HOP ESTABLISHMENT IMPACTED BY MULCH TYPE AND NITROGEN SOURCE

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ABSTRACT

Agronomic research is lacking for hops (*Humulus lupulus*), especially in North Dakota (ND) and the northern Great Plains, where demand has risen. This research was done to evaluate factors influencing hops establishment in ND. Factors for this research were hop cultivar, mulch type, and nitrogen source. Variables measured included weed suppression, soil temperature, soil moisture, hop growth, and yield. Nitrogen source did not affect hop growth. 'Cascade' outperformed 'Mt. Hood' and 'Santiam'. Mulch type affected hop establishment, weed suppression, soil temperature, and soil moisture readings. Landscape fabric provided the greatest weed suppression and retained the most soil moisture, but also had the highest soil temperature and greatest soil temperature fluctuation throughout the day. Further research is needed to determine many other optimum growing practices for hops in the northern Great Plains. However, this research is the first field trial showing that hops can successfully be grown in ND.

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Introduction

North Dakota is a main producer of Agriculture in the United States, with major cash crops of wheat, barley and soybean. Recently, there has been a higher demand for high-value crops in this region. One specific crop high in demand is *Humulus lupulus* (hops) due to the influx of microbreweries to the region. This alone puts great importance on research pertaining to efficient hops production in the upper Midwestern region. Research has been conducted in the Pacific Northwest, the Northeast and, more recently, in Michigan. However, Michigan's climate differs from the upper Midwest because it is mainly surrounded by water. Currently, little research on hops has been conducted for North Dakota and the surrounding area. Therefore, research on the establishment of hops is a logical place to start. The objectives of my research were to evaluate three nitrogen sources on the establishment of three hop cultivars as well as determine how three mulches affect weed suppression, hop growth, soil temperature, and soil moisture.

Literature Review

Hops production has been shown to be an increasingly profitable activity with the potential to be a very lucrative industry (USDA, 2006). Understanding the structure and growth of the plant as well as the basic needs for growth is very important in order to maximize hop yield and quality for profit.

Hop plants are hardy herbaceous perennial vines that grow in a wide variety of places, but are native to temperate zones of the northern hemisphere. Plants have permanent rootstock, which can spread over 3.6 m (12 ft.) underground, bines that grow up to 9 m (30 ft.) aboveground, and live for more than 25 years (Kneen, 2015). During the first year, above ground growth is usually less than 1.8 m (6 ft.) because the plant puts effort into establishing the root system. Each spring, the crown of the hop plant will sprout dozens of shoots, which climb clockwise up any nearby object or plant. They do this with the help of prickly hairs on the stems and undersides of the leaves and by twining. They will also wind around themselves. Each year, the plants die back to the ground and new shoots will be produced the following spring. Hop plants are most commonly grown on a trellis system that will be cut down at the end of the growing season. These plants are large and rapidly growing so they require a lot of solar energy, water and nutrients.

Hop plants produce both rhizomes and true roots and both root types make up the crown (Edwardson, 1952). As the plant matures, the true roots become fairly woody and do not produce reproductive buds. The rhizomes, however, produce many buds and rootlets. These grow just under the surface of the soil and fan out from the center of the crown. The rhizomes are thick and have juicy tissue that grow rapidly. Therefore, for commercial purposes, the most common propagation method is by replanting cut rhizomes.

Hop vines, botanically known as a bine, grow rapidly in the early spring and summer. They can grow as much as 30 cm (12 in.) in one day. Initially, all plant energy and resources are put towards vertical growth. Later in the year, flower-producing branches develop. Depending on the variety of hop, these branches vary in length. Golding is one variety known to produce some of the longest branches. These branches will sprout clusters of little burrs around mid-summer. They have a pointy appearance due to the styles sticking out in all directions. As these burrs develop, this is also the time for pollination if males are present. “Regardless if the burr is pollinated or not, the styles will eventually fall off as the florets grow into petals and form cones” (Kneen, 2015). Each branch has the capability to support several clusters of cones, which are mature for harvest between August and September. At this time or shortly after, the bines are cut back to the ground and the hop plant will build reserves for the next growing season by producing rhizomes until the ground freezes.

Hop plants are dioecious, meaning they have male and female flowers on separate plants. Male hop plants produce a lot of pollen, but unless breeding hop cultivars, producers do their best to keep male plants out of the hopyard. Male flowers produce little to no resins and are virtually useless for brewing. With male plants in a hopyard, accidental crosses can easily occur without the grower's knowledge. If the female flowers are fertilized, they will produce seeds that can add as much as 15% to the finished hop weight. Brewers dislike this because they end up paying for non-usable weight. Male plants are not totally useless. Pollination increases cone size, and therefore, promotes higher yield. However, since seeds can't be easily removed, special care is taken to keep areas isolated from unwanted pollination. Propagation by rhizome is most common because it produces genetically identical plants and, most importantly, female plants. In most cases, hopyards are made up of only female plants but many contain multiple cultivars.

There have been many beneficial properties documented for hops. Some of the first recorded date back to the 9^{th} century for medicinal purposes (Steenackers, 2014). Currently, the main use for hops is in brewing as they add bittering, aromatizing and preservative agents to beer as well as contain components that inhibit bacterial growth (Kneen, 2015). The female flower or cone is the useful part for brewing because it contains the components that will later add to the flavor and aroma of the beer. The cone is made up of four main components. First, the main stem that holds the cone together is called the strig. Attached to the strig are the bracts and bracteoles. The bracts contain no resin producing glands, while at the base of every bracteole is the lupulin gland. Lupulin glands are small, yellow and resemble pollen but are not. They are filled with a resin, which contains alpha acids, beta acids and essential oils. These components have different functions in the brewing process.

Alpha acids, which contain three main components: humulone, adhumulone, and cohumulone, add to the bitterness of beer and to the stability of beer foam (Eri, 2000). Beta acids consist of lupulone, adlupulone and colupulone, work in conjuction with the alpha acids, but are not considered as critical as alpha acids (Taniguchi, 2014). The third component to lupulin resin is the essential oil. A cone's essential oil is responsible for the aroma of the hop and the beer. This makes the essential oil profile of hop samples very valuable to the brewer.

Although these chemical components may seem significant only to the brewer, they are important to the grower, too. Formation of the lupulin gland components and their ratios are determined by the variety of hop grown, environmental factors, timing of various activities and are even suspected to be influenced by growing practices (De Keukeleire, 2007). This contributes to the importance of continued research on production methods, location, and climate.

The first states in America with significant hop production were Massachusetts and New York. However, because of the disease downy mildew, production along the Pacific coast surpassed Eastern US. Now hops are being produced across much of the northern part of the country. Hops generally are very tolerant plants but do require long day lengths to flower and produce cones. They also need a specific cold period with temperatures below 40 degrees Fahrenheit for 1 to 2 months. "Therefore, most commercial production worldwide occurs at latitudes from 35 to 50 degrees" (Sirrine, 2010). Typically, hop plants thrive in well-drained, deep, sandy loam soils. The pH of the soil may range from 5.7 to 7.5 and still be sufficient. Poorly drained soils are not favorable for production of high quality hops.

Nutrients also are essential to the production of hops. Annual soil tests are the best way to determine the amount of each nutrient needed (Darby, 2011). Nitrogen, potassium and phosphorus, respectively, are the three most important nutrients required for hop growth. Nitrogen is responsible for most of the bine growth. Without adequate upward growth, few if any cones will be produced. Nitrogen should be applied around mid-May to mid-June because the primary N uptake period for hops occurs during the vegetative stage, which is May through early to mid-July. Nitrogen application after flowering should be avoided as this can lead to unwanted vegetative growth. Potassium amounts needed are slightly less than nitrogen. Most of the potassium taken up by the hop plant is found in the leaves and stem of the plant. Although usually only required at low levels, phosphorus is still important to the yield of the plant as most of the P is found in the cones of the hop plant. Other micronutrients are needed, but only in small quantities.

Hop nitrogen requirement recommendations are 84.1 kg/ha (75 lbs/acre) for the first year of growth and 112.1-168.1 kg/ha (100-150 lbs/acre) for subsequent years, cultivar dependent (Gingrich, 2000). Many different types of N fertilizer are available. Generally, commercial synthetic fertilizers are considered to be 100% available to the plants. These fertilizers may be blended or nutrient specific and immediately available or a controlled release. A common immediately available, nutrient specific N fertilizer is urea, and a controlled release example includes environmentally smart nitrogen (ESN) as well as SuperU. Many also choose to apply compost or other organic amendments such as manure to their hops. Additionally, cover crops and other plowed down amendments have been used to provide nutrients to the soil (Darby, 2013).

Establishment of hop plants largely depends on production practices, environmental conditions and adequate nutrient levels. However, another important factor to consider is monitoring. Monitoring for pests (diseases, insects, and weeds) can help prevent detrimental effects on hop yield and quality. "In monitoring, the grower or a scout takes representative samples to assess the growth status and general health of the crop, the presence and intensity of current pest infestations or infections, and the potential for development of future pest problems" (Gent, 2009). Monitoring the environmental conditions such as temperature and relative humidity also are important to determine if conditions will increase the likelihood of pests being present.

According to Sirrine (2010), the most common pests to hops are hop aphids and spider mites. Hop aphids can cause a lot of damage if left unmanaged as they suck the juices out of the plant and secrete honeydew in the hop cone, causing mold to grow. Plants are weakened and yield reduced due to these pests. Spider mites are also a serious threat to hops. Females will begin feeding on leaves in the spring, causing the leaves to shrivel and eventually die. Even though insects can be very harmful, diseases are usually much more prevalent than insects, especially in humid locations. Some of the primary diseases include downy mildew, powdery mildew, and verticillium wilt. Both downy mildew and powdery mildew are fungal diseases that result in stunted growth, reduction in cone production and, potentially, expendable cones. Verticillium wilt on the other hand is caused by the fungi *Verticillium albo-atrum* and *V. Dahliae*. This disease has a range of effects from minor wilting and swelling of the bine to leaf and plant death.

In addition to monitoring and resisting pests, weed management also is very important. Weeds may compete with the hop plant for moisture and nutrients (Sirrine, 2010). The most common methods of weed control consist of mechanical cultivation (tillage), chemical herbicides and mulching. Tilling can immediately remove weeds but does not prevent them from coming back and has been shown to decrease soil quality. Very few herbicides are registered for hops and, with the increasing organic trend, many like to stay away from chemicals, even though they are convenient. Mulching has been observed to suppress weeds in hopyards and can increase moisture retention and soil fertility overtime.

Weed suppression can result from mulch in a couple different ways. The mulch may have substances that inhibit development of some weed species. Germination of some weed species depends on a light reaction, too, which stimulates plant emergence. The mulch layer can suppress weeds by limiting the amount of light reaching the soil surface (Zaniewicz-Bajkowska 2009). Although they can provide good conditions for perennial plants, mulches also tend to be expensive and difficult to use. Each weed management strategy has advantages and disadvantages. The main goals to strive towards when choosing a method should be weed control, maintaining water content, and adequate root aeration (Lipecki, 1997).

Hops have become a crop in demand. Although many studies and information on hops exist from Michigan to the Pacific Northwest, there are still large gaps in knowledge. Each location has a big impact on how successful or unsuccessful hop production will be. More research is needed to gain insight on hop responses to various environmental factors and the manipulation of these factors.

Materials and Methods

Site Description

Field experiments were conducted in 2015 and 2016 at the NDSU Horticulture Research and Arboretum Site (46º 59’27 N, 97º 21’7 W) near Absaraka, ND. This location is 32.4 hectares including the 14.2-hectare Dale E. Herman Research Arboretum. The trial area was 32.9 meters by 13.7 meters.

Treatments and Experimental Design

The experimental design was a randomized complete block with a split-split plot arrangement and four replicates. The whole plot was cultivar, the sub-plot was mulch type, and the sub-sub plot was nitrogen source (Fig. 1). There were 36 treatments, with 144 total plants and each plant was an experimental unit. The soil type is shown in Table 1. The cultivars used were 'Cascade', 'Mt. Hood', and 'Santiam'. These cultivars were chosen according to local brewer's requests. Hop plants were obtained from Great Lakes Hops (Zeeland, MI).

Table 1. Soil series†, taxonomy, and slope at Absaraka, ND in 2015 and 2016.

Location	Year	Soil Series	Soil Taxonomy	Slope
				%
Absaraka, ND	2015-16	Warsing	Sandy-skeletal, mixed, superactive, frigid Oxyaquic Hapludolls	0-2

† Soil data obtained from (USDA-NRCS, 2017).

The plot framework consisted of four rows with four telephone poles per row. Each telephone pole in one single row was spaced 11 meters apart. The distance between each row was 4.6 meters. Metal frames were placed on top of the telephone poles with a cable for stability. A cable connected all four poles in a row on either side of the telephone pole. Bailer twine was tied from a metal hook at the base of each hop plant to each side of the cable forming a "V" shape. Once established, the two strongest looking bines were trained up the twine, one on each side. There were twelve individual plants of each cultivar in each row. Each plant within a row was at a 0.9 meter spacing.

Figure 1. Field Setup with all treatments applied.

Nitrogen Application and Planting

Nitrogen for each of the three sources were weighed prior to transplanting. Urea, SuperU (Koch Industries, Wichita, KS) and environmentally smart nitrogen (ESN) (Agrium Inc., Calgary, Canada) each were applied at a rate of 84064 g N/ha. Each nitrogen experimental unit was 0.9 m by 0.9 m. Nitrogen was spread by hand and incorporated with a rake. Immediately after nitrogen application, hop plants were hand transplanted every 0.9 m of row resulting in 12 plants between each telephone pole and 36 plants in one row. Transplanting dates were June 11 of 2015 and June 2 of 2016. Following transplanting, plants received supplemental water from a mobile water tank to help with establishment.

Mulch Application

One week after transplanting, mulches were applied. Woodchips and straw were spread roughly 5-7 cm thick over the 0.91 m^2 experimental unit. Landscape fabric was laid and secured using turf staples with small x-shaped cuts for each plant. To record soil temperature and soil moisture, data loggers (Em50R, Decagon Devices, Inc., Pullman, WA) were placed within the same cultivar in every replication. Each data logger contained four sensors. One sensor was placed in each mulch type of the 'Cascade' hops roughly 15 cm below the soil. Only 'Cascade' was monitored due to instrumentation limits.

Data Collection

Aside from recording soil temperatures and soil moistures, percent weed cover data was taken starting one month after transplanting. For 2015, weed cover readings were taken on July 7, 22, August 5, and September 10. For 2016, weed cover readings were taken on July 7, 21, August 4, and 25. Weed cover data was taken using a 0 to 100% rating system with 0 = no visible weeds and 100 = entire area had weed cover. After each weed cover reading was taken, the plots were hand weeded to show no visible weeds. Other data collected included heights of each bine, chlorophyll readings using the Soil-Plant Analysis Development (SPAD) meter (SPAD 502DL Plus Chlorophyll Meter, Spectrum Technologies, Inc., Aurora, IL) and general notes on the hop growth. Heights and SPAD meter readings were taken once a month starting one month after planting. Repeated height measurements helped to assess establishment success, while repeated SPAD meter readings helped to evaluate plant nitrogen uptake. The height of the two bines per plant were averaged to give one measurement per plant. A SPAD meter reading was averaged from the top two leaves per bine per plant and compared to measurements from a second set of two leaves per bine per plant. Weed cover percentages, heights, and SPAD meter readings were taken until harvest in September. After harvest, additional information was collected on a per plant basis and included: weight of 25 randomly selected cones for each plant, fresh and dry weights, and the average length and diameter of five randomly selected cones.

Harvest

The hops were harvested early to mid-September and determined by the hop color, odor and squeeze test. The goal was to harvest the hops when the cone odor is the most aromatic and the cones are turning from a bright green to a pale green, almost-yellow color. The hops should be starting to dry so when you squeeze them with two fingers (the squeeze test) they will spring back to their original shape instead of staying flattened. Since it was only the first year of growth and hop plants generally are not expected to produce cones in the first year, the plants that did produce cones were hand harvested due to the smaller yield. Hand harvesting was done by cutting down the bines and picking off the cones. After the initial cone yield and quality data were collected, the hops were placed in a dryer set at 49^{o} Celsius for 14 hours. They were then removed from the dryer, weighed again (dry weights) and then packaged and stored in a freezer.

Statistical Analysis

The statistical analysis of data was performed using a linear mixed model for SAS 9.4 (PROC MIXED with the REML estimation method, SAS Institute, SAS Circle, Cary, NC). Cultivar, mulch, and nitrogen source were considered fixed effects in the model, while replicate and year were considered to be random effects. The analysis of variance for a split-split plot design was used for the analysis with the appropriate error terms assigned to each fixed main effect or interaction. For height and SPAD, a repeated measures analysis with compound symmetry covariance structure was used. For the repeated measures analysis, a nested effect of mulch within cultivar, or cultivar(mulch) was included in the analysis of the repeated variable time. Data logger recorded values were analyzed separately with mulch as a fixed effect, while replicate and year were again considered to be random effects. All interactions of fixed effects were considered fixed and interactions with a random term were considered random. LSMEANS with means separations were done through the PDIFF function standard error for a least significant difference calculation. All data were combined over 2015 and 2016 with the exception of weed cover, which was analyzed on a yearly basis. An alpha level of $P \leq 0.05$ was used for all hypothesis tests.

Results & Discussion

Weed Control

Weed control data was analyzed on a yearly basis instead of combined across years. This was due to a pre-emergence herbicide (flumioxazin/glufosinate mix) application in 2016 while the site in 2015 had no herbicide applied to it. The herbicide mixture was applied at a rate of 71.4 g ai/ha flumioxain and 1148 g ai/ha glufosinate and was not harmful to the hop transplants. There was no significant effect of weed control based on cultivar in 2015 or 2016. However, weed control was significant for mulch type across all weed cover readings and a cultivar by mulch interaction at the first weed cover evaluation in 2015 (Table 2). In 2016, weed cover results were similar to 2015 with different second, third and fourth weed cover evaluations for mulch type, while the first weed cover evaluation had a cultivar by mulch interaction (Table 3).

Table 2. P values for hop weed cover evaluation times during the 2015 growing season.

		WC[‡] 1	WC 2	WC 3	WC 4
Sources of Variation	df	----------Probability > F------------			
Cultivar	2	0.6345	0.4292	0.8855	0.4240
Mulch	3	<.0001***	<.0001***	<.0001***	<.0001***
Cultivar X Mulch	6	0.02*	0.6366	0.3945	0.5247

*, **, *** Significant main effects and interactions at P<0.05, 0.01, or 0.001, respectively.
[‡] WC = weed cover.

Table 3. P values for hop weed cover evaluation times during the 2016 growing season.

		WC[‡] 1	WC 2	WC 3	WC 4
Sources of Variation	df	----------Probability > F------------			
Cultivar	2	0.222	0.748	0.1579	0.4909
Mulch	3	0.1037	0.0359*	0.0048***	0.001***
Cultivar X Mulch	6	0.0495*	0.6005	0.7665	0.3941

*, **, *** Significant main effects and interactions at P<0.05, 0.01, or 0.001, respectively.
[‡] WC = weed cover.

In 2015, no mulch (control) had the greatest weed cover for the last three evaluation timings, while landscape fabric had the lowest weed cover (Table 4). Straw and woodchips provided similar intermediate weed control for the last three evaluation timings. In 2016, all mulches had very little weed cover. The herbicide mixture, even though unintended, managed most weeds together with mulch (Table 5). The no mulch and straw provided similar weed control the last three evaluation timings. Landscape fabric and woodchips provided greater weed control than straw at the second weed cover evaluation timing. Landscape fabric provided greater weed control than either the no mulch or straw mulched plot during the third weed cover evaluation timing, while woodchips provided greater weed control than the straw mulched plots. Landscape fabric provided greater weed control than the no mulch, straw or woodchip mulched plots during the fourth weed cover evaluation timing.

Table 4. Means for weed cover dates during the 2015 growing season.

Mulch	WC‡ 2	WC 3	WC 4
No Mulch	57.9	37.9	77.3
Landscape Fabric	3.1	2.6	2.3
Straw	17.9	15.0	41.7
Wood Chip	24.2	19.6	44.6
Mean	25.8	18.8	41.5
CV (%)	0.1	0.1	0.1
LSD (0.05) †	12.5	8.0	14.8

† LSD calculated to compare within columns.
‡ WC = weed cover.

Table 5. Means for weed cover dates during the 2016 growing season.

Mulch	WC‡ 2	WC 3	WC 4
No Mulch	1.6	2.2	2.1
Landscape Fabric	0.0	0.0	0.3
Straw	2.5	1.8	3.3
Wood Chip	0.6	0.9	2.5
Mean	1.2	1.2	2.0
CV (%)	0.7	0.5	0.3
LSD (0.05) †	1.7	1.2	1.3

† LSD calculated to compare within columns.
‡ WC = weed cover.

The cultivar by mulch interaction was only significant at the first weed cover reading in both 2015 and 2016. This suggests that some mulches may work better with some cultivars early on in the growing season. In 2015, weed cover in the no mulch plots was higher than any treatment that had an actual mulch applied (Table 6). For all three cultivars, landscape fabric had lower weed cover than all woodchip mulch treatments. The landscape fabric had lower weed cover than the straw mulch treatment for the cultivar Santiam. The woodchip and straw mulch had similar weed control for ‘Cascade’ and ‘Santiam’, however wood chip mulch had higher weed cover than straw for ‘Mt. Hood’. In 2016, the interaction occurred from higher weed cover in the woodchip mulched ‘Mt. Hood’ plot, as it had lower weed cover than any other treatment combination. The treatment of ‘Santiam’ and woodchip mulch had similar weed control to the

‘Mt. Hood’ woodchip mulch combination, but worse than three treatment combinations with 0% weed cover. Furthermore, even though ‘Cascade’ with the no mulch treatment was not statistically significant, there is a large difference compared to the ‘Mt. Hood’ and ‘Santiam’ readings with the no mulch treatment. Cannabis is known to have allelopathic capabilities (Mahmoodzadeh et al., 2015). Both Cannabis and hops are closely related species in the same family. Therefore, there is potential that certain hop plants could also have allelopathic capabilities.

Table 6. Means for cultivar x mulch in the first weed cover reading averaged over the 2015 and 2016 growing seasons.

Cultivar	Mulch	2015	2016
		------ % ------	
Cascade	No Mulch	75.0	0.0
Cascade	LF	4.3	0.0
Cascade	Straw	23.8	1.3
Cascade	Wood Chip	37.5	0.5
Mt. Hood	No Mulch	93.8	1.0
Mt. Hood	LF	5.0	0.0
Mt. Hood	Straw	11.3	4.3
Mt. Hood	Wood Chip	56.3	0.5
Santiam	No Mulch	93.8	2.3
Santiam	LF	2.5	0.5
Santiam	Straw	31.3	0.5
Santiam	Wood Chip	28.8	2.8
	Mean	38.6	1.1
	CV (%)	6.8	83.3
	LSD (0.05) †	20.1	2.5

† LSD calculated to compare within columns.

Applying mulch to new hop plants was a logical way of increasing establishment success. Mulches applied on the soil surface can suppress weeds from emerging as well as prevent weed seeds from germinating by blocking sunlight and acting as a physical barrier that the weeds must pass (Arentoft et al., 2013). Mulch application is also a probable weed control method for production.

The most abundant weed species present in 2015 included perennial sowthistle (*Sochus arvensis*), Canada thistle (*Cirsium arvense*), common purslane *(Portulaca oleracea*), crab grass (*Digitaria sanguinalis*), dandelion (*Taraxacum officinale*), and curly dock (*Rumex crispus*). Other species found in less abundance were common lambsquarters (*Chenopodium album*), redroot pigweed (*Amaranthus retroflexus*), cottonwood (*Populus deltoides*) seedlings, Siberian elm (*Ulmus pumila*) seedlings, and eastern black nightshade (*Solanum ptychanthum*). Some of the weeds were observed to be more prevalent in certain types of mulches. For example, perennial weeds such as dandelion, Canada thistle and sow thistle were observed to penetrate through the woodchip and straw mulches while annuals like common purslane were more prevalent in the untreated plots. This was expected as woodchip and straw mulches rarely stop the emergence of perennial weeds.

In 2016 (the year that had the herbicide treatment prior to planting) the trend was similar for perennial and annual weeds except that there were fewer weeds. The weed species observed in this year included field bindweed (*Convolvulus arvensis*), field pennycress (*Thlaspi arvense*), dandelion, goosegrass (*Elusine indica*), quack grass (*Elymus repens*), common purslane, white clover (*Trifolium repens*), and common lambsquarters.

According to Arentoft et al. (2013), little research has been done on how effective mulches are at suppressing weeds when the thickness of the mulch is altered. In their study, they used bark chips and cocoa husks to determine weed-suppressing effects at different thicknesses. They reported that weed emergence declined as the mulch layer increased and there was an increasing emergence of weeds over time for the thinner layers. The cocoa mulch performed better than the bark because thinner layers of cocoa mulch were required to provide similar weed control. After 90 days, a bark layer of 16.36 cm and a cocoa layer of 10.44 cm were needed to reduce the weed cover by 90%. Even though the layer needed to suppress weeds was thinner for cocoa than for bark, there was a period in the beginning where bark mulch better suppressed weeds. This may be very beneficial for the establishment of new hop plants as they are more likely to grow stronger with less weed competition early on.

In another study done by Zaniewicz-Bajkowska et al. (2009), the effects of straw mulch on vegetables were investigated. It was found that in dry years, straw mulch produced better results compared to a humid year. When straw was incorporated into the soil, the number of weeds were significantly higher compared to the farmyard manure-fertilized treatment. However, straw mulch that was left on the surface significantly reduced the number of weeds in comparison to the farmyard manure-fertilized plots and the untreated. In addition, straw mulch also favorably influenced their yields.

Most of the hop research has focused on specific chemicals produced in the hop cones, whereas agronomic research has been very limited (Turner et al. 2011). No research has evaluated mulching hops. Zaragoza (2003) concluded that all organic mulches used in his experiment suppressed weeds, but the efficacy depended on the thickness of the mulch layer on the soil surface. Thickness of mulch layers around hop plants may be a logical subsequent area of research, but one also needs to consider bine emergence delays due to less soil warming with the mulch layer.

Soil Moisture & Temperature

Soil moisture and soil temperature were logged throughout the growing seasons at one hour intervals. Hour 0 was equivalent to 12:00 am, hour 12 was 12:00 pm and hour 23 was 11:00

pm. Replicates were averaged across each hour in each mulch type. Mean values were then charted to determine the effect each mulch had on the soil temperature and moisture throughout the day.

Daily soil temperature under the landscape fabric was similar to the untreated (Fig. 2). Both produced the highest soil temperatures and had the most drastic fluctuation in temperature throughout the day. Both reached their lowest temperatures at the 10^{th} hour of the day and their highest temperature at the 21^{st} hour. Woodchip and straw mulch also had similar trends to each other. Both maintained lower soil temperatures that didn't fluctuate as much during the course of a day. They both reached their lowest soil temperature at the 11^{th} hour of the day and their soil highest temperature at the 21^{st} hour.

As expected, soil moisture stayed more consistent throughout the day than soil temperature. On a daily basis, landscape fabric retained the most soil moisture with its' low occurring at the 11^{th} hour of the day and the highest water content recorded at the 21^{st} hour (Fig. 3). Again, straw and woodchip mulch produced similar trends with woodchip mulch retaining a slightly higher soil water content than straw mulch. Comparatively, soil under the straw mulch had the lowest water content at the 10^{th} hour of the day while soil under the woodchips had the lowest water content at the 13^{th} hour. Soil under the straw mulch had the highest water content at the 1^{st} hour of the day, while soil under the woodchip mulch maintained a high water content for hours 19, 21, 22, 23, 0 and 1.

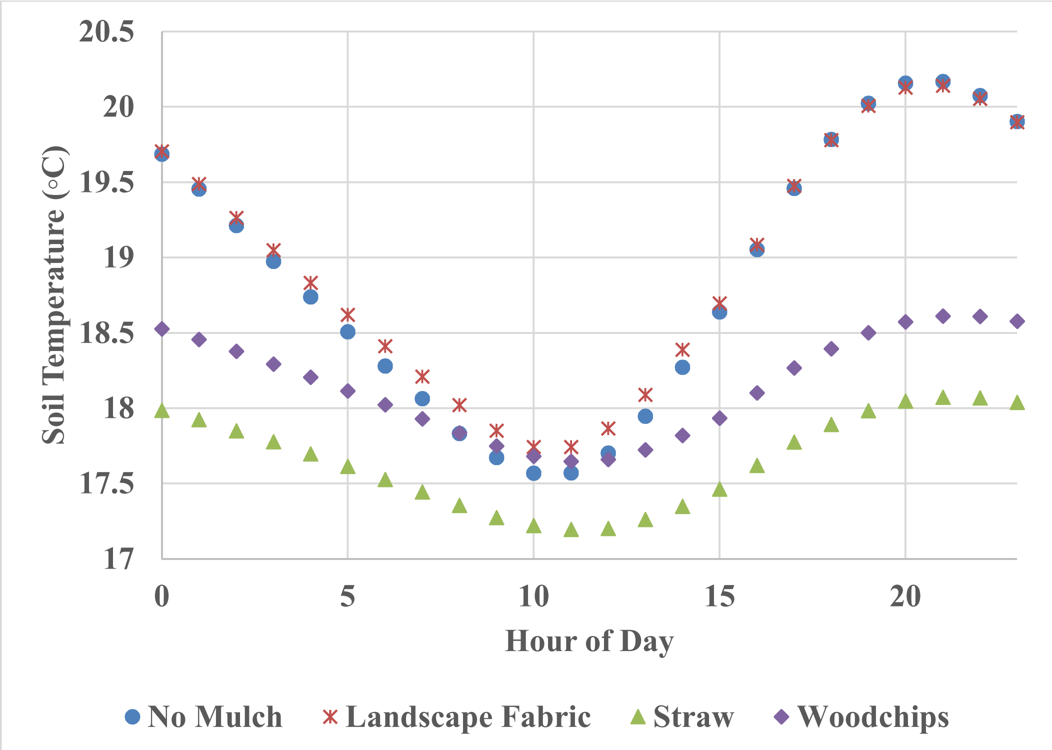

Figure 2. Soil temperature (C) for different mulches throughout each hour of the day combined over the 2015 and 2016 growing seasons.

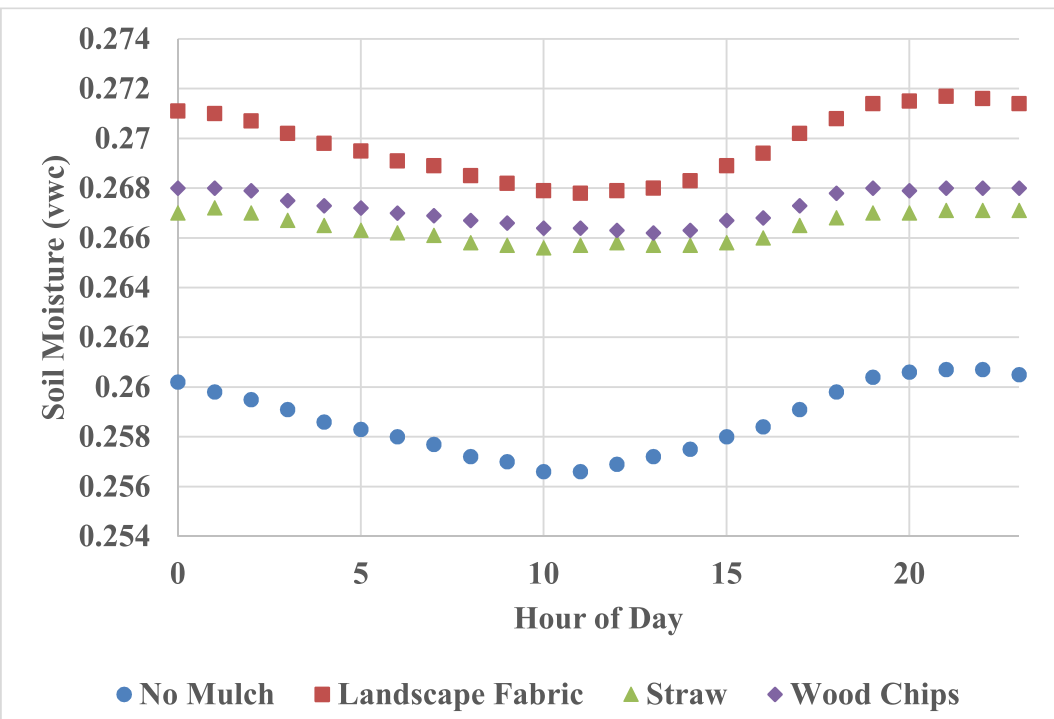

Figure 3. Soil moisture (m^3/m^3) volumetric water content (VMC) for different mulches throughout each hour of the day combined over the 2015 and 2016 growing seasons.

Mulching benefits are not limited to weed control. Applying mulch reduces water evaporation from the soil surface, which helps maintain higher soil water contents (Arentoft et al., 2013). The structural stability and fertility of soils is enhanced from mulches. Also, mulch helps prevent soil erosion. As for soil temperature, organic mulches decrease soil temperature fluctuations and can protect against frost. On the other hand, plastic mulches may favor soil warming, which could be beneficial to some horticultural crops. In addition, organic mulches contain nutrients and may increase the organic matter and water retention of the soil. The water conserving effect of mulch on soil may increase the length of the growing season and reduce drought effects and yield fluctuations (Taparauskiene and Miseckaite, 2014). This may be beneficial for hops by reducing the need for supplemental water.

In an experiment performed by Taparauskiene and Miseckaite (2014), effects of mulch on soil moisture in strawberry plants were determined. Treatments included no mulch, wheat straw mulch, and a black plastic polyethylene layer. Significant annual differences for soil moisture content were found in both the straw and the plastic polyethylene layer. Over the 3-year study, the highest average soil moisture content was found in the straw mulch with 18.0% while the lowest soil moisture content was 16.2% for the no mulch treatment. Soil moisture content for the black polyethylene averaged 16.5%. This was a little different from the current study where soil under the landscape fabric had the highest soil moisture content, but both the fabric and straw retained more water compared to no mulch. None the less, results from the current study confirm the findings of other research that mulch increases soil moisture content.

Taparauskiene and Miseckaite (2014) also state that mulching improved strawberry plant growth, berry weight, fruit yield and quality. Since soil temperature influences horticultural crop production, the higher temperature under the black polyethylene layer may result in better growth of some plants. However, different mulches can lead to differences in soil temperature, moisture content, canopy temperature, and the quantity and quality of light being absorbed, reflected or transmitted. These differences between mulches were also observed in my research.

Effects of mulching on soil temperature and moisture were also investigated in mounded grapevines (Jiang et al., 2016). Both wood and straw mulches were used and compared to soil-hilling. Soil moisture increased in both mulched treatments. The highest soil moisture was observed under the wood/bark mulch with 15.9% followed by straw at 14% soil moisture and soil-hilling at 12.9%. In my research, wood and straw mulch had similar soil moisture content and were higher than the bare ground treatment. Jiang concluded that soil moisture was likely conserved by the mulches ability to reduce evaporation from the soil surface and indirectly through suppression of weed competition for soil water. Results from the current study reinforce the conclusion by Jiang as landscape fabric had the least weed coverage between all mulches for both years and had the highest moisture content for the mulch types.

Ni et al. (2016) reported that organic mulches were found to conserve water more effectively than inorganic mulches. This contradicted the current study results where the inorganic mulch retained the highest soil moisture amount.

Mulching is also excellent in areas where irrigation is scarce. Mulch greatly reduces water loss from the soil, resulting in higher and more uniform soil moistures, and irrigation is needed less frequently (Ramakrishna et al., 2006). For places that have irrigation access, drip irrigation is the ideal irrigation method for hops. Drip irrigation is used to efficiently manage water by reducing water runoff, evaporation, or deep percolation in silty soils (Shock, 2013).

Growth Characteristics

Growth characteristics were analyzed and combined across the 2015 and 2016 growing seasons. The time by cultivar interaction was significant for SPAD and height measurements (Table 7). ‘Cascade’ had significant growth at the second height reading, causing the time by cultivar interaction for height (Table 8). Cascade also had the greenest leaves for the SPAD 60 days after planting (DAP) top leaves reading and the 90 DAP top leaves reading. There were no significant interactions of main effects and only cultivar was significant for yield measurements (Table 9). Again, ‘Cascade’ had the greatest cone dry weight, and produced the largest cones (Table 10). ‘Cascade’ was the easiest to train and the most vigorous cultivar throughout the growing season. In contrast, several ‘Mt. Hood’ and most of the ‘Santiam’ bines fell off the twine and had to be retrained multiple times. ‘Mt. Hood’ and ‘Santiam’ plants also appeared more yellow with some leaf necrosis (Fig. 4). Overall, ‘Cascade’ appeared healthier than the other two cultivars later in the season suggesting that certain varieties may perform better in North Dakota.

Table 7. P values for hop measurements combined over the 2015 and 2016 growing season.

Source of Variation	df	Spad T	Spad B	Height
		-------Probability > F---------		
Time (T)	2	<.0001***	<.0001***	<.0001***
Cultivar (C	2	0.06	0.24	0.04
T X C	4	<.0001***	<.0001***	<.0001***
Mulch (M)	3	0.31	0.08	0.41
T X M	6	0.55	0.13	0.20
C X M	6	0.86	0.25	0.82
T X C X M	12	0.84	0.92	0.98
Nsource (N)	2	0.64	0.42	0.54
T X N	4	0.36	0.98	0.76
C X N	4	0.56	0.97	0.65
T X C X N	8	0.45	0.98	1.00
M X N	6	0.39	0.44	0.85
T X M X N	12	0.36	0.98	0.99
C X M X N	12	0.44	0.96	0.85
T X C X M X N	24	0.41	0.36	1.00

*, **, *** Significant main effects and interactions at P<0.05, 0.01, or 0.001, respectively.

Table 8. Means of hop spad and height measurements combined over the 2015 and 2016 growing seasons.

Cultivar	Spad 30 DAP§ Top	Spad 30 DAP Bottom	Spad 60 DAP Top	Spad 60 DAP Bottom	Spad 90 DAP Top	Spad 90 DAP Bottom	Height 30 DAP	Height 60 DAP	Height 90 DAP
	--rcc--	--rcc--	--rcc--	--rcc--	--rcc--	--rcc--	--cm--	--cm--	--cm--
Cascade	21.1	29.5	22.9	28.5	37.7	40.4	58.5	153.3	194.8
Mt. Hood	20.6	29.7	17.8	24.5	20.9	27.7	51.9	86.4	125.4
Santiam	23.3	32.4	19.9	29.0	22.6	31.0	29.0	52.2	83.8
Mean	21.7	30.5	20.2	27.4	27.1	33.0	46.5	97.3	134.6
CV (%)	0.1	0.1	0.0	0.0	0.1	0.1	0.0	0.0	0.0
LSD (0.05) †	3.2	3.7	3.2	4.9	16.5	24.8	32.3	54.0	72.0

† LSD calculated to compare within columns.

§ DAP = Days after planting.

Table 9. P values for hop yield measurements combined over the 2015 and 2016 growing seasons.

Source of Variation	df	Wet Weight	Dry Weight	Hop Length	Hop Diameter
		----------------Probability > F------------------			
Cultivar (C)	2	0.13	0.03*	0.02*	0.01*
Mulch (M)	3	0.92	0.92	0.36	0.24
C X M	6	0.98	0.98	0.92	0.85
Nsource (N)	2	0.73	0.62	0.82	0.85
C X N	4	0.83	0.69	0.94	0.77
M X N	6	0.77	0.54	0.32	0.33
C X M X N	12	0.85	0.57	0.44	0.50

*, **, *** Significant main effects and interactions at $P<0.05$, 0.01, or 0.001, respectively.

Table 10. Means of hop yield measurements combined over the 2015 and 2016 growing seasons.

Cultivar	Wet Weight	Dry Weight	Hop Length	Hop Diameter
	----g----	----g----	----cm----	----cm----
Cascade	96.5	31.1	2.7	1.8
Mt. Hood	1.0	0.3	0.3	0.2
Santiam	0.4	0.1	0.1	0.1
Mean	32.6	10.5	1.0	0.7
CV (%)	0.1	0.2	0.5	0.6
LSD (0.05) †	129.3	20.1	1.2	0.7

† LSD calculated to compare within columns.

Even though cultivars may perform better in certain areas there is still varietal stability. Morphological characteristics were compared from clonal species in California, Washington, and Idaho (Davis, 1957). Some morphological characteristics were found to vary from location to location, but the difference in these characteristics were of little difference within the geographical range and the variation was not significantly greater than the individual plant variation.

Many aspects of basic hop agronomic research are lacking. Since the majority of public hop research is focused on the specific chemicals produced by the hop plant and little on the production, it is hard to know the best practices for top quality hop production. Different nitrogen sources did not influence hop establishment for the three cultivars used in the current study. Sullivan et al. (1999) concluded that little nitrogen was absorbed before mid-June, but by the end of July, hop plants have taken up the majority of the annual nitrogen. Established hops have generally taken up between 90 and 180 kg N ha^{-1} by the end of July. Typically, the first-year nitrogen requirements are 84.1 kg/ha while subsequent years are 112.1-168.1 kg/ha (Gingrich et al., 2000). 'Mt. Hood' and 'Santiam' plants appeared more chlorotic than 'Cascade' throughout the trial, suggesting that some cultivars may require more of certain nutrients than other cultivars during the year of establishment. Iron uptake may have been the cause for the chlorosis due to the alkaline soil in the plot area. Further research should evaluate nutrient needs by hops cultivars after transplanting in North Dakota.

Figure 4. Chlorosis seen on hop plants.

Conclusion

Field experiments were conducted to evaluate hop establishment for three different hop cultivars, the effects different mulches had on weed suppression, soil temperature and soil moisture, and whether different nitrogen sources impacted hop growth. The overall goal was to gain more insight and knowledge on the successful establishment and growth of hops in the northern Great Plains, particularly North Dakota.

Mulch type influenced weed control. In general, landscape fabric provided the best weed control in 2015 and 2016. Straw mulch and woodchips were less effective for weed control when compared to landscape fabric, but provided more weed control than the non-mulched plots. Weed pressure was greater in 2015 than 2016 due to an herbicide application early in 2016. Further research should evaluate the effect of mulch for weed control and bine emergence.

Soil temperature and soil moisture were influenced by mulch type. Landscape fabric and no mulch treatments had similar and the most drastic soil temperature fluctuations throughout the day. Woodchips and straw mulch provided more insulative properties with less soil temperature fluctuations and cooler soil temperatures compared to the non-mulched plots and those covered with landscape fabric. Straw mulch maintained the lowest average hourly soil temperature. Soil covered with landscape fabric had the highest soil moisture. Plots covered with straw mulched or woodchips had similar soil moisture values, slightly below those from the landscape fabric treatment. The non-mulched plots had considerably lower soil moisture compared to the mulch treatments. Mulches not only provided weed control but also reduced evaporation, decreased soil temperature fluctuations, and overall was beneficial in this experiment.

Cultivar was the only main effect that influenced the plant related variables. Hop cultivar Cascade outperformed cultivars Mt. Hood and Santiam in this trial. ‘Cascade’ grew the tallest and produced the largest cones with the greatest biomass. However, one needs to understand that this was only the initial year of establishment and that hops need three to four years to become fully established.

There is a lack of agronomic research on hop growing practices and an increasing number of farmers looking to grow hops in the northern Great Plains. The results of this experiment suggest mulching would be beneficial for hop establishment. Further research is needed to determine varieties with superior performance for the northern Great Plains region as well as basic growing practices for optimal hop production. This research poses a new question about optimal nitrogen rates for first year establishment and subsequent years for this region along with optimal mulch thickness. These results support the consideration of hops as a viable crop for production in North Dakota.

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APPENDIX

Table A1. P values for hop weed cover dates combined across both 2015 and 2016 growing seasons.

		WC‡ 1	WC 2	WC 3	WC 4
Sources of Variation	df	----------Probability > F------------			
Cultivar	2	0.3398	0.5042	0.142	0.4471
Mulch	3	0.4944	0.4761	0.4306	0.4685
Cultivar X Mulch	6	0.6471	0.4822	0.3992	0.6171

‡ WC = weed cover.

Table A2. P values for hop measurements taken during the 2015 growing season.

Source of Variation	df	Spad 30DAP§ Top	Spad 30DAP Bottom	Spad 60DAP Top	Spad 60DAP Bottom	Spad 90DAP Top	Spad 90DAP Bottom	Ht‡ 30 DAP	Ht 60 DAP	Ht 90 DAP	Wet Weight	Dry Weight	Hop Length	Hop Diameter
		-----------------Probability > F-------------------												
Cultivar (C)	2	0.00**	0.02*	0.00**	0.01**	<.0001***	0.00**	0.00**	0.00**	0.00**	0.00**	0.00**	<.0001***	<.0001***
Mulch (M)	3	0.00**	0.01*	0.17	0.05*	0.37	0.23	0.30	0.69	0.23	0.71	0.80	0.20	0.09
C X M	6	0.80	0.26	0.95	0.26	0.36	0.46	0.71	0.73	0.41	0.79	0.88	0.12	0.14
Nsource (N)	2	0.03*	0.37	0.76	0.45	0.40	0.86	0.26	0.53	0.52	0.99	0.96	0.80	0.51
C X N	4	0.17	0.23	0.13	0.53	0.30	0.61	0.06	0.34	0.75	1.00	0.99	0.55	0.50
M X N	6	0.40	0.29	0.65	0.99	0.15	0.44	0.71	0.17	0.18	0.32	0.26	0.19	0.21
C X M X N	12	0.33	0.33	0.45	0.65	0.06	0.37	0.19	0.36	0.29	0.33	0.25	0.45	0.31

‡Ht = Height.

*, **, *** Significant main effects and interactions at P<0.05, 0.01, or 0.001, respectively.

§ DAP = Days after planting.

Table A3. P values for hop measurements taken during the 2016 growing season.

Source of Variation	df	Spad 30DAP§ Top	Spad 30DAP Bottom	Spad 60DAP Top	Spad 60DAP Bottom	Spad 90DAP Top	Spad 90DAP Bottom	Ht‡ 30 DAP	Ht 60 DAP	Ht 90 DAP	Wet Weight	Dry Weight	Hop Length	Hop Diameter
		-----------------Probability > F-------------------												
Cultivar (C)	2	0.12	0.09	0.00**	0.06	0.15	0.04*	0.05*	0.00**	0.00**	0.00**	0.00**	<.0001***	<.0001***
Mulch (M)	3	0.95	0.78	0.27	0.04*	0.35	0.09	0.24	0.27	0.09	0.87	0.78	0.59	0.40
C X M	6	0.31	0.71	0.02*	0.35	0.58	0.70	0.47	0.96	0.66	0.94	0.87	0.94	0.97
Nsource (N)	2	0.70	0.59	0.19	0.42	0.52	0.20	0.65	0.26	0.50	0.16	0.21	0.86	0.64
C X N	4	0.93	0.72	0.50	0.78	0.49	0.46	0.34	0.24	0.48	0.11	0.19	0.87	0.88
M X N	6	0.42	0.71	0.89	0.24	0.38	0.42	0.76	0.53	0.34	0.22	0.34	0.04*	0.07
C X M X N	12	0.39	0.96	0.63	0.81	0.49	0.21	0.77	0.17	0.06	0.15	0.30	0.05*	0.16

‡Ht = Height.

*, **, *** Significant main effects and interactions at P<0.05, 0.01, or 0.001, respectively.

§ DAP = Days after planting.

Tables A4. Means of hop measurements taken during the 2015 growing season.

Cultivar	Spad 30DAP[§] Top	Spad 30DAP Bottom	Spad 60DAP Top	Spad 60DAP Bottom	Spad 90DAP Top	Spad 90DAP Bottom	Height 30 DAP	Height 60 DAP	Height 90 DAP	Wet Weight	Dry Weight	Hop Length	Hop Diameter
	--rcc--	--rcc--	--rcc--	--rcc--	--rcc--	--rcc--	--cm--	--cm--	--cm--	--g--	--g--	--cm--	--cm--
Cascade	19.2	27.7	23.4	30.0	43.1	48.8	63.7	171.2	237.8	133.3	36.6	3.2	2.0
Mt. Hood	18.0	26.7	17.5	24.3	22.0	29.2	57.3	93.6	161.2	1.7	0.5	0.4	0.3
Santiam	21.7	30.0	19.3	29.7	22.9	32.1	23.7	52.6	103.8	0.2	0.1	0.2	0.2
Mean	19.6	28.1	20.0	28.0	29.3	36.7	48.2	105.8	167.6	45.1	12.4	1.3	0.9
CV (%)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.2	0.3
LSD (0.05)[†]	1.7	2.0	2.1	3.3	4.7	5.7	12.2	29.6	35.4	37.3	10.2	0.3	0.3

[†] LSD calculated to compare within columns.

[§] DAP = Days after planting.

Tables A5. Means of hop measurements taken during the 2016 growing season.

Cultivar	Spad 30DAP[§] Top	Spad 30DAP Bottom	Spad 60DAP Top	Spad 60DAP Bottom	Spad 90DAP Top	Spad 90DAP Bottom	Height 30 DAP	Height 60 DAP	Height 90 DAP	Wet Weight	Dry Weight	Hop Length	Hop Diameter
	--rcc--	--rcc--	--rcc--	--rcc--	--rcc--	--rcc--	--cm--	--cm--	--cm--	--g--	--g--	--cm--	--cm--
Cascade	23.0	31.3	22.4	27.1	32.3	32.0	53.3	135.3	151.6	59.5	25.3	2.3	1.5
Mt. Hood	23.3	32.8	18.0	24.6	19.7	26.1	46.5	79.2	89.5	0.4	0.1	0.1	0.1
Santiam	25.0	34.8	20.6	28.4	22.4	29.8	34.2	51.7	64.1	0.5	0.1	0.0	0.0
Mean	23.8	33.0	20.4	26.7	24.8	29.3	44.7	88.8	101.7	20.1	8.5	0.8	0.5
CV (%)	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.1	0.2	0.4	0.5
LSD (0.05)[†]	2.1	3.2	1.7	3.1	14.1	4.2	14.9	22.8	21.7	23.3	12.2	0.4	0.3

[†] LSD calculated to compare within columns.

[§] DAP = Days after planting.

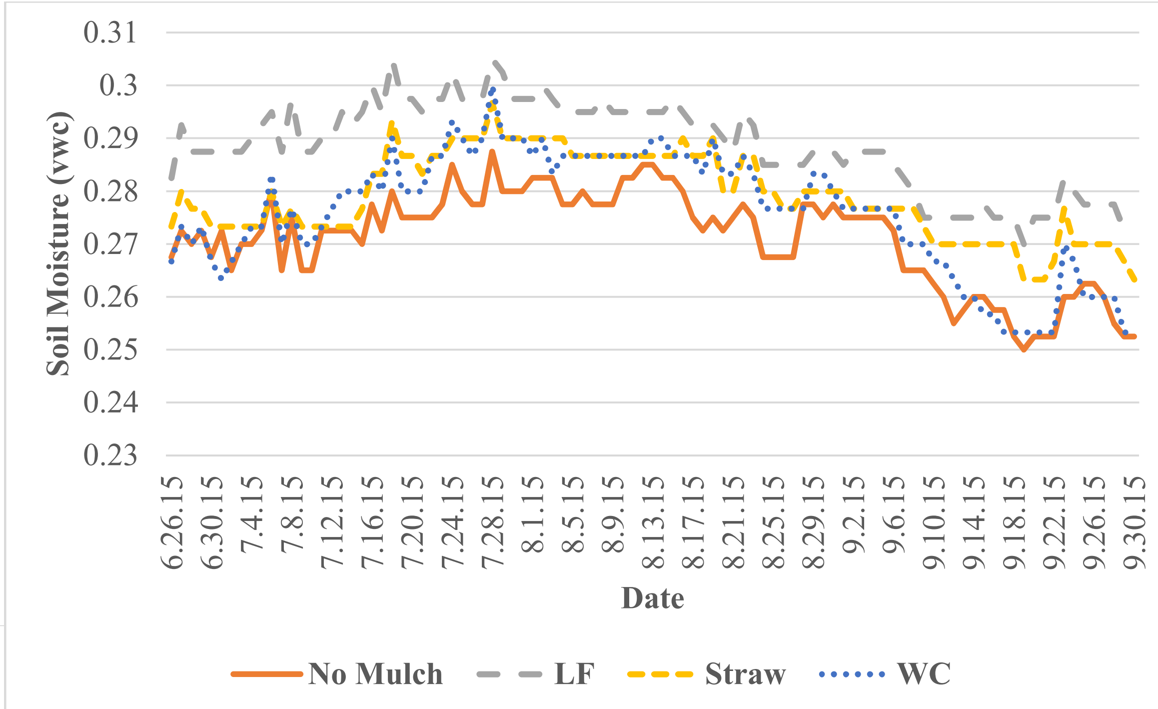

Figure A1. Soil moisture (m^3/m^3) volumetric water content (VMC) for different mulches for the noon hour (hour 12) throughout the 2015 growing season.

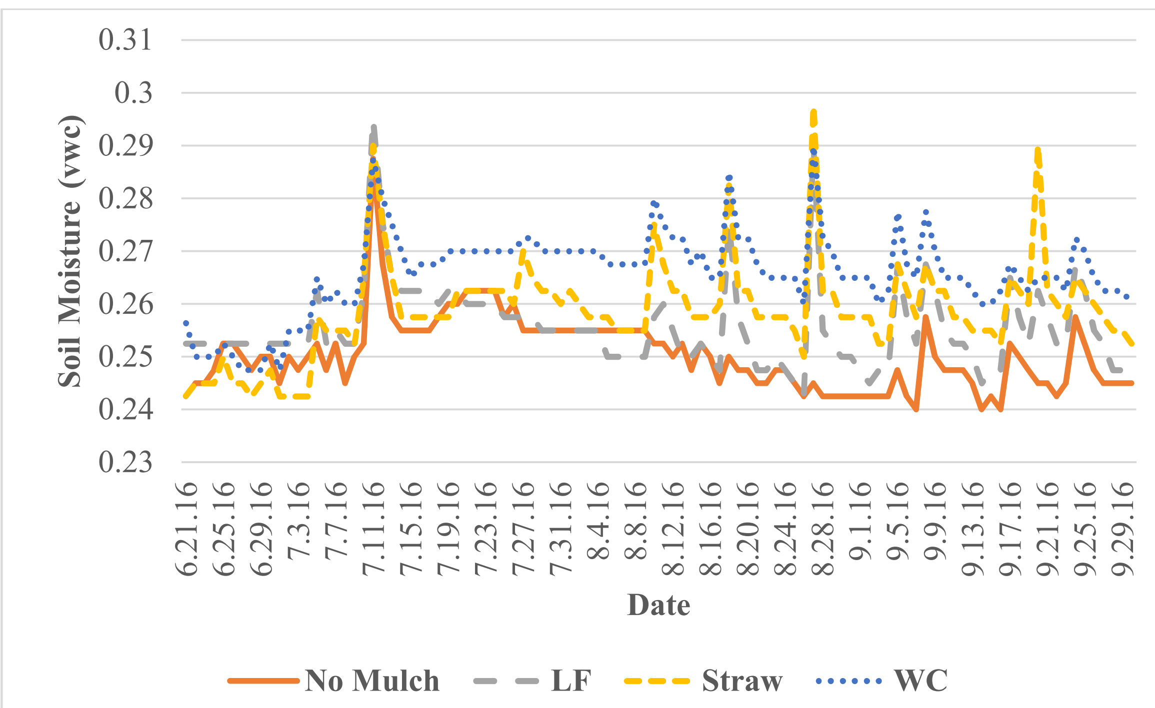

Figure A2. Soil moisture (m^3/m^3) volumetric water content (VMC) for different mulches for the noon hour (hour 12) throughout the 2016 growing season.

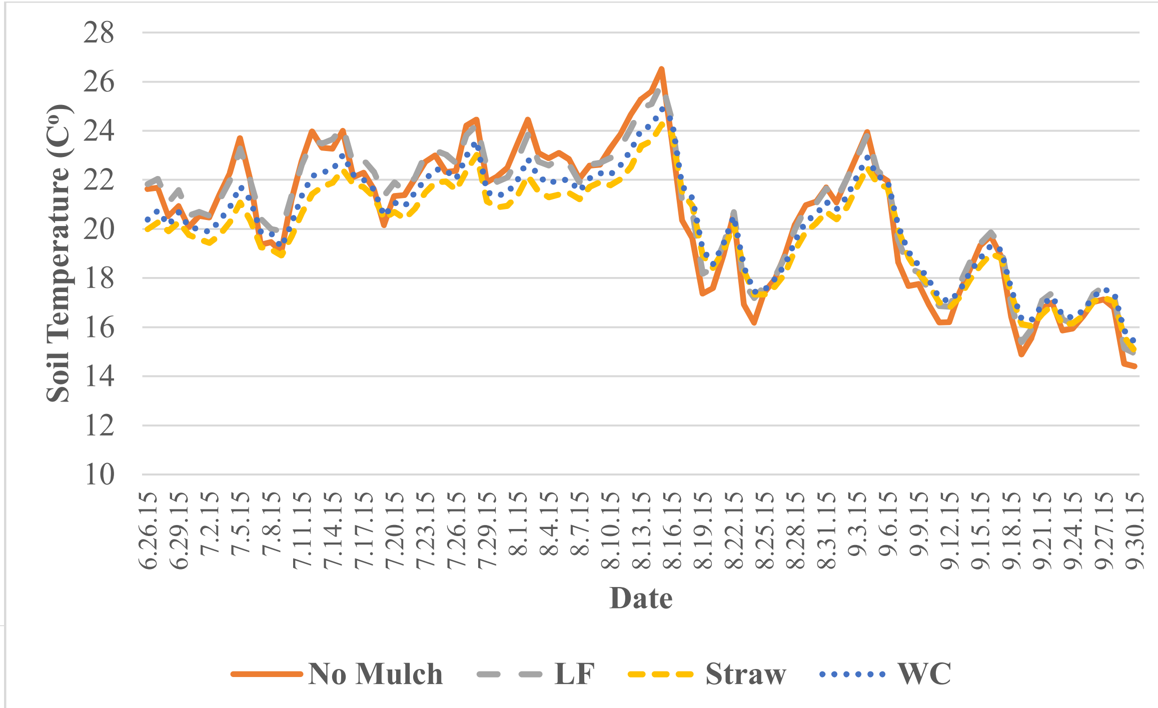

Figure A3. Soil temperature (C) for different mulches for the noon hour (hour 12) throughout the 2015 growing season.

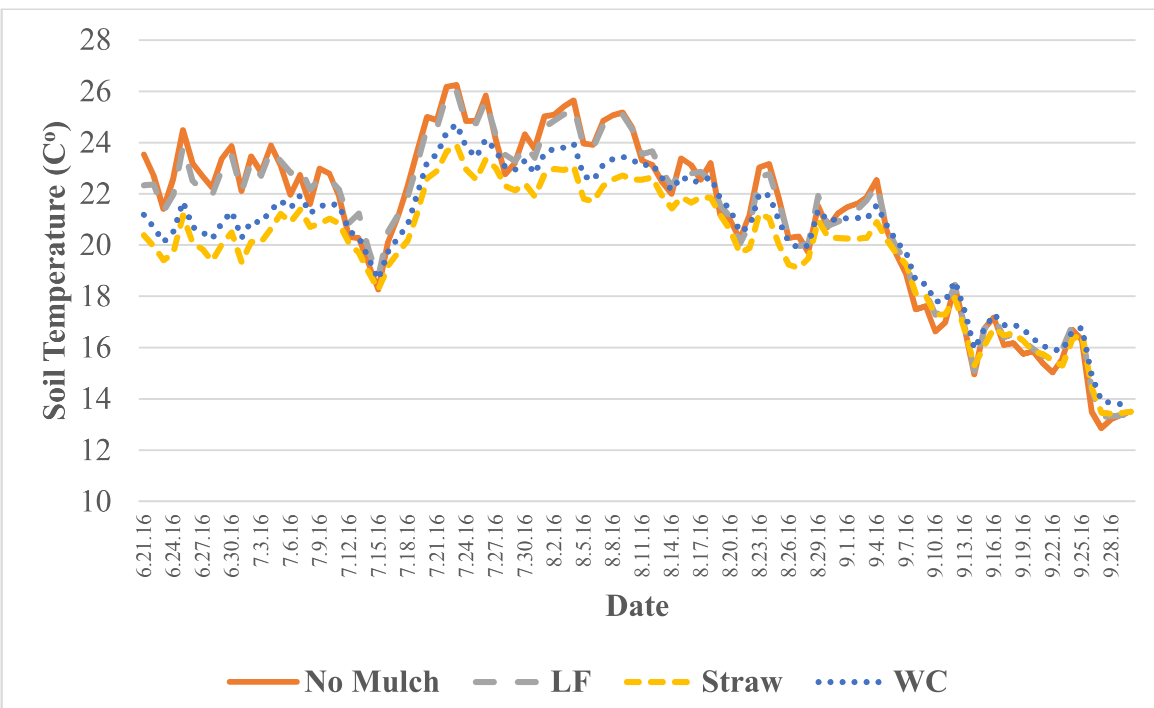

Figure A4. Soil temperature (C) for different mulches for the noon hour (hour 12) throughout the 2016 growing season.

Table A6. Monthly total rainfall, mean maximum temperature and normals for Absaraka[†], ND, 2015 and 2016.

	Absaraka		
Month	2015	2016	Normal
Rainfall		-----------mm-----------	
May	149	82	78
June	110	38	100
July	88	88	88
Aug.	36	26	67
Sept.	22	61	66
Oct.	31	49	62
Total	436	344	461
Temp.		------------C------------	
May	19	23	21
June	26	26	25
July	28	27	28
Aug.	26	28	28
Sept.	25	22	22
Oct.	16	14	14

[†]Weather data taken from the NDAWN station at Prosper, ND, 42 km from the research site.

Table A7. P values for soil moisture and soil temperature for the 2015 growing season as affected by mulch and date of reading (12 pm daily).

		Moisture	Temperature
Source of Variation	df	----Probability > F----	
Mulch	3	0.3032	0.0236*
Date	97	<.0001***	<.0001***
Mulch X Date	289	0.2399	<.0001***

*, **, *** Significant main effects and interactions at P<0.05, 0.01, or 0.001, respectively.

Table A8. P values for soil moisture and soil temperature for the 2016 growing seasons affected by mulch and date of reading (12 pm daily).

		Moisture	Temperature
Source of Variation	df	----Probability > F----	
Mulch	3	0.0326*	<.0001***
Date	101	<.0001***	<.0001***
Mulch X Date	303	<.0001***	<.0001***

*, **, *** Significant main effects and interactions at P<0.05, 0.01, or 0.001, respectively.

Table A9. P values for soil moisture and soil temperature for the 2015 & 2016 growing seasons as affected by mulch and averaged over all dates for every hour of the day.

		Moisture	Temperature
Source of Variation	df	----Probability > F----	
Mulch	3	0.5142	0.0163*
Hour	23	<.0001***	<.0001***
Mulch X Hour	69	0.2694	<.0001***

*, **, *** Significant main effects and interactions at P<0.05, 0.01, or 0.001, respectively.