EVALUATION OF YIELD AND PHENOLOGY OF GARLIC (*ALLIUM SATIVUM*) IN ALASKA

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ABSTRACT

Farmers have been growing crops across Alaska for over one hundred years. Because Alaska spans 16 degrees of latitude and encompasses numerous diverse ecoregions, growing criteria vary widely across the state. Increased agricultural research can help farmers diversify their crops without having to make a significant financial investment before knowing a crops' potential for success. One crop gaining popularity throughout Alaska is garlic. The goals of this thesis are twofold: to survey Alaskan farmers currently cultivating garlic to develop a better understanding of variations in cultivation practices, and to perform crop trials to demonstrate how small-scale independent growing projects can be used to replace the agricultural information formerly provided by an extensive network of agricultural research stations in Alaska. In my growing trials, the timeline of plant development changed between 2015 and 2016 with emergence, scape emergence, and harvest happening earlier in 2016 than in 2015. Despite this observed increase in the phenological timeline, and overall increase in bulb weights, circumference, and clove counts, the average return rate was 63% for the 2016 trials, compared to 73% in 2015. A number of factors could have resulted in the increases in phenological timeline and bulb phenotype observed in 2016, including low snowfall and mild winter temperatures. Pest appearance and inconsistent planting practices may have resulted in the decreased return rates observed in 2016. While Alaska may not see the reemergence of agricultural research stations, independent investigations may provide an alternative solution for important agricultural research.

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AN INTRODUCTION TO GARLIC IN ALASKA

Alaska is the largest state in the United States – covering 1,717,856 km^2 and 16 degrees latitude and comprised of 32 different ecoregions, ranging from coastal western hemlock-Sitka spruce forests in the south to Arctic coastal plains of the north (Nowacki et al., 2001a). Historically, farmers have been growing crops across the entire state; however, given the diverse range of environmental conditions found within Alaska, growing criteria can vary widely with location. Because growing criteria; such as when to plant, soil temperatures, soil types, and overwintering methods; are highly influenced by ecoregion, latitude, and altitude, it would be an oversimplification to promote statewide agricultural practices. Development of a knowledge base about region-specific growing criteria allows farmers in Alaska to have successful crops, higher returns, and better utilization of resources without investing time and energy into suboptimal growing practices.

Starting in 1898, the Department of Agriculture addressed the diversity of growing conditions in Alaska by establishing Agriculture Experimental Stations around the then-territory. Each year, these stations submitted reports to United States Department of Agriculture in Washington D.C. with information about crops tested, growing locations, and performance. For example, in the 1902 report, seeds from varieties that had performed well at the experimental stations were sent to over 750 homesteaders, gold miners, and residents within the territory (Georgeson, 1902), thereby expanding the range of the experimental station reports. The practice of sending seeds to residents around the state would continue for many years, enriching the agricultural knowledge of the territory. Feedback came from all regions within Alaska, with information about growing practices, failures, and success for each location. Today, Alaska lacks such a robust agricultural focus. Currently, only two experiment farms remain, and budget cuts threaten to further reduce agricultural services provided throughout the state. Because only two regions are now represented in formal crop research, the burdens of time, energy, and money for experimentation are put on farmers. This situation could be partially alleviated by increasing the ease with which information from small-scale independent research can be accessed by farmers in the agricultural community.

In addition to Alaska's large spatial extent, and consequent diverse ecological composition, changing agricultural and population dynamics within the state command further agricultural research. According to the 2012 USDA Census of Agriculture, over the past decade the number of farmers in Alaska is increasing (USDA NASS, 2014). While nationwide the number of farms of 0.4 – 3.6 Ha (1-9 acres) is shrinking; in Alaska, where nearly a third of farms fall into that size range, that number is growing. In addition, the demand for "Alaska Grown" products and farmers-markets has been growing. In 2005, there were 13 farmers-markets in Alaska compared to 40 in 2016 (Alaska DNR Division of Agriculture, 2016). With a growing number of small-scale farmers engaged in northern-latitude agriculture, and a higher demand for locally grown produce, resources and research need to be readily accessible to allow for greater increases in production. The ability to equip farmers with better data and more regionally-specific agricultural research has the potential to foster larger and more efficient agricultural production in Alaska.

Historically, carrots, potatoes, and cabbages have been grown in Alaska. However, focused research into other crops with potential for success would benefit Alaska's growing number of farming operations by allowing farmers to diversify their crops without incurring the significant financial risk associated with experimentation. One high-value crop growing in popularity throughout Alaska is garlic (*Allium sativum*). In the 2010 Alaska Grown Sourcebook, a comprehensive guide to agricultural operations throughout Alaska, 10 farmers reported growing garlic (Alaska DNR, 2010). In 2016, that number had grown to 41 (Alaska DNR, 2016). The earliest recording of garlic being grown in Alaska was on May 14, 1903 when three bulbs were planted in Copper Center (Georgeson, 1903). The report simply stated that “none started”, and garlic was never included in any further agricultural trials. Given the brief nature of the report, the reasons for the crop’s poor performance and any differences from current agricultural practices are unknown. However, the recent success of small-scale garlic cultivation in Alaska, and the successful cultivation of garlic in other arctic and sub-arctic regions in the world, contradict the findings of this early test.

Garlic Types

Since garlic has been traded, transported, and dispersed throughout Asia, Europe, and sub-Sahara Africa during multiple millennia, it has evolved to encompass many variants. Distinctions are widely manifested through bulb size, color, shape, maturity date, taste, bolting ability, scape height, scape shape, number of cloves, fertility, flower development, and number and size of bulbils (Etoh and Simon, 2002). Domesticated garlic is commonly separated into two types: hardneck, which develops scapes (also known as bolting), and softneck, which does not develop scapes (also known as non-bolting). Scapes are the edible flower stalk it will bend, twist and coil differently for each variety as it develops, before uncoiling and standing upright (Rosen & Tong, 2001). Generally, hardneck types are better suited to cooler climates, while softnecks are better suited to warmer climates. Recent genetic research and growing trials indicate the existence of a possible third type described as “weakly-bolting” or “semi-bolting” – meaning that the plant may sometimes develop a scape under specific conditions (Etoh and Simon 2002, Ovesna et al., 2010).

Within these types, there are a number of subtypes characterized by morphology, as well as variation among isozymes and DNA markers (Volk et al., 2004). Subtypes of softneck include Silverskin and Artichoke; and subtypes of hardneck include Purple Stripe, Marbled Purple Stripe, Porcelain, and Rocambole. Some confusion remains concerning the Asiatic, Turban, and Creole subtypes. While these subtypes are genetically similar to softnecks (Pooler and Simon, 1993) they develop scapes under certain conditions. Genetic research completed by Volk et al. (2004) classified some Asiatic subtypes as both hardneck and softneck. While Creole subtypes grouped with hardneck subtypes in some studies, in other research they grouped with softneck subtypes. For this study, I considered Asiatic, Creole, and Turban as weakly- bolting subtypes since they reflect aspects of both hardneck and softneck types. Information about the categorization and performance of these subtypes allows farmers to develop predictions and expectations for crop performance and harvest.

During a series of growth trials assessing performance under different environmental conditions, Volk and Stern (2009) observed phenotypic plasticity in the form of variations in skin wrapper color, clove number, and yield among genetically identical plants grown under distinct environmental conditions. Given that Alaska spans nearly the same longitude as the contiguous United States, as well as 16 degrees of latitudinal range compared to the 6 degrees in the study, it is important to note that Alaskan growers may see increased phenotypic diversity in garlic compared to growers in the continental United States

Garlic Nomenclature

Garlic has never had a formally standardized nomenclature of cultivars. Bulbs have been traded, passed down, and given various names throughout different regions of the world for so long that some bulbs with different names may be genetically identical and bulbs with the same name may exhibit significant genetic differences. Most varieties, such as German White, Spanish Roja, and Chengdu were named according to location of origin and others for a series of morphological characteristics (e.g. the shape of the scape, clove number, height, and bulb wrapper color). The garlic in this trial was purchased from Filaree Farms in Okanagan, Washington and follows their naming scheme for garlic (Engeland, 1991), which is widely used in the U.S., and is mostly supported by genetic research (Volk, et.al 2004).

Garlic Marketability

Garlic has unique marketability to both farmers and consumers in Alaska. Farmers may find appeal in the potential to get two harvests from the same garlic crop (if it is a hardneck type where scapes and bulbs can be harvested), garlic's ability to withstand long-term storage, the ease with which garlic seeds can be saved (Meredith, 2008; Engeland, 1991), and the potential to charge a premium for this niche crop. Consumers may appreciate garlic's renowned health benefits (Rivlin, 2001; Lawson, 1996; Hahn, 1988b; Block, 1986) and access to a greater range of garlic subtypes. Garlic found in grocery stores is usually a softneck type, with only one option available. Farmers who choose to grow garlic can grow different varieties consumers would be unable to find elsewhere. Hardneck types, which are well suited for the cooler northern latitudes of Alaska, produce an edible scape that can be harvested and sold about a month before the bulb is ready to be harvested. Not only does this generate additional profits for farmers, but again, it is a product not normally found in grocery stores. Similar to the carrot and potato crops, garlic is a long-term storage crop that can be sold through fall and winter markets. While garlic is an expensive crop to start growing (garlic seed is commonly sold at $20+ per pound and seed potatoes can be sold around $5-12 per pound), bulbs can be saved and replanted or sold as local seed garlic. After the initial investment, the replanting of garlic can also result in larger planting stock for years afterward.

The Future of Garlic in Alaska

Garlic may not have been well documented in Alaska in 1903, but today it is becoming a crop that can be found at farmers-markets from Southeast to Interior Alaska. Even though garlic is gaining popularity, there has been very little formalized research into how garlic grows in the diverse climates in Alaska. It was not until 2015 that the Alaska Cooperative Extension Service published the first document about growing garlic in Alaska. Since this crop can thrive in the subarctic, does not have diverse representation commercially, and provides numerous harvests and stock for the following growing season, it has great potential for success throughout the state. More research could help new and experienced garlic farmers discern which cultural practices suit their unique climates and set them up for successful harvests

EVALUATION OF CURRENT GROWING PRACTICES IN ALASKA

Introduction

Garlic has been grown for decades throughout the environmentally-diverse regions in Alaska, yet very little research has been conducted to study the potential effects of this environmental diversity on the performance of the crop. It was only in 2015 that the Alaska Cooperative Extension Service released a publication about growing garlic in Alaska. Documentation on how farmers mitigate the effects of heavy rains, substantial seasonal temperature variation, and diverse terrain while producing successful garlic crops can help to develop better agricultural practices that lead to more predictable harvests for farmers within Alaska or the circumpolar region in general. The goals of this work were to survey Alaskan farmers currently cultivating garlic to develop a better understanding of variations in garlic cultivation practices among the environmental gradients observed within this high latitude region and to provide Alaskan farmers with useful production information to better understand how garlic can be grown in Alaska.

While Alaska is comprised of over 30 different ecoregions (Nowacki et al., 2001a), the state is commonly divided into five rough geographic regions: Southeast, Southcentral, Interior, Southwest, and the Northwest/Arctic. Although each of these geographic regions (hereafter simply called *regions*) are comprised of multiple ecoregions and numerous microclimates; each of the regions can be characterized according to its general biogeophysical and climatic characteristics. In Alaska, there are three regions where agriculture is widely practiced: Southeast, Southcentral, and Interior. The three regions vary enormously in climate and terrain. Southeastern Alaska is characterized as a fjordland in a cool, maritime climate with temperate rainforests, abundant precipitation, and little seasonal temperature variation (Nowacki et al., 2001b). Southcentral Alaska is a mix of continental and maritime climates with moderate seasonal temperature fluxes, post-glacial valleys, high alpine communities, as well as coastal flats and wetlands (Nowacki et al., 2001b). Interior Alaska has a continental climate with frigid winters and short, warm summers, permafrost valleys, and boreal forests (Nowacki et al., 2001b).

Alaskan garlic farmers have applied many adaptive strategies to mitigate against unfavorable growing conditions. Two common strategies are the use of a protective winter mulch and using a high tunnel. A protective winter mulch is placed over the planted garlic cloves in the fall, and may stay on the crop through the seasons or may be removed in the spring to allow beds to warm. This winter mulch helps insulate the garlic beds and moderates the soil temperature, protecting cloves from temperature fluctuations which can damage the plants. Another popular adaptive measure is the use of high tunnels. These structures are essentially unheated greenhouses that can buffer crops from cool or warm temperatures, as well as rain. In Alaska, high tunnels are commonly used as season extenders, allowing farmers to plant in unfrozen soils in the spring, and continue to grow as the season begins to cool in the fall. High tunnels are especially useful in areas like Southeastern Alaska where the structures can help mitigate against the high amounts of precipitation farmers see throughout the year.

Here, I report the results of a survey designed to assess the agricultural practices of garlic farmers in Southeast, Southcentral, and Interior Alaska and identify potential patterns in the use of adaptive agricultural strategies among the regions. Identifying similarities in the planting methods, planting dates, and environment modifiers used by garlic farmers within and among the three regions can both indicate how farmers adjust to regionally-specific growing conditions to ensure a successful crop and inform future farmers on how to amend or modify their methods to account for these conditions.

Methods

In late 2015, all commercial farmers who reported growing garlic (n=30) in the Alaska Grown Source Book (Alaska DNR, Division of Agriculture, 2015) were contacted via email. The Alaska Grown Source Book is a directory of farms and their products, as well as farmers-markets, community sponsored agriculture locations, and other farm-related business. The initial contact email posed a series of questions concerning farmers' garlic growing history, methods, and yields. Specific information requested included planting and harvest dates, varieties grown, quantities planted and harvested, seed source, planting methods, bed rotation practices, if the farmer had noticed any changes within their stock, and what the farmer considered a marketable bulb. These survey questions were designed to assess potential differences in growing practices and yields from latitude 56° 76' to 64° 84', the total range in which farmers growing garlic are located in Alaska. Emails were sent to farmers in the winter of 2015 to collect data on the crop that had planted in the fall of 2015 and the resulting harvest in the summer of 2016.

Survey results were compiled into a dataset that included latitude and longitude, planting date, harvest date, fertilizer, mulch type, soil amendment, number planted, number returned, use of a high tunnel, varieties used, and additional comments or issues the farmer experienced. High tunnel use and mulch use and type were included in the final dataset because they were the two adaptive agricultural techniques most frequently implemented by survey respondents to modify growing environments. Average total precipitation and annual extreme low temperature were also included for each location. These environmental features were included because they vary widely throughout Alaska and are primary determinants of agricultural practices. Average total precipitation data for Alaska for the years 1961-1990 was obtained from the Arctic Landscape Conservation Cooperative. Annual extreme low temperature data for Alaska for the years 1976-2005 was obtained from Oregon State University and the PRISM Group. Annual extreme low temperatures were provided in a format developed by the United States Department of Agriculture (USDA) to numerically categorize similar growing zones in the United States. ArcMap 10.4.1. was used to create spatial representations of the farm locations, use of environmental modifiers, and environmental parameters.

Results

Of the 38 farmers contacted, 17 responded. Of those, eight farmers declined to participate and nine farmers submitted responses. The farmers who declined did so due to poor garlic returns in previous years, they felt they were still learning about garlic cultivation, they felt their growing operations were too small to provide useful information, or they had forwarded the email to caretakers and were never heard from again. The farmers who did respond sent emails, documents, spreadsheets, photographs, and even called to talk about their history and garlic growing practices in Alaska.

The nine farmers that responded were evenly distributed between the three major agricultural regions, with three farmers in Southeast, three in Southcentral, and three in the Interior (Table 1). Seven farmers planted exclusively hardneck types of garlic and two farmers in the Southcentral region grew a combination of hardneck and softneck types. Nearly all farmers replant from their own seedstock, but also buy seed garlic from other local farmers or ship seed stock from the Lower 48. Farmers generally reported that replanting the largest and most robust cloves has resulted in larger bulbs over time; although one farmer did not engage in this practice as they had heard that replanted garlic would be too small to regrow. One interesting observation made by the two Interior farmers and a Southcentral farmer was that Porcelain types of garlic tend to develop large, but fewer cloves per bulb (only 2-3 big cloves).

Garlic return rates were reported in two ways: percent return (number of plants harvested divided by number of plants planted) and number of pounds returned for every one pound planted (Table 1). There was no significant pattern in either the return rates themselves nor the reporting method between the regions. In addition, no clear pattern in the subtypes of garlic planted was evident among the three regions, with the exception that everyone grows at least one Porcelain variety of hardneck. In the Interior region, reported return rates ranged between 2.6 and 4 lbs/ lb planted; with one farmer reporting return rates of 4 lbs/ lb planted for the subtypes Music and German White, and a second farmer reporting return rates of 2.6 lbs/ lb planted of the subtypes Turkish Giant, Music, and Deerfield Purple. The third Interior farmer reported average return rates of 3 lbs/ lb planted (average 88% return – this farmer reported return rates as both ratios and percentages) across six varieties. Varieties Chesnok Red, Purple Glaser, Kraznador, Siberian, and Romanian Red had return rates between 93-95% with German Red at 60% return rate. In addition, the farmer’s Chesnok Red had been saved and replanted since 2011. In the Southcentral region, two farmers reported return rates of 92% for subtypes German Red, Music, Polish Softneck, Western Rose, and Spanish Roja and 95% for subtypes German Red, Russian Red, Russian Giant, Siberian, Shantang Purple, Spanish Roja, and a mystery purple. The third farmer in the Southcentral region reported average returns of 4.6 lbs/ lb planted for subtypes

Silverskin, Red Toch, Nootka Rose, Chesnok Red, Romanian Red, Georgian Red, Lorz, Xian, Music, Killarney Red, Purple Glazer, and Inchelium Red. Two of the farmers in the Southeast region reported return rates of 95% for subtypes Russian Giant, Killarney Red, Pskem, Purple Glazer, and Chesnok Red and 94% for subtypes Georgian Crystal, Music, Killarney Red, Russian Giant, and Island Rocambole. One of these farmers, from Petersburg, commented that although average return rates were 94%, the return rates in the individual Georgian Crystal beds varied from 87-100%. The third farmer in the Southeast region grew an inherited garlic (possibly Music) and reported harvesting 41 pounds from a 52 ft^2 bed. It was unknown how many pounds were originally planted

Planting dates were similar among the three regions. All of the farmers planted their garlic in September and October. However, harvest dates differed between the regions. Farmers in the Southeast region had the earliest harvest in July, Southcentral farmers harvest from July to August, and Interior farmers harvest from August to September.

One aspect of garlic production that varied widely between farmers, but with no regional pattern, was how farmers defined a “marketable bulb.” One farmer in the Southeast region looked at the size of the bulb (a 2.5 inch/6.35 cm diameter); whereas another farmer in the Interior region assessed marketability based on number of cloves present (7 cloves or more being preferred). Still another farmer judged marketability by how many bulbs where in a pound, 8 bulbs/pound on the low end with 4 bulbs/pound being ideal. Three farmers looked at the return rates in their field; indicating that a low performing garlic type in the field (2 lbs/ lb planted) would not be as ideal as one with higher return rates (4 lbs/ lb planted). One farmer from Interior Alaska assessed success as return rates of at least 2 lbs/ lb planted.

High tunnel use was common among respondents from all three regions (Figure 1). All three farmers in the Southcentral region reported using high tunnels (but two of these farmers also plant garlic outside the high tunnel), as did one farmer in the Interior region, and two farmers in the Southeast region (one of whom also planted outside of the high tunnel). Two of the farmers noted some unique attributes to their use of high tunnels. One farmer in the Southcentral region reported adding two inches (5 cm) of foam insulation surrounding the high tunnel. In the Southeast region, where the highest amount of precipitation occurs, one farmer installed their high tunnels on wheels to roll them over crops in the winter (during the wettest time) and removed when not needed. Another farmer in the Southeast region put tarps over the mulched garlic beds from November until March as a way to mitigate against the heavy precipitation. While high tunnel usage was common in all three regions, farmers implemented unique, regionally-specific high tunnel modifications and techniques.

Protective mulch use was also common throughout the three regions (Figure 2). Mulch types varied by region and included seaweed, hay, straw, grass clippings, wood chips, IRT plastic, or no mulch at all. In the Southeast region all three farmers used seaweed, while farmers in the Southcentral and Interior regions primarily used straw, hay, grass clippings, or wood chips. Not all farmers removed protective mulch in the spring, opting to keep it on crops through the entirety of the growing season, albeit with somewhat mixed results. For example, one Southcentral farmer commented that softneck varieties struggled to emerge through a trial run of wood chip protective mulch, while an Interior farmer indicated that leaving mulch on over the growing season can protect the growing garlic plants from sudden, unexpected temperature drops in late spring.

Location	Altitude (m)	Average Precipitation (cm)	Average Lowest Temperature (F)	Garlic Growing Experience (Years)	Mulch	High Tunnel (Yes/No)	Bed Rotation (Years)	Return Rate	Plant Date	Harvest Date
Ester Interior 64°840', -148°136'	502	42.4	-45 to -40	13+	None	N	Yes	4 lbs per 1 lb	September	August
Ester Interior 64°808', -148°130'	241	36.3	-45 to -40	5	Hay	N	3	88%	September	August
Delta Junction Interior 64°061', -145°877'	347	36.8	-50 to -45	3	Hay, grass clippings	Y		2.6 lbs per 1 lb	October	September
Anchorage Southcentral 61°10', -150°49'		38.9	-20 to -15	2	Woodchips	Y	n/a	92%	October	August
Homer Southcentral 59°684', -151°412'	100	72.5	-10 to -5		Straw	Y	n/a	95%	October	July
Homer Southcentral 59°71', -151°29'	137	72.5	-10 to -5		Hay	Y		4.6 lbs per 1 lb	September - October	July - August
Juneau Southeast 58°37', -134°73'	40	167	5 to 10	30+	Seaweed, IRT	Y	2	95%	Fall equinox	July
Sitka Southeast 57°05', -135°33'	4	239	5 to 10	6	Seaweed	N	Yes	---	October	July
Petersburg Southeast 57°11', -133°27'	15	198.5	5 to 10	20+	Seaweed	Y	3	94%	September	July

Table 1. Responses from the garlic farmers surveyed in 2015. Variability in the mensuration and reporting of return rates may have been prevented by contacting farmers before planting instead of after the planting had been completed.

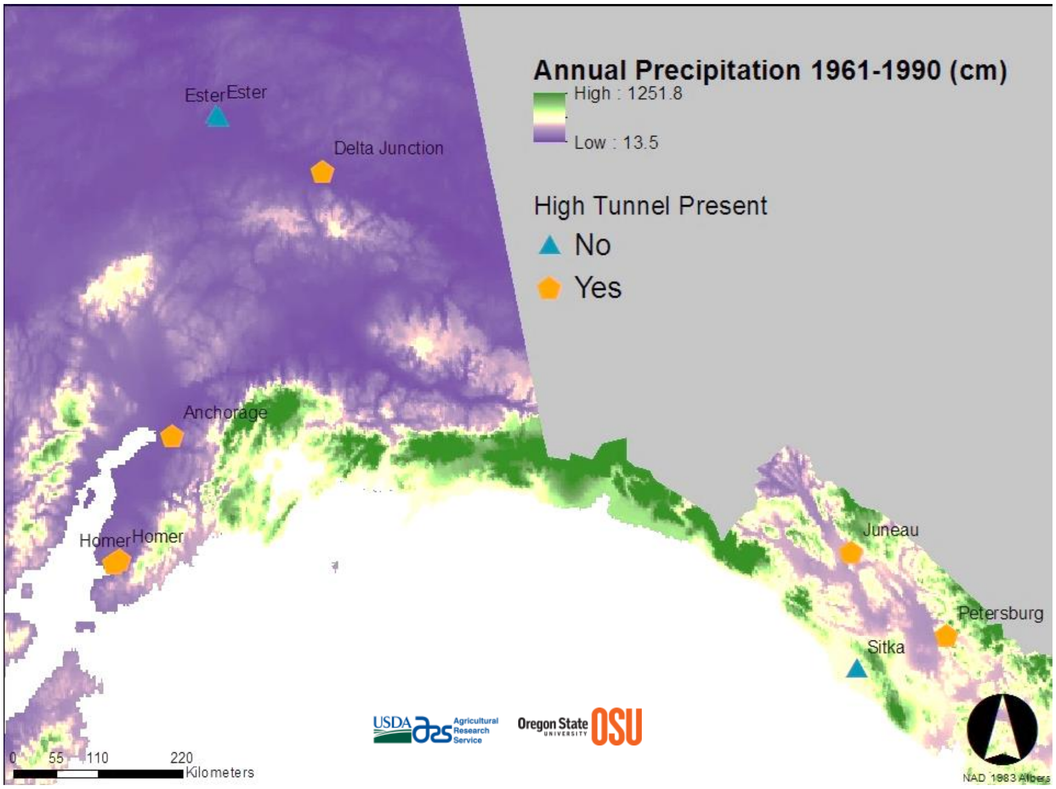

Figure 1. Average annual precipitation over a 29-year period and high tunnel use among Alaska garlic farmers. High tunnels help control temperature and precipitation that plants are exposed to. No regional patterns in high tunnel use were observed from survey responses.

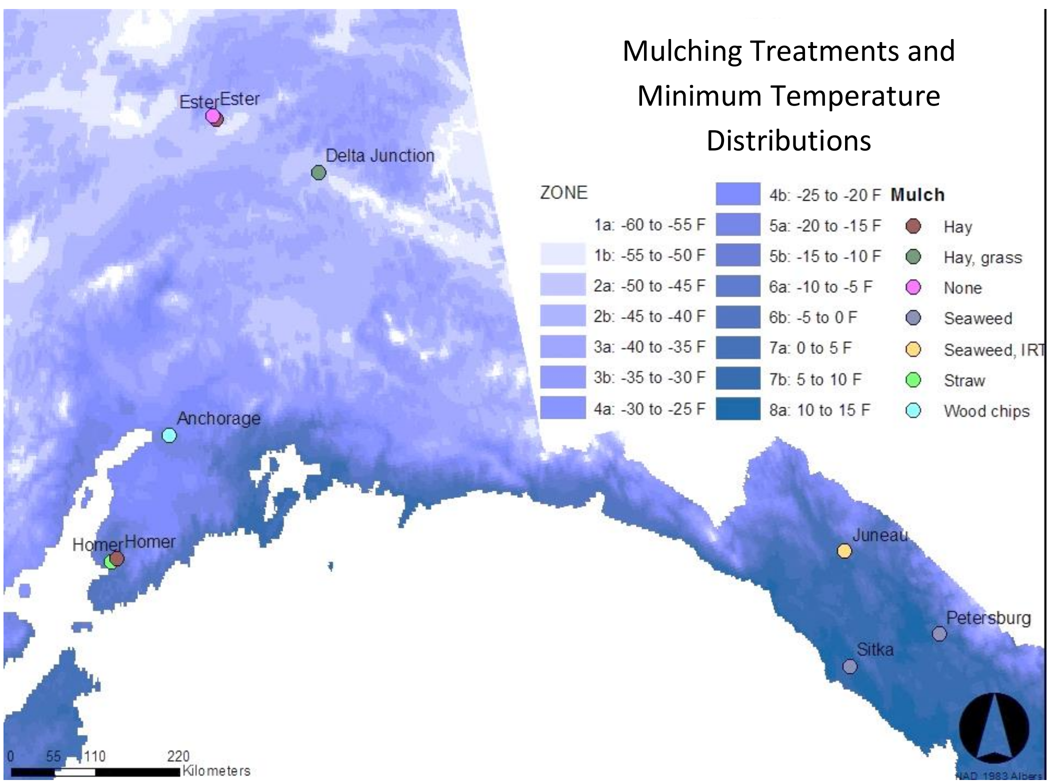

Figure 2. Mulching treatments and minimum temperature distributions across Alaska.Mulch use was common and consistent among the three regions; however mulch type varied by region.

Eight of the nine farmers used some sort of fertilizer and/or soil amendment to enhance the productivity of their fields. Farmers in the Interior region reported using compost, gypsum, and aged manure. Farmers in the Southcentral region used compost, blood meal, bone meal, liquid fish emulsion, and lime. Southeast farmers used fishmeal, fish fertilizer, rock phosphate, and salmon carcasses. While farmer around Alaska have differing soil profiles characteristic of their respective ecoregions, it was unclear as to whether the fertilization practices of farmers between the three regions were specifically-suited to the region's soil type or if fertilization treatments were chosen based simply on cost and availability. The overall high prevalence of fertilizer and/or soil amendment use is not; however, surprising as Alaska soils tend to be fairly acidic (Seefeldt, 2016), and soil in Interior Alaska is not naturally fertile and deficient in many micronutrients (USDA NRCS, 2004).

Discussion

Survey responses showed few regionally-specific agricultural practices, and, in many cases, greater variation was seen among farmers within a region that among the three regions. In the following sections, I address potential reasons for this variability and offer insight as to how increased communication, documentation, and dissemination of information on agricultural practices among garlic farmers in Alaska might foster the development of regionally-specific strategies to increase production efficiency.

Among the three regions, farmers differed in their cultivation practices. However, there was no clear region-specific differences. Interestingly, some of these practices counter the advice by the Alaska Cooperative Extension Service and other far-north "best practice" guides (Rosen et al., 2016; Delahaut and Newenhouse, 2003; Goldy, 2000). For example, not all farmers use a protective winter mulch, or the recommended mulch which has been set forth by these guides. The mulching materials used by respondents to my survey may be primarily a function of availability, rather than a thorough study of which is the best protective mulch. Similarly, mulch removal practices differed between farmers, but not in a region-specific fashion. Farmers who used mulch in their high tunnels did not remove the mulch in the spring. These treatments would have been protected from snowfall, thereby, avoiding impact from spring freeze-thaw cycles (Waterer and Schmitz, 1994; Rosen and Tong, 2001). Only one other farmer reported not removing mulch in the spring. This farmer, located in the Interior region, left mulch on in the spring in order to protect again unexpected cold spells that could damage garlic once the protective mulch was removed. This was one of the few examples of region-specific cultivation practices evidenced in my survey results. This practice was not; however, shared by other Interior garlic farmers.

Variability in reported growing practices may have also been influenced by the mild winter temperatures and relatively low snowfall experienced by Alaska during 2015/2016 (Di Liberto, 2016). For example, two farmers in the Southeast region reported that for the 2015/2016 growing season, the harvest dates were 1-4 weeks earlier than in previous years. Low snowfalls and higher temperatures would allow fields to thaw sooner, resulting in crops emerging earlier and consequently, being harvested earlier. In addition, warmer winter temperatures and lower snow levels may reduce the impact of environmentally adaptive cultivation practices and consequent biased survey results. Future surveys would be required to understand the magnitude of this potential effect.

Inconsistency in data reporting may be a function of poor study design and timing rather than poor record keeping. Ideally, farmers should have been contacted before garlic was planted with a request for a standard measurement of return. Instead, farmers were contacted in late October of 2015, after garlic had been planted and farmers were shutting down their farming operations for the winter. As a result, farmers provided return data that was calculated using multiple unrelated mensuration techniques. Based on this discrepancy, I recommend contacting farmers early in the summer with explicitly defined metrics for evaluation.

The lack of regionally-specific cultivation practices described in this work demonstrates the determinate nature of garlic farming practices in the State of Alaska and exposes the need for increased information sharing among farmers. Compiling information on growing practices from farmers in different regions of Alaska, making this information readily available, and fostering increased dialogue among farmers will assist current and future farmers to improve their own growing operations in ways specific to their regional environments.

EVALUATION OF YIELD AND PHENOLOGY OF *ALLIUM SATIVUM*

Introduction

Almost 120 years ago, Alaska began to create a robust agriculture research system with research stations across the state growing subarctic-hardy varieties of fruits, vegetables, and grains (School of Agriculture and Land Resources Management, 1998). Reports of growing trials conducted at these stations were sent to the US Department of Agriculture headquarters in Washington D.C. Seed packets from successful growing trials were subsequently sent to citizens throughout Alaska, thereby functionally replicating growing trials and expanding trials to include a variety of regional conditions. In 1909 alone, crop trials were reported from experimental stations at Sitka, Rampart, Kodiak, and Fairbanks, along with letters from homesteaders and rural residents in Hollis, Shelter Island, Juneau, Klukwan, Valdez, Hope, Afognak, Sannak Island, Unalaska, Quinhagak, Bethel, Anvik, Holy Cross Mission, Eagle, McCarty, Shungnak, and Coldfoot. As a result of this program, understanding of agricultural production in Alaska grew to rival that of high-latitude nations such as Sweden, Finland, and Norway – countries that had been experimenting with high-latitude agricultural production for over a thousand years (Widgren and Pedersen, 2011; Alenius et al., 2008; Libæk and Stenersen, 1991).

During this time, research stations in Copper Center, Kenai, Kodiak, Rampart, and Sitka created arctic hardy varieties of potato, strawberry, barley, wheat, clover, oats, cabbage, tomato, corn, and raspberries to name a few (School of Agriculture and Land Resources Management, 1998). Unfortunately, between 1908-1932 lack of funding resulted in the closure of these five research stations (School of Agriculture and Land Resources Management, 1998). Since 1984, only two agricultural research stations (Fairbanks and the Mat-Su Valley) have remained in operation. While still valuable, these two stations represent only a small fraction of the environmentally-diverse regions found in Alaska. Alaska spans 16 degree of latitude and encompasses over 30 uniquely defined ecoregions in Alaska (Nowacki et al., 2001a). Consequently, the whole state cannot possibly be captured and recommendations made based on two research stations that are less than 4 degrees of latitude apart. As a result, work performed at these stations is not necessarily applicable to other regions in the state.

The need for increased agricultural research in Alaska goes beyond addressing the diversity of environmental conditions found within the state. Increases in population (Department of Labor and Workforce Development, 2017), the potential effects of climate change (Alaska Climate Research Center, 2016; Commane et al., 2017; National Snow and Ice Data Center, 2017), increased demand for locally-grown foods (Bradner, 2017), escalations in the establishment of small-acreage farms (2012 Census of Agriculture, 2014); and concerns about food security (Stevenson et al., 2014) are all current issues in Alaska that demand research into agricultural practices. Without a network of agricultural research stations, Alaskans must engineer a novel method by which agricultural practices can be tested and communicated. Independent investigations by small-scale farmers and gardeners might provide an alternative solution to this need.

Small-scale investigations are not dependent on federal or state funding – a major reason for shuttering previous agricultural research operations. Research can be implemented where infrastructure or growing operations already exist, using what is available in regions to inform the surrounding communities on agricultural possibilities. Information can be collected, processed, and disseminated online, through gardening groups, or smart phone applications. Research can be conducted in tandem with university students for multi-year crop investigations that allow students the opportunity to perform scientific work that may benefit farmers. Here, Ipresent one case study developed and performed as such an independent investigation on a relatively novel crop species for Alaska – garlic (*Allium sativum*).

Garlic cultivation was first documented in Alaska in 1903 when a grower in Copper Center wrote the following two lines: "*Garlic.* – Three bulbs accompanied the onion sets [in May] and were set out at the same time, but none started." No details on the name of the garlic variety, how it was grown, yield, or other specific information accompany the documentation. Since this initial mention, garlic has been grown in various locations throughout the state, but there is little formalized research or documentation concerning practices for growing garlic in Alaska. This research aims to both alleviate the lack of information on practices for cultivating garlic in Alaska and to demonstrate how small-scale independent growing projects can be used to provide the information formerly provided by the once-extensive network of agricultural research stations. Briefly, a two-year trial grew a variety of garlic types to investigate the effects of garlic type, phenology, mulch depth, and replanting bulbs on overall yield.

Methods

Sixteen hardneck garlic cultivars were chosen for a two-year growing trial based on prior growing success and availability in Alaska as determined by the staff at the Alaska Botanical Garden (Table 2). Between 10-14 individual cloves of each cultivar were planted in equidistant rows (15cm to nearest neighbor) in raised beds (121.5 cm x 51.5 cm x 16.5 cm). Variations in the number of cloves planted between cultivars was the result of clove wrappers breaking, double cloves, and weak cloves, which were not included in the planting. The cloves were placed into holes 10 cm deep with a tablespoon of organic soybean meal. Soybean meal is high in nitrogen, which is critical to high yields of garlic (Tyler et al., 1988; Diriba-Shiferaw et al., 2013). Cloves were planted in late September through early October 2014. Typically, cloves are planted in the fall in regions with cold winters, before the ground freezes so they can develop roots before winter temperatures slow growth (Walters, 2008; Bratsch, 2009). To increase thermal insulation and give the garlic more time to develop a healthy root system, 30 cm of straw mulch was put on top of the beds (Bratsch,2009; Engeland, 1991).

The straw mulch was taken off the beds when the freeze-thaw cycle began (roughly mid-April). This allowed the beds to warm and helped prevent the common problem of straw mulch forming an icy mat (Waterer and Schmitz, 1994; Rosen and Tong, 2001). The plants were evaluated throughout the summer for emergence and scape development by weekly visual recordings. Scapes were removed when they began to become woody, but before straightening, so energy could be focused on bulb development (Rosen and Tong, 2001; Guenther and Stonaker, 2006). Garlic bulbs were harvested when roughly a third of the leaves per plant began to turn brown. Harvest started July 31, 2015 with the final harvest date on August 19, 2015. Garlic bulb roots were trimmed to half a centimeter and dirt brushed off. Roots were trimmed off to prevent additional moisture from wicking into the plant. Dirt was brushed off to assess for bulb damage and to reduce moisture around the bulb in preparation for curing.

Variety	Subtype	Average Clove #	Storage Capability (months)	Collected From
Blossom	Turban	7-11	~4	
Basque	Turban	7-11	~4	
Chengdu	Turban	7-11	~4	China
Dugansky	Marbled Purple Stripe	4-7	4-6	
German Red	Rocambole	6-11	4-6	German communities
Georgian Fire	Porcelain	4-7	~6	
Khabar	Marbled Purple Stripe	4-7	4-6	Siberia
Korean Mountain	Asiatic	4-8	~4	Republic of Georgia
Montana Zemo	Porcelain	4-7	~6	Republic of Georgia
Music	Porcelain	4-7	~6	
Polish Hardneck	Porcelain	4-7	~6	
Red Grain	Purple Stripe	8-12	~6	Republic of Georgia
Shandong	Turban	7-11	~4	China
Siberian	Marbled Purple Stripe	5-7	4-6	
Spanish Roja	Rocambole	6-11	4-6	
Xian	Turban	7-11	~4	China

Table 2. Garlic varieties included in 2014-2015 growing trials. Garlic cloves were purchased from Filaree Farms (Okanagan, Washington) following their naming scheme (England, 1991), which follows systematics widely used in the U.S. and largely supported by genetic research (Volk, et.al 2004). Characteristics as described from Filaree Farms.

For the curing process, garlic was bundled by variety with twine wrapped around the stems and hung along the beams in a shed to cure for a minimum of three weeks. The curing process reduces the moisture content in the bulbs allowing for a longer storage period (Meredith, 2008). After curing, bulbs were individually examined for any damaged, poor quality bulbs, with those bulbs excluded from the study. Grounds for exclusion included evidence of rot, shriveled cloves, broken wrappers exposing cloves, and pest-damaged bulbs. The resulting bulbs were weighed, their circumferences measured, and their cloves counted. Bulbs were weighed and cloves were counted post-curing to account for the desiccation of the outer bulb wrappers during the curing process and improvements in the accuracy of clove counts resulting from the removal of the outer wrappers.

For the 2015/2016 growing season, cloves were planted on September 23 and 26 2015. Only 12 of the original 16 cultivars were replanted since 4 cultivars (Blossom, Chengdu, Xian, and Shandong) had poor returns during the 2014/2015 growing trial resulting in few cloves.

Nine of the cultivars had 20 cloves planted (Spanish Roja, Montana Zemo, Korean Mountain, Dugansky, Polish Hardneck, Georgian Fire, Basque, Red Grain, and Khabar), two cultivars had 15 cloves planted (Music and Siberian), and one cultivar had 12 cloves planted (German Red); three kinds per bed planted in rows of five (Figure 4). The variation in number of cloves planted was due to the number of quality cloves available to plant. When garlic farmers around the state regrow from their own crop they choose the largest cloves to replant as it is commonly believed that replanting the largest cloves each year will result in larger bulbs. The largest cloves were chosen for replanting to test for this effect. Effects of mulch depth on garlic cultivation were explored by varying the depth of mulch between subplots at 30, 40, and 50 cm (Figure 5). Onset HOBO temperature probes (Onset Computer Corporation, Bourne, MA, USA) were placed in each bed, two under the sides of the beds with a single layer of mulch and two under the sides with the additional layer of mulch, 10 cm deep to monitor soil temperature among the mulch treatments. The probes were set to take temperature readings every hour from November 15, 2015 until September 17, 2016. An additional probe collected air temperature by the beds at the same interval and duration. All other planting procedures did not differ from the previous season.

Garlic was harvested following the same procedures as the 2014-2015 season. Physical measurement data was recorded along with information on mulch level and position in the planting bed for each bulb. Any bulb that was found to have additional damage during this final inspection process was excluded from further analysis. The Onset HOBO temperature probes were removed from the soil September 17, 2016. Data uploaded to the HOBO application then exported into Excel to aggregate data.

Statistical Analysis

Hourly temperature data from beds were pooled within mulch treatments and aggregated to create daily average soil temperature for each mulch treatment. The Onset HOBO probe from Bed 1 malfunctioned early in the season. Consequently, temperature data from this probe was omitted from the analysis, and only one bed was included to represent temperature for the 50 cm mulch treatment group. Differences in average daily soil temperature between mulch treatment groups were examined by subtracting the pooled average daily soil temperature values from the 30 cm mulch treatment group from those for the 50 cm mulch treatment group (Figure 7).

Effects of environmental and cultivation practices on garlic yield success were examined using a binomial generalized linear model (GLM) in R Version 3.1.2. I defined successas bulbs that emerged, yielding a binary response variable. Model covariates included mulch level, garlic variety, position of bulb within the bed (e.g. on the edge or not on the edge), and test bed number. Final model selection was conducting using AIC (dredge function in R package MuMIn).

Results

During the first growing season, clove counts per bulb were most consistent in Porcelain (Mean = 3.77 SD= ± 0.99 n=48) and Purple Stripe (Mean = 6.41 SD= ±0.09 n=12) varieties. Rocambole averaged 6.23 cloves (SD= ±1.61) and Marbled Purple Stripe Varieties averaged 5.72 cloves (SD= ±1.73), the Asiatic variety averaged 5.11 cloves (SD= ±1.90), and the Turban variety averaged 7.75 cloves (SD= ±2.63). Turban had the most consistent weight (Mean = 38.50g SD = ±4.80g n=4), and Porcelain had the highest weights (Mean = 68.02g SD= ±20.15g n=48). The Asiatic variety averaged 48.66 g (SD = ±22.32g n=9), Rocambole varieties averaged 44.47 g (SD = ±12.92g n=21), the Purple Stripe variety averaged 25.91 g (SD = ±6.91g n=12), and Marbled Purple Stripe varieties averaged 35.37 g (SD =±10.30g n=43). The first year of growing trials had an average return rate of 73% while the second year of growing trials saw a decline in success rates with an average of 63%. However, the resulting bulbs in the second year were, on average, nine grams heavier and produced one more clove than bulbs in the 2015 harvest (Table 3). Overall, garlic weights, size, and clove counts increased from 2015 to 2016 even with the poor return rates. The only exception was the Purple Stripe which saw a decrease in weight (Figure 8).

Subtype/Variety	Average Clove # 2014/2015-**2015/ 2016**	Average Weight (g) 2014/201-/**2015/ 2016**	Average Circumference (cm) 2014/2015-**2015/ 2016**
Asiatic			
Korean Mountain	4.1 **5.1**	35 **48.6**	15.1 **16**
Marbled Purple Stripe			
Siberian	4 **4.8**	29.1 **30.5**	14.3 **13.9**
Dugansky	6.2 **7.6**	24.4 **41.4**	12.7 **15.4**
Khabar	4.5 **5**	35.6 **35**	15.2 **14.6**
Porcelain			
Polish Hardneck	3.1 **3.8**	83.7 **65.8**	18.7 **16.9**
Montana Zemo	3.1 **4**	54.1 **76.3**	15.6 **17.9**
Music	3.1 **3.6**	48 **72**	15.1 **16.5**
Georgian Fire	2.8 **3.7**	58.3 **61.8**	16.6 **16.5**
Purple Stripe			
Red Grain	6.8 **6.6**	29.5 **25.9**	13.5 **12.3**
Rocambole			
Spanish Roja	4.7 **6.6**	32.4 **50.3**	13.5 **16.1**
German Red	4.2 **5.6**	26.5 **36.6**	13.4 **14.7**
Turban			
Blossom	2	18	10.5
Basque	4.9 **3.4**	20.9 **33.9**	11.9 **15.2**
Shandong	3.5	19.3	11.7
Xian	3	17.0	10.7
Chengdu	2	N/A	N/A

Table 3. Average weight, circumference, and clove counts between 2015 and 2016. Most cultivars grew larger, heavier, and produced more cloves in 2015/2016 compared to 2014-2015 with the exception of Red Grain, Khabar, and Polish Hardneck which decreased in weight and/or circumference.

Covariants	ΔAIC
Bed + Mulch + Edge	---
Bed + Variety + Mulch + Edge	2.37
Bed + Edge	3.69
Mulch + Edge	4.59
Variety + Mulch + Edge	6.5
Bed + Variety + Edge	6.5
Bed + Variety + Mulch + Edge + Variety:Mulch	7.93
Bed + Variety + Mulch	12.52

Table 4. GLM model selection covariates and fits as determined by AIC value. The covariates bed, mulch, and edge were shown to be the best predictors for emergence success.

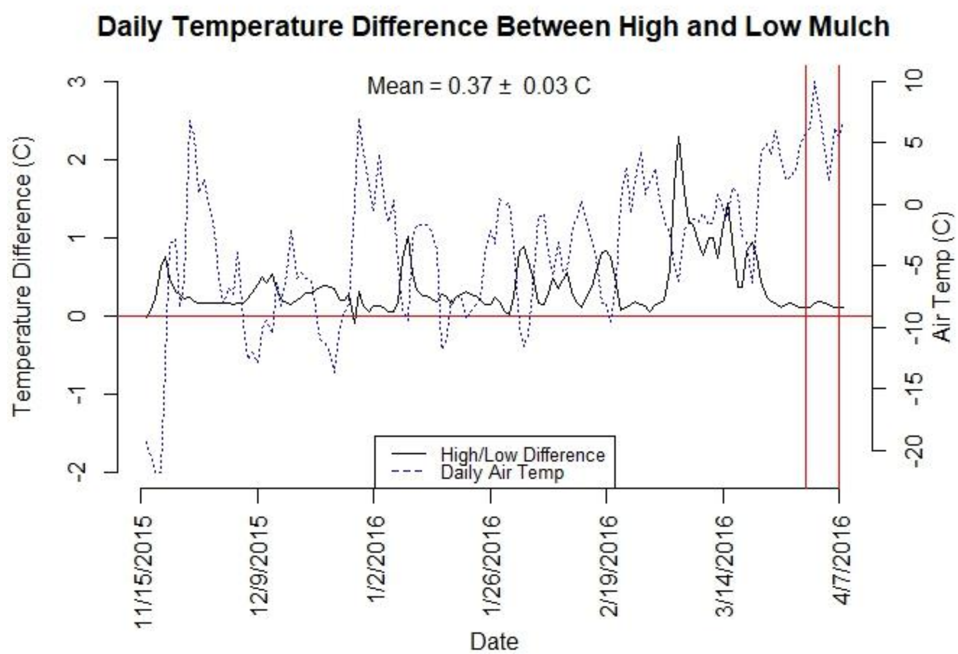

Figure 3. Daily temperature difference between high and low mulch as determined by Onset HOBO data loggers (solid line) ranged between November 15, 2015 and April 7, 2016. When daily air temperatures (dashed line) stayed above freezing, temperature differences fell to zero suggesting an extent to when mulch treatments can be effective. The vertical red lines indicate when mulch was removed from the beds.

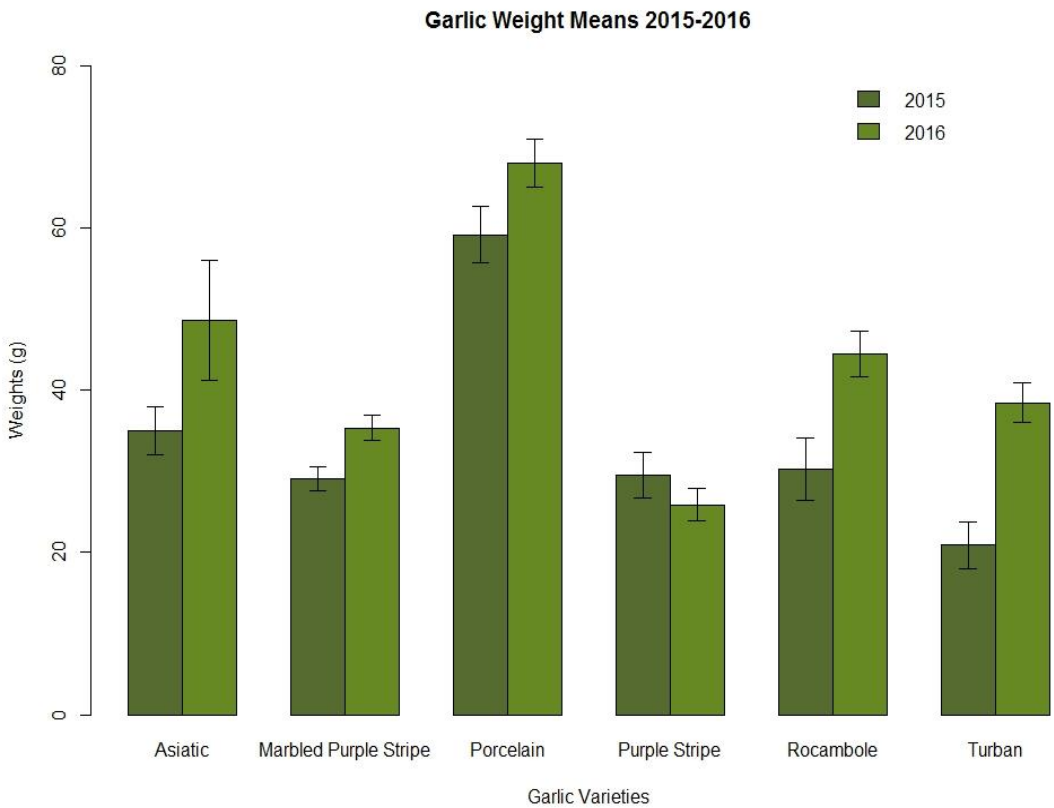

Figure 4. Garlic weight means 2015 – 2016. Overall most garlic varieties were heavier the second growing season except for Purple Stripe varieties.

GLM model selection indicated that mulch level, edge position, and raised bed number were the best predictors of garlic emergence (Table 4). The timeline of plant development changed between 2015 and 2016 with emergence occurring 11 days earlier, scape emergence six days earlier, and harvest occurred finished 16 days earlier in 2016 than in 2015 (Table 5). The daily temperature difference between high and low mulch showed that high mulch was on average 0.37 °C warmer than the low mulch (Figure 7).

Phenology Observations	2015	2016
Emergence	May 6	April 25
Scape emergence	June 23	June 17
Harvest start	July 31	July 29
Harvest complete	August 19	August 2

Table 5. Phenological data for the 2014/2015 and 2015/2016 growing trials. Phenological observations occurred 2-17 days earlier in 2015/2016 than in the previous 2014/2015 growing season.

Discussion

Despite this observed increase in the phenological timeline, as well as observed increases in bulb weights, circumference, and clove counts between 2015 and 2016, the average return rate was significantly lower in 2016 than in 2015. Average return rate for the 2016 trials across all subtypes was 63%, with one variety producing a 20% return rate. This is in contrast to both the 2015 growing trials, for which average return rate across all subtypes was 73%, and to garlic farmers around Alaska who, despite also seeing earlier emergence and harvest dates for the same time period, noted return rates of 90% and higher. In the following sections, I explore potential reasons for these observed differences, offer advice to prospective garlic farmers in Alaska based on my results, and comment on the use of small-scale independent growing trials as a substitute for a network of large agricultural research stations in Alaska.

Potential Influences on Observed Differences in Phenological Timeline and Yield between 2015 and 2016

The increased phenological timeline, phenotypic variation, and lower return rates observed in the 2015/2016 growing trials may have been the result of variations in weather conditions, pest predation, and planting practices between the 2014/2015 and 2015/2016 trials. Unlike 2014/2015, low levels of snowfall and record high temperatures were recorded in Alaska during the 2015/2016 winter (Di Liberto, 2016). While these decreases in the levels of snow and ice (and the associated shorter time in which bare ground was covered) may have allowed emergence to happen sooner in 2016, the lack of insulating snow made the beds more vulnerable to freeze-thaw damage. In a study conducted on winter wheat in Sweden, Vico et al., (2014) demonstrated decreases in the depth and duration of snow cover can lead to damage in overwintering crops in northern temperate latitudes by leaving plants exposed to temperature oscillations, such as freeze-thaw cycles and extreme cold spells. The low thermal conductivity of snow allows crops to stay better insulated. Without this protection, plants are vulnerable to fluctuations in temperature. While not performed on garlic, the same principles observed in Vico et al.'s (2014) work are applicable to my project. Damage from freeze-thaw cycles can include extracellular ice formation and consequential collapse, weakness to molds, and root tissue damage due to soil heaving, all of which would have resulted in the low return rates observed in my 2015/2016 growing trial. Furthermore, in a study investigating the growth and yield of winter wheat in Denmark, Patil et al. (2010) found that warmer soil temperatures allowed crop development to happen sooner, corresponding to the increased phenological timeline I observed in the 2015/2016 growing trials, but also resulted in reductions in nitrogen in above ground biomass and a consequent reduction in ear number (grain kernel) similar to the low return rates I observed in 2016.

Differences in pest assemblages with the raised beds and pest predation rates may also have played a role in the decreased return rate I observed in the 2015/2016 growing trials. In mid-May 2016, a sample of cloves was exhumed to assess potential reasons for the low observed emergence. Sampled cloves were either rotting or only the clove wrapper remained (meaning the clove had already decomposed entirely). Other recovered cloves had almost no root development. In early June of the same year, leaf and clove specimens from the Montana Zemo and Spanish Roja cultivars were taken to the Plant Materials Center in Palmer, AK where stem tissue and basal root plate samples were analyzed for the presence of viruses or pests. Samples were taken in triplicate and placed in Petri dishes with potato dextrose, water agar, and iron agar in an attempt to culture any bacteria, fungi, or virus that may have affected the cloves. A number of pests and virus strains were found in tissue samples that could be salvaged from the damaged cloves, but no silver bullet emerged to explain the lowered emergence rates. However, three pupae and an adult of an unidentified *Anthomyiidae* family member were found in bulbs after they had been cured, and one adult was captured on one of the plants in July. Since many members of the *Anthomyiidae* family, like Seedcorn maggot or Onion maggot, are saprophagous, it is likely that pests were drawn to the bed after the cloves were damaged, potentially from the freeze/thaw cycles described above. This is in contrast to the 2014/2015 growth trials, in which snow levels and temperature were less atypical for the region (Alaska Climate Research Center, 2017), and no pests, aside from spiders and mosquitos, were observed in the beds.

Cloves that did not suffer from freeze/thaw damage or pest predation during the 2015/2016 growing trials were generally larger and heavier than those observed in 2014/2015. When the cloves were planted at the start of the 2015/2016 trial, the largest ones were chosen from the previous crop with the expectation that planting larger cloves would result in larger bulbs (Meredith, 2008). This form of artificial selection may be a key reason behind the general increases in bulb weights, circumferences, and clove counts observed in 2016. Not all cloves; however, followed this pattern. This variability may be the result of variations in planting technique or pest introduction among beds. For the 2015/2016 growing trial, planting was done in tandem with a garlic growing class taught at the Alaska Botanical Garden. While the cloves had been preselected for size, and the students taught planting technique, it is possible that cloves were not buried at a uniform depth, leaving some cloves closer to the surface and prone to freeze-thaw and soil heaving damage. In addition, while all four beds were amended with compost from the same compost pile, the pupae and adult pests collected came solely from Bed 1. According to Cornell University, Onion maggot (*Delia antiqua* Meigan) will establish multiple generations in a single growing season and can reduce crops by over 50% (Smith and Nault, 2013). Unfortunately, I am unable to determine whether these pests were introduced with compost or were dormant in the bed soil.

Recommendations on Practices for Garlic Cultivation Based on Growing Trials

GLM model selection criteria indicated that mulch, bed, and edge were the best predictors of emergence success. The inclusion of mulch in the final model is in agreement with the results of garlic growing studies performed in Colorado, Illinois, and Virginia that showed positive relationships between crop yields and the use of protective winter mulch (Guenther and Stonaker, 2006; Walters 2008; Bratsch et al., 2009). The mulch types used in these studies varied, and included grass hay, floating row cover, wheat straw, black plastic, sorghum sudangrass, lablab, and sunhemp. In addition, the inclusion of mulch in the model is not surprising as many garlic farmers within Alaska currently employ some type of mulching practice as shown by in a survey of Alaska garlic farmers conducted by Reeder (refer to Chapter 1). Based on the inclusion of mulch in the model, I recommend additional experimental mulch trials to assess the efficacy of different materials, depths, and placement timing on a region-specific basis.

It should be noted, that all of the high mulch treatment groups in this study were placed on the south side of the raised beds. While this consistent placement may have resulted in differences in the levels of solar radiation experienced by the three mulch treatments, particularly during the midwinter months when the sun is lowest; the relative speed with which differences in the average soil temperature between mulch treatment groups fell to zero after the mulch was removed (Figure 7) implies that potential differences in solar radiation between mulch treatment groups did not have a significant effect on my results. Differences in the levels of solar radiation received by the different raised beds could; however, have contributed to beds inclusion as a predictor of emergence success in the final GLM. Consequently, I recommend that future experimental growing trials consider solar effects when designing treatment plots.

Unlike the open plots and fields used by commercial garlic farmers in Alaska (refer to Chapter 1) and in many agricultural research trials (Guenther and Stonaker, 2006; Walters 2008; Bratsch et al., 2009), temperature differences between the center and sides of the raised beds used in my trials may have resulted in thermal edge effects. Growers who choose to use raised beds should consider using a protective mulch for better emergence rates. One farmer in Southcentral Alaska insulates the bottom of his high tunnel with two inches (5 cm) of foam insulation (Reeder, refer to Chapter 1). Growers with raised beds may consider mitigating a potential edge effect by adding insulation around the perimeter.

Independent Growing Trials as a Substitute for Agricultural Research Stations in Alaska

While Alaska may not see the reemergence of agricultural research stations, independent, small-scale investigations performed by farmers, gardeners, and students might provide an alternative source for important agricultural research. These growing operations are not reliant on federal or state funding to remain operational, and, in many cases, much of the necessary infrastructure is already available. Even if farmers are not always able to perform multi-year trials, having students who are dedicated to multi-year research projects, as well as scientific equipment from universities, could generate new agricultural knowledge, growing techniques, and varieties that would benefit farmers around Alaska.

Unlike agricultural research stations, small-scale, independent assessments can make use of novel funding sources, such as the Alaska Department of Natural Resources Specialty Crop Grant program. Awards from this program range between $15,000-$40,000, can fund multi-year projects, and are available to industry professionals (University researchers, producers, nonprofits, cooperatives, and Extension Services) for projects that impact multiple businesses, produce measurable outcomes, and bolster the competitiveness for Alaska grown crops. In 2014, Alaska Department of Natural Resources Specialty Crop Grant funding was used to assess the storage and marketability of garlic in five Southeastern Alaska towns (Love, 2014). Because farmers have great demands on their time and resources, and may not be able to meet the expectations of the grant funding, farmers can collaborate with university students or other partners to add diverse expertise and value to grant-funded projects. Students also have access to academic professionals to help create scientifically-informed project designs and provide mentorship through the process. Students and farmers can work together as an innovative partnership throughout the state, not bound to university research farms, to contribute to the body of agricultural knowledge in Alaska.

Limits exist to this sort of research. Limitations in sample size and replicate test beds were issues in this research, and could be issues in further research projects depending available space at farms and gardens. A student may design a project that requires 12 replicate test plots, but the farmer can only dedicate 5 plots for research. These sorts of challenges have to be thoroughly addressed by the study design. Likewise, grant and funding requirements may pose challenges in and of themselves. A farmer and student may plan and design a project, write a proposal, and fail to obtain funding. As long as these small-scale researchers acknowledge potential limitations, and have a backup plan in place, they may still contribute to the body of agricultural knowledge in Alaska, and their work may serve as a jumping off point for future funded research.

Disseminating this information does not need to be relegated to the academic journals accessible only to subscribers. Changing technologies have created numerous platforms for grassroots and community-driven participation, such as apps for phones and interactive databases. For example, Heidi Rader of the Alaska Cooperative Extension Service and Tanana Chiefs Conference recently created an app called Grow & Tell (Rader, 2017) for growers to share information about what they have grown, rating crops on reliability, taste, and yield. This allows anyone with a smartphone to upload crop data for dissemination. Platforms such as Grow & Tell are available in real-time to any grower, large or small, to access data on what crops have been reliably grown all over Alaska without having to pay or subscribe to access the data.

Online databases offer an alternative to app-based information platforms. One example of such an online information platform is the Local Environmental Observers (LEO) Network (Alaska Native Tribal Health Consortium, 2016; available at www.leonetwork.org), an observation-sharing site in which “citizen scientists” can report unusual environmental, weather, or animal events in their communities. This same principle can be adopted and modified with an agricultural focus. Farmers and growers could upload photographs and information, such as plant and harvest dates, planting methods, crop varieties, and phenological timelines. This would allow other farmers and growers to learn and benefit from past experiences. In addition to providing information to growers, these online platforms can act as a data storage site, thereby allowing for potentially important legacy datasets to allow for future studies on large temporal and spatial scales.

Nearly 120 years after Alaska began to create a robust agriculture research system, there is still a need for greater knowledge about agricultural possibilities in the rapidly-changing circumpolar north. Through this small study, I ascertained that replanting the largest garlic cloves from the previous season successfully produced garlic that was larger, heavier, and with a higher number of cloves per bulb than the previous year. Further research is needed to address the low emergence rates that accompanied these phenotypic changes. Future small-scale investigations in the form of independent growing trials, such as that described here, have the ability to contribute significantly to the growing body of agricultural knowledge for northern latitudes.

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Table 6. 2014-2015 Growing Season Summary

Subtype	Variety	Scape Presence	Average Clove #	Average Weight (g)	Average Circumference (cm)	Harvest Date	Sample Size*	Return Rate
Asiatic	Korean Mountain	Most	4.1	35	15.1	8/19	19	79%
Marbled Purple Stripe	Siberian	Yes	4	29.1	14.3	8/12	12	100%
Marbled Purple Stripe	Dugansky	Yes	6.2	24.4	12.7	8/12	16	89%
Marbled Purple Stripe	Khabar	Yes	4.5	35.6	15.2	8/19	11	92%
Porcelain	Polish Hardneck	Yes	3.1	83.7	18.7	8/19	11	92%
Porcelain	Montana Zemo	Yes	3.1	54.1	15.6	8/19	10	83%
Porcelain	Music	Yes	3.1	48	15.1	8/19	19	79%
Porcelain	Georgian Fire	Yes	2.8	58.3	16.6	8/19	8	67%
Purple Stripe	Red Grain	Yes	6.8	29.5	13.5	8/19	6	50%
Rocambole	Spanish Roja	Most	4.7	32.4	13.5	8/19	7	58%
Rocambole	German Red	Most	4.2	26.5	13.4	8/19	4	17%**
Turban	Blossom	No	2	18	10.5	7/31	1	--
Turban	Basque	No	4.9	20.9	11.9	8/12	12	67%
Turban	Shandong	Only 1	3.5	19.3	11.7	7/31	4	--
Turban	Xian	No	3	17.0	10.7	7/31	5	--
Turban	Chengdu	No	2	N/A	N/A	8/4	4	--

Table 6. The results from the 2014-2015 growing season. Although the average return rate was 73%, the Turban varieties Blossom, Shandong, Xian, and Chengdu produced a weak sample size after harvest mainly due to the fact that so many bulbs were rounds; producing a large singular clove and no differentiation and were excluded in calculations for 2014-2015 returns..

*Sample size is the final number of successful bulbs that had no damage and produced more than 1 clove.

** The German Red were harvested late resulting in bulbs that had split and were not included in the return rate.

Table 7. 2015/2016 Growing Season Summary

Subtype	Variety	Scape Presence, Shape	Average Clove #	Average Weight (g)	Average Circumference (cm)	Harvest Date	# Planted	Sample Size*	% Return
Asiatic	Korean Mountain	Yes, half circle	5.1	48.6	16	July 29	20	9	45%
Turban	Basque	No	3.4	33.9	15.2	July 29	20	4	20%
Porcelain	Polish Hardneck	Yes, pretzel twirl	3.8	65.8	16.9	August 2	20	10	50%
Porcelain	Montana Zemo	Yes, 2 full curls	4	76.3	17.9	August 2	20	10	50%
Porcelain	Music	Yes, 1 full curl	3.6	72	16.5	August 2	15	11	73%
Porcelain	Georgian Fire	Yes, 1 full curl	3.7	61.8	16.5	August 2	20	17	85%
Rocambole	Spanish Roja	Most, 1 full curl	6.6	50.3	16.1	July 29	20	12	60%
Rocambole	German Red	Most, half turn	5.6	36.6	14.7	July 29	12	9	75%
Purple Stripe	Red Grain	Most, half curl	6.6	25.9	12.3	July 29	20	12	60%
Marbled Purple Stripe	Siberian	Yes, full circle	4.8	30.5	13.9	July 29	15	14	93%
Marbled Purple Stripe	Dugansky	Most, half curl	7.6	41.4	15.4	July 29	20	12	60%
Marbled Purple Stripe	Khabar	Most, full curl	5	35	14.6	July 29	20	17	85%

Table 7. The results of the 2015-16 growing season. Resulting bulbs were larger, heavier, and more cloves produced per bulb than the previous growing season, however the average return rate was 63%.

*Sample size is the final number of successful bulbs that had no damage and produced more than 1 clove.

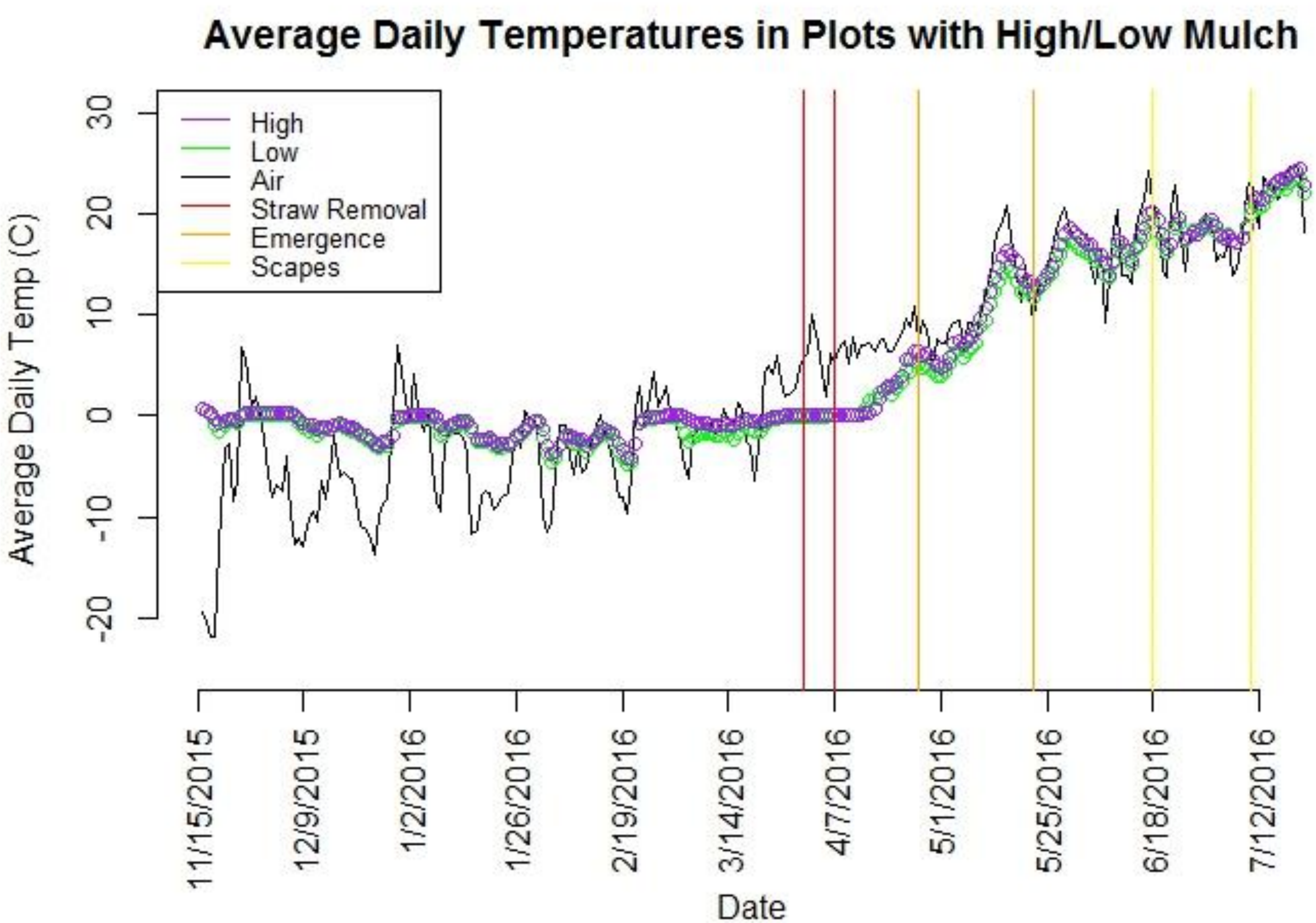

Figure 3. Average daily temperatures between high and low mulch treatment in the test beds from November to August as determined by Onset HOBO temperature data loggers . The vertical lines represent events during the garlic growing process. Straw removal (red lines) took about a week and even then, the temperature in the test beds hovered around freezing almost weeks after their removal. Garlic shoots first appeared (orange lines) on April 21 and continued to emerge over 27 days. Scapes appeared (yellow lines) nearly a full 30 days afterward and continued to appear for 23 days.