The Economic Viability of Suppressive Crop Rotations for the Control of Verticillium Wilt in Organic Strawberry Production

Organic strawberry production in California totaled 94 million dollars in farm level sales in 2012, around 4% of the total value of strawberry production in California (Klonsky & Healy, 2013). Its potential for expansion is limited by soil borne diseases and a lack of nitrogen in the soil caused by the unavailability of time-release fertilizers certified for organic use. Verticillium wilt, caused principally in strawberries by *V. dahliae,* is a major disease for organic strawberries. Prior to the widespread use of methyl bromide for pre-plant soil fumigation beginning in the 1960s, verticillium wilt was the major disease that affected strawberries (Wilhelm et al., 1961). Fusarium wilt (Koike et al., 2009) and charcoal rot (Koike, 2008) have emerged as important diseases in recent years for organic strawberries as well (Shennan & Muramoto, 2016). Regarding fertilizer, strawberries have a high nitrogen demand relative to many other crops, and yield is sensitive to the type and amount of fertilizer being used.

Crop rotations are commonly used to suppress disease and enhance the amount of nitrogen in the soil for nitrogen-using crops. The "Mother Trial" tested a set of verticillium wilt suppressive crop rotations coupled with ASD (anaerobic soil disinfestation) or mustard seed meal (MSM) (Shennan et al., 2016). Each treatment was evaluated based on its capacity to suppress disease, its nitrogen content, and its economic viability. The economic viability of the rotations considered in this trial is the outcome of a classic dynamic tradeoff between current and future returns that occurs in many bio-economic systems: is it better to forego current returns for better disease control, yielding higher option value for future strawberry production, or to sell something with higher revenue potential, and realize higher current net returns, but lower future net returns due to inadequate disease control?

I. Data and Methods

The Mother Trial was conducted from November 2011 to November 2015 at the University of California, Santa Cruz. The trial was conducted using a split-split plot design. Each treatment was randomly assigned into different areas in four blocks. Within a block, treatments were split into two-year and four-year rotations. Two-year rotations were repeated twice, and four-year rotations occurred once. Strawberries were planted in the final year of each rotation, so strawberries were planted in years 2 and 4 for the two-year rotation and year 4 for the four-year rotation. Within each rotation length, rotations were included that used a revenue-generating cash crop (lettuce) or a non-host cash crop (broccoli). In turn, each of these rotations were split into different fertility treatments which would add different levels of nitrogen to the soil. In total, there was one replicate per rotation in each block totaling sixty-four replicates in the entire trial.

In the first year of each two-year rotation, a cover crop or fallowing was followed by a commercial crop. There were two cover crops: mixed cover crops designed to give the soil low and high nitrogen levels, and a cereal cover crop plus MSM. Two commercial crops were included: broccoli and lettuce. In total, eight two-year rotations were considered, four per commercial crop.

As was the case for the two-year rotations, the first year of the four-year rotations consisted of one of the soil fertility treatments followed by either lettuce or broccoli. In the second year, lettuce was planted in the spring followed by a summer planting of a second cash crop. For rotations in which lettuce was the first-year cash crop, broccoli was the second-year cash crop following lettuce. For rotations in which broccoli was the first-year cash crop, cauliflower was the second-year cash crop following lettuce. For each rotation, the third year repeated the first year. In total,

eight four-year rotations were considered, four per cash crop in the first year. Table 1A in the Appendix summarizes the entire set of treatments.

Economic viability is assessed using a partial budget analysis, which evaluates costs and revenues that vary across treatments in order to identify any differences in net returns. Most cost data, including seed costs, listing and shaping beds, transplanting, laying and removing drip tapes were collected during the trial and calculated on a per-plot basis. Weeding times were averaged across plots for each treatment. Water and harvest labor cost estimates required adjustments because the trial was conducted at a university farm under conditions that do not approximate commercial operations. Because water costs were prohibitively expensive at the UCSC farm for commercial agricultural production ($174 per acre-inch), we used the price of water from a University of California for strawberry production on the Central Coast (Bolda et al. 2014) of $22.50 per acre-inch. Harvest was conducted by student researchers, so the harvest rate was considerably lower than that for experienced harvesters. Consequently, for the purposes of the economic analysis, we used harvest rates from various cost studies for organic lettuce, broccoli, cauliflower and strawberries (Bolda et al. 2014, Tourte et al. 2004, Tourte et al. 2009, Smith et al. 2001). Following Bolda et al. (2014), fully loaded wages (including benefits) were assumed to be $25 per hour for machine operation and $12.50 per hour for other field work. Plastic tarp costs were obtained from Bolda et al. (2014).

Because many operations, such as transplanting and irrigation, were performed for many plots at once, the cost per plot was calculated by dividing the total cost of the operation by the total acreage involved. These costs did not vary across plots for each rotation in a given year, but did vary across rotations with different crops in a given year.

Yields were yearly per plot yields in the case of all crops except strawberries, which had weekly per plot yields. Strawberry yields were recorded every week from the months of April to September for year 2 strawberry production and from the months of April to September for year 4 strawberry production. Price data were from the USDA Agricultural Marketing Services (AMS) for the Salinas/ Watsonville shipping point for romaine lettuce, cauliflower, broccoli and organic strawberries. Weekly prices during the harvest season were used for organic strawberries. The average daily price in the month of harvest was used for broccoli, cauliflower, and lettuce. Price data were not available for organic broccoli, lettuce or cauliflower during the trial period; AMS only began reporting those data in 2016. Instead of using conventional prices, the average 2016 daily organic-conventional price ratio was calculated for the harvest month. This multiple was then multiplied by the conventional price to obtain the price used to calculate net returns. Using the organic strawberry price data as a point of comparison, the average organic-conventional price multiple for years of 2009-2015 was around 1.6, which is similar to those used for lettuce (1.8), broccoli (1.5) and cauliflower (1.3).

Strawberry prices were weekly prices for 8-1 lb containers from April to September 2013 and from April to September 2015. Broccoli prices per carton were for August 2012, October 2013, and July 2014. Lettuce prices per 12 3-count package (heads of lettuce) were for August 2012, June 2013, and July 2014. Cauliflower prices per film-wrapped carton were for October 2013. Table 1 reports the conversion factors used to convert the price per commercial unit to dollars per pound. Table 2 reports prices for each crop, including the average price for strawberries. Because weekly prices were used for strawberries, the annual average is reported in the table for ease of exposition.

Gross returns were calculated by multiplying price by yield. In the case of strawberries, revenues were calculated on a weekly basis and summed. For broccoli, lettuce and cauliflower, 100% of reported yield was assumed to be marketable. Revenue is

$$R_{tr} = p_t \phi Y_{tr}$$

where p_t is the conventional price at harvest month in year t, ϕ is the organic-conventional multiple described above, and Y_{tr} is the yield in year t of rotation r.

Because the treatments were done over the course of several years, we discount the stream of net returns. Following Bolda et al. (2014), we use a return on capital of 0.0575, yielding a discount factor of $\delta = 0.946$. The present discounted value of net returns for rotation r is

$$\pi_r = \sum_{t=0}^{4} \delta^t (R_{tr} - C_{tr})$$

where C_{tr} is the cost for year $t + 1$, respectively.[1]

II. Results

To begin, we examine discounted gross revenues, R_{tr}. Figure 1 shows the discounted gross revenues for each rotation stacked by year, averaged across plots. Here, the four-year rotations are denoted by "a," and two-year rotations are denoted by "b," with the numbers corresponding to each replicate. The largest source of gross returns was strawberry production in year four for both two-year and four-year rotations. Another large source of revenue were second year revenues, which were from strawberry production in two-year rotations, and from lettuce and cauliflower or broccoli production in four-year rotations.

[1] The expression is defined in terms of year $t + 1$ to take into account that mathematically time starts at year 0, prior to incurring expenses and earning revenues, not year 1.

Figure 2 shows average discounted net returns across plots for each rotation. Certain questions of note can be seen from this graph: (1) for rotations with the same first-year plantings, why do two rounds of the two-year rotation consistently result in lower net revenues than the four-year rotation (2) for rotations with different first-year plantings, can broccoli in the first or second year be part of a profit-maximizing rotation despite generating less revenue than either lettuce or cauliflower? Appendix table 1A-B reports discounted profits.

Two vs. Four Year Rotations: Second Year Strawberry Net Returns

One reason to consider a two-year rotation rather than a four-year rotation is that it yields two years of strawberry production during a four-year period. However, in the trial second year strawberry gross revenues were far outweighed by costs; all two-year rotations had negative returns that year, regardless of the first year treatment. This was due to significantly lower strawberry yields in the two-year rotations than in the fourth year of the four-year rotation for each pair with the same crops in years one and three. The low yields in second year strawberry production were due to an exacerbation of Verticillium wilt disease caused by poor drainage and lower than normal bed heights (Shennan et al. 2016).

Effect of Broccoli on Strawberry Returns

Six of the eight pairs of two-year and four-year rotations with broccoli grown in year 1 had higher strawberry returns in year 4 and year 2 than rotations in which lettuce was grown instead. The difference was due to greater verticillium wilt damage in lettuce plots. The two exceptions were the cases in which there was fallowing, rather than a soil fertility treatment.

The choice of commercial crop in year 1 affected the magnitude of year 2 net returns losses. Growing lettuce in the two-year treatments resulted in larger losses than growing broccoli. Figure

3, which compares net returns for four-year and two-year rotations, shows that four-year treatments significantly outperformed two-year treatments (except for the pair of treatments with low nitrogen, 1b and 5b).

Low Net Returns in Years Two and Three

The second question regards the determinants of the low net returns across both two-year four-year rotations in the second and third years, both within rotation lengths, and across rotation length. Prices of the crops in the rotations played an important role.

Effect of Cauliflower Price on Net Returns.

Rotations 1a-4a had higher net returns than rotations 5a-8a due to the high price of cauliflower in October 2013. The October 2013 price of cauliflower was much higher than prices in the other years of the trial; over twice as high as the October average for the four-year period of the trial (Figure 4). (The gaps in the time series are periods during which the USDA did not report prices.) In order to ascertain the extent to which net revenues were driven by this unusually high price, net returns were recomputed using the average October price for the 2008-2015 period. Figure 5 shows the difference in net returns due to the difference in the cauliflower price. Using the historical average price, we see that cauliflower is no longer a large contributor to net returns.

Effects of Broccoli and Lettuce Prices on Net Returns

For four-year treatments, part of the net returns in the trial were driven by differences in relative prices. In other words, lettuce and broccoli net returns were not driven by differences in yields or costs across treatments. Instead, the rotations grew one crop when higher net returns would have been generated by the other, *given* the realized yields and costs. Figure 6 shows organic lettuce prices for the 2011-2015 period, where the square point shows the price for potential marketing of

yields in 2013. Lettuce had a relatively high harvest price causing positive returns for the third year of the trial in all four-year treatments including lettuce in year 3. Rotations would have been negative if the price of lettuce had been at its four-year average.

However, in the third year, broccoli was unprofitable, due to its low price. The circular points in Figures 6 and 7 represent trial harvest dates in July 2014. More broadly, examining the movement in lettuce and broccoli prices suggests that a rotation which provided more flexibility for growers to respond to relative prices and net returns would be economically viable under a broader set of market conditions. However, technical efficacy may limit growers' crop choice flexibility due to the different crops' differing degrees of susceptibility to verticillium wilt. More research is required to determine how much flexibility is feasible or attractive to growers. Specifically, it would be important to analyze the extent to which growers who produce both vegetables and strawberries value such flexibility and to what extent the prices of lettuce, broccoli and strawberries correlate. If crop choice is sufficiently constrained by the need to suppress wilt, growers might wish to stagger the implementation of a rotation across time.

Land Rents

One cost that isn't included in the partial budget analysis is land rent. For renters, this is a direct cost. For owners, land rent is the opportunity cost of using their land in production rather than renting to another grower. Bolda et al. (2014) assumed land rent for organic land to be $3,000 per acre per year. Applying their figure to this study, the present discounted value of land rent would be $11,056.27 for the four-year period. This would offset much of the realized profits, but would not lead to negative returns.

As a back of the envelope calculation, if we assume that land rents would have stayed constant over the course of the trial, we can calculate break even land rents for the worst and best

performing replicates of the trial. If the land rents were about $4600 per acre per year, then even the worst performing rotation would break even (rotation 7b), which was a two-year rotation with lettuce and cereal cover crop with MSM fertility treatment. At the other side of the spectrum, if land rents were about $15,000 per acre per year, then only the highest performing rotation would be able to break even (rotation 6a), which was a four-year rotation with lettuce and high nitrogen cover crop treatment.

III. Statistical Analysis

The effects of rotation length, choice of year 1 crop and other factors that contribute to net returns were examined using several statistical analyses. Because the trial used a split-split-plot design, a split-split-plot ANOVA test was run to evaluate the effect of each factor. The analysis was repeated excluding block 4. Block 4 used to be a compost pile, which influenced nitrogen availability and fertility, so there is a question as to whether this would create outliers in the data (Shennan, et al., 2015).

Split-Split-Plot ANOVA

Leveraging the split-split-plot design of the trial, we ran ANOVAs on net returns, yields and gross revenues. Table 5 reports the results for net returns. Two factors were significant at the 10% level: rotation length (p= ~0.018) and fertility treatment (p=~0.078). The interactions of rotation and fertility were very significant (p=~0.0027). The importance of rotation length alone is likely due to the very low returns caused by second year strawberry production. This suggests that the type of cover crop planted plays an important part in managing verticillium wilt.

Results for gross revenues were consistent with those for net returns. Table 6 reports that the most important factor to gross revenues were the fertility treatments (p=~0.004) and again, the interactions between rotation and fertility (p=~0.001). This consistency implies that the

nitrogen in the soil is vital to the long-term success of a suppressive crop rotation and its commercial viability. It is important not only that a non-host crop be given enough time to suppress verticillium wilt, but that it be coupled with enough nitrogen so that the strawberry crop yield is sufficiently high to contribute positively to net returns.

Examining fourth year strawberry yields in Table 7, we see that the choice of revenue-generating cash crop vs. non-host cash crop have a significant effect on yields in the fourth year (p=~0.01). Again, fertility and interaction effects between rotation and fertility are significant (p= ~0.03 and p=~0.04, respectively). This result shows that suppressive crop rotations were effective at increasing strawberry yields, the main driver of commercial viability.

Omitting Block 4

Given that Block 4 had higher than usual land fertility and exhibited higher yields than the rest of the blocks, we performed the same ANOVA analysis on Blocks 1-3. Results are reported in the appendix. The results were largely consistent with the above analysis. Cash crop choice was significant (p=~0.06), as were fertility treatments (p=~0.01) and interactions between rotation and fertility treatments (p=~0.03). Moreover, the exclusion of block 4 made cash crop choice much more important in regards to gross revenues and net returns, since broccoli is a large driver of yield increases, second potential gains provided by fertilizer.

IV. Robustness of Net Returns

In order to evaluate the extent to which crop prices affected the relative size of net revenues across treatments, we recalculated net returns in two ways: using average low and average high prices from the Salinas/Watsonville shipping point for the harvest month, and using the historical averages from 2011-2015. We then performed an ANOVA on net returns to see whether they

were significantly different from the primary analysis. Results show that using the historical average prices is not statistically different with a p-value of 0.013, but is on average $3,014 more in net returns than the results shown in the paper. The ANOVA with the average low price shows no statistically significant difference from base results, and that the average difference across rotations is $2,505 less in net returns. Using average high prices, however, shows a largely significant difference (p= ~0.002) with average high prices generating, on average across rotations, almost $15,000 more in net returns than the figures in the paper. Results are reported in the Appendix.

V. Conclusion

The primary economic question examined in the trial is the dynamic tradeoff between increasing current returns with revenue-generating crops or increasing future returns through the current planting of non-host crops in exchange for higher strawberry yields later. Strawberry yields in the fourth year of the four-year rotations are profitable and are the biggest driver of net returns. Relative to four-year rotations, the two-year rotations do not perform as well economically because of the larger incidence of Verticillium wilt disease in the two-year rotations.

When comparing rotations of a given length, it is difficult to reach firm conclusions regarding the relative profitability of different crop combinations. While broccoli tended to increase future strawberry yields, current revenues from lettuce were higher. Net returns were driven not just by yields or costs, but by prices. If crop choice had been made independently of the choice of rotation for disease suppression, the profit-maximizing crop choice would have been different. Specifically, given the prices that were available at each harvest *during the trial period* broccoli prices were low in year three and lettuce prices were high in year two.

The ANOVA analysis shows that the choice of rotation, coupled with fertility treatment choices are important factors in net returns. The choice of planting lettuce or broccoli was an important determinant of fourth year strawberry yields, showing that suppressive crop rotations were effective, but did not have a discernible effect on the present discounted value of net returns. This shows that the suppressive crop rotation is effective in managing disease but, due to the prices realized during the trial, it was not possible to identify a consistent effect.

There are several caveats regarding this analysis. In addition to standard caveats and cautions regarding partial budget analysis and using field trial results to project commercial scale returns, there are some issues related to this study specifically. First, some treatment costs were obtained from sources outside the trial. Water and harvest labor costs were computed based on information in cost of production studies because the UCSC experimental farm's operating costs for labor and water do not reflect the costs that would be incurred in commercial production. Furthermore, the costs studies that were utilized were not from the trial years. As such, they may not adequately reflect actual costs. Another significant caveat is that organic prices were not available for the years that the trial was performed. The assumption of a constant margin was made by using organic/conventional price ratios derived from 2016 data. This could potentially introduce bias into the results if the price ratios during the trial period were significantly different from the observed 2016 values. According to Shennan et al. 2016, poor drainage and lower than normal bed heights exacerbated the Verticillium wilt in the soil, which led to low second year strawberry yields, and likely biased the net returns downward for the two-year rotations. A new bed shaper was added to create better conditions in the fourth year and higher strawberry yields were realized in the two-year rotations.

There are several exciting new directions for future research. One is the evaluation of the Mother Trial as more years of the rotations become available. This will provide the ability to calculate a more precise evaluation of these suppressive crop rotations' commercial viability. Another topic to explore is incorporating the trial's findings into a grower decision-making model that enables the identification of the key grower characteristics that would influence the adoption of such rotations.

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Tables and Figures

Table 1. Price Unit Conversions to Dollars per Pound.

Crop	Conversion Assumption	Conversion Factor
Broccoli	1 unit at 1 lb, 20 units in a carton	20
Lettuce	36 units in a package, 1.5 lbs/unit	54
Cauliflower	14 in carton, at 1.5 lbs each	21
Strawberry	8, 1 lb. containers	8

Source: University of Georgia Cooperative Extension 2014
http://extension.uga.edu/publications/detail.cfm?number=C780

Table 2. Organic Prices per Pound by Year*

Year	Broccoli	Lettuce	Cauliflower	Strawberry
2011	0.53	0.38	-	-
2012	0.76	0.58	1.60	1.71
2013	0.39	0.78	-	-
2014	-	-	-	1.83

Source: Agricultural Marketing Service.
https://www.ams.usda.gov/
*Converted from conventional prices using factors in Table 1.

Table 3. Average October Organic Cauliflower Price per Pound*

Year	Dollars per Pound
2008	0.82
2009	0.93
2010	0.51
2011	0.51
2012	0.50
2013	2.05
2014	0.81
2015	1.07

Source: Agricultural Marketing Service
https://www.ams.usda.gov/
*Converted from conventional prices using factors in Table 1.

Table 4. Average Harvest Month Organic Price: Lettuce*

Year	Price
2011	0.36
2012	0.38
2013	0.58
2014	0.78
2015	1.07

Source: Agricultural Marketing Service
https://www.ams.usda.gov/
*Converted from conventional prices using factors in Table 1.

Table 5. Split-Split Plot ANOVA: Net Returns

Source	*Degrees of Freedom*	*Sum of Squares*	*Mean Square*	*F-Statistic*	*P-value*
Block (A)	3	5,222,000,000	1,741,000,000		
Four-year vs. Two-year (B)	1	5,951,000,000	5,951,000,000	22.41	0.02
Error A*B	3	796,700,000	265,600,000		
Cash Crop vs. Non-host Crop (C)	1	321,700,000	321,700,000	1.30	0.30
B*C	1	126,300,000	126,300,000	0.51	0.50
Error A*B*C	6	1,481,000,000	246,800,000		
Fertility (D)	3	750,500,000	250,200,000	2.46	0.08
B*D	3	1,737,000,000	579,100,000	5.70	0.003
C*D	3	254,400,000	84,800,000	0.84	0.49
B*C*D	3	418,900,000	139,600,000	1.37	0.27
Error A*B*C*D	36	3,650,000,000	101,500,000		
Total	63	20,720,000,000			
Grand Mean	37,340				
CV(block*fouryear)	43.64				
CV(block*fouryear*lettuce)	42.07				
CV(block*fouryear*lettuce*fertility)	26.99				

Table 6. Split-Split-Plot ANOVA: Gross Revenues

Source	*Degrees of Freedom*	*Sum of Squares*	*Mean Square*	*F-Statistic*	*P-value*
Block (A)	3	12,360,000,000	4,121,000,000		
Four-year vs. Two-year (B)	1	1,315,000,000	1,315,000,000	2.07	0.25
Error A*B	3	1,905,000,000	635,100,000		
Cash Crop vs. Non-host Crop (C)	1	1,102,000,000	1,102,000,000	2.09	0.20
B*C	1	16,750,000	16,750,000	0.03	0.86
Error A*B*C	6	3,171,000,000	528,500,000		
Fertility (D)	3	3,511,000,000	1,170,000,000	5.13	0.005
B*D	3	5,218,000,000	1,739,000,000	7.62	0.0005
C*D	3	154,700,000	51,550,000	0.23	0.88
B*C*D	3	586,000,000	195,300,000	0.86	0.47
Error A*B*C*D	36	8,218,000,000	228,300,000		
Total	63	37,560,000,000			
Grand Mean	117,009				
CV(block*fouryear)	21.54				
CV(block*fouryear*lettuce)	19.65				
CV(block*fouryear*lettuce*fertility)	12.91				

Table 7. Split-Split Plot ANOVA: Fourth Year Strawberry Yields

Source	*Degrees of Freedom*	*Sum of Squares*	*Mean Square*	*F-Statistic*	*P-value*
Block (A)	3	304,400,000	102,000,000		
Four-year vs. Two-year (B)	1	20,100,000	20,100,000	0.59	0.50
Error A*B	3	102,600,000	34,220,000		
Cash Crop vs. Non-host Crop (C)	1	914,000,000	914,000,000	14.76	0.009
B*C	1	221,000,000	221,000,000	3.57	0.11
Error A*B*C	6	371,500,000	61,910,000		
Fertility (D)	3	300,500,000	100,000,000	3.32	0.03
B*D	3	268,500,000	89,510,000	2.97	0.04
C*D	3	136,700,000	45,570,000	1.51	0.23
B*C*D	3	162,700,000	54,240,000	1.8	0.16
Error A*B*C*D	36	1,085,000,000	30,140,000		
Total	63	3,887,000,000			
Grand Mean	33,109				
CV(Block*Four-year)	17.67				
CV(Block*Four-year *Cash-crop)	23.76				
CV(Block*Four-year *Cash-crop *Fertility)	16.58				

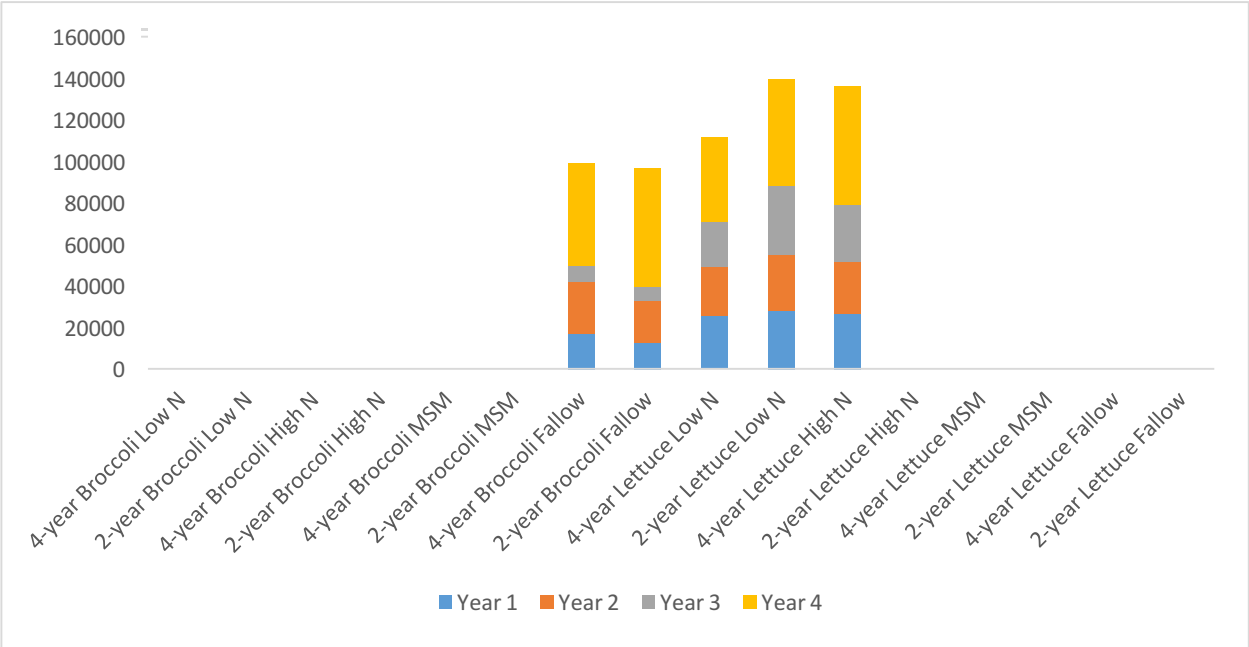

Figure 1. Present Discounted Value of Gross Revenues by Year

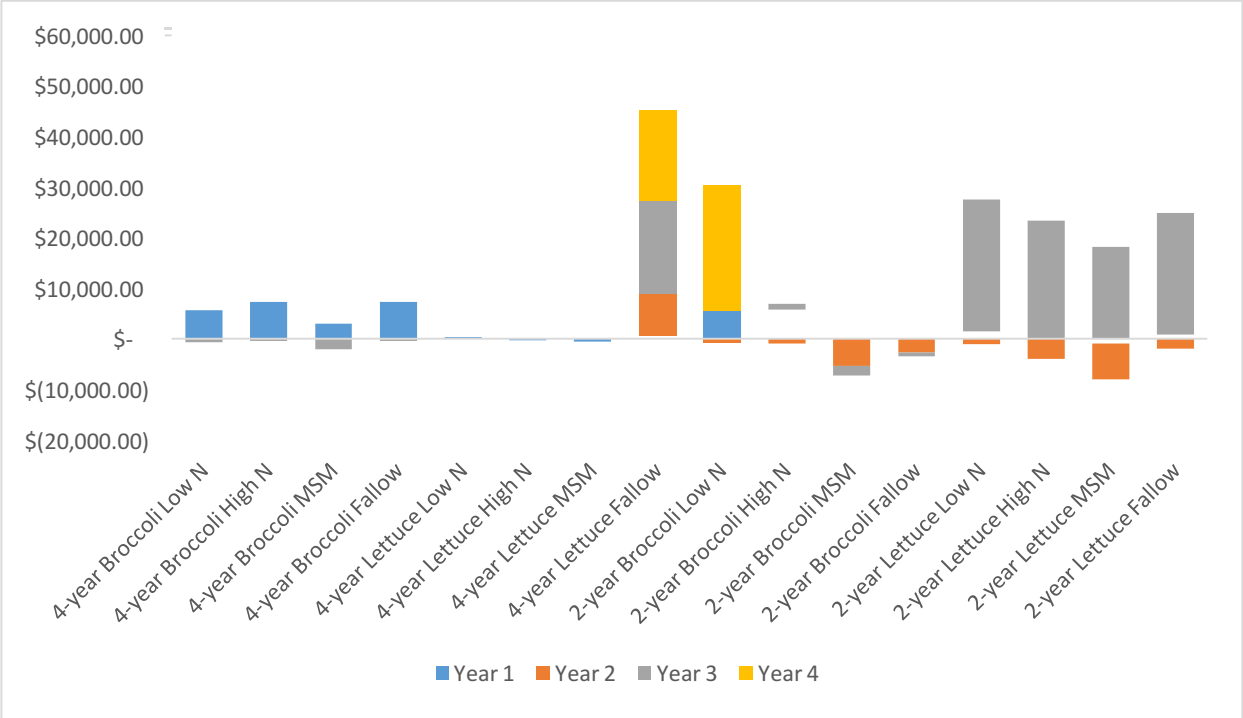

Figure 2. Present Discounted Value of Net Returns by Year

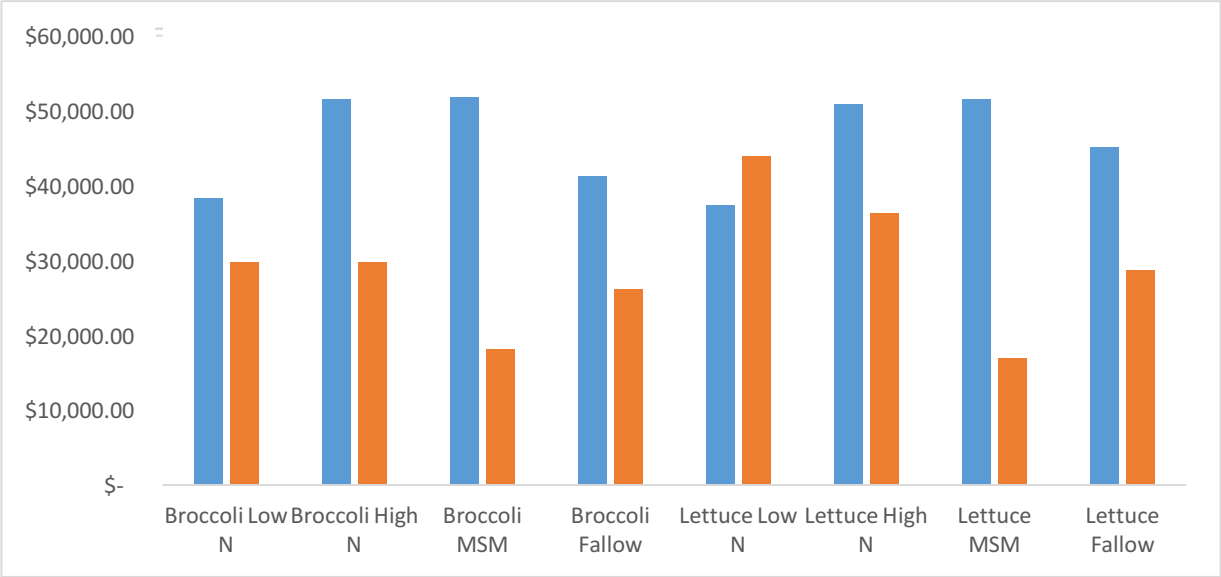

Figure 3. Present Discounted Value of Net Returns, Treatment Averages

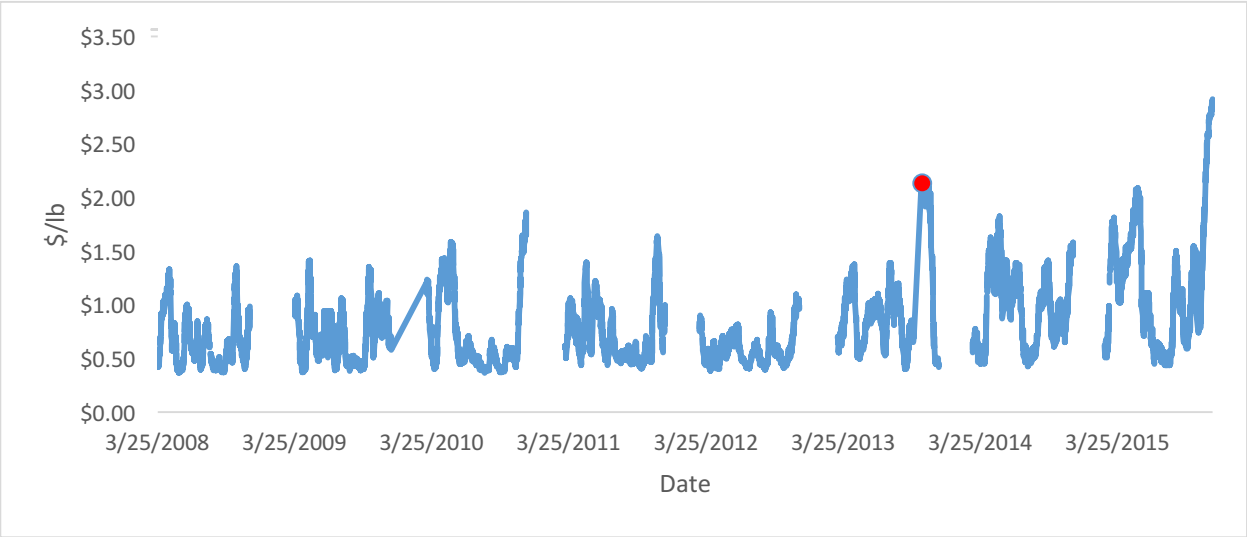

Figure 4. Organic Cauliflower Price per Pound: 2008-2015*

*Converted from conventional prices using factors in Table 1.

Figure 5. Effect of Changing Cauliflower Price to Historical Average on Present Discounted Value of Net Returns

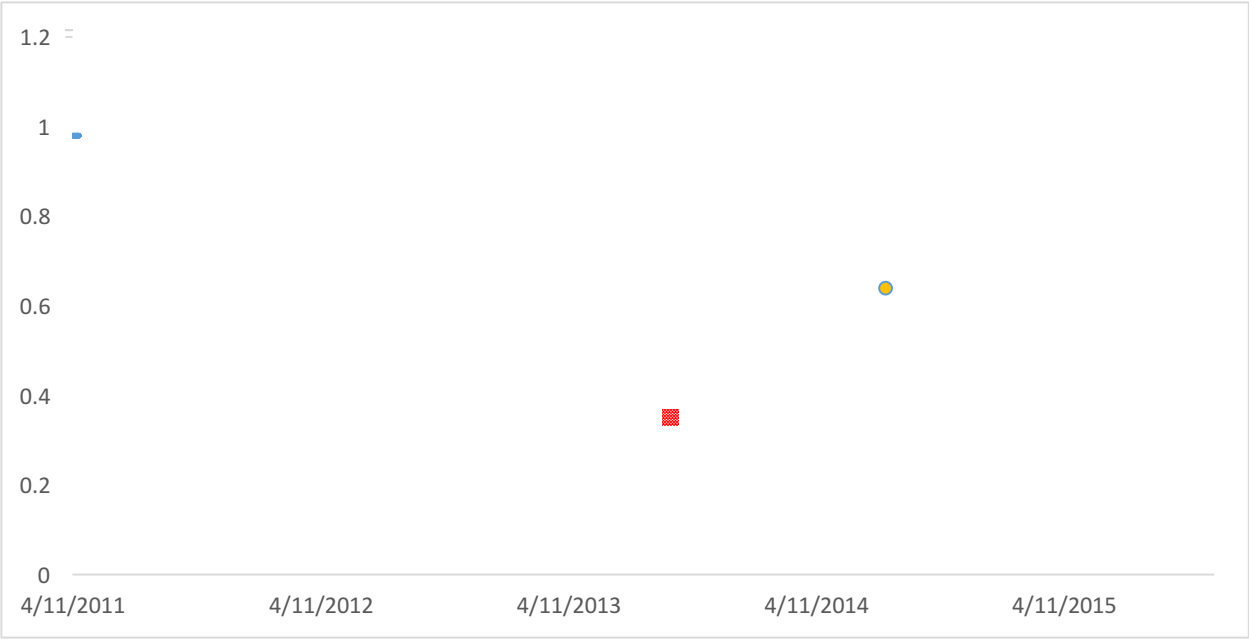

Figure 6. Organic Lettuce Price per Pound: 2011-2015*

*Converted from conventional prices using factors in Table 1.

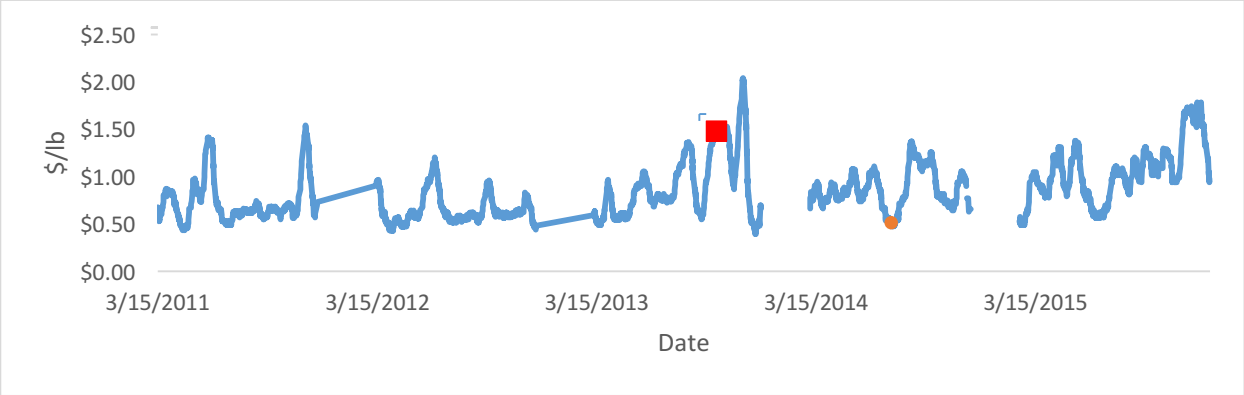

Figure 7. Organic Broccoli Price per Pound: 2011-2015*

*Converted from conventional prices using factors in Table 1.

Appendix

Table 1A. Overview of the Mother Trial Treatments

	Year 1		**Year 2**			**Year 3**		**Year 4**
	Initial	Crop	Initial	Crop 1	Crop 2	Initial	Crop	Crop
				Four-year rotations				
1a	CC* low N	Broccoli	CC low N	Lettuce	Cauliflower	CC low N	Broccoli	Strawberry
2a	CC high N	Broccoli	CC high N	Lettuce	Cauliflower	CC high N	Broccoli	Strawberry
3a	Cereal CC + MSM**	Broccoli	Cereal CC + MSM	Lettuce	Cauliflower	Cereal CC + MSM	Broccoli	Strawberry
4a	Fallow	Broccoli	Fallow	Lettuce	Cauliflower	Fallow	Broccoli	Strawberry
5a	CC low N***	Lettuce	CC low N	Lettuce	Broccoli	CC low N	Lettuce	Strawberry
6a	CC high N	Lettuce	CC high N	Lettuce	Broccoli	CC high N	Lettuce	Strawberry
7a	Cereal CC + MSM	Lettuce	Cereal CC + MSM	Lettuce	Broccoli	Cereal CC + MSM	Lettuce	Strawberry
8a	Fallow	Lettuce	Fallow	Lettuce	Broccoli	Fallow	Lettuce	Strawberry
				Two-year rotations				
1b	CC low N	Broccoli	----------Strawberry----------			CC low N	Broccoli	Strawberry
2b	CC high N	Broccoli	----------Strawberry----------			CC high N	Broccoli	Strawberry
3b	Cereal CC + MSM	Broccoli	----------Strawberry----------			Cereal CC + MSM	Broccoli	Strawberry
4b	Fallow	Broccoli	----------Strawberry----------			Fallow	Broccoli	Strawberry
5b	CC low N	Lettuce	----------Strawberry----------			CC low N	Lettuce	Strawberry
6b	CC high N	Lettuce	----------Strawberry----------			CC high N	Lettuce	Strawberry
7b	Cereal CC + MSM	Lettuce	----------Strawberry----------			Cereal CC + MSM	Lettuce	Strawberry
8b	Fallow	Lettuce	----------Strawberry----------			Fallow	Lettuce	Strawberry

Source: Mother Trial Study

*: Cover Crop

**: Mustard Seed Meal

***: Nitrogen

Table 2A1. Current and Present Discounted Value of Net Returns by Treatment and Year: Four-year Rotations

Treatment	Net Revenues		2012	2013	2014	2015
1a	$38,354.84	4 yr-bro-low N	Cover Crop/ Broccoli	Cover Crop/ Lettuce/ Cauliflower	Cover Crop/ Broccoli	Strawberry
		Current	$5,677.01	$13,273.03	$(771.09)	$24,617.20
		Discounted	$5,677.01	$12,551.33	$(689.52)	$20,816.02
2a	$51,582.26	4 yr-bro-high N	Cover Crop/ Broccoli	Cover Crop/ Lettuce/ Cauliflower	Cover Crop/ Broccoli	Strawberry
		Current	$7,295.77	$26,443.33	$(373.83)	$23,197.19
		Discounted	$7,295.77	$25,005.51	$(334.28)	$19,615.26
3a	$51,835.35	4 yr-bro-MSM	Cereal Cover Crop/ Broccoli	Cereal Cover Crop/ Lettuce/ Cauliflower	Cereal Cover Crop/ Broccoli	Strawberry
		Current	$3,067.06	$30,226.84	$(2,338.84)	$26,344.26
		Discounted	$3,067.06	$28,583.30	$(2,091.41)	$22,276.39
4a	$41,261.33	4 yr-bro-fallow	Fallow/ Broccoli	Fallow/ Lettuce/ Cauliflower	Fallow/ Broccoli	Strawberry
		Current	$7,304.02	$17,976.28	$(485.27)	$20,568.40
		Discounted	$7,304.02	$16,998.85	$(433.94)	$17,392.40
5a	$37,343.29	4 yr-lettuce-low N	Cover Crop/ Lettuce	Cover Crop/ Lettuce/ Broccoli	Cover Crop/ Lettuce	Strawberry
		Current	$320.01	$12,482.95	$15,903.00	$12,039.87
		Discounted	$320.01	$11,804.21	$15,038.30	$10,180.77
6a	$50,888.83	4 yr-lettuce-high N	Cover Crop/ Lettuce	Cover Crop/ Lettuce/ Broccoli	Cover Crop/ Lettuce	Strawberry
		Current	$(317.60)	$10,921.30	$22,813.04	$24,219.03
		Discounted	$(317.60)	$10,327.47	$20,399.64	$20,479.32
7a	$51,533.29	4 yr-lettuce-MSM	Cereal Cover Crop/ Lettuce	Cereal Cover Crop/ Lettuce/ Broccoli	Cereal Cover Crop/ Lettuce	Strawberry
		Current	$(545.74)	$13,046.43	$25,380.63	$20,159.20
		Discounted	$(545.74)	$12,337.05	$22,695.60	$17,046.38
8a	$45,159.69	4 yr-lettuce-fallow	Fallow/ Lettuce	Fallow/ Lettuce/ Broccoli	Fallow/ Lettuce	Strawberry
		Current	$563.38	$8,880.33	$20,577.05	$21,048.84
		Discounted	$563.38	$8,397.48	$18,400.20	$17,798.65

Table 2A2. Current and Present Discounted Value of Net Returns by Treatment and Year: Two-year Rotations

Treatment	PDV of Net Revenues		2012	2013	2014	2015
1b	$ 29,778.97	2 yr-bro-low N	Cover Crop/ Broccoli	Strawberry	Cover Crop/ Broccoli	Strawberry
		Current	$5,630.30	$(747.36)	$88.31	$29,300.82
		Discounted	$5,630.30	$(706.72)	$78.96	$24,776.43
2b	$ 29,741.80	2 yr-bro-high N	Cover Crop/ Broccoli	Strawberry	Cover Crop/ Broccoli	Strawberry
		Current	$5,808.37	$(972.40)	$1,308.30	$28,007.77
		Discounted	$5,808.37	$(919.52)	$1,169.90	$23,683.04
3b	$ 18,168.50	2 yr-bro-MSM	Cereal Cover Crop/ Broccoli	Strawberry	Cereal Cover Crop/ Broccoli	Strawberry
		Current	$3,171.05	$(5,622.33)	$(2,187.53)	$26,336.92
		Discounted	$3,171.05	$(5,316.62)	$(1,956.11)	$22,270.19
4b	$ 22,947.94	2 yr-bro-fallow	Fallow/ Broccoli	Strawberry	Fallow/ Broccoli	Strawberry
		Current	$6,597.54	$(2,756.79)	$(860.64)	$27,185.79
		Discounted	$6,597.54	$(2,606.89)	$ (769.59)	$22,987.98
5b	$43,880.32	2 yr-lettuce-low N	Cover Crop/ Lettuce	Strawberry	Cover Crop/ Lettuce	Strawberry
		Current	$1,455.97	$(1,037.88)	$29,187.92	$20,465.86
		Discounted	$1,455.97	$(981.45)	$26,100.11	$17,305.69
6b	$36,313.26	2 yr-lettuce-high N	Cover Crop/ Lettuce	Strawberry	Cover Crop/ Lettuce	Strawberry
		Current	$165.79	$(4,147.61)	$26,047.72	$19,841.16
		Discounted	$165.79	$(3,922.09)	$23,292.11	$16,777.45
7b	$16,901.71	2 yr-lettuce-MSM	Cereal Cover Crop/ Lettuce	Strawberry	Cereal Cover Crop/ Lettuce	Strawberry
		Current	$(944.59)	$(7,415.22)	$20,423.01	$7,800.35
		Discounted	$(944.59)	$(7,012.03)	$18,262.45	$6,595.88
8b	$28,680.84	2 yr-lettuce-fallow	Fallow/ Lettuce	Strawberry	Fallow/ Lettuce	Strawberry
		Current	$890.64	$(1,953.64)	$26,798.40	$6,710.50
		Discounted	$890.64	$(1,847.42)	$23,963.30	$5,674.32

Source: Mother Trial Study, Agricultural Marketing Service and Author's Calculations

Table 3A. Split-Split-Plot ANOVA excluding Block 4, on Net Returns

Source	*Degrees of Freedom*	*Sum of Squares*	*Mean Square*	*F-Statistic*	*P-value*
Block (A)	2	1,500,000,000	750,200,000		
Four-year vs. Two-year (B)	1	3,698,000,000	3,698,000,000	11.33	0.0781
Error A*B	2	652,700,000	326,400,000		
Cash Crop vs. Non-host Crop (C)	1	824,800,000	824,800,000	4.44	0.1028
B*C	1	168,600,000	168,600,000	0.91	0.3946
Error A*B*C	4	742,700,000	185,700,000		
Fertility (D)	3	1,240,000,000	413,300,000	7.19	0.0013
B*D	3	1,266,000,000	422,000,000	7.34	0.0012
C*D	3	237,800,000	79,280,000	1.38	0.2732
B*C*D	3	237,100,000	79,030,000	1.37	0.2745
Error A*B*C*D	24	1,380,000,000	57,490,000		
Total	47	11,950,000,000			
Grand Mean	32937				
CV(block*fouryear)	54.85				
CV(block*fouryear*lettuce)	41.37				
CV(block*fouryear*lettuce*fertility)	23.02				

Table 4A. Split-Split-Plot ANOVA excluding Block 4, on Gross Revenues

Source	*Degrees of Freedom*	*Sum of Squares*	*Mean Square*	*F-Statistic*	*P-value*
Block (A)	2	3,432,000,000	1,716,000,000		
Four-year vs. Two-year (B)	1	549,600,000	549,600,000	0.67	0.5004
Error A*B	2	1,652,000,000	826,000,000		
Cash Crop vs. Non-host Crop (C)	1	2,144,000,000	2,144,000,000	5.20	0.0847
B*C	1	24,860,000	24,860,000	0.06	0.8181
Error A*B*C	4	1,648,000,000	412,100,000		
Fertility (D)	3	4,737,000,000	1,579,000,000	11.36	0.0001
B*D	3	4,036,000,000	1,345,000,000	9.68	0.0002
C*D	3	297,900,000	99,290,000	0.71	0.5531
B*C*D	3	264,700,000	88,220,000	0.63	0.5999
Error A*B*C*D	24	3,336,000,000	139,000,000		
Total	47	22,120,000,000			
Block (A)					
Grand Mean	110188				
CV(block*fouryear)	26.08				
CV(block*fouryear*lettuce)	18.42				
CV(block*fouryear*lettuce*fertility)	10.70				

Table 5A. Split-Split-Plot ANOVA excluding Block 4, on Fourth Year Strawberry Yields

Source	*Degrees of Freedom*	*Sum of Squares*	*Mean Square*	*F-Statistic*	*P-value*
Block (A)	2	197,000,000	98,600,000		
Four-year (B)	1	25,600,000	25,600,000	0.53	0.5432
Error A*B	2	97,100,000	48,600,000		
Cash-crop vs. Non-host (C)	1	524,000,000	524,000,000	6.47	0.0637
B*C	1	193,000,000	193,000,000	2.38	0.1975
Error A*B*C	4	324,000,000	81,000,000		
Fertility (D)	3	347,000,000	116,000,000	4.64	0.0107
B*D	3	277,000,000	92,400,000	3.71	0.0253
C*D	3	84,800,000	28,300,000	1.13	0.3552
B*C*D	3	89,800,000	29,900,000	1.2	0.3303
Error A*B*C*D	24	598,000,000	24,900,000		
Total	47	2,760,000,000			
Grand Mean	32362				
CV(Block*Four-year)	21.53				
CV(Block*Four-year*Cash-crop)	27.8				
CV(Block*Four-year*Cash-crop*Fertility)	15.42				

Table 6A. ANOVA for Difference in Net Returns using Historical Prices for Crops

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Historic Price Returns	16	645676.2509	40354.76568	135341305.5
Net Returns in Paper	16	597444.4657	37340.27911	159336499.5

ANOVA

Source of Variation	*Sum of Squares*	*Degrees of Freedom*	*Mean Square*	*F*	*P-value*	*F crit*
Between Groups	72697034.3	1	72697034.3	0.493400134	0.487829358	4.170876786
Within Groups	4420167075	30		147338902.5		
Total	4492864109	31				

Table 7A. ANOVA for Difference in Net Returns using Average Low Prices for Crops

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*	
Low Returns	16	557355.2968	34834.70605		116714239.3
Net Returns in Paper	16	597444.4657	37340.27911		159336499.5

ANOVA

Source of Variation	*Sum of Squares*	*Degrees of Freedom*	*Mean Square*	*F*	*P-value*	*F crit*
Between Groups	50223170.78	1	50223170.78	0.363869128	0.550898928	4.170876786
Within Groups	4140761082	30		138025369.4		
Total	4190984253	31				

Table 8A. ANOVA for Difference in Net Returns using Average High Prices for Crops

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
High Returns	16	835194.8	52199.67	1.57E+08
Net Returns in Paper	16	597444.5	37340.28	1.59E+08

ANOVA

Source of Variation	*Sum of Squares*	*Degrees of Freedom*	*Mean Square*	*F*	*P-value*	*F crit*
Between Groups	1,770,000,000	1	1,770,000,000	11.18044	0.00223	4.170877
Within Groups	4,740,000,000	30	158,000,000			
Total	6,510,000,000	31				

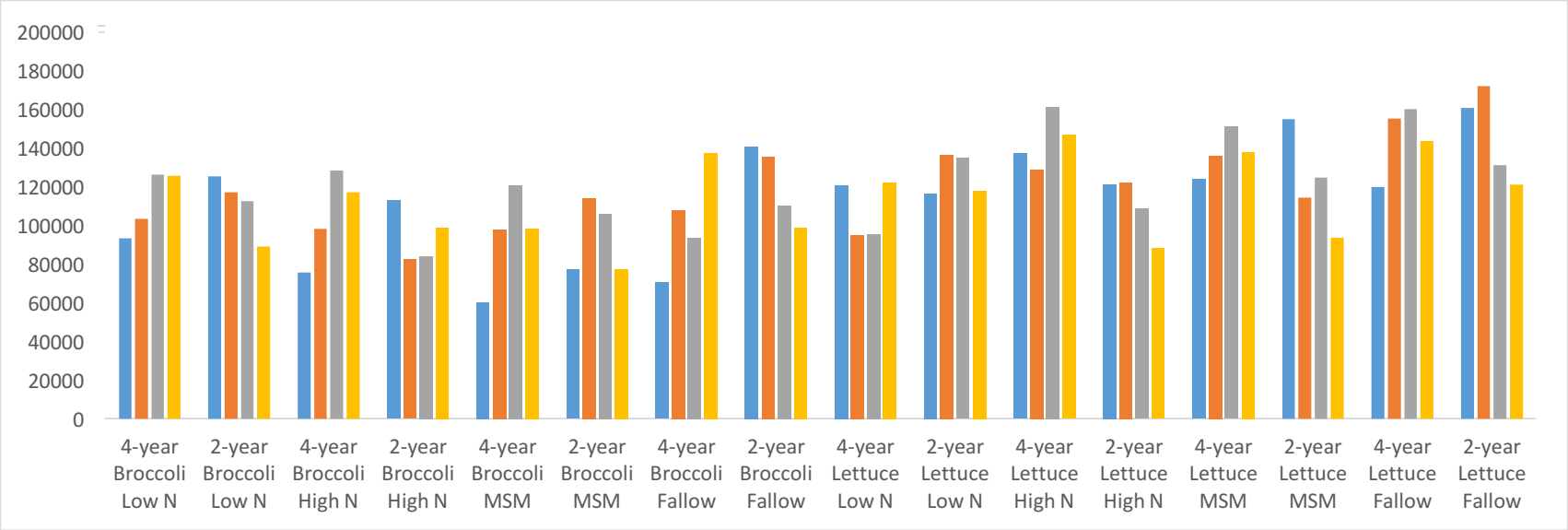

Figure 1A. Present Discounted Value of Gross Revenues by Plot

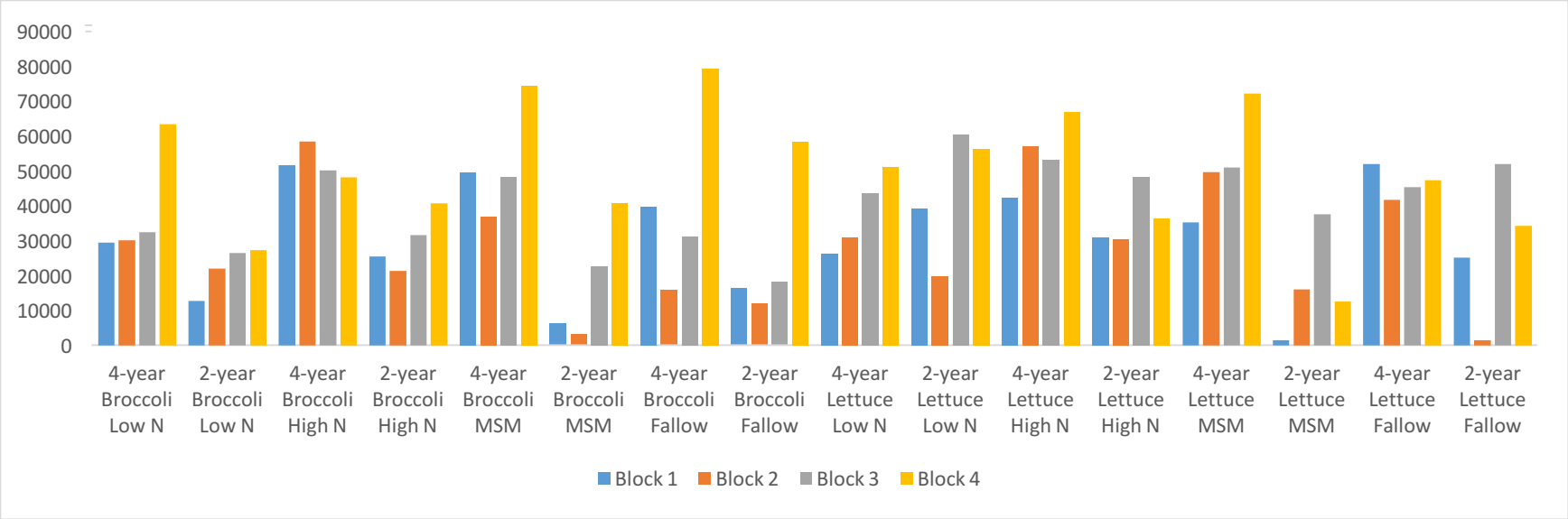

Figure 2A. Present Discounted Value of Net Returns by Plot

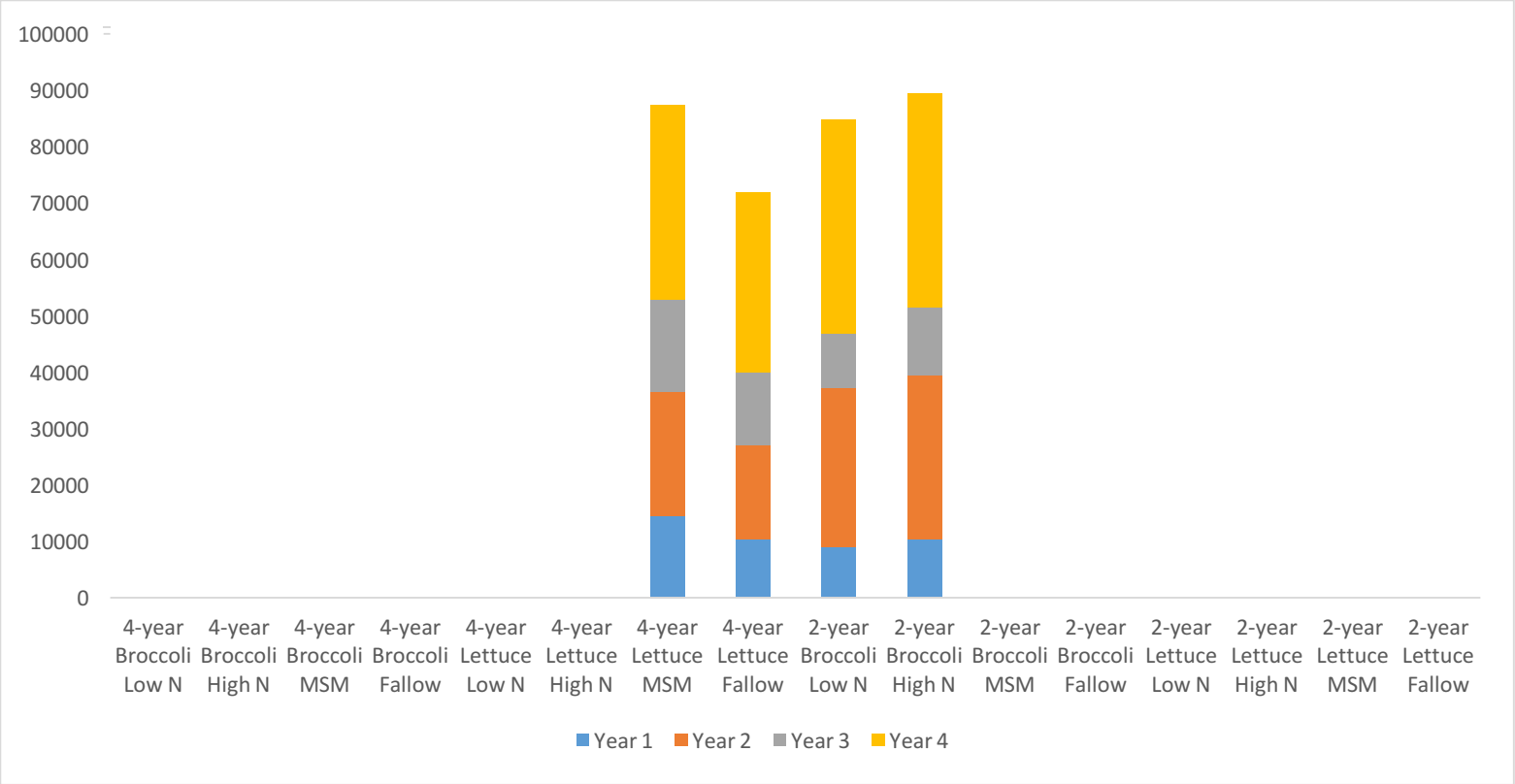

Figure 3A. Present Discounted Value of Costs per Year by Treatment, Averaged by Plot

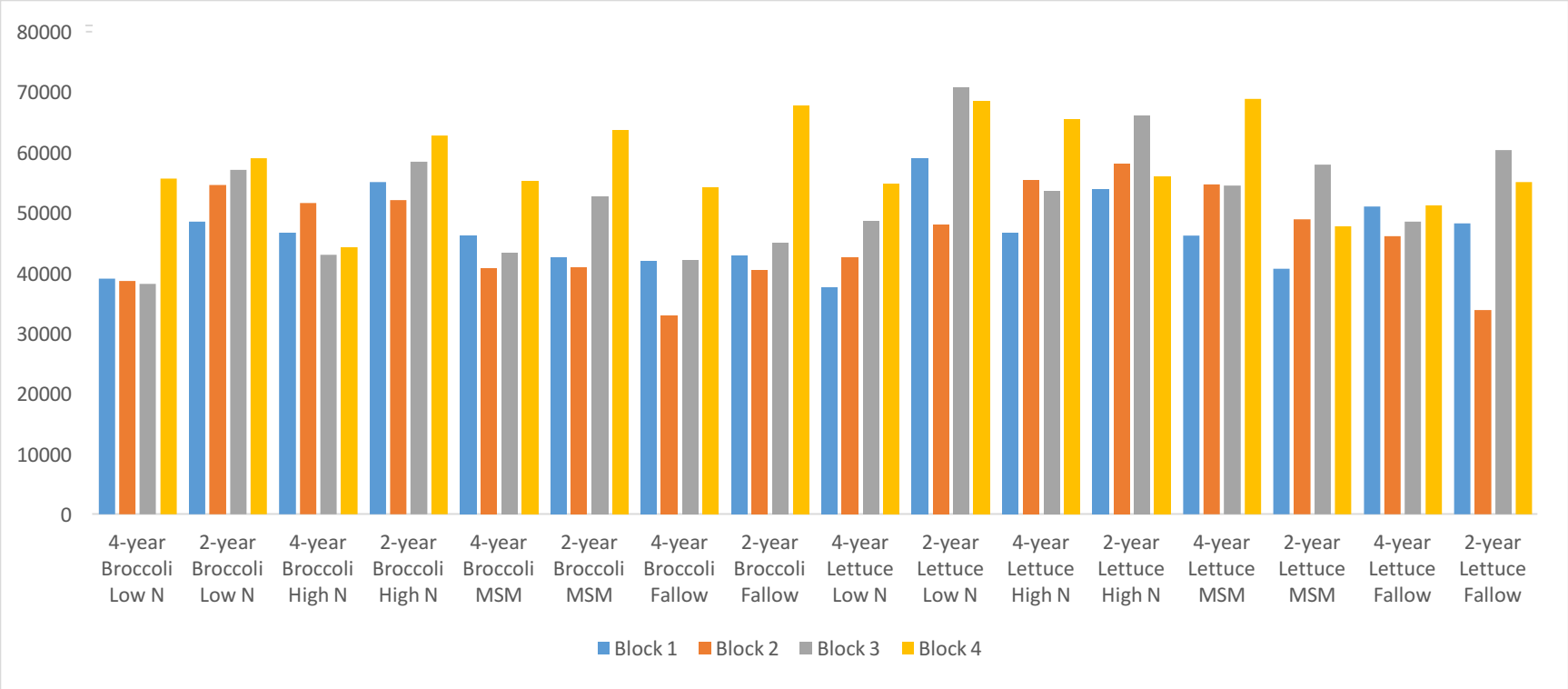

Figure 4A. Present Discounted Value of Harvest Costs per Plot

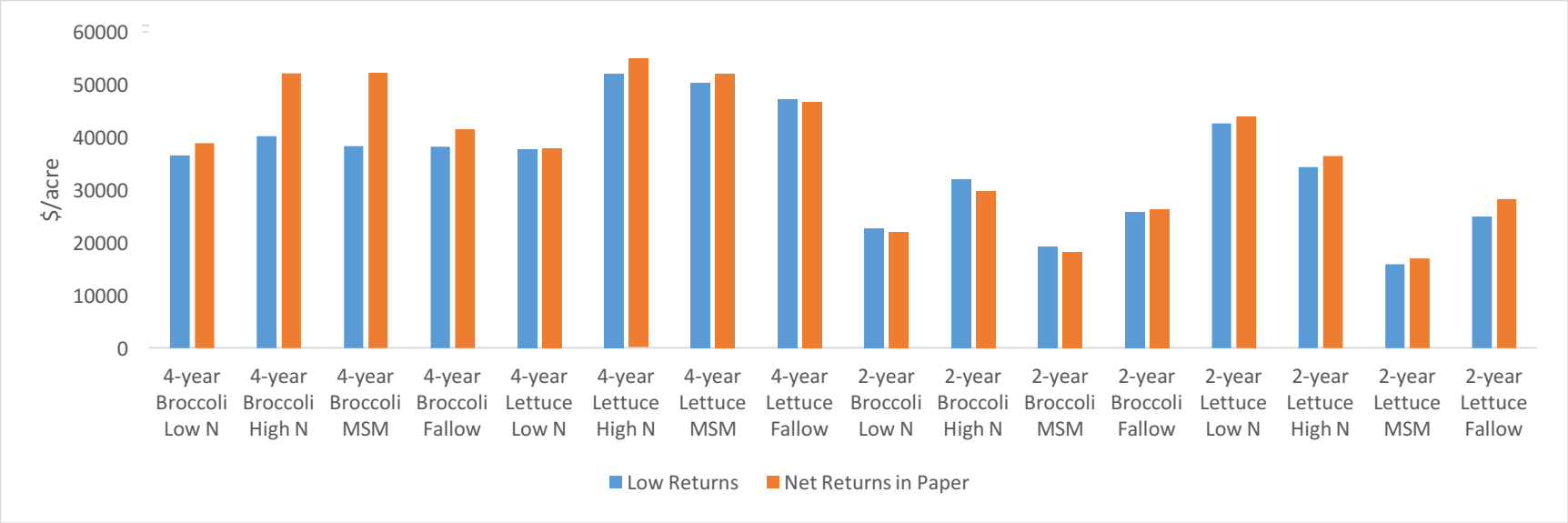

Figure 5A. Differences in Net Returns: Low Price

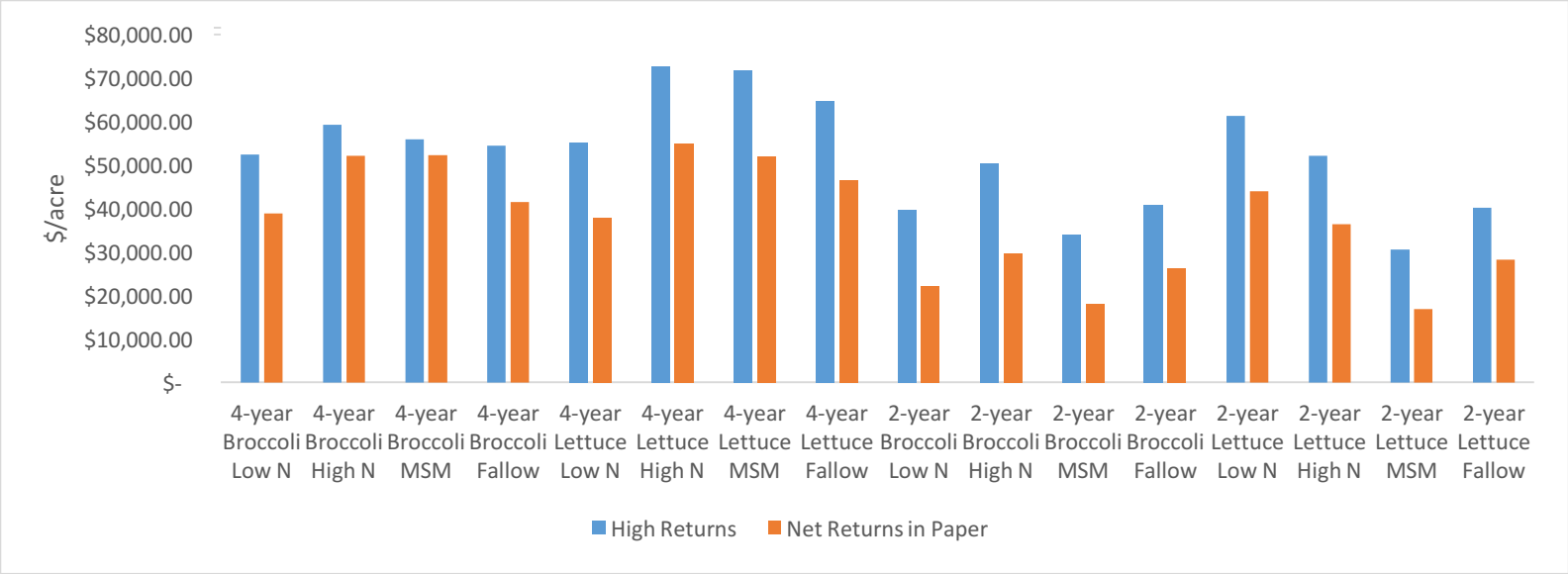

Figure 6A. Differences in Net Returns: High Price

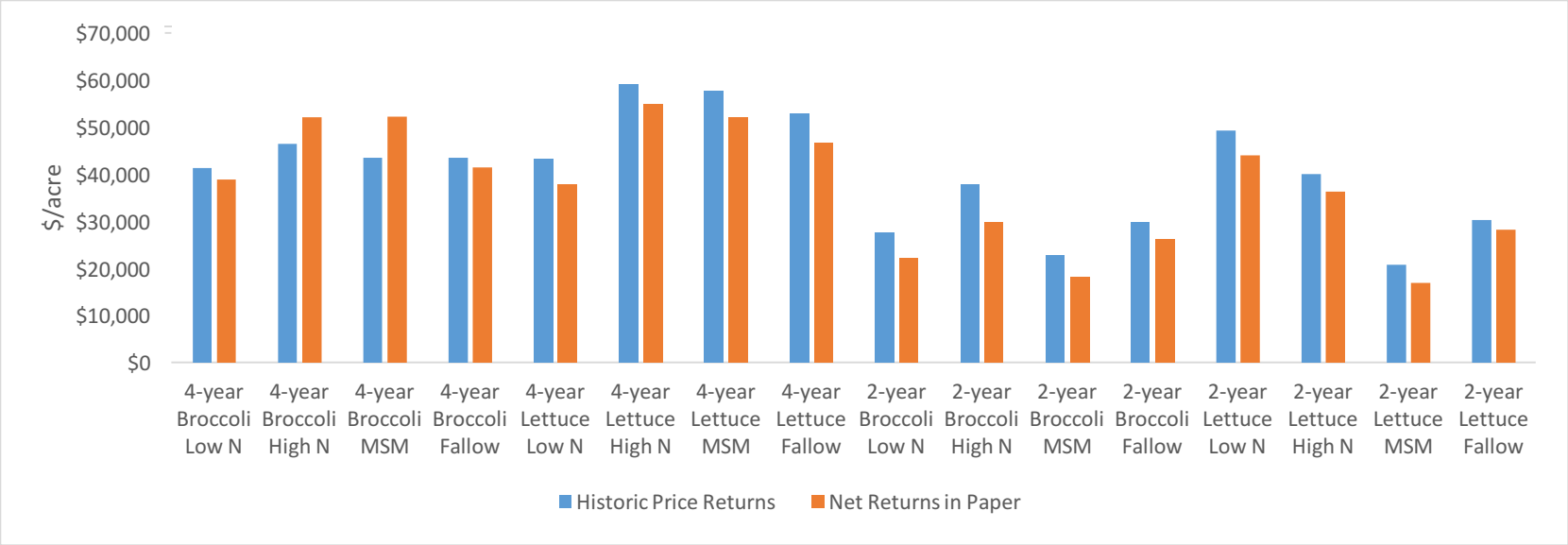

Figure 7A. Differences in Net Returns: Historical Price