NORTHEAST SARE Sustainable Agriculture Research & Education	2011 USDA Northeast SARE Final Outreach Report "An Experiment on the Effectiveness of Irrigation and Cover Cropping to Produce Sustainable Hops in Maine"

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Report summary

The purpose of this project was to investigate the effect of irrigation and two mulching methods on yield and net revenue of hops. We conducted a two-factor experiment to examine the impact of irrigation (irrigated or not) and cover between plants (summer alfalfa or straw), using two and three yield old Nugget, Cascade, Centennial, and Willamette hops. Drip irrigation was established on half the rows and either straw or summer alfalfa was established in a 1 meter strip surrounding the hops hills. Wet hops mass, labor, and all costs were measured in order to determine both yield and cost-effectiveness of the four approaches. Soil samples were also taken. Even in a growing season with 9" more rain than average, the yield and net revenue benefits of drip irrigation were unequivocal. Three-year old Nugget plants produced over 3 times the yield as non-irrigated plants, resulting in a revenue increase of $1,610 per acre. We strongly recommend other farms utilize drip irrigation. Summer alfalfa did have, in some but not all cases, a measurable and statistically significant effect of increasing yield and soil nitrates. However, given the extra cost of planting summer alfalfa, plus potential competition with hops growth, straw is more favorable as a summer mulch.

1. Farm profile
Aroostook Hops, LLC began growing hops in 2009, incorporated in 2010, and by 2011 had an established 1-acre hops farm in Westfield, northern Maine, in Aroostook County. We are a husband (Jason Johnston) and wife (Krista Delahunty) team who has been growing hops for Northeast brewers using organic methods. We currently grow Nugget, Cascade, Willamette, and Centennial varieties. In 2012, we are planning a 3-acre expansion of our hopyard to increase our existing production of Cascade and Centennial, and also to add a new variety - Mount Hood. We have presold our first two years' crop with little marketing effort to several Northeast craft brewers or brewpubs.

2. Participants
Our technical advisor is Steven Johnson, Ph.D., Crops Specialist and Extension Professor for University of Maine cooperative extension. Dr. Johnson has a breadth of experience with crops research of more typical northern Maine crops, e.g. potatoes. Furthermore, he has experience with hops research and outreach in the

Northwest. Dr. Johnson has made several recommendations that have improved our SARE application, and has been an invaluable resource as we continued to explore methods to improve yield and weed control.

3. Goal
After preliminary research and on-farm trials using green manures, composted cow manure, and tilling practices, we sought a Northeast SARE to examine the effectiveness of cover cropping methods and irrigation on increasing yield and decreasing labor. We conducted a two-factor experiment to examine the impact of irrigation (irrigated or not) and cover between plants (alfalfa or straw) on yield and net revenue. We measured hop yield in four common commercial varieties (Nugget, Centennial, Cascade, and Willamette) and three planting ages (1, 2 and 3-year old plants). We also conducted soil testing in each treatment/age/variety category to investigate the effect on soil quality of using summer alfalfa as a cover crop. Our goal was to make recommendations to small-scale hops farmers about the cost-effectiveness of investing in irrigation and cover cropping.

4. Project activities
We provided a standard set of growing conditions, as follows. We have established 1.5 m wide rows to maintain reduced competition for hops roots and rhizomes; we maintain this by shallow tilling several times per season. We continued to till one strip on either side of the row, but stay 25 cm away from the row center to avoid tilling the current year's growth. We had supplemented all hops rows with composted cow manure the previous year (top-dressed in spring, 2010 with 6 cm deep by 1 m wide and tilled during autumn, 2010). In spring, 2011 we added 10 lb. bloodmeal per 1000 sq. ft. to increase nitrogen (based on low soil N in Fall, 2010). We also added lime at a rate of 30 lbs. per 1,000 sq. feet. The between-row space (3 m) had previously consisted of grass and weeds that we controlled by mowing. We had this tilled in early spring 2011, and planted with a mix of perennial leguminous and flowering plants (white clover, buckwheat, alfalfa) to increase soil nitrogen, reduce compaction, and attract beneficial insect predators. Hops bines were strung in mid to late May using coir twine on 15' (above ground) trellising consisting of 4X4" center posts, 6X6" end posts at an angle, and 3/8" aircraft cable.

We surveyed all plants weekly for insects, and planned to use manual methods to remove them unless an infestation required us to use an organic-approved insecticide. During 2009, we did not have problems with aphids or spider mites, but we did have a moderate problem with a Lepidoptera larvae, likely *Polygonia interrogationis,* which we controlled by hand picking. This year (2011) we had the caterpillars return at the beginning of July. We decided that with the numbers we observed, hand picking was not a feasible control method, and sprayed Thuricide (a *Bacillus thuringiensis* product) once weekly for the month of July, which we found to be a very effective control.

We also monitored for other problems, especially powdery and downy mildews, and consulted with our technical advisor, Dr. Steven Johnson, and the Northeast Hops

Alliance technical advisor, Steve Miller, for advice. In late August just prior to hops harvest, we experienced downy mildew outbreak, observed by browning of cones and clusters of cones with stunted development. We first noted it in our Centennial hops, but it quickly spread to all varieties and impacted Nugget the most, perhaps since it was later to mature and pick and thus had longer exposure time to the pathogen. We did spray Serenade ASO fungicide upon identification of the downy mildew (Aug 19th), but did not repeat spray since we were so close to harvest. We acted as quickly as possible to harvest, but still had a significant impact on our hops and anticipate that management of downy mildew will be a challenge for us in 2012 as it will likely return. For hops yield measurement purposes reported here, we included all cones on a bine, but culled browned cones before drying and packaging for sale of our hops.

Aside from the standard growing conditions described above, we manipulated two factors that we anticipated to have the greatest impact on increasing yield or reducing labor – irrigation and weed cover. We used two cover methods to examine weed suppression effectiveness within the 90 cm row center: straw and summer alfalfa. Straw was applied in the space between plants, but not right up to the plant so as not to promote mold or fungal growth. Straw that was used for winter mulching (imperative to avoid winterkill) was removed from the crown in early spring, and additional straw was added to achieve 8 cm of straw. Summer alfalfa was planted as the other cover. We planted in mid-May, in 1 m wide strips around the hops plants, except for the 10 cm around the hops crown. We came to decide upon summer alfalfa because we were looking for a plant that would act as a nitrogen fixer, grow to a moderate height to not outcompete bine growth, and also be easily winterkilled in order to not become invasive around the hops crowns where tilling is not possible. We sought an annual crop because other hops farmers we communicated with had reported that the fibrous roots of clover reduced hops yield due to competition. During 2009 we experimented with cowpeas and found that they were a fairly effective weed competitor if planted densely. We had planned to use this same cover crop for 2010, but were concerned that cowpeas may not be hardy enough to withstand a cool spring despite our 2009 success with them. Thus, we settled on summer alfalfa for previously mentioned reasons and also because it grows long taproots which aids to reduce soil compaction.

Irrigation was the second manipulated factor. Alternating rows were irrigated or non-irrigated by a drip emitter irrigation system, purchased from Allens Seed (Exeter, RI). Our system originated at the external faucet from our garage (3/4" diameter plumbing), which had a hose thread watering timer (9001D, DIG Irrigation Products, Vista, CA) that then connected to a ¾" garden hose. The garden hose ran down to our hopyard, where it hooked in to a 1" screen filter using an adapter and a 2" schedule 80 nipple. From the filter, a 1" 12 psi/2-20 gpm pressure regulator was connected, followed by a 0-30 psi pressure gauge mounted to a stake driven in the ground. A 180' Toro flat tube 1" header line ran from the pressure gauge perpendicular to the hops rows in front of the first post for each row. From the header line, a shut-off valve connected 15 mil T-tape which was laid close to the hops crowns along the length of the row (1 x 250', 4 x 200', 1 x 150', 1 x50', see Hopyard Plot) and ended a foot past the last crown, where end sleeves fitted over folded T-tape completed the line. Irrigation was conducted as needed, i.e. every day it did not rain. We found that we could run our system of seven lines without losing pressure at the end, though it was designed to shut off individual lines in order to alternate watering, if needed. Running the system for 3-4 hours in the morning was sufficient to completely soak the ground near the crowns on dry days. If we had not received a soaking precipitation for two to three days, we irrigated. This criterion resulted in little use of the system for the excessively rainy months of June and August 2011, but we used irrigation the most in July. We also measured weekly precipitation at our farm in order to assess the value of irrigation versus ambient precipitation, and obtained NWS precipitation records for comparison of monthly average rainfall and monthly totals from our local airport (Northern Maine Regional Airport, PQI) located in 11 miles away in Presque Isle, ME.

In order to assess the two factors we manipulated (irrigation and weed cover), we measured three main components: wet hop whole cone yield on established 2 and 3-year old plants (mass in grams), first year bine growth (height in cm) of spring-planted rhizomes, and soil macronutrient changes from autumn, 2010 to autumn, 2011. See HopyardPlot for a map of our varieties and treatments. The wet hop cone yield was taken for all four varieties (Willamette, Nugget, Cascade, and Centennial) and two plant ages (2-years and 3-years). We measured cone yield by measuring wet mass per bine for 10 bines. We systematically selected bines for a particular variety/treatment combination by either selecting every second bine when there were greater than 20 hops per age/treatment combination, or by selecting every bine for hops with less than 20 plants per group. We did not select bines that had been significantly defoliated, stunted by fungal growth, or were less than 3 m in height. The bine height of 1-year old plants was measured for Centennial in mid-August, since cone growth is not usually substantial until the second year. The soil samples were taken in early November 2011, post-harvest and after fall tilling was completed. Each of the experimental treatment categories had a separate sample taken, resulting in comprehensive soil data for 20 total treatment/variety/age combinations. Soil was obtained using a spade dug 3-4" deep in multiple areas over the section being measured, which was then placed in a clean plastic bucket and mixed well before a subsample of roughly less than a pint in volume was finally placed in the labeled sample box. Soil samples were analyzed by the Maine Soil Testing Service at the University of Maine (Orono, ME). The comprehensive test yielded the following soil data; pH, organic matter (%), nitrate-N (ppm), lime index, phosphorus (lb/A), potassium (lb/A), magnesium (lb/A), calcium (lb/A), sulfur (ppm), copper (ppm), iron (ppm), manganese (ppm), and zinc (ppm); soil microbial activity tests were also determine on two-samples.

We statistically analyzed wet mass as a dependent variable by conducting a two-factor ANOVA followed by Tukey's HSD test for specific pairwise comparisons. A separate model was conducted for each age/variety combination. Then, we used mean yield per plant, converted to predicted dry yield per plant and total input costs of labor, cover cropping, and irrigation by treatment to calculate mean gross net revenue per plant, using the average hops price for 2011 of $2.77/dry pound (summarized in Table 5). By measuring both yield and net revenue we were able to distinguish between simple yield versus yield corrected for labor, irrigation, and other inputs. In order to do this we kept track of all labor time per treatment (we recorded labor cost per row and divided by number of plants) and calculated per bine costs of labor as well as the costs associated with each treatment. Therefore, we are able to tell farmers (in particular) whether it is cost-effective to utilize irrigation and alfalfa versus straw.

5. Results

Hops wet mass

Irrigated hops plants produced significantly higher wet mass of cones for all varieties pooled (Figure 1), regardless of age (2-year plants, $p=0.0026$, 3-year plants, $p<0.0001$). For the four age X variety combinations for which we tested both factors results are summarized in Table 1 and Figures 1 and 2. All four had significantly ($p< 0.05$) higher wet mass with irrigation. Comparing irrigated to non-irrigated plants (Table 2) under straw cover, irrigated plants produce 0.88 to 3.04 times the yield of non-irrigated plants. The effect of cover type is more equivocal. Two-year Cascade plants had higher ($p=0.0201$) wet mass with alfalfa, whereas yield in two-year old Nugget had higher yield ($p=0.0038$) with straw cover. Yield did not differ by cover type in two-year old Centennial plants ($p=0.26$) or three-year Nugget ($p=0.093$). While we did not measure weeds, anecdotally we found weeds to be more dense in the alfalfa versus the straw rows.

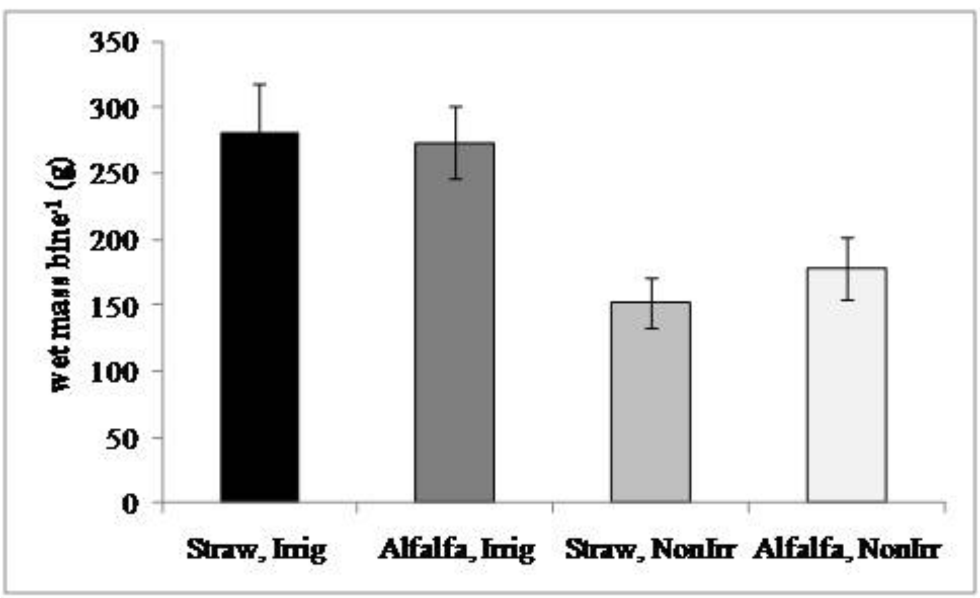

Figure 1: Irrigated plants produced more hops yield than non-irrigated plants for all varieties and ages combined.

Table 1: Hops wet mass per bine (grams, mean+/-SE) by irrigation and cover condition (number after variety indicates age of plant).

	Irrigated		Non-Irrigated	
	Straw	Alfalfa	Straw	Alfalfa
Cascade, 2	144.9 ± 34.4	353.2 ± 37	165.3 ± 28.7	132.7 ± 42.9
Centennial, 2	94.6 ± 12.6	123.9 ± 14.9	56.9 ± 14.9	59.4 ± 12.1
Nugget, 2	66 ± 10.3	36.5 ± 4.2	32.2 ± 10.3	12.8 ± 4.4
Nugget, 3	707.6 ± 48.1	431.4 ± 58.8	233.1 ± 44.8	348.2 ± 31

Table 2: Ratio of hops yield for irrigated versus nonirrigated plants (number after variety indicates age of plants).

Ratio of Irrig vs. NonIrr Yield	
Cascade, 2	0.88
Centennial, 2	1.66
Nugget, 2	2.05
Nugget, 3	3.04

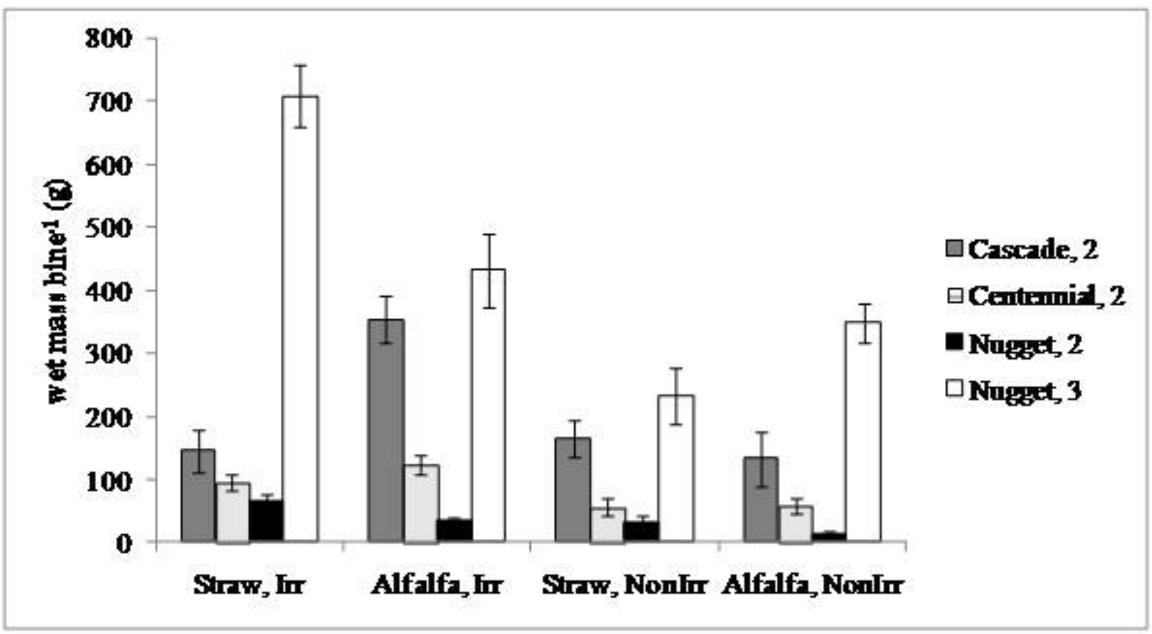

Figure 2: Wet hops mass yield per bine (grams, mean+/-SE) by irrigation and cover condition (Irr = irrigated, NonIrr = nonirrigated, number after hops variety indicates age of plant).

Growth of first year plantings

Late season bine height of first year centennial plants did not differ by cover or irrigation ($F_{3,14}$ = 1.71, p =0.21).

Soil tests

Raw soil test summaries are provided in Table A1, with one soil test result for each variety X age combination, irrigation, cover type, and soil history. While we only had one soil test result for the two different crop histories of our one-acre plot (previously potato versus previously lawn) from 2010 prior to our study, we calculated the difference between 2011 post-experiment versus 2010 soil testing (Table A2). Furthermore, we compared differences in macronutrients, organic matter, and pH for soil tests from within the hopyard portion that was previously planted in potato (Table 3). pH was higher in straw versus alfalfa (p=0.0345) and in irrigated over non-irrigated (p=0.0022). Both phosphorus and magnesium (pounds per acre) were higher in straw versus alfalfa (p=0.021 for phosphorus and p=0.02 for magnesium), and were higher in irrigated versus non-irrigated (p=0.0048 for phosphorus and p=0.0016 for magnesium). Conversely, nitrates were higher in alfalfa versus straw (p=0.0218), while there was no effect of irrigation on nitrates. There was no effect of cover or irrigation on either potassium pounds per acre or organic matter.

Table 3: Soil test results by irrigation and cover conditions for subset of hopyard previously planted in potatoes.

	pH	P	K	Mg	Organic	NO_3
Alfalfa, Irrig	6.2±0.04	41.3±1.8	620.3±63.5	243.3±10.1	4.13±0.32	6±0.71
Alfalfa, NonIrr	5.9±0.12	35±1.8	480.7±25.4	235.7±6.5	4.07±0.03	6.67±1.3
Straw, Irrig	6.5±0.12	50.6±4.4	587±164	344±26.5	4±0.21	4.33±1.5
Straw, NonIrr	6.05±0.1	39.1±1.7	643.5±89.2	219.5±14.5	3.78±0.11	3.25±0.25

6. Economics

We determined the economic benefit of the use of different cover and irrigation strategies by using the yield of our 3-year old Nugget plants. These hills are closest to reaching the full hops production potential. However, the yields reported here are not close to other commercially-produced hops which we attribute both to age, land use history, cultural practices, and yield loss due to downy mildew during 2011. We converted wet yield to dry yield by multiplying by .25, from our own estimates based on drying wet hops. We then determined yields per acre by multiplying the per plant yields by 1245 hills, which is the density of hills for our hopyard (again, less dense than other commercial operations). We calculated revenue per acre using the 2011 U.S.D.A National Agricultural Statistics Service average price for hops of 2.77/lb. Then, we calculated the annual cost of materials and labor (at $15/hour) for irrigation, straw, and alfalfa. Alfalfa costs were based on 19 lbs. of alfalfa seed, straw costs were based on 4 round bales. Irrigation costs were based on all material costs (Table 4) divided over 5 years, which may be expected to be the replacement time of the materials. Annual operating costs were based on electricity costs of pumping water, and assume no cost for water supply.

Table 4:

Irrigation Installation Costs	
21 X 200 feet rows (@ 10' row spacing, plants spaced 3.5")	
4200	l.f. driptape
$39.00	spigot timer
$82.00	head setup (regulator, filter, guage, etc.)
$232.00	mainline ($1/ft. * 220)
$184.39	drip tape
$2.10	endsleeves
$10.00	repair
$53.60	freight
$603.09	Total Installation costs/acre
$120.62	Ammortized cost (assumes 5 year life)
$48.07	annual operating costs (water free)
$168.68	total annual material cost/acre
$120	estim. Installation labor costs/acre
$24	annual cost (assume 5 year grub/dripline replacement)
$192.68	total ann. Material + labor cost/acre over 5 years

Table 5 summarizes the revenue increase from experimental treatments. Treatment net revenue assumes a minimum investment of straw with no irrigation. Thus, the other three treatments are compared to this baseline. Alfalfa may increase yield under no irrigation, but, the differential benefit of alfalfa with irrigation is negligible. However, it is clear that the combination of irrigation and straw yields both the highest hop yield as well as the highest revenue per acre. From an economic standpoint it is clear that the minimal investment in irrigation equipment produces substantial revenue increases. In our analysis, $200 in irrigation per acre yields $1,610 in increased revenue. Even if a larger expenditure of a dedicated well or irrigation pond were factored in, there would likely still be net revenue gains. (Note: this is not total net revenue. Instead we set non-irrigated, straw as zero and calculated the increase in revenue, while subtracting irrigation costs, for the other treatments. Individual farmers would need to figure their own breakeven point based on their other farm costs.)

Table 5: Revenue increase per experimental treatment, with non-irrigated straw as baseline for comparison.

	Non-Irrigated		Irrigated	
	Straw	Alfalfa	Straw	Alfalfa
Wet yield bine^{-1}	233.1	348.2	707.6	431.4
Wet yield plant^{-1}	466.2	696.4	1415.2	862.8
Wet yield (kg) acre^{-1}	580.2	866.7	1761.3	1073.8
Dry yield (kg) acre^{-1}	145.1	216.7	440.3	268.5
Gross revenue acre^{-1}	$885.82	$1,323.22	$2,689.01	$1,639.40
Irrigation install	$0.00	$0.00	$144.62	$144.62
Irrigation annual	$0.00	$0.00	$48.07	$48.07
Straw bales	$191.47	$0.00	$191.47	$10.00
Straw labor	$105.00	$0.00	$105.00	$0.00
Alfalfa seed	$0.00	$310.19	$0.00	$310.19
Alfalfa labor	$0.00	$45.00	$0.00	$45.00
Treatment costs acre^{-1}	$296.47	$355.19	$489.16	$557.87
Treatment revenue gain acre^{-1}	$0.00	$378.69	$1,610.50	$492.18

7. Conditions

Our one-acre hops plot has two different land use histories. About one-quarter of the area was previously lawn, while the remainder was previously used for potato/grain/broccoli rotation. The lawn portion had hops rows tilled into it and rhizomes were first planted in 2009. The agricultural portion was planted with rhizomes in 2010, and the year prior to that it was planted in potatoes by the adjacent farmer landowner. Thus, within a variety X age comparison of irrigation or cover factors, the hills have had the same land use history. However, when comparing across ages, for example, this is also comparing across different land use histories as well as fertilizer and other cultural inputs. We took one soil sample each to get a sense of the two different soil profiles to plan for spring, 2011. However, at that time we didn't even anticipate applying for a SARE grant. Thus, in making soil test comparisons between 2010 and 2011 we have much more detailed info for 2011.

The second site condition directly relevant to our field study was the exceptionally high amount of precipitation in our region during summer, 2011. Rainfall totals at Aroostook Hops for June, July, and August, were approximately 10, 2, and 9 cm above the average for Presque Isle, ME (Fig. 3). Thus, any beneficial effect of irrigation was expected to have been dampened or completely negated. Thus, our significantly higher yields for irrigated plants represent a conservative estimate of the benefits of irrigation. However, while the season was much higher than normal, there was still one period of relatively low rainfall. Between 10 July and 20 July only 0.94 cm (0.37 inches) of rain fell at Aroostook Hops. Thus, the benefit of irrigation is underscored by the importance of water during this final period of bine growth and flower production.

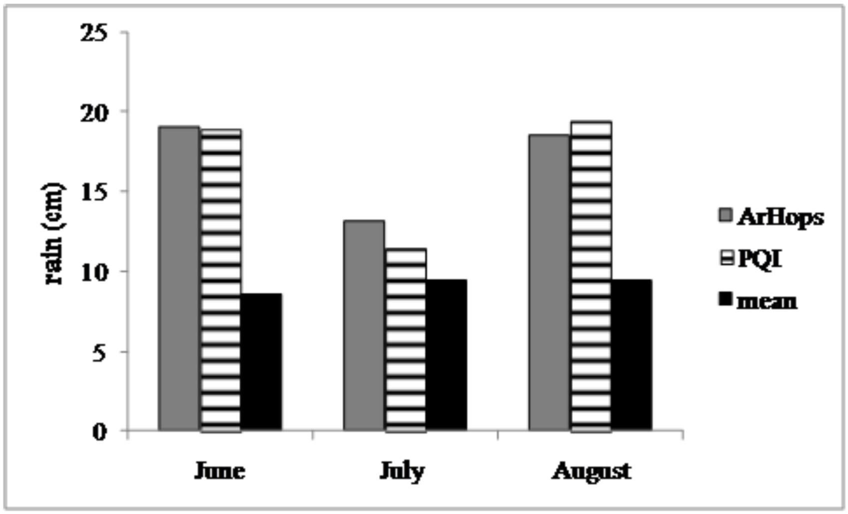

Figure 3: Summer precipitation at Aroostook Hops (ArHops) and the nearby airport (PQI) compared to averages for the month.

We also experienced a fairly significant and late (third week in August) infection by downy mildew on all of our bines. This certainly reduced yield. We measured mass of all cones, even though we separated commercially viable versus low grade cones.

8. Outreach

Since the outcomes of this experiment are highly relevant to hops farmers in the Northeast, we made the information available to others through all avenues available. We have added a page to our website (www.aroostookhops.com) about our current and future research and outcomes so that interested parties can read a short summary directly from the website and view pictures. In addition, we have made a .pdf version of this report available to download from this website page if anyone is interested in more detail. Secondly, we have made the document available to the Northeast Hops Alliance through their hops expert, Steve Miller, for inclusion in newsletters sent regularly to all members. We have also communicated our results with the hops research team at University of Vermont, Dr. Heather Darby and Rosalie Madden, so that they can share it at the annual UVM Extension Winter Hops Conference in March 2012. Fourth, we have shared our irrigation findings with John Harker, of the Maine Department of Agriculture (http://www.maine.gov/agriculture/mpd/irrigation/WaterUseReporting.shtml) so that they can make recommendations to other Maine hops growers about irrigation needs. As a result of our SARE and our website we occasionally receive emails about the logistics of setting up a hops yard, and we have been willing to share what we've learned. We've also been contacted by UVM Extension hops group about presenting at the 2012 meeting; while we couldn't attend this one, we hope to attend future events (if they are held on a weekend) to learn from others and to share what we've learned.

9. Adoption

We investigated two practices that may have impacted yield, weed growth, and nutrient levels. Based on our results we will continue to expand drip irrigation into all portions of our hops farm, since there was a clear effect on yield that resulted in 3 times greater yield in 3-year old Nugget bines. The cost of installing and maintaining irrigation is small and results in a substantial net increase in revenue per acre of $1,610. We will not continue to use alfalfa between plants, since it had only a small or equivocal increase in yield, and while it resulted in a statistically significant increase in soil nitrates, this was not enough to justify it use. Instead, we will use straw as a weed mulch and use bloodmeal to raise nitrogen levels to the levels needed by hops bines.

10. Assessment

While the use of irrigation is clearly supported, we have thought about the logistics of maintaining irrigation while reducing labor, given some potential conflict with other hops maintenance needs such as tilling, weed management, winter mulching, and grubbing. In this year, we removed the irrigation in the fall, in order to do fall tilling/weedwacking to reduce established weedy plants. Removing irrigation is labor intensive, especially if they are entangled with weeds. Farmers should consider the best way to install irrigation in their hopyard, while considering multi-year integrated pest management plans, especially for weed control.

Straw was not an overly effective weed mulch. While not quantified, this was especially evident in the area of our hopyard that was formerly lawn. Thus, the most important thing having a good hopyard (without using herbicides) is maintaining a relatively weed-free plot from the start. Once rhizomes are established it is labor intensive to manage weeds, and difficult to remove weeds from close to the established rhizome. Understanding the best way to establish and maintain a low-weed hopyard is the next step that northeast organic hops farmers should collectively consider.

Appendix.

Figure A1: Hopyard plot at Aroostook Hops, Westfield, ME (Ct = Centennial)

Row #	**13**	**12**	**11**	**10**	**9**	**8**	**7**	**6**	**5**	**4**	**3**	**2**	**1**
Growth Year	2	2	2	2	2	2	3	3	2	3	3	3	3
Cover Method	A	S	A	S	A	S	A	S	mix	A	S	A	S
Irrigation	Y	N	N	Y	Y	N	N	Y	Y	N	Y	Y	
# hills	71	71	57	57	57	57	14	14	43	57	57	57	57

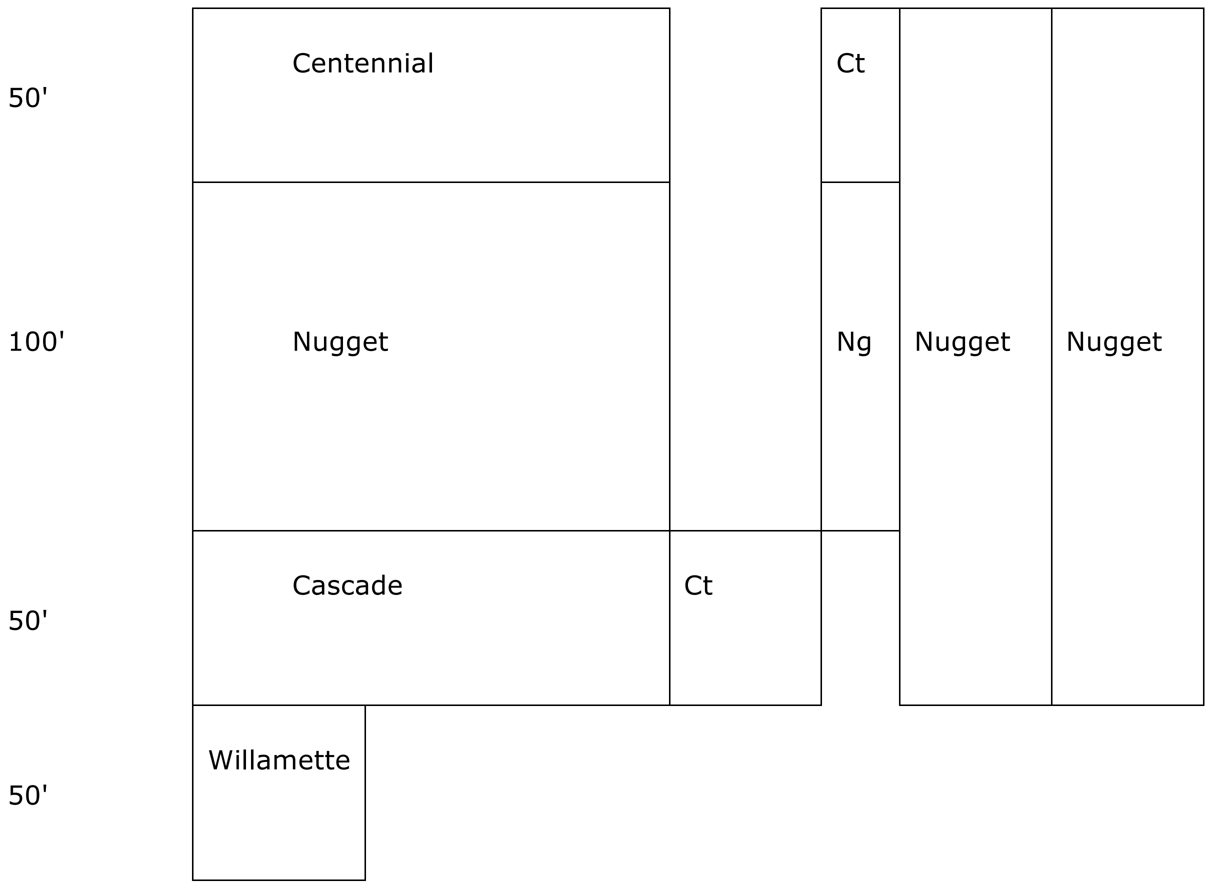

Table A1: Soil test results by cover (A=alfalfa, S=straw), irrigation, soil history (Gr=grass, Po=potatoes), variety (N=Nugget, CT=Centennial, W=Willamette, CA=Cascade) and age of plants (in years).

Cover	Irrig	SoilHist	Variety	Age	pH	Lime2	Plbs	Klbs	Mglbs	Calbs	CEC	Ksat	MgSat	CaSat	Acid	Org	Sulf	Copp	Iron	Mn	Zn	NO_3	NH_4
A	Irrig	Gr	N	3	6.9	6.37	33.5	642	428	5421	11.3	7.2	15.5	77.3	0	6.3	12	0.69	4.8	7	0.7	8	4
S	Irrig	Gr	CT	3	6.9	6.28	51	920	347	5187	11	10.7	13	76.3	0	5.9	9	0.6	4.7	8.9	0.9	3	5
S	Irrig	Gr	N	3	6.5	6.12	30.8	843	308	3706	9.3	11.5	13.5	74.9	0	5.3	11	0.87	5.9	7	0.7	3	3
A	Non	Gr	CT	3	6.8	6.31	39.2	763	375	4883	10.9	8.9	14	77.1	0	6.2	11	0.6	4.8	7.6	0.9	6	4
A	Non	Gr	N	3	6.4	6.09	29.3	588	327	3268	9.1	8.2	14.7	77.1	0	5.4	10	0.78	5.7	5.6	0.7	3	3
S	Non	Gr	N	3	7.2	0	18.1	484	484	13231	12	5.1	16.5	78.4	0	6.1	9	0.44	5.2	14.3	0.7	4	2
A	Irrig	Po	W	2	6.3	5.99	41.7	608	256	3019	8.4	9.2	12.4	78.4	0	4.9	10	1.07	5.7	6	0.9	6	4
A	Irrig	Po	CA	2	6.2	6.01	44.5	802	257	2845	7.7	13.3	13.7	73	0	4.4	11	1.12	5.1	6.2	1	7	4
A	Irrig	Po	N	2	6.1	5.99	36	515	214	2584	6.6	9.9	13.2	77	0	3.5	10	0.97	7.1	5.3	0.9	7	5
A	Irrig	Po	CT	2	6.2	6.01	42.8	556	246	2791	7.1	10	14.2	75.9	0	3.7	10	0.96	5.7	5.5	0.9	4	5
S	Irrig	Po	CA	2	6.5	6.16	48.8	614	351	3737	8.5	9.2	16.8	73.9	0	4.4	9	0.88	5.3	6.1	0.7	2	2
S	Irrig	Po	N	2	6.3	6.05	44.1	788	295	2546	7.3	13.7	16.4	69.9	0	3.7	8	1.17	7.2	4.6	0.9	7	2
S	Irrig	Po	CT	2	6.7	6.18	59	1169	386	3277	8.6	17.3	18.5	64.2	0	3.9	9	1.02	6.1	4.8	0.8	4	2
A	Non	Po	CA	2	6.1	5.92	35.4	496	248	2782	7.1	8.8	14.3	76.9	0	4	10	1.13	7.1	4.7	0.9	4	3
A	Non	Po	N	2	5.9	5.87	31.6	431	226	2103	6.6	8.2	13.9	77.9	0	4.1	10	1.03	7.7	4.7	0.9	8	3
A	Non	Po	CT	2	5.7	5.76	37.9	515	233	1890	8.3	8	11.6	56.7	23.7	4.1	13	1.53	11.2	4.9	1	8	4
S	Non	Po	W	2	5.9	5.86	42.2	612	243	2480	6.5	12	15.3	72.7	0	3.9	11	1.27	6	6.1	1	4	4
S	Non	Po	CA	2	6.3	6.07	41.6	900	246	2731	7.6	15	13.2	71.8	0	4	9	0.92	5.5	6.6	0.9	3	6
S	Non	Po	N	2	6.1	5.95	37	573	198	2167	6.6	10.9	12.1	77	0	3.5	8	0.94	5.7	4.1	0.7	3	1
S	Non	Po	CT	2	5.9	5.85	35.4	489	191	1830	5.9	10.5	13.2	76.3	0	3.7	9	1.22	6.9	3.6	0.9	3	2

Table A2: Soil test differences between 2011 and 2010 by cover (A=alfalfa, S=straw), irrigation, soil history (Gr=grass, Po=potatoes), variety (N=Nugget, CT=Centennial, W=Willamette, CA=Cascade) and age of plants (in years).

Cover	Irrig	SoilHist	Variet	Age	pH	Lime2	Plbs	Klbs	Mglbs	Calbs	CEC	Ksat	MgSat	CaSat	Acid	Org	Sulf	Copp	Iron	Mn	Zn	NO_3	NH_4
		Po (2010)			7	0	17.4	518	349	7628	11.1	5.9	13	81.1	0	6.6	9	0.56	5	9.6	14.9	6	3
		Gr (2010)			5.8	5.82	33	397	169	1896	7.3	6.9	9.5	64.2	19.4	3.4	16	1.39	7.2	3.8	2.7	1	1
A	Irrig	Gr	N	3	1.1	0.55	0.5	245	259	3525	4	0.3	6	13.1	-19.4	2.9	-4	-0.7	-2.4	3.2	-2	7	3
S	Irrig	Gr	CT	3	1.1	0.46	18	523	178	3291	3.7	3.8	3.5	12.1	-19.4	2.5	-7	-0.79	-2.5	5.1	-1.8	2	4
S	Irrig	Gr	N	3	0.7	0.3	-2.2	446	139	1810	2	4.6	4	10.7	-19.4	1.9	-5	-0.52	-1.3	3.2	-2	2	2
A	Non	Gr	CT	3	1	0.49	6.2	366	206	2987	3.6	2	4.5	12.9	-19.4	2.8	-5	-0.79	-2.4	3.8	-1.8	5	3
A	Non	Gr	N	3	0.6	0.27	-3.7	191	158	1372	1.8	1.3	5.2	12.9	-19.4	2	-6	-0.61	-1.5	1.8	-2	2	2
S	Non	Gr	N	3	1.4	-5.82	-14.9	87	315	11335	4.7	-1.8	7	14.2	-19.4	2.7	-7	-0.95	-2	10.5	-2	3	1
A	Irrig	Po	W	2	-0.7	5.99	24.3	90	-93	-4609	-2.7	3.3	-0.6	-2.7	0	-1.7	1	0.51	0.7	-3.6	-14	0	1
A	Irrig	Po	CA	2	-0.8	6.01	27.1	284	-92	-4783	-3.4	7.4	0.7	-8.1	0	-2.2	2	0.56	0.1	-3.4	-13.9	1	1
A	Irrig	Po	N	2	-0.9	5.99	18.6	-3	-135	-5044	-4.5	4	0.2	-4.1	0	-3.1	1	0.41	2.1	-4.3	-14	1	2
A	Irrig	Po	CT	2	-0.8	6.01	25.4	38	-103	-4837	-4	4.1	1.2	-5.2	0	-2.9	1	0.4	0.7	-4.1	-14	-2	2
S	Irrig	Po	CA	2	-0.5	6.16	31.4	96	2	-3891	-2.6	3.3	3.8	-7.2	0	-2.2	0	0.32	0.3	-3.5	-14.2	-4	-1
S	Irrig	Po	N	2	-0.7	6.05	26.7	270	-54	-5082	-3.8	7.8	3.4	-11.2	0	-2.9	-1	0.61	2.2	-5	-14	1	-1
S	Irrig	Po	CT	2	-0.3	6.18	41.6	651	37	-4351	-2.5	11.4	5.5	-16.9	0	-2.7	0	0.46	1.1	-4.8	-14.1	-2	-1
A	Non	Po	CA	2	-0.9	5.92	18	-22	-101	-4846	-4	2.9	1.3	-4.2	0	-2.6	1	0.57	2.1	-4.9	-14	-2	0
A	Non	Po	N	2	-1.1	5.87	14.2	-87	-123	-5525	-4.5	2.3	0.9	-3.2	0	-2.5	1	0.47	2.7	-4.9	-14	2	0
A	Non	Po	CT	2	-1.3	5.76	20.5	-3	-116	-5738	-2.8	2.1	-1.4	-24.4	23.7	-2.5	4	0.97	6.2	-4.7	-13.9	2	1
S	Non	Po	W	2	-1.1	5.86	24.8	94	-106	-5148	-4.6	6.1	2.3	-8.4	0	-2.7	2	0.71	1	-3.5	-13.9	-2	1
S	Non	Po	CA	2	-0.7	6.07	24.2	382	-103	-4897	-3.5	9.1	0.2	-9.3	0	-2.6	0	0.36	0.5	-3	-14	-3	3
S	Non	Po	N	2	-0.9	5.95	19.6	55	-151	-5461	-4.5	5	-0.9	-4.1	0	-3.1	-1	0.38	0.7	-5.5	-14.2	-3	-2
S	Non	Po	CT	2	-1.1	5.85	18	-29	-158	-5798	-5.2	4.6	0.2	-4.8	0	-2.9	0	0.66	1.9	-6	-14	-3	-1