Evaluating field inputs for productivity and profitability in wild blueberry fields in Maine.
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INDEX WORDS: input management high low medium and organic, soil and leaf analysis, systems approach, yields, weeds.

ABSTRACT
The goal of the project was to provide growers with information on how different management systems affect the crop, its environment and the ecological and economical sustainability of wild blueberry production. A critical issue affecting growers is how to optimize increasingly expensive inputs to achieve economically and environmentally sustainable yields. We conducted a multi-disciplinary large-scale study of four cropping input systems consisting of Organic, Low input, Medium input and High input that provided diverse gradients of capital inputs and potential environmental effects to quantify system effects on yield, fruit quality, pest communities, the environment, and economic effects of inputs. In the 2010 to 2012 cycle, the cropping systems were applied to two fields (n=8 fields), and this was expanded to have each of the cropping systems applied to an additional four fields (n=16 fields) in 2011 to 2013. This paper will discuss the fertility and weed aspects of the study. Leaf and soil samples were taken in the non-bearing years, and weeds and blueberry were evaluated in June and July. There was large variation on variables measured between years and among locations. Leaf nutrient levels were highest at the High input sites with N, P and B much higher and on the Organic input sites leaf nutrient levels for N and P were deficient but Ca was higher. Weed cover was highest in Organic and Low input systems. Yields were highest in the High input system, but with higher
costs it was not the most profitable. Data from both years verify trends that the Medium input system was the most profitable. The Low input system was not profitable on most sites. Organic yields were lowest but with higher fruit value were profitable.

**INTRODUCTION**

Munson (1898, 1901) first described the wild blueberry (*Vaccinium angustifolium*) in Maine and its potential for culture as a crop and possible ornamental use. The wild blueberry barrens in Eastern Maine comprised 150 thousand acres; its management consisted of burning the fields over and hand-picking for the fresh market and raking for the canning market. Chandler and Hyland (1941) and Hall (1978) described the growing economic importance and distribution in Maine and Atlantic Canada, respectively. Hepler and Yarborough (1991) found that although there was great genetic variability in wild blueberry fields, the average yield under intensive management could obtain and average 7,726 kg/ha with a maximum yield of 17,000 kg/ha. Smagula and Yarborough (1990) first described the changes in pruning management from the traditional burning to flail mowing and the beginning of mechanical harvesting. Yarborough (1997) documented a tripling of the wild blueberry yield in Maine over the previous 15 year period with increases in the intensity of management without increase of the land base.

Yarborough (2004) elaborated on the improvement in weed, fertility and pest management, increased use of honey bees for pollination and irrigation to continue to improve the productivity of wild blueberry fields in Maine, and the addition of increased production and land base in Quebec and Atlantic Canada. Strik and Yarborough (2005) documented that the increase in both cultivated (*V. corymbosum* and *V. ashei*) and wild blueberry production was principally from increased number of hectares under production.
An educational program was instituted to help wild blueberry growers improve production efficiency, develop enterprise budgets (Yarborough et al., 2003), develop business and marketing plans (Anon., 2011), eliminate marginal and unprofitable operations and improve production on the most viable fields. Research conducted on organic wild blueberry production using a systems approach identified that the use of burning for pruning combined with sulfur to reduce weed competition could triple the yields for organic producers, and Drummond et al., (2012) developed a path systems model to identify causal effects and correlations among the factors influencing production.

The objective of this multi-disciplinary large-scale study of four cropping input systems - Organic, Low input conventional, Medium input conventional and High input conventional - that fit along gradients of capital inputs and potential environmental effects was to quantify system effects on yield, fruit quality, pest communities, the environment and the economic effects of inputs. This paper focuses on the fertility and weed management aspects of this study, and evaluates the systems’ effects on yield and returns to production.

**MATERIAL AND METHODS**

In spring of 2010, a four-year study was initiated using a systems approach to evaluate the effects of four different cropping management systems: Organic, Low, Medium and High input, characterized by the inputs following the parameters in Table 1. Growers were asked to perform their usual activities within these blocks as part of the larger field management. Wild blueberry is managed on a two-year crop cycle; the first year of a cycle is a non-bearing year and the second a cropping year. The project has completed two crop cycles from 2010 to 2013. In the first cycle of the study, each input system consisted of two fields with four one acre blocks each, containing nested 15 x 30 m sampling sub-blocks, each with four 15 m transects used for sub-
sampling for a total of eight sites and 32 blocks. In the second cycle, each input system consisted of four sites with two one acre blocks set out, and as in the first year containing nested 15 x 30 m sample sub-blocks with four 15 m transects each for a total of 16 fields and 32 blocks (Fig. 1). Along the 30 m baseline (the outer long edge) of each sub-block, four 15 m long transects were located 5 m apart in order to set up 1 m$^2$ sample plots to assess weed cover. One, 1 m$^2$ sample plot was staked on each transect in such a manner that the sample plots ranged diagonally across the sub-block. For example, in a 15 x 30 m sub-block, transects were located at 5, 10, 15 and 20 m along the 30 m baseline. Within this sample plot A was located at 3 m on the first transect, B at 6 m on the second, C at 9 m on the third and D at 12 m on the fourth (Fig. 2). Although this study also looked at many other aspects of production, including plant disease, pathogens for food safety, fruit quality, insects, pollinators, and soil chemistry and health, this study will only cover the fertility, weeds, yields and economic returns.
Table 1. Management systems overview of inputs for 2010 to 2014.

<table>
<thead>
<tr>
<th>Production Factors</th>
<th>Organic</th>
<th>Low Input</th>
<th>Medium Input</th>
<th>High Input</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pruning</td>
<td>Burned</td>
<td>Burned</td>
<td>Mowed</td>
<td>Mowed</td>
</tr>
<tr>
<td>Land leveling</td>
<td>Not land leveled</td>
<td>Not land leveled</td>
<td>Land leveled</td>
<td>Land leveled</td>
</tr>
<tr>
<td>pH management</td>
<td>pH may be managed</td>
<td>No pH management</td>
<td>pH managed</td>
<td>pH managed</td>
</tr>
<tr>
<td>Fertility</td>
<td>No fertilizer</td>
<td>Some fertilizer</td>
<td>Fertility (both cycles)</td>
<td>Fertility rate much higher</td>
</tr>
<tr>
<td>Pest, disease, and weed control</td>
<td>Weed whacking, cutting woody weeds, grazing with goats, no pesticides used</td>
<td>Herbicides insecticides, some sites with fungicides</td>
<td>Scouting, herbicides, insecticides, fungicides in crop year</td>
<td>Scouting, herbicides, insecticides, fungicides in both years</td>
</tr>
<tr>
<td>Treatment of bare spots</td>
<td>Mulch</td>
<td>No mulch</td>
<td>No mulch</td>
<td>Mulch</td>
</tr>
<tr>
<td>Irrigation</td>
<td>No irrigation</td>
<td>No irrigation</td>
<td>No irrigation</td>
<td>Irrigation as needed</td>
</tr>
<tr>
<td>Pollination</td>
<td>Bees 0 to 2 hives/acre</td>
<td>Bees 1-3 hives/acre</td>
<td>Bees 2 hives/acre</td>
<td>Bees 5-7 hives/acre</td>
</tr>
<tr>
<td>Harvest method</td>
<td>Hand raked</td>
<td>Hand raked</td>
<td>Mechanical harvest</td>
<td>Mechanical harvest</td>
</tr>
</tbody>
</table>
Figure 1. Location of fields in the second cropping cycle by management system.

Figure 2. Example layout of an acre block, 15 x 30 m sub-block and 15 m transects.
In each one acre block at each management site, soil was sampled in July 2010 and 2012 using a standard soil sample tube removing a 2 cm diameter core 7.6 cm deep. Forty cores, collected by sampling along two diagonal transects in each block were combined and analyzed for soil pH (water), organic matter and nutrients. Organic matter was measured by loss on ignition (LOI) at 375° C. Available nutrients were extracted in pH 4.8 ammonium acetate (Modified Morgan method) and measured by plasma emission using a TJA Model iCAP 6300 ICP-AES.

Composite leaf tissue samples from 50 stems were also sampled in early July along the same diagonal transects to determine leaf nutrient concentrations (Trevett et al., 1968). Leaf samples were prepared according to the methods of Kalra and Maynard (1991) and submitted to the University of Maine Soil and Plant Tissue Testing Laboratory for nutrients analysis. Data were analyzed by ANOVA with mean separation obtained by Duncan’s Multiple Range Test at the 5% level.

Blueberry cover, woody weed cover, broadleaf weed cover and grass cover were assessed in all 1 m$^2$ sample plots approximately one and three months after the timing of pre-emergence weed control in the High and Medium input systems (early June and late August) each year. The 15 x 30 m sub-blocks were weed whacked using a string trimmer above the height of the blueberry plants in June, July and August in the Organic system only. Blueberry and weed cover in the Organic system were assessed prior to the June and August weed cutting. Weed and blueberry cover were assessed using the Daubenmire Cover Class scale (Muller-Dombois and Ellenburg, 1974), which was converted to percent cover, and weed species were also identified. Because the data failed the assumptions of the General Linear Model, the data were analyzed using a non-parametric one-way median exact test ($\alpha=0.05$). The overall blueberry cover and weed cover comparisons were made among all treatments; therefore, a Bonferroni adjustment was applied
(α=0.0125). Weed cover values were plotted against yield via linear regressions, and significance was determined by a hierarchical or nested general linear model SAS PROC GLM (SAS Institute Inc., 2006).

All sites were harvested the first week of August in 2011 and between 30 July and 6 August in 2013. The blocks were harvested along the 15 m long transects, and went through the 1 m² weed cover plots. The Medium and High sites were harvested using two walk-behind harvesters built by Maine Blueberry Equipment Company of Columbia Falls, ME, with 2-ft wide heads, and the Low and Organic sites were harvested by hand using rakes of the same width as the harvesters. The berries were weighed on-site using two Homs Model 40 platform scales, and were not winnowed prior to weighing. Yields were converted to pounds per acre, yield by system was analyzed using a Tukey’s test (α=0.05), and yield by site was compared using the Standard Error of the Mean. The explained variance in a hierarchical or nested ANOVA (SAS GLM) was partitioned according to source (year, system, site and block, ie. in this hierarchical ordering). Expected mean squares were used to subtract out multiple sources of variation for an estimate of each sources variance (Cochran 1977).

Cooperating growers were also asked to provide the level of inputs and costs and the actual yields for their field operation. This information was put in an enterprise budget program (Yarborough, 2011) to determine the relative returns of the inputs.

**RESULTS**

In 2012, overall soil pH in the Organic and Low input systems were significantly higher than in the Medium input system (Fig. 3), which followed the trend seen in the first cycle with the exception that the High input system was also significantly lower than the Organic and Low systems in 2010. Overall, percent organic matter did not differ among management systems.
Leaf N in the Organic system was both significantly lower than the High and Medium input fields and below the leaf standard of 1.6% (Yarborough and Smagula, 2013) but did not differ from the Low system which also was not significantly different from the High and Medium sites (Fig, 4). The Medium input system had the highest P leaf level and the Organic input system the lowest, which was also deficient below 0.12%. The Low input fields overlapped with the High and Medium fields, while the High input fields overlapped with the Low and Organic fields (Fig. 5). Leaf Ca was the highest in the Organic input system and exceeded the maximum (Yarborough and Smagula, 2013); it overlapped with the Low system and was significantly higher than the Medium and High systems, which did not differ (Fig. 6). Leaf B concentrations exhibited a significant increase from Organic to High input systems, but all sites were above the standard level (Fig. 7). The levels for all of the above showed the same trends for 2010 so these data are not presented.

**Figure 3.** Soil characteristics organic matter and pH by management system, 2012.
**Figure 4.** Leaf nitrogen concentrations in the input management systems compared across systems, 2012.

**Figure 5.** Leaf phosphorus concentrations in the input management systems compared across systems, 2012.
Figure 6. Leaf calcium concentrations in the input management systems compared across systems, 2012.

Figure 7. Leaf boron concentrations in the input management systems compared across systems, 2012.
Wild blueberry cover was measured in June and July/early August of each year of the study; the trends are the same for each year with lower cover levels in June and higher in July as expected. There were significantly lower wild blueberry levels in 2011 for the Low and Organic fields, but although still lower in 2013 the differences were not significant that year (Fig. 8). Weed cover was also measured in June and July to early August of each year of the study, and the trends are the same for each year with lower cover levels in June and higher in July as expected and similar results were found in 2011 and 2013 for weed cover by (Fig. 9). Organic fields had the highest levels of weeds and the Low and Medium levels had more broadleaf weeds than the High input fields; grasses were very low except on the Organic fields. Wild blueberry yield obtained in pounds per acre from the sample strips harvested in 2011 and 2013 were plotted against the weed cover in percent and a linear regression for the yield vs weed cover for each (Fig. 10). Both years show a decline in production as weed cover increased but with 2013 with a more severe slope and greater decline; however, in both years, weed cover was not found to be a significant predictor of yield. The reason that weed cover was not a significant explanatory of yield was that the management system classification accounted for most of the variance in yield that weed cover also explained, thus weed cover and management system were highly correlated. In partitioning the explained variance we estimated that in 2011, 73% of the variability was attributed to site (location of the field), and in 2013, 53% of the variability was attributed to the system. In 2011 the site effect was significant and in 2013, the system effect was highly significant. When the effect of year, site and system was evaluated (Fig. 11) for the effect on yield, year had the greatest effect with 53% of the variability followed by site at 41%, and system accounted for just 6% of the total model explained variation.
The average of the yields obtained from the sites converted to pounds per acre, and the net return plotted as a line with a bar for the high and low returns for each management system taken from the partial budget analyses (Fig. 12). Yield was significantly higher in 2013 for all systems. The High input system had the greatest yield followed by the Medium and Low systems, with the Organic system having the lowest yield. Net returns were highest on the Medium input system followed by the High and Organic systems. The Low input system was the least profitable and had a negative return, except for one site in 2013.

**Figure 8.** Percent wild blueberry cover in crop years 2011 and 2013.
Figure 9. Percent weed cover in crop years 2011 and 2013.

Figure 10. Weed cover vs wild blueberry yield for 2011 and 2013.
**Figure 11.** Effect of year, system and site on wild blueberry yield.

**Figure 12.** Systems study yield and profitability in crop years 2011 and 2013.
DISCUSSION and CONCLUSIONS

Soil organic matter was slightly lower in the Organic and Low systems and soil pH lower in the High and Medium systems likely because of the effect of burning on the former and use of sulfur on the latter. The higher leaf N in the Medium and High systems was reflective of the higher fertilizer inputs, but the P was actually higher in the Medium system because of their practice of fertilizing both years. The Organic sites were below the recommended standard values for N and P (Yarborough and Smagula, 2013) because of the inability to add fertilizer without increasing weed pressure which would result in a decrease in yields (Smagula et al., 2009). The Organic sites did have a higher level of leaf calcium which would improve fruit firmness. The boron levels which were added as part of a micronutrient package to improve pollen tube germination were much higher on the High input fields to support the much higher pollination levels (Table 1) on these fields.

Blueberry cover was only significantly different in the Low and Organic systems in 2011. That year had significant Septoria leaf spot disease, heat stress and lower precipitation which resulted in leaf drop in the Low input system and contributed to the low yield obtained that year (Fig, 12). Weed pressure is a significant factor in the productivity of wild blueberry fields (Yarborough, 2004). The High input sites had the lowest overall weed pressure consisting mostly of broadleaf weeds with the Low and Medium sites being equivalent. The Organic sites, with only some sulfur use and cutting weeds, had the greatest weed levels consisting mostly of grasses followed by broadleaf weeds (Fig. 9) which contributed to the consistently lower yields.

The reduction in yield as weed cover increased was evident in the regression lines for both crop years, but because of the large variability in production from the wild clones (Hepler and Yarborough, 1991) the effect of weed cover was not significant. In 2011, the site effect
accounted for more of the variation than in 2013. The site or location of the field was significant for yield in 2011. Poor pollination weather on the fields in 2011 for the Low and Organic sites located in the more western locations resulted in much lower yields on those sites. In 2013 the effect of system was highly significant and yields were higher overall, and with four sites per system sampled in 2013 vs. only two sites per system in 2011, there was an improved sampling of the systems effect within year. However, if the data are combined for the effect of year, then year had the greatest influence on yield followed by the site or location of the field with the system only having a minor effect (Fig. 11). So the weather conditions in any given year had the greatest effect on yield, followed by the location which is also related to weather as the fields in the western Knox and Lincoln Counties had different pollination and rainfall conditions compared to the eastern Hancock and Washington Counties. The fields also tended to be clustered with the Low and Organic sites being principally located in the western counties and the Medium and High in the eastern counties, because the fields with Medium and especially High inputs are located on the wild blueberry barrens in Washington County.

The yields of the High input system were the highest and were greater than the Medium input system for 2011 but not 2013. The net return using the yields and grower field prices and costs provided by the cooperators were highest for the Medium input sites. Therefore, the additional cost of additional inputs, principally the higher number of hives for pollination and the addition of irrigation, did not result in sufficient additional berry yields to recover the additional costs. The Medium input fields also had the least variability in net return as shown by the smallest range of values (Fig. 12). The Low input and Organic fields had the lowest yields but also had the highest costs since these fields had to be burned and hand-raked, and these are the two highest input costs of production (Yarborough, 2011). The returns for the Low input systems
were negative, meaning it cost more in input costs to the grower than it would have cost if the grower or processor were able to buy berries if they were available at $0.70 to $0.90 per pound paid by the processors. The Organic system was still profitable with the lowest yields as input costs were less and most of the fruit was direct marketed to the public as fresh or frozen, and the certified organic fruit could be sold at more than $4.00 per pound.

The study indicated there is diminishing return for inputs and the Medium input system provided the most profitable return. Although the Low input fields consistently had the lowest yields and least returns, the cost of leveling some of these sites may be prohibitive and most eventually will go out of production. The reason they are still managed is that there is not enough wild blueberry fruit to meet the demand and the processors need the fruit to support the freezer operations, and since processors also profit on the value added fruit, they will continue to manage these low input fields.

The issue of the clustering of the fields will be addressed as this study will be continued one more production cycle in 2014 to 2015 with a more even distribution of input systems over the study area. There was also an issue of getting adequate input data for the economic analysis of the Organic management with only two sites used for the analysis on both crop cycles (two cooperators did not provide input costs for the second cycle); we will have four sites for each input system in the third cycle of this study.

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