for lentil, pea, and dry bean will likely have a positive effect on global market prices, although the magnitude of increase will likely be less significant for U.S. growers. Finally, since Pennsylvania could serve as a processing hub for these crops due to the high density of food processors and proximity to large markets, the supply chain for these products could be shortened which could increase the local market price. All of these scenarios, individually or in combination, could raise crop prices for these crops, and improve their profitability.

Nutrient Production Efficiency

Dry yield and caloric yield comparisons indicate that the most efficient systems for producing total yield and calories are cereal grain cropping systems. This suggests that if food production was facing a calorie deficit, then cereal grain systems, especially corn and wheat, would be the best way to meet those needs. This can be attributed to the higher overall dry yields of these crops; therefore, it is reasonable to conclude that if the dry yields of other crops being compared were to increase, then their calorie production efficiency would follow suit.

While overall and caloric yields are greater among cereal crops, the protein content and yields tell a very different story. The high protein content of legumes means their protein yields will be equal to or higher than cereal production. Higher concentrations of protein also mean that less food needs to be consumed in order to meet dietary protein requirements, which is an important consideration in the developing world, where access to protein may be most limiting, and meeting protein requirements with low protein foods (e.g. cereals) can be challenging. Protein concentration is also relevant in the developed world, as protein-dense foods could help limit caloric intake (compared to low protein foods), addressing growing concerns over obesity, and could help meet increased protein demand in the future. Although meat has the highest protein content of any system in this analysis, the low yields still make these relatively inefficient sources of protein production, with only chicken having a comparable yield to any of the grain systems. Therefore, in food systems where a protein deficit exists, land resources would be best utilized in legume production, and, to a lesser extent, chicken production. However, protein quality is highest in meat-based protein, having all essential amino acids, whereas legumes are deficient in sulfur-containing amino acids (cysteine and methionine), and cereals are deficient in lysine. While the amino acid profiles of legumes and cereals are complimentary, and dietary requirements for all nine essential amino acids can be met with these foods in combination, protein quality should be taken into consideration when trying to match production with human dietary needs.

One important caveat of these results is that all land acres are not created equal. These results can be interpreted as if all land was equally adequate for crop production, which is rarely the case, especially in a topographically dynamic area such as Centre County. Many areas are simply not suitable for grain crop production and are better utilized in other ways, such as for forage production to feed ruminant animals. Thus, it would be useful to consider land quality, production potential and suitable crop types within a landscape, across all landscapes within a region, when assessing regional crop productivity and land use efficiency. However, for the purpose of this report, a basic land use efficiency analysis, calculated in a non-spatially explicit manner, is a very useful tool to broadly determine the production efficiency of various cropping and animal systems. Because agricultural land use is already at or near its maximum capacity, comparing different measures of efficiency (e.g. calorie vs protein) among production systems can help shed light on ways to match the food we grow with nutritional needs, and will become especially important in the face of increasing global demand for food.

In the future, as the demand for food rises within a changing environmental landscape with minimal opportunities for agricultural land expansion, pulse crop production will likely become increasingly valuable. These production systems are capable of producing more protein on an equivalent amount of land, and when eaten with cereal crops in the diet, can be a complete, high quality protein source. It is unrealistic to expect that only vegetarian diets will exist in the future, however, as world population grows and more is required from each acre, these results suggest that we rethink our current and future land use. In order to maximize protein production efficiency, production trends will have to shift in favor of pulse crops, away from cereals, and, to a certain extent, away from livestock. However, the importance of ruminant animals, which can utilize lower quality or otherwise unusable land to produce high quality protein, as well as land-efficient animal production systems such as chicken, also need to be considered. In the future, as pressure on food production and supply systems increases from global food demand and, likely, changing economics, diets may need to shift to match global production capacity.

In order to strengthen the results of this study, the variety trial should be replicated to include multiple years and locations. There are also many other pulse crops that could help produce protein cheaply and efficiently, and that may be suitable for cultivation in Pennsylvania, such as chickpea, cowpea, mungbean, or adzuki bean. Additionally, future research could be improved by removing the lowest yielding crops such as the heirloom beans, which appear to lack agronomic and economic promise, in order to maximize space for the most promising crops or varieties. With better soil fertility and weed control, a more accurate yield estimate can be determined for each crop and variety if this study was to be replicated in the future.

Appendix A

Nutrient Production Efficiency Calculations

Swine Production

Weekly feeding requirements were obtained and converted to a per month basis (Table A). This was multiplied by the feed component breakdown (Table B) to obtain the amount of each feed input required per month. These numbers were converted to bushels (Table D) and then converted to acres needed per animal based on average crop yields (Table E). This was compared to the final yield per animal, which was converted to a dry yield basis, in order to determine the yield per acre (Table F).

A Feeding requirements[7]

	Jan	Feb	March	April	May	June	July	Aug	Sept	Oct	Nov
Feed consumed/week (lb)	60	60	60	60	45	45	45	45	45	45	45
Feed/month (lb)	260.4	260.4	260.4	260.4	195.3	195.3	195.3	195.3	195.3	195.3	97.65

B Feed components as a fraction of total feed ration[7]

	Jan	Feb	March	April	May	June	July	Aug	Sept	Oct	Nov
Corn	34.2%	38.6%	57.8%	66.2%	74.4%	74.4%	74.4%	74.4%	74.4%	74.4%	74.4%
Soybean	15.0%	20.0%	25.0%	30.2%	23.3%	23.3%	23.3%	23.3%	23.3%	23.3%	23.3%
Dried whey	31.3%	25.0%	10.0%	-	-	-	-	-	-	-	-
Other	19.5%	16.4%	7.2%	3.6%	2.2%	2.2%	2.2%	2.2%	2.2%	2.2%	2.2%

C Total feed required (lb)

	Jan	Feb	March	April	May	June	July	Aug	Sept	Oct	Nov
Corn	89.11	100.49	150.49	172.25	145.38	145.38	145.38	145.38	145.38	145.38	72.69
Soybean	39.06	52.08	65.10	78.69	45.54	45.54	45.54	45.54	45.54	45.54	22.77
Dried whey	81.38	65.10	26.04	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

D Total feed requried (bu)

	Jan	Feb	March	April	May	June	July	Aug	Sept	Oct	Nov
Corn	1.59	1.79	2.69	3.08	2.60	2.60	2.60	2.60	2.60	2.60	1.30
Soybean	0.65	0.87	1.09	1.31	0.76	0.76	0.76	0.76	0.76	0.76	0.38
Dried whey*	-	-	-	-	-	-	-	-	-	-	-

*not included in land use because it is a by-product of the cheese industry and relatively small diet component

E Total feed inputs per animal

Total corn (bu)	26.02
Total soybeans (bu)	8.85
Corn (A/yr)	0.163
SB (A/yr)	0.161
Total A/yr	**0.324**

F Final land use calculations

Average slaughter weight[16]	250
Dressing percentage[19]	74%
lb dressed pork/A/year	572
Moisture percentage	69
lb dressed pork/A/yr (dry)	**177**

Broiler Production

A feed component breakdown that was both economical and met nutrient requirements was created and reviewed by Penn State Extension specialists (Table A). These components were multiplied by the total amount of feed required per week (Table B) and according to average local production specifications (Table C), the total amount of each feed component was calculated over the life of the animal (Table D). Based on typical local yields, the acreage required to produce these feedstuffs were determined (Table E). These were compared against total chicken yields and converted to a dry weight basis in order to determine the yield per acre (Table F).

A Feed component breakdown[3,9,10,14]

	Starter	Grower	Finisher
	% of feed		
Yellow corn	60.62%	58.82%	66.43%
Soybean meal	33.93%	29.88%	23.13%
Fish meal	1.01%	2.33%	1.43%
SB oil	0.40%	0.75%	0.81%
Wheat bran	0.53%	5.60%	5.26%
Ca/di-phosphate	1.52%	1.40%	1.43%
Lysine	0.10%	0.09%	0.24%
Methionine	0.32%	0.19%	0.31%
Limestone	1.57%	0.93%	0.96%
Total	**100.00%**	**100.00%**	**100.00%**

B Weekly feed intake requirements[6,10]

Life Stage	Week	lb feed
Starter	1	0.65
Starter	2	1.25
Grower	3	1.75
Grower	4	2.00
Grower	5	2.40
Finisher	6	2.90
Finisher	7	3.40
	Total	**14.35**

C Production specifications[6]

7	weeks for full production
8	production cycles per year
5.1	slaughter weight (lb)
75%	dressing percentage

D Pounds of feed per week per animal

	Week 1	Week 2	Week 3	Week 4	Week 5	Week 6	Week 7	Total
Yellow corn	0.394	0.758	1.029	1.176	1.412	1.926	2.259	8.955
Soybean meal	0.221	0.424	0.523	0.598	0.717	0.671	0.786	3.939
Fish meal	0.007	0.013	0.041	0.047	0.056	0.042	0.049	0.253
SB oil	0.003	0.005	0.013	0.015	0.018	0.024	0.028	0.105
Wheat bran	0.003	0.007	0.098	0.112	0.134	0.152	0.179	0.686
Ca/di-phosphate	0.010	0.019	0.025	0.028	0.034	0.042	0.049	0.205
Lysine	0.001	0.001	0.002	0.002	0.002	0.007	0.008	0.023
Methionine	0.002	0.004	0.003	0.004	0.004	0.009	0.010	0.037
Limestone	0.010	0.020	0.016	0.019	0.022	0.028	0.032	0.147
Total	**0.650**	**1.250**	**1.750**	**2.000**	**2.400**	**2.900**	**3.400**	**14.350**

E Acres required for each feed component

	Yield (lb/A)	Acres/animal	Acres/year**
Yellow corn	8960	0.00100	0.00800
Soybean Meal	3300	0.00119	0.00955
Wheat Bran	5400	0.00000	0.00003
Total	**17660**	**0.00220**	**0.01758**

**Acres required to produce 1 year's worth of animals = acres/year

***Other feed components not included in calculations because they are byproducts of other industries

F Final land use calculations

Lbs/animal	5.1
Animal cycles/yr	8
Lbs/year	40.8
Dressed lbs/yr	30.6
lb chicken/A (wet)	1741
Moisture %	66
lb chicken/A (dry)	**592**

Beef Production

Monthly feed inputs in order to meet dry matter and nutrient requirements for each life stage were determined and reviewed by Penn State Extension specialists (Table A). Body weight and average daily gains were calculated and a final slaughter weight was determined and deemed appropriate by Penn State Extension specialists (Table B). Daily dry matter needs were obtained (Table C) and broken down into individual feed components (Table D), then converted to monthly needs (Table E). Based on local yields of pasture and grain crops (Table F) which were then converted to pounds per acre, (Table G), the acreage required to produce the feed components over the life cycle of one animal was obtained (Table H). These were compared against total beef yields and converted to a dry weight basis to determine the yield per acre (Table I).

A Monthly feed inputs (pounds per animal)[18]

	Calf						Weaning		Stocker									Finishing		
Month	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Milk	100	100	100	100	100	50	25	10	5	-	-	-	-	-	-	-	-	-	-	-
Pasture***	-	-	-	-	-	25	10	-	-	-	-	-	5	100	100	60	60	-	-	-
Hay	-	-	-	-	-	25	65	90	95	100	100	100	95	-	-	40	40	25	-	-
Grain	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	75	100	100

***Pasture availability assumes average-producing (3 tons/A annually) orchardgrass-white clover

B Body weight & gains[8]

	Calf						Weaning		Stocker									Finishing		
Month	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Wt gain: lb/day	2	2	2	2	2	1.8	1.8	1.8	1.75	1.75	1.75	1.75	1.75	1.75	1.75	1.75	1.75	3.5	3.5	3.5
Wt, end of month	135	197	257	319	381	435	491	544.8	599	653	702	757	809	863	916	970	1024	1129	1238	1343
DMI % of bodyweight	3.74	3.577	3.43	3.29	3.15	3.04	2.93	2.826	2.73	2.64	2.57	2.49	2.42	2.35	2.29	2.24	2.188	-	-	-

Calf birth weight = 75 lbs

C DMI values[5]

	Calf						Weaning		Stocker									Finishing		
Month	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Mother's DMI (lbs)	24	25	25.4	24.4	23.5	22.7	21.1	21.1	-	-	-	-	-	-	-	-	-	-	-	-
Calf + Stocker DMI	-	-	-	-	-	13.2	14.4	15.4	16.4	17.3	18	18.8	19.6	20.3	21	21.7	22.41	22	23.5	23.5

D DMI (lbs/day)

	Calf						Weaning		Stocker									Finishing		
Month	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Pasture	1.2	25	25.4	14.6	14.1	16.9	2.49	-	-	-	-	-	0.98	20.3	21	13	13.45	-	-	-
Hay	22.8	-	-	9.76	9.4	12.4	29.4	34.96	15.5	17.3	18	18.8	18.6	-	-	8.68	8.964	5.5	-	-
Grain	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	16.5	23.5	23.5

E DMI totals (lbs/month)

	Calf						Weaning		Stocker									Finishing		
Month	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Pasture	36	775	762	454	437	508	77.2	-	-	-	-	-	29.3	629	630	404	416.8	-	-	-
Hay	684	-	-	303	291	371	911	1049	482	535	505	583	557	-	-	269	277.9	165	-	-
Grain	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	495	728.5	705

F Productivity: annual yields[16]

Bluegrass pasture	1.3	ton/a
White clover pasture	0.7	ton/a
Corn	160	bu/a

G Total feed intake (lb)

Year 1 DMI pasture needs	3049
Year 1 DMI forage	2560
Year 2 DMI pasture needs	2109
Year 2 DMI forage	3374
Year 2 DMI grain	1929

H Acreage requirements

	Tons DMI/yr	A/yr
Year 1 forage	2.8	1.4
Year 2 forage	2.74	1.37
Grain		0.11
Total		**2.9**

I Final land use calculations

Dressing %[19]	0.62
Moisture content	0.63
Dry yield (lb/A/yr)	**107**

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Academic Vita

Kaitlyn Rimol
kaitlynrimol@gmail.com

EDUCATION

THE PENNSYLVANIA STATE UNIVERSITY, University Park, PA
Schreyer Honors College
Bachelor of Science in Plant Science
Agribusiness Management, Agronomy Minors
Graduation Date: May 2015

WORK EXPERIENCE

THE BRICKMAN GROUP – Billerica, MA — Summer 2014
Landscape Intern
- Collaborated with Account Managers to maintain customer contact, address concerns, and propose new work
- Acquired proficiency with routine maintenance and installation equipment and techniques
- Supervised landscaping crews of 6 workers on 55 job sites
- Maintained professionalism and safe working procedures at all times

PENN STATE DEPARTMENT OF PLANT SCIENCE – University Park, PA — January 2014 - Present
Weed Ecology Undergraduate Lab Assistant
- Acquired experimental data and interpreted results to laboratory technicians, emphasis on data accuracy
- Became proficient with field techniques and tools used for both soil and plant tissue sampling
- Collaborated with faculty on an independent thesis project; completion anticipated upon graduation
- Awarded Undergraduate Research Grant from the Weed Science Society of America

DUPONT PIONEER – Union Springs, NY — Summer 2013
Agronomy Research Intern
- Acquired and recorded product data; internship focus on data quality
- Provided technical support and education to 50+ growers
- Planted and maintained corn and soybean research data plots, presented findings at the Empire Farm Show
- Responsible for company vehicle, overnight travel, and expense reports

SHADY HILL GREENHOUSES AND NURSERY - Londonderry, NH — April 2010 - September 2012
Horticultural Specialist
- Maintained annuals, perennials, shrubs, trees, and mums, including planting, watering, fertilizing, and pruning
- Advised customers on plant selection, horticultural techniques, and troubleshooting
- Worked in teams on residential landscaping jobs and delegated responsibilities to newer employees

ACTIVITIES AND HONORS

Penn State Crew – *Varsity Rower, Women's Captain* - January 2013 - Present
- Managed conflicts, maintained behavior and work ethic in a way that served as an example to all team members
- Raised money through the development of Rent-A-Rower, providing landscaping services to local residents

Collegiate FFA – *President* - January - December 2013
- Managed officer team, delegated responsibilities, ran general meetings
- Agricultural Student Council Representative, 2011