NORTHEAST SARE Sustainable Agriculture Research & Education	2014 USDA Northeast SARE Final Report: FNE 12-742 "Evaluating cover cropping and non-herbicide weed management strategies in hops, a perennial crop"

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Summary

In order to investigate the best weed management practices in small-scale, organic Northeast hop production, we conducted an experiment that addressed the following two questions: 1) what is the best non-herbicide cultural practice to control weeds (none, straw, tilling), and 2) is a weed-suppressing cover crop effective in reducing weed populations and is it worth delaying hops planting by a year. In 2012, we established a new 3-acre hopyard with about half the area planted in four varieties: Cascade, Centennial, Mount Hood, and Willamette. We implemented three cultural approaches to weed management: straw mulch, tilling, and nothing (control). The other half of the hopyard was planted in a weed-suppressing cover crop of rapeseed, and a smaller area was left fallow to serve as a control. In the spring of 2013, the overwintered rapeseed was tilled in to allow for hop rhizomes to be planted in either previously rapeseed or previously fallow plots. We measured hop plant linear growth in both years, as well as cone mass for the 2-year old hop plants. To assess weed growth, we measured 0.5 m^2 quadrats in which i) all stems were cut and massed for total weed biomass, and ii) percent cover for each weed species were measured. We found that rapeseed did not have a measurable positive effect on plant growth or weed suppression, and that there was little evidence that waiting a year to plant hops was beneficial. Straw cover showed better measures of weed suppression, but hops wet mass in two-year old plants was actually higher in the tilled plots. Sorrel was the predominant weed by coverage in one-year old plots, while goldenrod was predominant in two-year old plots. Weed management should address persistence and establishment of perennial weeds like goldenrod, which can be propagated by rhizomes and seed. The best practice may involve a mixed approach that involves more intensive springtime tilling and weed management, followed by summer straw mulching.

Introduction

Aroostook Hops is a 4-acre, 6-year old established hop farm in northern Maine, owned by Jason Johnston and Krista Delahunty, a husband and wife team. We grow using organic methods, and are pursuing organic certification for 2014. We sell whole cone hops and rhizomes, and the varieties that we grow include Nugget, Willamette, Mount Hood, Centennial, and Cascade.

Our technical advisor is Marcus Flewelling, crop specialist with Crop Production Services in Mapleton, Maine. Marcus continues to support us with product recommendations, IPM management, and visits on-site to aid us where needed. We also regularly consult with Dr. Heather Darby at The University of Vermont's Hops Project for advice and guidance.

At this time of a robust revival of the hops industry in the Northeast (with considerable desire for non-herbicide production), it is important that new hops farmers have the best information to establish and maintain a good weed management plan. While there is increasing demand for local and/or organic hops production, there is little information on non-herbicide weed control.

A primary challenge for the small-scale and organic northeast hops grower is weed control. Little attention has been paid to establishing a hopyard from fallow, cultivated, or other land, that may have a substantial weed seed bank. Historically, practices mainly born out of Pacific Northwest hopyards emphasize routine mechanical cultivation and herbicide application to control weeds. Additionally, some consideration has more recently been given to cover cropping as a weed suppression method. A comprehensive review on the topic of weed management challenges in organic hopyards was included in a recent review article (Turner *et al.*, 2011).

With the Northeast hops industry in an early and robust state of expansion, best practices for establishment of a hopyard with a sound weed management strategy is paramount to maximizing production and profitability, especially when farmers are responding to market demands for non-pesticide produced hops. Perennial hops have unique weed management challenges versus annual crops. While tilling may be used to control weeds, too much tilling may reduce proper rhizome and root growth and may negatively impact soil health. Thus, establishment of hops in a relatively weed free soil is much more important than in annual crops given that the soil cannot be completely worked for the life of the hops (15+) years.

A considerable body of research on hops has been conducted in association with production in Europe and the Pacific Northwest, in particular. This research has stressed the value of green manures between rows for both nutrients and soil physical characteristics, the use of cover crops for pest control, and the tradeoffs between mechanical, chemical, and cover crop methods to control weeds. While much of this knowledge is directly applicable to improving hop yield at small Northeast hops farms like Aroostook Hops, much remains unknown about how these practices would impact profitability and sustainability of small-scale hops farms in the Northeast for several reasons. First, the Northeast has a later spring, and much higher precipitation and humidity than the arid regions where most hops are produced in the U.S.; this may impact the emergence, growth rates, and composition of weed species. Second, small-scale hops farmers may not be able to bear the expense of cultivation or herbicide application systems used on larger farms. Third, much of this research has been conducted in conventional systems, which utilize a high input of insecticides, fungicides, herbicides, fertilizers, and mechanical cultivation. With increasing demand and value of organic hops production, we need to understand how organic methods impact yield and labor input to determine if these methods are economically viable.

Literature on weed control in other crops may be relevant and applicable to hops production. In terms of establishing a weed-controlled hopyard from a previously fallow field, one approach that has greatly reduced weed populations in potatoes and soybeans is a one-year cover crop of allelopathic crops such as rapeseed (*Brassica napus*). Rapeseed produces high amounts of glucosinolates, which break down into isothiocyanates and other compounds that inhibit germination and root and shoot growth in adjacent seeds and plants (Petersen et. al., 2001). In potatoes (Boydston and Hang, 1995), using rapeseed as a fall planted cover crop reduced weeds 70-90%, and in soybeans (Krishnan et al., 1998) using rapeseed as green mulch reduced weeds by 40% and 49%, at four and six weeks after emergence, respectively. While cover cropping and tilling prior to planting potatoes increased potato yield, rapeseed as green manure actually reduced soybean yield. Thus, using rapeseed as a cover that is incorporated prior to planting rhizomes may work to substantially reduce weed growth. Such a weed-suppressing management strategy could be very useful for hops, as long as it was paired with a sound management strategy to control weeds during the 15+ year subsequent life of the perennial plantings.

We have used green manures in our hopyard with moderate to little success in weed suppression. In 2010, cowpeas were fairly effective outcompeting weeds, but in 2011, summer alfalfa established too slowly to be an effective weed suppressor. Polyethylene row cover has also been used to control weeds by some hops farmers in the Northeast and Ontario. There are a number of tradeoffs to use of row cover, which would need to be considered by hops farmers. These include: 1) cost of non-biodegradable polyethylene versus more expensive biodegradable row cover, 2) logistics of application just after shoot emergence, but, before weeds begin robust spring growth, 3) effects on water and nutrient management, and 4) the need for drip irrigation to be in place. However, straw has been demonstrated to be an effective cover, in one study controlling 83% and 95% of weeds (Law et. al., 2006). Finally, tilling between plants is part of the weed management strategy used (along with herbicides) in large farms in the Pacific Northwest. Each of these strategies come with different tradeoffs, and what remains to be determined for sustainable Northeast hops production is what approach best maximizes profit while maintaining soil and plant health. The tradeoffs for each practice are as follows: one year of cover crop before planting (an extra year on top of 3 years to establish plants and business in a rapidly expanding Northeast market), leaving intrarow fallow (significant loss in plant growth, age to maturity and yield), straw mulch (increased labor/materials cost), and tilling (significantly increased labor). Again, while others have optimized inputs versus yield by using a combination of mechanical methods and herbicides, these are generally large-scale, non-organic producers.

Our experimental methods addressed the following two questions: 1) what is the best non-herbicide cultural practice to control weeds (none, straw, tilling), and 2) is a weed-suppressing cover crop effective in reducing weed populations and is it worth delaying hops planting by a year.

Objectives/Performance target

For the past two years, we have conducted an experiment to investigate the best approach to non-herbicide weed management in a newly established Northeast hopyard. In 2012, we established a new 3-acre hopyard with four varieties: Cascade, Centennial, Mount Hood, and Willamette. We have implemented three cultural approaches to weed management: straw mulch, tilling, and nothing (control). We are also investigating whether planting a weed-suppressing cover crop (rapeseed) is effective enough in suppressing weed emergence to justify delaying planting rhizomes for the first year.

Methods

In 2012, we established a new 3-acre hopyard in addition to our existing 1-acre yard. After logs were peeled and treated, holes were dug, and poles were set, the first rows of hops rhizomes were planted. The field had been disced multiple times the previous season, and we amended the soil within hops rows with addition of lime to increase pH, as well as ProBooster (10-0-0) fertilizer (North Country Organics, VT) to increase nitrogen levels.

Our hopyard design consists of 1 m wide rows spaced 3 m on center, with hops rhizomes planted every 3.5’ within a row. The center poles are 4” wide and 18’ above ground, with 4’ in the ground. Perimeter poles are 6” wide and angled outward, with 5/16” aircraft cable used to attach to ground anchors. The hopyard consists of 41 rows, each 250’ long. Heavier 5/16” aircraft cable was used to construct trellis support perpendicular to the rows, while 3/8” cable was run on top of this along the length of a row. Once hops were about 3’ long, they were strung on coir twine attached to the 3/8” row cable using a Rustgo lift and then anchored into the ground with w-clips.

In 2012, we worked to establish the new hopyard as soon as the ground allowed in the spring, and once completed we planted over half of the hopyard in rhizomes by mid-June. The varieties we planted were Cascade, Centennial, Willamette, and Mount Hood, which have different growth characteristics and represent common varieties grown within the Northeast. We sourced many of the rhizomes we planted through a co-operative purchase coordinated by the Northeast Hops Alliance (NeHA). The Cascade rhizomes were problematic, with our own 10% success rate on par with the overall report of widespread failure. This resulted in low numbers of Cascade in some of our experimental groups.

In the part of the hopyard not planted in hop rhizomes in 2012, we left some rows of each variety fallow to serve as a control in comparisons, and the rest was planted mid-season (start of July) in dwarf Essex rapeseed (*Brassica napus*) at a rate of about 10 lb/acre. The late planting allowed for the rapeseed to establish to full maturity without going to flower before fall, thus, it was overwintered and tilled in to the soil the following spring 2013, prior to year two of rhizome establishment. We also maintained an area of uncultivated land in the unplanted area of the hopyard to serve as a control in same-year comparisons.

For those rows planted with the four varieties of hops in 2012, we maintained two rows each in one of the three cultivation approaches: (1) straw mulch, (2) maintenance tilling, or (3) nothing (control). For the "straw mulch" treatments, straw was placed at least 5 cm thick within rows and between plants to suppress weeds, up to a few inches away from the new shoots, as well as in front and behind the crown, leaving a circle of unmulched area around the crown of the plant. For the "maintenance tilling" group, tilling between the plants was done three times per growing season, using a Troy-Bilt Pony rototiller, which was maneuvered in a figure-eight pattern back and forth along a row. Tilling at the edge of the row (right up to the crown) was done using a 60" tilling attachment on our tractor. The control row had no cultivation of any sort after rhizome planting right through the full growing season.

In spring of 2013, we tilled in the over-wintered rapeseed, again amended the soil with lime and fertilizer based on soil tests from 2012, and planted the remaining half of the hopyard with rhizomes by late May. The new rhizomes were planted in either: (1) previously rapeseed, or (2) previously fallow, and were straw mulched between plants within rows. We had decided to use this approach prior to beginning the experiment because we wanted to apply the same cultivation approach across all rows that were newly planted in 2013, and straw mulch was our current best-practice at that time. The rows that had been maintained in each of the three cultivation approaches in 2012 were continued in the same approach again in 2013, to allow for one year old versus two year old plant comparisons.

We measured variables within two general categories: hop plant growth and weed growth. To assess plant growth, we measured linear bine growth (from soil to apical tip) for both 1 and 2-year old plants, as well as wet mass of hop cones in 2-year old plants. To assess weed growth, we measured 0.5 m^2 quadrats (n=10 per group), in which i) all stems were cut and massed for total weed biomass, and ii) percent cover for each weed species were measured. In consultation with University of Maine at Presque Isle professor of biology Dr. Robert Pinette, we created a table to record the common weed species found, which included; sorrel (*Rumex acetosa*), grass (family *Poaceae*), dandelion (genus *Taraxacum*), clover (genus *Trifolium*), low cudweed (*Gnaphalium uliginosum*), goldenrod (genus *Solidago*), common purslane (*Portulaca oleracea*), lambsquarters (*Chenopodium album*), wild strawberry (*Fragaria vesca*), corn spurrey (*Spergula arvensis*), wild radish (*Raphanus raphanistrum*), evening primrose (genus

Oenothera), fireweed (*Epilobium angustifolium*), vetch (genus *Vicia*), "woody" (usually willow, genus *Salix*, or red osier dogwood, *Cornus sericea*), pigweed (genus *Amaranthus*), and "other". The weed growth was measured for both 2012 (three cultivation methods by each of the four varieties) and 2013 (year 2: three cultivation approaches, and year 1: plants in previously fallow or cover-cropped for each of the four varieties).

Soil biology was tested in the second year (2013) to assess microbial activity differences between fallow, previously fallow/straw, and previously rapeseed/straw plots. Soil samples were taken from multiple sites within each plot, mixed together, and a subsample was then sent for analysis to the University of Maine Analytical Laboratory and Soil Testing Service (Orono, ME). Standard soil test results with recommendations were returned, including soil pH, N, P, K, calcium, magnesium, sulfur, and various micronutrients. In addition, we added a test for soil microbial biomass, done at U. Maine based on the Haney-Brinton CO_2-burst method. (http://anlab.umesci.maine.edu/). However, since only one soil test per treatment was conducted, our soil biology results are qualitative only.

To assess question one, we compared straw mulched, maintenance tilled, and control (nothing) in one year and two year hops. To assess question two, we compared previously fallow versus previously cover cropped plots' one–year old hops plant linear growth and weed biomass and composition. We compared hops planted after cover in 2013 with hops planted after fallow in 2012, as well as hops planted on fallow plots during 2013 to control for year effects. ANOVA with Tukey's tests were used to test significance of potential differences in plant linear growth and second-year hop cone mass, as well as weed mass and composition (percent cover). Statistical analyses were conducted using JMP software, version 8.

We also measured the time spent conducting all activities throughout each growing season, as well as all material costs. This allowed us to produce a standardized value for cost per acre by treatment in order to assess the economic tradeoff of each cultivation method employed.

Outcomes and Impacts

There were significant effects of weed management treatments on hop bine height, yield, weed percent coverage, composition, and wet mass. Among one-year old plants in 2012, bines were taller under straw mulch than either tilled or control treatments (Table 1). Among one-year old plants in 2013, there was no difference ($p = 0.64$) in bine height between plants in previously fallow compared to previously rapeseed plots (Table 2). Ignoring potential year effects and combining all treatments for one-year old plants (Fig. 1), bines were taller in previously rapeseed, previously fallow, and straw compared to both control and tilled plots. Among two-year old plants in 2013, bines were generally shorter in control plots, while straw and tilled plots were generally not significantly different (Table 3). Hops cone wet mass per trained bine was highest in Cascade versus all other varieties ($F_{1,121} = 11.6$, $p<0.0001$; by LSD) and tilled plots produced higher hops yield than straw and control plots when all varieties were pooled (Table 4).

Among one-year old plots, our results indicate that straw has the best influence on plant height and that the history (previously fallow or previously rapeseed) is equivocal (Tables 1 and 2). While there may be year effects that confound comparisons, the fact that straw in 2012 is not different than previously fallow or rapeseed (both then covered in straw) in 2013 (Fig. 1) suggests that straw on a one-year old plot is the key determinant. However, in second-year plots, bine height did not generally differ between straw and tilled treatments – which were both taller than control plots (Table 3). Futhermore, some plant competitors, e.g. goldenrod, were indicated to be more prevalent in straw versus tilled plots (Table 8). Hops cone wet mass, which is the best indicator of plant success for a grower, was highest in tilled compared to straw and control (Table 4).

Table 1: Hops plant average height (cm) for 1-year old plants in 2012.

	Variety				
Treatment	Pooled	Cascade	Centennial	Mt. Hood	Willamette
Control	61.6 b†	37.1 a	65.0 a	51.8 b	92.6 a
Straw	93.5 a	92.1 b	70.6 a	98.8 a	112.5 a
Tilled	55.8 b	--	28.5 b	59.6 ab	79.4 a

† Within columns, means followed by the same letter are not significantly different according to LSD (0.05).

Table 2: Hops plant average height (cm) for 1-year old plants in 2013.

	Variety				
Treatment	Var. Pooled	Cascade	Centennial	Mt. Hood	Willamette
PrevFallow	108.1	141.9	76.7	102.1	102.6
PrevRapeseed	114.3	132.1	121.92	103.6	98.7

Table 3: Hops plant average height (cm) for 2-year old plants in 2013.

	Variety				
Treatment	Var. Pooled	Cascade	Centennial	Mt. Hood	Willamette
Control	131.1 b†	192.8 b	63.2 b	161.8 a	100.3 b
Straw	197.4 a	222.1 b	100.8 a	276.6 a	187.5 ab
Tilled	229.2 a	332.5 a	88.4 ab	266.7 a	218.7 a

† Within columns, means followed by the same letter are not significantly different according to LSD (0.05).

Table 4: Hops cone wet mass (g) for two-year old plants in 2013.

	Variety				
Treatment	Var. Pooled	Cascade	Centennial	Mt. Hood	Willamette
Control	28.8 b†	99.0 ab	0	8.95	0.34
Straw	25.3 b	56.6 b	1.98	33.4	6.0
Tilled	94.2 a	271.7 ab	0.82	45.8	22.8

† Within columns, means followed by the same letter are not significantly different according to LSD (0.05).

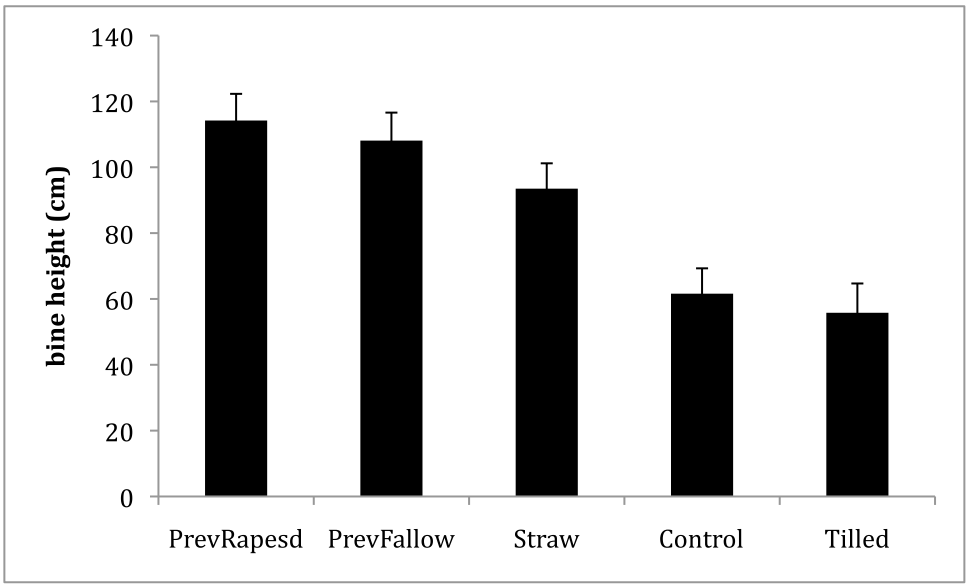

Fig. 1: Bine height (cm) of all varieties pooled in one-year old plots (from both 2012 and 2013).

The difference between one and two year old plots is likely due to the combination of weed suppression immediately surrounding the establishing plant, plant footprint, and competition for nutrients and water. Straw is the superior cover for weed suppression from a spatial coverage perspective because it can be applied right up to the growing bines, whereas tilling must maintain a distance of roughly 25 cm away from the growing stems. This likely contributes to year one patterns. However, by year two hops roots are better established and longer. Thus, they are better able to absorb water and nutrients generally and from a wider radius, and may also benefit more from tilling.

Weed wet mass in one-year old plots was lower for control, previously fallow, and previously rapeseed plots compared to straw and tilled plots for all varieties pooled (Table 5, Fig. 2), but patterns differed by variety. Weed wet mass was lowest for previously rapeseed plots in one of four varieties (Mount Hood plots). Weed wet mass among two-year old plants was generally lowest in tilled plots (Table 6, Fig. 3), and control plots had the highest weed wet mass among varieties pooled, Centennial, and Willamette plots. The percentage of weed plots that were mostly bare was highest ($F_{4,185} = 11.1$, $p<0.0001$; by LSD) for previously rapeseed (33.1%), previously fallow (30.7%), and straw (29.8%), than both control (17.5%) and tilled (9.8%) among one-year old plots. Among two-year old plots the percentage of plot mostly bare was highest in straw (43.1%), lower in tilled (25.0%), and lowest in control plots (7.7%), and all differed by LSD. The relative percent composition of weeds/cover in one-year old plots is summarized in Table 7 and Fig. 4. For seven of the cover types there were significant differences between treatments for type of weed, e.g. ruderal annuals like sorrel and cudweed are higher in tilled plots whereas perennials like goldenrod are higher in previously fallow. The relative percent composition of weeds/cover in two-year old plots is summarized in Table 8 and Fig. 5. Goldenrod was highest in control plots versus straw versus tilled, whereas sorrel was highest in tilled compared to both straw and control.

Table 5: Weed wet mass by hops variety and treatment for 1-year old plots.

	Variety				
Treatment	Var. Pooled	Cascade	Centennial	Mt. Hood	Willamette
Control	176.25 b†	137 b	167	112 bc	289 a
PrevFallow	171 b	101 b	336	133 bc	114 c
PrevRapesd	153.25 b	230 ab	183	61 c	139 bc
Straw	267 a	349 a	260	244 ab	215 ab
Tilled	291 a	--	287	298 a	288 a

† Within columns, means followed by the same letter are not significantly different according to LSD (0.05).

Table 6: Weed wet mass by hops variety and treatment for 2-year old plots.

	Variety				
Treatment	Var. Pooled	Cascade	Centennial	Mt. Hood	Willamette
Control	228.5 a†	262 a	215 a	236 a	201a
Straw	164 b	220 a	117 b	225 a	94 b
Tilled	105.25 c	91 b	83 b	112 b	135 ab

† Within columns, means followed by the same letter are not significantly different according to LSD (0.05).

Table 7: Weed percent cover by treatment for 1-year old plots.

	Treatment				
Weed	Control	PrevFallow	PrevRapesd	Straw	Tilled
Sorrel	42.7 ab†	32.1 b	44.1 ab	35.5 b	55.5 a
Low Cudweed	19.8 b	0.0 c	0.0 c	12.8 b	35.3 a
Bare	17.5 b	30.7 a	33.1 a	29.8 a	9.8 b
Goldenrod	12.9 b	36.1 a	5.9 b	12.1 b	5.7 b
Grass	2.5 ab	1.5 b	5.9 a	2.7 ab	1.3 b
Spurrey	2.1	0.0	1.5	0.5	1.0
Woody	1.4	0.7	0.6	1.6	1.2
Wild Radish	1.3	4.0	2.0	1.0	0.1
Strawberry	1.2	0.0	0.3	0.7	1.0
Other	1.1	3.2	3.6	2.9	1.5
Lambsquarter	1.0	0.0	0.3	2.2	0.7
Fireweed	0.3	1.3	0.0	0.3	0.7
Vetch	0.2	0.0	0.0	0.0	0.0
Pigweed	0.1 b	2.7 ab	7.6 a	0.0 b	0.0 b
Dandelion	0.0	0.0	0.4	0.0	0.0
Clover	0.0 b	1.4 ab	4.5 a	0.0 b	0.7 ab
Purslane	0.0	0.0	0.0	0.0	0.0
Ev. Primrose	0.0	0.8	0.0	0.0	0.0

† Within rows, means followed by the same letter are not significantly different according to LSD (0.05).

Table 8: Weed percent cover by treatment for 2-year old plots.

	Treatment		
Weed	Control	Straw	Tilled
Goldenrod	49.5 a†	34.4 b	11.5 c
Sorrel	15.2 b	15.7 b	36.3 a
Grass	14.4	7.0	8.8
Clover	13.2 a	2.3 b	7.0 ab
Bare	7.7 c	43.1 a	25.0 b
Other	4.5	4.1	7.3
Strawberry	4.4	2.3	3.0
Woody	2.0	0.0	0.9
Lambsquarter	1.7	0.0	0.2
Vetch	1.6	1.0	0.1
Dandelion	1.0	1.3	0.6
Low Cudweed	0.8	2.0	0.3
Pigweed	0.6	0.0	0.1
Purslane	0.3	0.0	0.1
Fireweed	0.3	0.0	0.3
Spurrey	0.0	0.0	0.3
Wild Radish	0.0	0.0	0.0
Ev. Primrose	0.0	0.5	0.6

† Within rows, means followed by the same letter are not significantly different according to LSD (0.05).

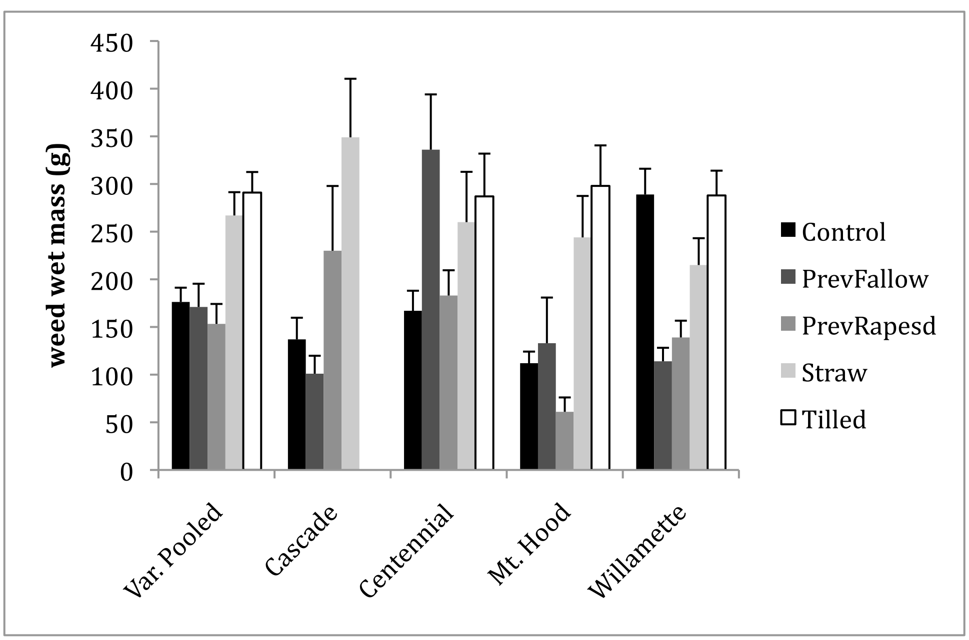

Figure 2: One-year post-establishment weed wet mass by treatment and hops variety.

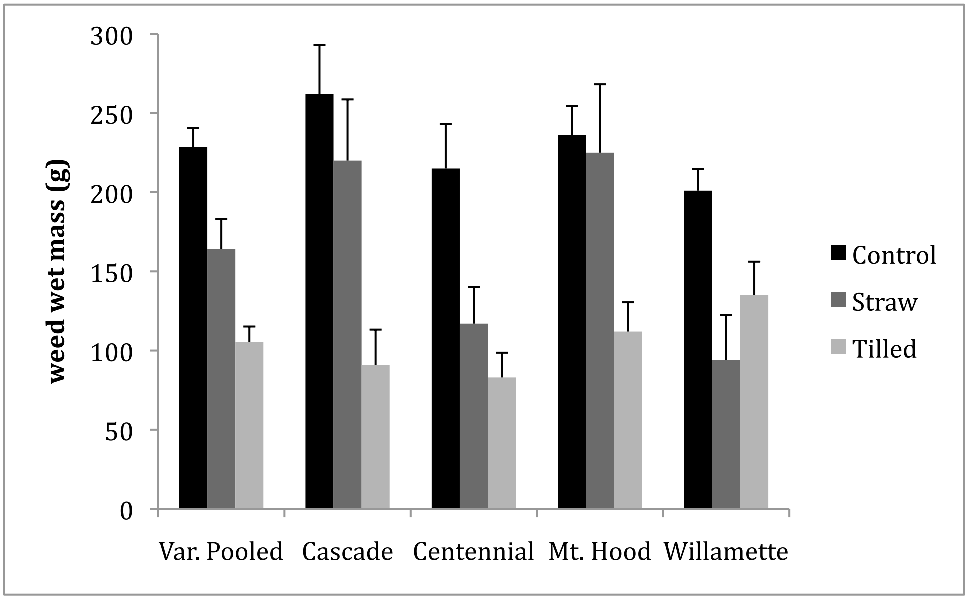

Figure 3: Two-year post-establishment weed wet mass by treatment and hops variety.

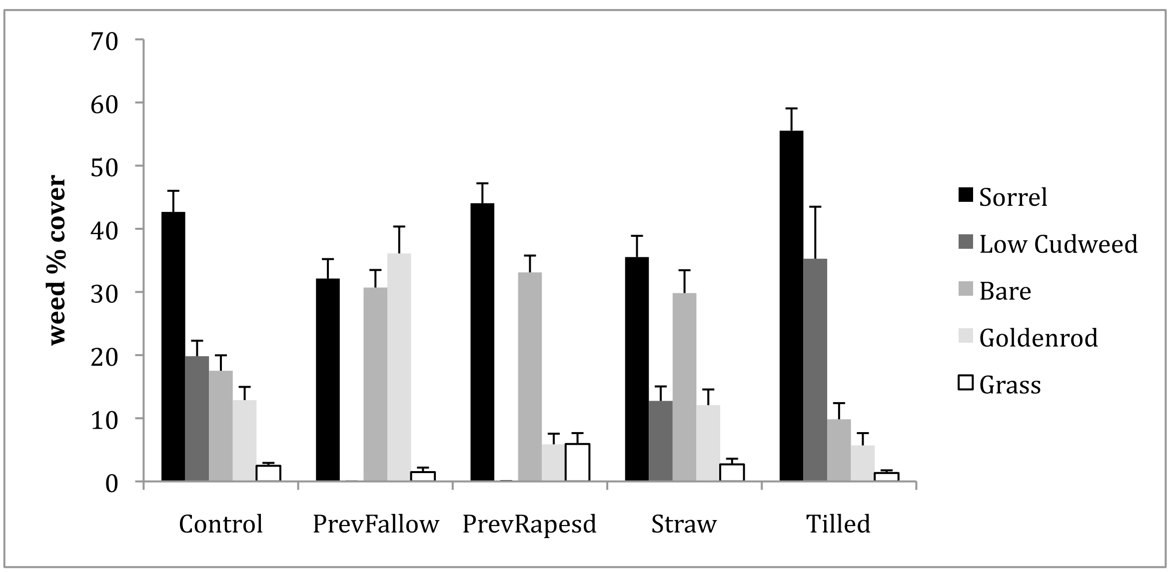

Figure 4: One-year post-establishment weed percent cover by treatment for five most predominant coverage types.

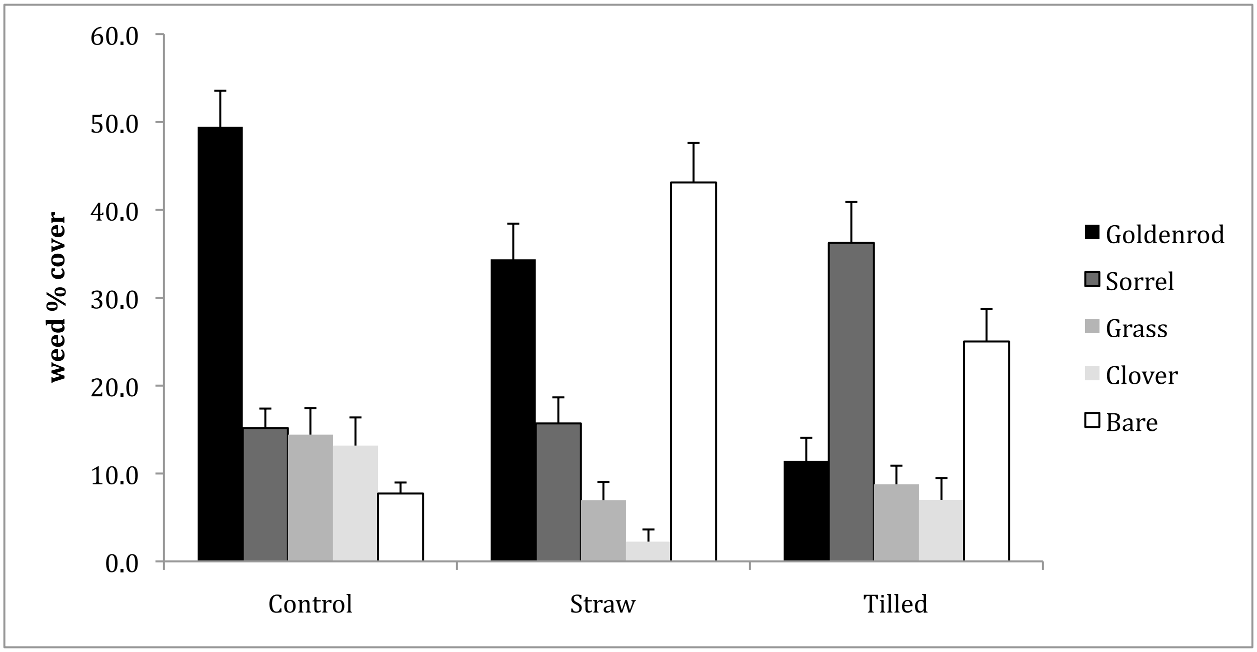

Figure 5: Two-year post-establishment weed percent cover by treatment for five most predominant coverage types.

Among one-year old plots straw and tilled plots had higher weed wet mass for all varieties pooled, suggesting that tilling or straw mulching are ineffective at reducing weeds in these plots. This is in contrast to plant height, which responded positively to straw mulch. Secondly, rapeseed did not differ from fallow or control for weed wet mass. These conclusions are based on late summer weed measurements. While weed measurements were not taken in the spring following rapeseed tilling, anecdotally we observed that the rapeseed plots had fewer weeds starting. Thus, we suggest that our study can't rule out a positive allelopathic benefit of planting rapeseed, but, it may be short-lived or overcome by remnant weed seeds or rhizomes in the soil. By year two, the benefits of tilling or straw versus control treatments is more clear: control plots had higher weed mass than tilled in all hops varieties, and control plots had higher weed mass in two of four hops plots and all varieties pooled.

Clearly, the shift in weed mass may also be related to a shift in weed species composition. Sorrel is the predominant weed by coverage in one-year old plots, while goldenrod is predominant in two-year old plots. While tilling favors establishment of sorrel in weed plots, it is likely that goldenrod would also continue to be a weed problem under tilling because it would persist immediately adjacent to the hill where tilling cannot be done. Clover also becomes more prevalent in two-year old plots. Regardless, each of these weeds has the potential to compete with hops for water and nutrients, and methods to control them will need to be further refined.

Soil biology tests were conducted in the second year (2013) to compare the plots that were: (1) fallow, (2) previously fallow during 2012 and then covered in straw for 2013, and (3) previously planted in rapeseed during 2012 and then covered in straw for 2013.

Since one sample per plot was analyzed, no quantitative comparisons could be made. However, there were no noticeable differences between the three plots in any of the standard soil parameters (Table 9). In addition, the microbial biomass test returned values in the "moderate" range (31-70 ppm-CO2-C) for all three plots, indicating no major difference in soil microbial biomass by treatment.

Table 9: Soil test results taken after the second year of experiment (Fall 2013).

Soil Test	Fallow	Prev. Fallow	Prev. Rapeseed
Biomass (ppm CO2-C)	60 (moderate)	58 (moderate)	44 (moderate)
pH	5.9	5.8	5.6
organic matter (%)	3.6	4.7	4.7
nitrate-N (ppm)	1	3	3
phosphorus (lb/A)	19.6	24.5	24.9
potassium (% Sat)	4.5	5	5.2

One primary goal of our study was to determine whether a season of rapeseed cover would substantially reduce weeds, and justify delaying hops establishment for a year in favor of weed management. Given little to no evidence of a positive effect on hops bine growth or weed biomass following a year of rapeseed, we cannot recommend using rapeseed and delaying production by a year. However, we do maintain that there is an impact on weed production noticeable in the spring following rapeseed (though not measured). Thus, if a decision to plant hops is made for a subsequent season but after the spring rhizome planting time, the ground could be planted in mid-summer with rapeseed. However, weed management that would reduce propagation from existing rhizomes or new seed establishment should then be followed.

We also considered the costs of tilling and straw versus doing no weed management (an experimental control that is relatively unrealistic in a production hopyard). Table 10 summarizes the labor time, materials and costs on a per acre basis based on our actual time and material inputs. Straw spreading was estimated at 75 minutes for 200 feet, while tilling labor was estimated at 70 minutes per 200 feet. Given that straw is spread once, but, tilling is done three times over the season, labor costs for tilling are more substantial. Thus, even though the material costs of straw mulch are more considerable, tilling is $335 more per acre than straw. If tilling produced more hops cones than straw this could be worthwhile. Assuming $8 per dry pound of hops, tilling would need to yield 42 extra dry pounds per acre. We did find that tilling yielded over three times the yield of straw treatments for all varieties pooled (Table 4). However, given that two-year old plants are not well established and produce relatively few hops, these results may be spurious even though they are statistically significant. It was also interesting that one year bines were taller in straw versus tilled while two year old bines didn't differ in height in straw versus tilled, but, tilled produced more hops. We hypothesize that this may be due to two year old plants having better established roots, which are able to draw nutrients and water from the tilled area in between hops hills.

Table 10: Standardized labor and materials costs per acre of three weed management strategies.

Treatment	Labor hours acre^{-1}	\$ Labor† acre^{-1}	\$ Material†† acre^{-1}	Total \$ acre^{-1}
Control	0	$0.00	$0.00	$0.00
Tilling	63.525	$762.30	$26.25	$788.55
Straw	22.6875	$272.25	$181.50	$453.75

† based on $12 USD per hour labor,

†† based on 6.6 cm thick straw at $40 USD per round bale

It is interesting to note that recent work out of Ontario (Evers, 2012) concluded that plastic mulch was the "most effective" weed cover method recommended, and reported that though straw mulch suppressed weeds in the first one and two years of a study, "weed cover started to increase in year three". Plastic mulch does have drawbacks, however, as it would likely need to be replaced on an annual basis, is relatively labor intensive, doesn't allow access to soil in the hop rows during the growing season, and presents significant disposal and environmental issues (Grundy & Bond, 2007). In addition, some have presented concerns about increased soil temperatures due to the black plastic mulch, but whether this actually adversely affects hops remains to be seen.

Overall, our two-year on farm experiment has led us to conclude the following about the value of alternate weed suppression practices, and the benefit of waiting a year before planting hops in a previously fallow field. First, rapeseed did not have a measurable positive effect on next-season hop plant growth or weed suppression. Second, there was little evidence (e.g. from weed plots) that waiting a year to plant hops was beneficial in our case. Third, while straw may show better measures of weed suppression, hops wet mass was actually higher in tilled plots. Given that these data are based on mainly one productive variety (Cascade) and in only the second year of hops plant establishment, this finding should be further examined, e.g. in older hops plants. However, the differences in treatment effects between bine height and hops mass may be due to the relative importance of different resources for which weeds and hops are competing. For example, tilled plots may have higher water and phosphorus availability for mid-summer flower production. Fourth, weed management should address persistence and establishment of perennial weeds like goldenrod, which can be propagated by rhizomes and seed. Goldenrod persisted in two-year old plots, even those with straw mulch. Since our study had nearby plots with goldenrod producing seed, establishment in nearby straw plots in year two may have come from here. Either way, hops farmers should dedicate effort to controlling both persistent rhizome propagation and new seed establishment of goldenrod, clover and other perennial weed species. Given the fact that straw suppressed weeds best, but hops wet mass was higher in tilled plots, the best practice may involve a mixed approach that involves more intensive springtime tilling and weed management, followed by summer straw mulching.

Future recommendations

We set out to answer two general questions when we began our investigation of best organic weed management practices in small-scale Northeast hopyards: 1) what is the best non-herbicide cultural practice to control weeds (none, straw, tilling), and 2) is a weed-suppressing cover crop effective in reducing weed populations, and is it worth delaying hops planting by a year.

The answer to question one is not a straightforward "one or the other" best recommended approach. Clearly, our control (doing nothing) has a negative impact on weed persistence and hops growth, as expected. While straw mulching showed better measures of weed suppression, we saw that hops wet mass was actually higher in tilled plots, based mainly on Cascade and in only the second year of hops plant establishment. Goldenrod weeds persisted in two-year old plots, even those with straw mulch, and thus, hops farmers should dedicate effort to controlling both persistent rhizome propagation and new seed establishment of goldenrod, clover and other perennial weed species. The best practice may involve a mixed approach that involves more intensive springtime tilling and weed management, followed by summer straw mulching. It may be of interest and value to further investigate the tradeoffs between tilling and mulching in older hop plants where hop cone yield can be more robustly assessed.

To answer our second question, our project showed little to no benefit of planting rapeseed on either next-season hop plant growth or weed suppression. We conclude that waiting a year to plant hops was not beneficial in our case, though caution that proper soil preparation and weed control should be carefully considered in hopyard establishment.

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