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Optimizing Fertilizer and Compost Rates in Organic Reduced Till Agriculture

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OPTIMIZING FERTILIZER AND COMPOST RATES

IN ORGANIC REDUCED TILL AGRICULTURE

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An Abstract of the Thesis Presented
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Interest in reduced tillage systems has been increasing and advanced by a need to practice agriculture in a sustainable way to limit environmental degradation. The focus on preserving soil integrity has become commonplace in all scales of agriculture. Recently trends in agricultural production have given rise to numerous small farms centered on local and sustainable farming. In turn, this has led to a growing desire to implement conservation tillage into these systems.

In 2015 and 2016 a collaborative effort between the University of Maine at the Maine Agricultural and Forestry Experiment Station: Highmoor Farm and Cornell University at the Homer C. Thompson Vegetable Research Farm and the Long Island Horticultural Research and Extension Center took place to explore combinations of popular fertility sources available to small-scale organic growers; with the goal of optimizing rates of these amendments in a reduced tillage system.

Multiple combinations with different rates of pre-plant bloodmeal, compost and side-dressed bloodmeal applied by total N were created. Compost and pre-plant bloodmeal were applied either in a band or by broadcasting, side-dressed bloodmeal was always applied as a band. Pre-plant bloodmeal fertilizer was applied at a rate 40 lbs·acre^{-1} of N at all sites. In the 2016 growing season an additional treatment in Maine included bloodmeal at a rate of 80 lbs· acre^{-1} of N. Compost was applied at 80 lbs·

acre^{-1} of N at all sites, additional treatments in Maine included compost at 40 and 120 lbs· acre^{-1} of N as well. Side-dressed bloodmeal at 40 lbs· acre^{-1} of N was applied mid-season at all sites.

The experiment was set up as a randomized complete block with 4 replications and Honey Bear acorn squash (*Cucurbita pepo 'Honey Bear'*) was used as the crop. Fruit number, fruit weight, dry stem weight and petiole %NO_3-N data were taken at all sites. Site data was analyzed separately using ANOVA at P<.05 on all the treatments. Individual comparisons of interest were analyzed using contrasts for fruit number, weight and dry stem weight. Petiole data was analyzed with ANOVA at P<.05 followed by a Tukey's HSD test at all sites for %NO_3-N. Additionally, %P was analyzed in Maine.

In Maine, compost increased yields in 2015. However, levels exceeding 40 lbs· acre^{-1} of N were found to provide no additional benefit within the same year. Bloodmeal had no effect on yield in either year of the experiment. In Freeville, bloodmeal increased yields in 2015. Pre-plant applications were found to have a greater effect on yield then mid-season applications. Compost was found to have a negative effect when banded. In Riverhead, the combination of compost with pre-plant and sidedressed bloodmeal produced the greatest yields.

Except for Freeville in 2015, little difference was found when comparing banding or broadcasting of materials. When N was limiting, compost failed to supply N for crop growth even with a C:N ratio lower than 20:1. When P was limiting, compost was able to significantly increase yields. Results from 2015 were not repeated at any site in the 2016 year, possibly due to high levels of background fertility.

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1. INTRODUCTION AND RESEARCH OBJECTIVES

Promoting sustainable agricultural practices has benefits on-farm and beyond. The unnecessary application of nutrients in agriculture is literally and figuratively fruitless, resulting in wasted money and potential environmental harm. Optimizing fertility rates in agriculture is one method of achieving this goal. It is unlikely, due to ecological and environmental complexity, that there will ever be one specific fertilization rate for each crop. Currently general fertility ranges are available to use in the Northeastern United States and recommendations can vary by state within region.

Reduced tillage and agricultural applications of compost promote soil health and further the building and maintaining of soil organic matter. Doing this has many benefits which may change the rate of fertilization needed. These include: the increased efficacy of fertilizer rates, increased cation exchange capacity, greater potential for mineralized N, and increased water holding capacity (Weber et al., 2007; Ozores-Hampton et al., 2005; Evanylo et al., 2008; Rivenshield and Bassuk, 2007; Khalilian and Sullivan et al., 2002; Brady, 1974; liu et al., 2003; Magdoff & Van Es, 2009).

With the adoption of reduced-tillage methods, such as strip tillage, it is possible that fertility rates will change due to an increase in the overall health of the soil. Plant interactions within distinct zones differing by physical and chemical characteristics may affect fertility rates as well (Williams et al., 2016; Luna et al., 2012; Harmoto & Brainard 2012). Research must be carried out to further understand the interaction of a tillage system with limited soil disturbance and fertility rates.

The objective of this study is to explore nutrient amendment optimization in small-scale reduced-till agriculture by utilizing organic nitrogen sources, timing, and placement in a combined way that provides the most benefit to squash production with the least amount of organic resources.

The specific objectives of this experiment were to:

1. Determine if there is a difference in squash production (fruit number, Fruit Yield and dry stem weight) between two N sources: organic N fertilizer (bloodmeal) and compost applied at agronomic rates.
2. Determine if there is a difference in squash production due to the placement of the compost or bloodmeal (banding or broadcasting).
3. Determine if there is a difference in squash production with time of organic N fertilizer: pre-planting application or mid-season application.
4. Determine if there is a difference in squash production with combinations of nitrogen source (Compost N or bloodmeal) and rates, timing (side-dressing or no side-dressing), or placement (banding or broadcasting).

2. SECTION 1: LITERATURE REVIEW

Organic Production with Sustainable Focus

Organic agriculture is a farming system that adheres to philosophical guidelines to produce agricultural products without the use of synthetic inputs such as, fertilizers, pesticides and hormones. However fundamentally, organic production focuses on promoting sustainability by reducing ecological and environmental degradation, implementing practices that maintain soil structure and promoting biodiversity, while still being able to achieve economically acceptable yields.

The most recent organic survey from the National Agricultural Statistics Service (NASS) shows in Maine, there were 494 certified Organic farms in 2016. The most current census data (2012) lists 8,173 total farms, of these farms the total number of Maine farms producing vegetables was 1,473. Eighty-three percent of these Maine farms operated on less than 15 acres. Additionally, many organic farms are small supplemental sources of family incomes and are exempt from organic certification. 65.4% of all farms in Maine have sales under ten-thousand dollars. Furthermore, the census may not accurately report all organic farms in the state.

Many newer farms are becoming National Organic Program (N.O.P.) certified or N.O.P. exempt organic. NASS's 2015 survey shows that 32% of all organic farms in the United States have operated for ten years or less. New England states follow this trend where nearly one-third of the organic farms have operated under ten years. Specifically, in Maine 31% of the farms fall in this category.

There are two main reasons for sustainable agriculture practices: the environment and economics. Sustainable practices maintain the quality of the land, air, water and biome. However, these practices also maintain production quality and increase efficiencies of arable land. Achieving both is an ideal of organic production.

All businesses face difficult challenges; cost of materials, labor, market fluctuations and product loss are just some examples, organic farming is no exception. Organic production costs are generally

thought of as higher than conventional cost, but this is not always the case. Research has found evidence that both supports and refuses this assumption (Post and Schahczenski, 2012). Resources are potentially allocated differently between the two production methods. For example, conventional farms typically have higher fossil fuel and pesticide costs; where organic farms most notably have an intensive labor cost (David et al., 2005). A key difference between the two systems is the type of products used to manage fertility. Organic nutrient inputs such as fertilizers usually contain a lower percentage of guaranteed nutrients and are more expensive on a per acre basis compared to conventional fertilizers. Organic farmers often must purchase a larger amount of more expensive product to meet crop nutrient demands, making optimization of fertility inputs economically important. (Klonsky, 2011).

Squash Production in the North East

The cucurbit family (*Cucurbitacea)* is especially important as a food crop, making it an economically important crop for farmers. There are five common cucurbit species that are grown as winter squash and the three that could be considered most economically important in New England are *Cucurbita maxima*, *Cucurbita moschata*, and *Cucurbita pepo*.

In the Northeast cucurbits are harvested throughout most of the growing season as summer squash (*Cucurbita pepo.*) and cucumbers (*Cucumis sativus*). Later-season cucurbits are winter squash, pumpkins (*Cucurbit pepo, Cucurbita maxima*) and melons (*Citrullus lanatus* and *Cucumis melo*). Winter squash is consistently available into the late winter from storage. According to NASS, at the 2012 census the USDA found there were 1,059 farms growing a total of 2,165 acres of winter squash in New England.

Winter squash cultivars exhibit a spectrum of growth habit from sprawling vine to compact bush. This growth habit determines plant spacing. Typically, bush varieties are grown with tighter in-row spacing of 18” to 24” with 4 to 5 feet between rows. Vine type plants require more room and do

best 24” to 72” between plants in-row with 6 to 12 feet between rows (New England Vegetable Management Guide, 2016-2017). Squash can be planted either by seed or transplant and is adaptable to production systems using plastic, bare ground, or reduced tillage (Crop Profile for Squash(Winter) in New England, 2006).

Winter squash is a good choice for systems using reduced tillage methods, such as strip tillage, due to the crop’s growth habits, seed characteristics and plant spacing. The relatively wide intra- and inter-row spacing even on bush varieties leaves increased potential for erosion due to the lack of plant matter to stabilize the soil in clean-cultivated fields. Strip tillage has surface residue which can help prevent this soil loss by wind, precipitation or irrigation. If direct seeded, the larger seed size works well with reduced tillage because prepared seed beds can be coarse; potentially causing small-seeded crops to become buried to deeply or to have poor seed to soil contact. Finally, the vigorous growth habit of squash competes well with weeds, which can be challenging to control using reduced tillage in an organic system.

Squash is a warm-weather crop and must be planted when the soil reaches a temperature greater than 60°F. Squash prefers a slightly acidic pH of 6.5 to 6.8 and to be grown on well-drained sandy loam soil with a high percentage of organic matter. In New England winter squash is generally planted between May and June and harvested in late summer or fall. Squash is commonly transplanted through black plastic around the three-leaf stage but can be direct-seeded as well. (New England Vegetable Management Guide, 2016-2017).

Squash plants are moderately heavy N feeders and require between a 110-140 $lbs \cdot acre^{-1}$ of N per acre to achieve optimum yields. The 2016-2017 New England Vegetable Management Guide recommends splitting N application for squash into both pre-plant and side-dress fertilization to meet the targeted total season rate. Total N needs could be less in soils with high organic matter or production in plastic culture.

Nitrogen Cycling: Gains and Losses in Plant Available N

Additions of nitrogen to the soil happen naturally through decomposition of animal and plant materials and to a lesser extent, from atmospheric deposition (Havlin et al., 1999). Although nitrogen may be plentiful in arable soils in the form of soil organic matter it may not be in the inorganic forms ammonium (NH_4^+) and nitrate (NO_3^-) that are usable to the plant. Furthermore, these forms are highly interchangeable in their role in the active nitrogen cycle (Maathuis, 2009).

Organic matter in the soil serves as a bank for potential nitrogen in the form of organic N. Typically, Maine soils contain up to 5% soil organic matter which can be mineralized at a rate of 5-15% per year adding 15-65 $lbs{\cdot}acre^{-1}$ (Erich). Organic N may be converted to the ammonium cation NH_4^+ and then quickly converted to the nitrate anion NO_3^-. Likewise, NO_3^- may be converted to $NH_4^+$and then immobilized in the form of organic nitrogen, such as amino acids, where it is unavailable for plant uptake (Gaskell and Smith, 2007; Maathuis, 2009).

The N mineralization process is catalyzed by the soil microbial community, where it is dependent on external factors such as temperature and moisture. It is the complex between the environment, soil microorganisms and nutrients that ultimately determine the rate of the mineralization process (Leiros et al., 1999).

Nitrogen is also subject to other losses in the nitrogen cycle. Nitrate with its negative charge does not readily adhere to soils with a net negative charge, the typical charge for acidic soils. Thus, nitrate is dissolved in the soil solution where it is easily lost through leaching during heavy precipitation or irrigation events. Although the positively-charged ammonium can be held by the soil it is often quickly converted to other forms such as nitrate through the nitrification process (Maathuis, 2009).

Denitrification is the gaseous loss of soil inorganic N to the atmosphere in the form of $N_{2,}$ N_2O, and NO. This process is facilitated by facultative anaerobic bacteria and fungi in the soil that use nitrate as an electron receptor in place of oxygen (Havlin et al., 1999). Anaerobic conditions prevail when soil

pore space becomes saturated with water. Bacteria and fungi then reduce NO_3^- and NO_2^- to carry out respiration causing the loss of nitrogen to the atmosphere (Hartz and Johnstone, 2006).

Organically Sourced Nitrogen: Organic Fertilizers, Plant Materials, Manure and Compost.

Nutrients are often a limiting factor in vegetable production systems and adding these nutrients to farmed land can be costly. This is especially true for nitrogen inputs certified for organic use. Nitrogen management in agriculture is a continuous process and achieving acceptable yields and food production is highly dependent on it. (Vance, 2001). Nitrogen can be added practically to crop land in three ways: fertilizers, plant residues (cover crops, green manures and residual cash crops), and materials composed from plant and animal waste (manures and compost).

Organic Fertilizers

There is an assortment of organic fertilizers available to organic growers to provide N and other macronutrients. These natural products are derived from fish, livestock and plant processing byproducts and vary in their composition and guaranteed nutrient analysis (Gaskell and Smith, 2007). N availability from these sources is complex due to the dependence on soil microorganisms and the conditions which affect the mineralization process. These conditions could vary between regions, soil properties and local micro-climates, making optimization difficult.

Hartz and Johnstone, (2006) found that higher temperatures allowed more total nitrogen (Total N = NO_2^-+ Organic N, + NO_3^- + NH_4^+ + NH_3) to be mineralized over time when comparing four organic fertilizers at different temperatures. The fertilizers used and listed in order of greatest to lowest N mineralization were: sea bird guano, bloodmeal, fish powder and feather meal. In the same experiment, they also observed that the greatest % of nitrogen was mineralized within the first two weeks after application. This occurred even at lower soil temperatures regardless of the fertilizer. Research has shown that when crop nitrogen requirements are high, organic fertilizers that quickly

deliver plant available nitrogen (PAN), can supply sufficient N to support crop growth. Relying on the mineralization of soil organic matter alone may not supply enough PAN for desired yields (Gaskell and Smith, 2007)

Plant Residues

Plant residues from cover crops and green manures can add nitrogen to the soil through two mechanisms: nitrogen scavenging and nitrogen fixation. Nitrogen scavenging is the plant uptake and trapping of nitrate and subsequent release after plant death. Available nitrogen is stored in plant tissue where it is less subject to loss through leaching (Kladivko, 2016). Typical N scavenging cover crops are non-legumes such as brassicas and cereal grains. Nitrogen scavenging is one benefit of cover-cropped soils in typical fallow periods such as winter; another benefit is erosion control.

Nitrogen fixation involves the capture of atmospheric N in the form of N_2 through biological N fixation. Although both aerobic and anaerobic bacteria can fix N_2; the symbiotic relationship between legumes and anaerobic rhizobium bacteria is the most important to agriculture production. Rhizobium bacteria invade the roots of leguminous plants and in turn the plants encase the bacteria in nodules creating an anaerobic environment. N fixation is carried out by the enzyme nitrogenASE in the bacteria which is able to break the triple-bonded dinitrogen gas and form ammonium (Kladivko, 2016; Wagner, 2011; Vance, 2001). This form of N or further conversion through nitrification is usable to the host plant during the growing season.

Nitrogen available to succeeding crops is dependent on decomposition of the plant material and mineralization of the N. Plant available N (PAN) is contingent upon the C:N ratio of the cover crop which changes throughout the growth stages of the cover crop (Kladivko, 2016). Typically, younger plants in the vegetative stage contain a higher amount of N. Termination at this stage results in a greater amount of PAN to the following crop. Later termination, at the reproductive stage immobilizes N in the soil due to a higher C:N ratio.

Generally N fixers like legumes have a higher percentage of nitrogen in plant tissues than non-legumes, and therefore a lower C:N ratio which speeds decomposition. Plant nitrogen percentage is closely related to PAN. When plants have a greater percentage of N, soil microbes cannot tie up all the N through organic matter formation and more PAN is available to crops (Sulivan and Andrews, 2012). A field study at Oregon State University grew broccoli while comparing vetch and oat cover crops with organic feather meal (12-0-0) at 0, 90, 180 and 270 lbs·acre^{-1} of N. In plots without cover crops they saw broccoli yields increased up until the 270 lbs·acre^{-1} rate. They found that a vetch cover crop could reduce the amount of nitrogen needed to grow the crop by 110 lbs of N per acre. Yet, the oat cover crop tied up PAN causing 50 lbs of feather meal to be used to make up the N deficit to the crop (Garett, 2009).

Manure and Compost

Manure and compost applications are commonly used for additional nutrients. While adding these forms of organic matter are not new, increasing popularity in compost as a part of the sustainable waste stream for farms, businesses and municipalities has further encouraged its use in agriculture.

Manure is a raw product, which has a high amount of ammonium nitrogen that is quickly available to crops. It also contains an organic N component that can supply long-term nitrogen release (New England Vegetable Management Guide, 2016-2017). However, ammonium N is highly volatile and is subject to loss from manure applications depending on age, type, and incorporation timing of the manure (Cornell University Cooperative Extension, 2005).

A study by Eghball and Powers (1999), compared annual and biennial applications of compost and manure based on N and P removal from corn in fertilized and unfertilized plots. In a four-year period, Eghball and Powers observed that corn grain yields were similar between the compost, manure

and fertilizer treatments; suggesting that both manure and compost can add nitrogen and phosphorus to the soil and replace some or all the fertilizer application.

Compost on the other hand, is the product of the natural decomposition of raw materials into a humus-like substance (Rynk, 1992). Typically, compost is made from a combination of feedstocks, which often include animal manure, bedding, wood shavings or chips, food waste or byproducts, yard debris, plant materials and municipal waste (Rynk, 1992; New England Vegetable Management Guide, 2016-2017). Compost suited for agriculture should have a C:N ratio of less than 25:1 with a lower ratio being able to provide more N to the crop in the year of application (The Composting Council of Canada; New England Vegetable Management Guide, 2016-2017). A compost with a C:N ratio greater than 25:1 will tie up nitrogen in the soil through increased microbial consumption of N.

Compost applications have the potential to create soils with high salinity. This occurs when composts contain high amounts of ionic compounds. Composts with an electrical conductivity below 4 $mmhos \cdot cm^{-1}$ are considered safe to use. Another criterion for useable compost is pH. The pH of finished compost should be near neutral and additions of compost should have little effect on the pH of the amended soil. Composting creates a phytotoxic amount of volatile organic acids present in immature compost. Cured compost allows time for these volatile organic acids to be transformed into a stable state which does not negatively affect plant growth or germination (Rynk, 1992; The Composting Council of Canada).

Like manure, compost contains nitrogen, phosphorus, and potassium as well as secondary macro- and micro-nutrients. However, compost unlike manure is more stable and contains very little plant useable inorganic N. Nitrogen from compost must be transformed through mineralization from organic forms into plant available N ($PAN=NH_4^+ + NO_3^-$). PAN amounts can vary depending on the feedstocks used in the initial compost recipe and the C:N ratio of the finished product. A laboratory and field study by Gale, et al. (2006) found these two factors influenced compost N availability over time

and that 0-20% of the total N in compost was transformed into PAN. Composts that provided no available N had C:N ratios exceeding 20:1 which caused N tie up. Targeting N rates based on total N amounts will add lower actual amounts of available N considering the low percentage of total N that is converted to PAN. However, compost has been used as a fertility source and experimentation has shown comparable yields to crops grown with fertilizer. Khalilian and Sullivan, et al. (2002) found that the addition of municipal solid waste compost applied at 5, 10 and 15 tons·acre^{-1} increased cotton (*Gossypium sp.*) yields up to 30% when compared to a planting that contained cotton supplied with only recommended fertilization rates. Likewise, Delate et al., (2003) found yields of peppers fertilized with a composted poultry litter based-fertilizer matched yields of peppers grown with conventional 14-14-14 fertilizer each applied at 100 lbs·acre^{-1} of N.

The variation in feedstock composition ultimately affects the composting process and the time it takes for the raw materials to go through the decomposition process. The final percentage of plant nutrients in the compost will also vary due to the feedstocks making nutrient content uncertain and hard to guarantee as a fertilizer. However, it is often assumed that a finished compost will have considerably low percentages of N-P-K, around 1-1-1 (Rynk, 1992; New England Vegetable Management Guide, 2016-2017).

Potassium and phosphorus from compost differ from nitrogen due to their higher availability. About 30 to 40% of the total phosphorus added to the soil from compost will be available for use in the first year. Additionally, compost may be able to supplement P requirements for multiple years after application (Rynk, 1992). However, phosphorus availability is reliant on the relationship between clays, metal oxides and organic matter which can push P to adsorb to the soil or decrease phosphorus precipitation rates leading to greater P solubility. Furthermore, these rates can change based on soil type (Leytem, 2008). Evanylo. et al. (2008) found that available P in the soil increased rapidly with the amendment of compost applied at recommended N rates suggesting a greater availability of P

compared to N or a higher concentration of P. Targeting N rates could potentially lead to an over application of P that would be more vulnerable to loss and perhaps increase the chance of pollution.

Potassium does not get tied up into organic matter through composting and remains largely available for plant use. However, this availability also makes it subject to loss through leaching. Weber et al. (2007) found that compost-amended plots had higher levels of K, as well as, Ca and Mg than non-amended plots, due to their greater level of availability. Like P, over application of K can occur when using high compost rates to provide recommended N levels (New England Vegetable Management Guide, 2016-2017).

Nitrogen Use Efficiencies: Environmental Concerns, Application Timing and Placement

Environmental contamination from agriculture runoff is a serious concern. Non-point nutrient pollution from agricultural production can affect ecosystems and local economies through eutrophication and increased turbidity of surface water. The overabundance of nutrients can trigger algal blooms that use up dissolved oxygen in the water leading to a hypoxic environment. This change is detrimental to aquatic ecosystems, fisheries, and tourism based upon these natural resources. Likewise increased turbidity caused by erodible sediment, can have similar negative effects (Cestti et al., 2003).

When nitrogen escapes from agricultural production it is a economic loss for farmers. Reduction of nitrogen supplies can ultimately reduce yields affecting overall profits (Van Eerd, 2010; Buwalda and Freeman, 1986; Mohammad 2004). With organic fertilizers being costlier per unit of N than conventional fertilizers, it is more of a financial concern (Klonsky, 2011). Furthermore, application takes time, equipment, and labor adding to the potential loss. Reducing N loss and using optimum application rates is a goal to strive for in agriculture to mitigate both environmental and economic loss.

Combining compost with fertilizer can lower the total fertilizer needed to meet crop nutrient needs. Berjon et al. (1997) found that compost alone produced lower yields compared to mineral

fertilizer on potato (*Solanum tuberosum L.* Var 'Edzina'); However, compost in combination with mineral fertilizer was able to reduce the optimal N fertilization rate. This increased the efficacy of the N fertilizer while limiting the amount of leachable N from mineral fertilizers in the field. Ozores-Hampton et al. (2005) saw that compost application to sandy soils increased pepper plant (*Capsicum annuum L.*) growth while producing higher yields with lower amounts of additional fertilizer.

Splitting application rates over time is one way to limit N loss. Timing for cucurbit side-dressed N in the northeast is at the first sign of flowers on bush squash or when vining initiates for vine squash (New England Vegetable Management Guide, 2016-2017). Chance et al. (1999) found that the ratio of NO_3^- to NH_4^+ affected the yield of squash. With higher levels of N in the nitrate form during early vegetative growth and an increased amount of N in the ammonium form during the reproductive stage producing the greatest yield.

There is concern that nitrogen, being both highly interchangeable into unavailable or easily lost forms, may potentially be applied at a time or in a year when crop nitrogen uptake is low, or crops are unresponsive to additional nitrogen. Van Eerd (2010) in Ontario found that there was a positive correlation with nitrogen fertilizer applications and soil nitrate-nitrogen. But, that the additional nitrogen only could explain up to 20% of the variability in increased squash yields. Furthermore, plots treated with nearly 100 and 200 lbs·acre^{-1} of N were found to have approximately 40% to 60% more nitrate nitrogen left in the field at squash harvest compared to the control plots with no additional N fertilizer added. This suggests that there was a wasteful use of nitrogen, which would then be subject to loss.

Buwalda and Freeman (1986) and Mohammad (2002) each found a positive response of squash yield with additional nitrogen. Buwalda and Freeman (1986) conducted a fertilizer rate experiment with winter squash (*Cucurbita maxima*) and found that the marketable yields of squash increased as fertilizer rates increased up to 160 kg·ha^{-1} or 143 lbs·acre^{-1}. Furthermore, in the same experiment they

also found that nutrient uptake was strongest during early squash growth and the lack of available nutrients at this stage likely led to decreased yields for some of the treatments even if more N was applied later.

Placement of N source is another concept to consider with N management. Is there an increased efficacy of nutrient sources with banding or broadcasting nutrient amendments? Khalilian and Sullivan, et al. (2002) found that banded or broadcasted application of equal rates of municipal solid waste compost equally increased both the amount of organic matter and the amount of nitrogen in a cotton field. Parish, Bracy and McCoy (2008) found that banding or broadcasting a complete fertilizer before planting had no significant difference in summer squash (*Cucurbita pepo)* yield grown conventionally over a three-year period. In the same experiment, they also found no difference between banding or broadcasting when applying side-dressed fertilizer.

Manuck (2006) found that banding dairy manure compost at a rate of 40 and 80 tons·acre^{-1} showed a decrease in root growth in corn (*Zea mays)* compared to broadcasting with 80 tons·acre^{-1} of the same compost or banding with 160 lbs·acre^{-1} 10-10-10 fertilizer. However, ear yields were not significantly different between the application methods. A study by Harmoto & Brainard (2012), assessed cabbage yield in a comparison between conventional and strip tillage with and without an oat cover crop. All plots were fertilized the same based on soil test recommendations directly before tillage. It was suggested that their broadcasted urea application did not get incorporated into the soil in the strip-tilled plots and was therefore more subject to loss. However, even with the lack of incorporation there were no significant difference in cabbage yields between any of the plots. In discussion, it was hypothesized that banded subsoil application applied at tillage would be the most efficient use of N fertilization.

Compost Soil Health

Organic agriculture strives for sustainability and one way this happens is through maintaining soil health. "Feed the soil not the plants" is a phrase commonly read in current organic agriculture literature. Recently much attention has been given to soil health and maintaining soil integrity is a goal common to both organic and conventional production. Organic matter is a key component of healthy soils and preserving it or increasing it in arable land offers many benefits. Additions of compost are one way to contribute organic matter to the soil (Khalilian et al. 2002).

Organic matter is unique in that it works in two very important ways depending on the type of soil it is applied to. Additional compost increases soil macro porosity and decreases bulk density alleviating soil compaction and promoting friability. In sandy or light-textured soils compost promotes water holding by binding soil particles together in aggregates. While, in clay or fine textured soils composts promotes drainage and aeration, also by forming larger soil aggregates. Weber et al. (2007) observed that soil water holding capacity increased with compost application on a sandy soil. Khalilian and Sullivan et al. (2002) found that broadcasted compost decreased soil compaction and multiple applications reduced the hard pan in a cotton field when incorporated with a sub-soiler. Rivenshield and Bassuk (2007) found that additions of compost correlated negatively with bulk density and positively in the formation of macropores in both sandy loam and clay loam soils in New York state. Evanylo. et al. (2008) carried out an experiment with annual and biannual compost applications targeting agronomic N rates (64 $tons \cdot acre^{-1}$). One of their treatments was a low compost rate reduced to 20% of the target agronomic N rate (13 $tons \cdot acre^{-1}$). This was included to see if physical soil changes occurred when compost additions where not applied to target high N rates, because applying at these high rates is not always economically feasible. They found that there were still soil benefits from compost applications at this lower rate. They observed a decrease in bulk density of a silty clay loam within three years. However, higher rates were able to decrease the bulk density within one year after

application. Likewise, the same experiment saw increased soil porosity with the addition of these experimental compost rates. A similar experiment conducted by Weber et. Al. (2007) found significant increases in total porosity and water holding capacity shortly after application of municipal solid waste compost on a sandy soil.

The cation exchange capacity (CEC) is the soils ability to adsorb cations. The CEC is important for nutrient availability and works by holding cations in negatively charged exchange sites until they are released into the soil solution, where they become accessible for plant uptake. Compost has been used to increase the CEC of soils. A study by Weber et. al. (2007) using three different one-time application rates of 12, 24 and 48 tons·acre^{-1} found an increase in CEC with increasing compost applications rates. This was observed in the first and second year after the application in all treatments compared to the control, but in the third year only the highest experimental rate still showed an increased CEC. Ozores-Hampton et al. (2005) saw that compost applications to sandy soils were able to increase nutrient holding which lowered fertilizer rates while increasing yields in pepper (*Capsicum annuum L.*)

U.S Compost Council states in the fact sheet: Compost and its Benefits, that compost has further beneficial effects on soil health and ultimately plant growth in the ability to improve pH, as well as, buffer changes in pH. The ability to withstand drastic pH changes maintains soil pH in the optimal range for greater solubility of plant nutrients and therefore availability.

The composting process goes through a thermophilic stage which can reach temperatures exceeding 160 degrees Fahrenheit (Rynk, 1992). The temperature increase destroys susceptible microbes including pathogens, as well as most seeds. The compost is then colonized by beneficial microorganisms such as actinomycetes, mesophilic bacteria and fungi. Microbiota in compost may suppress disease facilitated by soil-borne pathogens. This can occur chemically through the production of antibiotics. These microbes have also been shown to compete with fungal pathogens, such as *phythium* sp., for available nutrients and create a disease suppressive-environment in container studies

(Chen et. al, 1988). Malandraki et. al. (2008) found that members of *Pseudomonas fluorescens* and non-pathogenic *Fusarium oxysporum* introduced through field compost applications suppressed *Verticillium dahilae* in eggplant (*Solanum melongena*) through antagonism.

<u>Introduction to Reduced Tillage</u>

Soil health is promoted and maintained through farming practices such as conservation tillage. Conservation tillage includes reduced till and no-till tillage techniques and in definition leaves greater than 30% crop residues on the soil. Reduced tillage is any form of land preparation that reduces the amount of soil disturbance that would take place in conventional agriculture by reducing tillage intensity in both primary and subsequent tillage. The goal of this tillage method is to provide the workability of conventional tillage with some of the soil health benefits of no-till. Lopez-Garrido et. al. 2014 found that physical parameters of a no-till soil limited sunflower (*Helinathus annuus L.*) germination, stand, growth and quality compared to both reduced-till and conventional-till in a Mediterranean climate. Deep-zone tillage, vertical tillage or strip tillage are terms used interchangeably for a reduced tillage method that combines coulters; to cut plant residue, deep shanks; to break the plough pan and fracture the soil and a rolling basket; to create a seedbed.

The reduction of the repeated use of the moldboard plow, was perpetuated by the Dust Bowl in the 1930s. Through this, the development of the chisel plow created a way for farmers to leave residue on the surface while undercutting the soil (Higgins and Cuello, 2000). Within the past century, agricultural engineering has produced a variety of conservation tillage equipment that can be used to reduce physical soil disturbance. Sub-soilers, zone builders, yeoman plows and seed drills are some examples of these implements.

More recently conservation tillage has been widely adopted and about 50% of the total cultivated acreage in the U.S uses conservation tillage practices. In 2012 there were 96,476,496 acres in conservation tillage. Out of these acres 19,836,692 were in no-till production and the remaining

76,639,804 acres were in another form of conservation tillage (NASS, 2016). Common crops for conservation tillage are large scale agronomic crops such as corn, cereal grains, cotton and soy beans.

Traditionally, conservation tillage relied on a greater usage of herbicides and genetically-engineered, herbicide-tolerant crops. However, since dormant weed seeds do not make it to safe sites on the soil's surface, conservation tillage can lead to less weed competition (Fernandez-Cornejo et. al., 2012). Concepts like this foster the adoption of reduced-tillage practices by organic farmers who tend to use tillage as one of the only means of weed eradication; but in doing so, are likely bringing buried seeds to the surface where they can break dormancy (personal communication, Bill Pluecker, Hatchet Cove Farm, Warren ME, 2017).

Crittenden et. al. (2015) compared reduced tillage and moldboard plowing in plots of conventional sugar beets (*Beta vulgaris*) and organic spring wheat (*Triticum* aestivum). After six years of tillage or plowing with the same crop rotations they found that yields did not differ between plots, suggesting that conservation tillage can be substituted for conventional tillage methods. In another organic plot included in the previous experiment, Crittenden et. al. (2015) found that yields were higher with reduced tillage in a wheat and faba bean (*Vicia* faba) mixture compared to moldboard plowing. Other studies have compared tillage methods in organic and conventional production and found similar results (Mader and Berner, 2012; Krauss et. al., 2010; Luna and Staben, 2012)

Reduced tillage offers some economic benefits through labor and fuel cost saving (Brainard et. al.). Since this tillage method reduces the amount of land you are working by roughly two-thirds it reduces the amount of time and passes it takes to prepare a field (Idowu et al.). In typical reduced tillage the process is carried out in one pass compared to a conventional tillage system that might use multiple passes with different equipment. For instance, primary tillage carried out by a moldboard plow then secondary tillage utilizing disk harrows, rototillers or shallow tillage implements for seed bed preparation. Luna and Staben (2002) compared strip till with conventional tillage in sweet corn (*Zea*

Mays L.*)* production on 20 farms operating on vastly different soil types for a duration of four years. Their experiment found machinery and labor cost were reduced by approximately 50% with strip tillage.

Soil Health Benefits of Reduced Tillage

Soil aggregates are grouped soil particles that form a bigger mass composed of minerals, organic matter and pore space. Organic matter plays a vital role in the formation of soil aggregates by binding soil mineral particles together. This happens chemically when inorganic cations Ca^{2+}, Mg^{2+}, Fe^{2+}, and Al^{3+} attach to negatively charged sites on organic or mineral components acting as an "ionic bridge" between particles (Brady, 1974).

Conventional tillage systems physically degrade soil particle size by hammering, mixing, crushing and inverting the soil. The reduction in size destroys stable aggregates which help prevent compaction in the field. Smaller particle size leads to less pore space which limits the amount of oxygen and water that can penetrate through the soil profile. Soils in conventional tillage that undergo the same repeated disruption develop compacted layers such as disk or plow pans (Dejong-Hughes et. al 2016). Compacted soils may decrease yields by limiting water and nutrient uptake and reducing root respiration.

Conservation tillage reduces physical disruption of the soil aggregates by limiting the amount of tillage that takes place. A study by Beare et al. (1993) found that macroaggregates were smaller, fewer and had less stability in conventional tillage compared to no-till. Likewise, improved aggregate stability in conservation tillage was observed by Aziz et al. (2013) and in a long-term tillage study by Tebrugge and Durring (1999). Kushwaha et al. (2001) found that macroaggregates increased up to 42% within two years with the adoption of reduced tillage practices. Crittenden et. al. (2015) found that aggregate stability increased, and bulk density was lowered when using reduced-till in an organic system.

Aggregate stability is also an important factor in limiting environmental degradation by preventing erosion; and therefore, nutrient, pesticide and soil pollution of surface water. Through rain simulation experimentation, Tebrugge and Durring (1999) saw up to a 30% decrease in runoff, soil sediment loss and herbicide loss contributed to better water percolation rates and increased pore conductivity. However, nutrient and pesticide leaching could be worsened in some soils using conservation tillage where soil water flows in a non-uniform rapid pattern called “preferential flow”. Preferential flow may occur when large connected pore pathways in the soil are not broken up through repeated disturbance, such as conventional tillage, leading to contamination due to accumulation of herbicides in high concentrations. But, in soils where preferential flow is minimal, reduced and no till systems have been shown to degrade herbicides more quickly by adsorbing more herbicides due to high soil organic carbon amounts (Larsbo et al. 2009).

Soil organic matter is an important characteristic of agricultural soils due to the promotion of productive crop growth and its attributes to soil physical quality. But soil organic matter is a sink for carbon as well. In a long-term tillage experiment Arshad et. al. (1993) saw an increase of soil organic carbon in no-till production. Kushwahs et al. (2001) found a strong increase in soil organic carbon, total nitrogen and microbial biomass with an increase in soil aggregation promoted by conservation tillage and plant residue cover.

Agricultural soils can sequester atmospheric carbon when sustainable practices are used to manage soil organic matter. Carbon sequestration is an important topic when considering the current state of increased atmospheric CO_2 levels and global climate change. Soil organic carbon has been observed to decline with increased cultivation, which also decreases the CEC due to the loss of soil organic matter (Liu et al. 2003; Magdoff & Van Es 2009)

Soil aggregates protect organic matter through biological, chemical and physical means which prevents decomposition from soil microbiota. Reducing OM decomposition lowers the release of CO_2

into the atmosphere (Goebel et al. 2009). Reicosky and Lindstrom (1993) found that deep inversion tillage with a moldboard plow created rough soil surface texture with large aerated cavities which produced a greater amount of CO_2 emissions when compared to disk harrow or chisel plowing. Similarly, Al-Kasi and Yin (2005) suggested that that CO_2 emissions were initiated by a tillage event which changed the soil pore structure and the population of the soil microbial community. This occurred because aeration from tillage increased microbial activity and microbial contact with vulnerable organic carbon and nutrients once protected by soil aggregates; leading to decomposition and the increased production of CO_2 emissions (Anger et al. 1993). Al-Kaisi and Yin (2005) compared CO_2 emissions after various types of tillage methods were used. tillage methods were: no-till with residue, no-till without residue, strip-tillage, deep-rip, chisel plow and conventional moldboard plowing. They found that the conservation tillage practices resulted in 19 to 41% less CO_2 released into the atmosphere compared to moldboard plowing.

Potential Draw Backs of Reduced Till in the North East

A benefit of soil aeration from conventional tillage, is a quicker soil temperature increase in the spring. Particularly in climates with cold winters and short growing seasons like the north-eastern United States. Reduced-till soil tends to warm up slowly possibly contributing to later plantings, poor germination, stunted growth and reduced yields (Logan et al. 1991). Fausey (1989) found significantly lower temperatures in no-till compared to soil that had been plowed in the spring. However, in a two-year experiment comparing strip tillage with conventional full-width tillage Harmoto & Brainard, (2012) found no difference in soil temperature between tillage methods.

An experiment in Pennsylvania compared reduced tillage to plastic culture for warm-season crops; summer squash (*Cucurbita pepo* 'Lioness') and muskmelon (*Cucumis melo* 'Athena'). Unacceptable yield reductions were found in two years of muskmelon production and in one year of the summer squash production in the strip-tillage plots. These plots were found to have lower soil

temperature and therefore likely less nitrogen mineralization leading to lower yields compared to plastic culture (Lilly & Sanchez 2016). Lower soil temperature may impede growth of warm-season crops; however, cool-season crops may benefit from or not be affected by lower soil temperatures. In Michigan Harmoto & Brainard (2012) grew cabbage (*Brassica oleraceae* Var. *capitata*) and found that yield did not differ between conventional and strip-tilled plots.

Reduced tillage tends to have a greater water holding capacity and due to water's high specific heat it also warms up more slowly (Coolman and Hoyt 1993). Harmoto & Brainard (2012) observed findings consistent with other research and found that strip tillage left more residue on the soil surface and increased soil moisture in one year of their experiment. This could be a benefit in dry years of the Northeast, or in areas where water-use efficiencies are needed at a greater extent. However, where compacted layers have formed, deep-zone tillage in the fall can facilitate early drainage and faster warming in the spring (Idowu et al.).

Reduced tillage may have other limitations depending on crop and field history. For small-seeded crops, a rougher soil texture and presence of unincorporated plant residues may provide a poor environment for germination and early seedling growth. Large-seeded crops such as squash, sweet corn and beans have been successfully grown by direct seeding in reduced till in the Northeast (Idowu et. al.). Plant residues can make weeding difficult causing mechanical devices to clog and be ineffective. This may add to labor intensity if hand weeding becomes the only means of weed control. Furthermore, reduced tillage may encourage the establishment of perennial, low-creeping weeds that can be difficult to manage organically. In a survey produced by Michigan State University, weed management was the first concern with adoption of reduced tillage (Brainard et. al.)

Another reduced-tillage method in the focus of current research is implementing reduced tillage with an overwintering or early-spring-planted cover crop as a mulch. The mulch is terminated by roller-crimping or mowing and then strip tillage can be used to open the mulch and create a narrow

seedbed; or no-till can be used instead with a seed drill. Ideally the early-season mulch will limit light exposure and therefore hamper weed growth through the critical period of weed control. As the mulch breaks down over the season the crop, with a head start, grows competing for resources with the weeds. Doing this adds another level of complexity where cover crops must be planted at the right time to grow enough biomass to have the desired effect and termination must be at the right time to permanently lay down the mulch (Wallace et al.; Silva; Harmoto & Brainard, 2012).

Nutrient Availability in Strip Tillage

Nutrient availability may change in strip tillage due to soil characteristics of two distinct zones; the in-row zone where tillage has taken place and the between-row zone were no tillage occurred. These zones are expected to have different rates of N mineralization due to differences in temperature, moisture content, and presence of soil microbiota; which affect the nutrient transformation processes. (Williams et al., 2016; Luna et al., 2012). Soil disturbance is usually a catalyst for N mineralization due to the increase in microbial activity. In a tillage simulation study performed by Calderon et al. (2000) increased nitrogen accumulation was seen when sifting a vegetable production soil and a soil that had been under grassland management of the same soil type. Harmoto & Brainard (2012) suggested that complex patterns in inorganic soil N seen while growing strip-tilled cabbage were created by freely movable N and different mineralization between the two distinct zones.

Initially N may be tied up through the incorporation of residues. This was noted by Harmoto & Brainard (2012). In one year of their experiment N was tied up in strip- and conventional-tillage plots with oat residue. In another year, strip tillage with oat residue lead to less N immobilization compared to conventional tillage with oat residue. This suggests that the increase incorporation of the conventional-tilled oats led to N tie up. Sainju and Sing (2008) found that a bi-culture of vetch and rye cover crop was best at increasing soil N storage in conventional, no-till and strip-till production. This enabled them to reduce fertilizer rates by half. However, non-legume covers such as rye incorporated

at a mature stage might initially tie up N mineralization due to the high carbon content (Kladivko, 2016; Sulivan and Andrews, 2012).

Strip tillage has been shown to conserve soil aggregates and soil organic matter (Beare et. al., 1993; Aziz et. al., 2013; Tebrugge and Durring, 1999; Kushwaha et. al., 2001). The increase in soil organic matter serves as a bank for potential nitrogen in the form of organic N. Typically, soil organic matter can be mineralized at a rate of 5-15% (Erich). Increasing soil organic matter increases CEC and soil N. This can reduce the need for additional fertilizer inputs.

3. SECTION 2: EXPERIMENT

Materials and Methods

This experiment is one part of a multi-university and multi-objective research project funded by the National Institute of Food and Agriculture's Organic Research and Extension Initiative grant program (OREI). A key component of this project is to increase soil health through reduced tillage. The purpose of the overall project is to transition small-scale organic farmers into the adoption of reduced-tillage techniques in the Northeast. Thus, one part of this fertility experiment is to rotate into different fields each year simulating the adoption of new tillage practices in fields that have previously had conventional tillage.

Three sites were used in this experiment. Two of the sites were in New York, one at the Homer C. Thompson Vegetable Research Farm in Freeville NY, and the other located at the Long Island Horticultural Research and Extension Center in Riverhead, Long Island, NY. A third site and the focus of my graduate research was located at Highmoor Farm in Monmouth, ME. The three sites used a similar experimental design focusing on the same goal; however, some treatments were expanded upon with the experiment at Highmoor farm increasing the number of treatments in the experiment **(Table 1)**. Weather data for all three sites is listed below in **Table 2**. Data was collected using NOAA weather stations near each site. Actual weather stations were in Augusta, ME; Ithaca, NY and West Hampton, NY for the Monmouth, Freeville and Riverhead sites respectively. Compost analysis was completed by the University of Maine Soil Testing and Analytical Lab. A summary of the analysis is listed in **Table 3**.

Table 1. Fertility treatments broken down by total lbs·acre[1] of N by source.

X represents sites were treatment was included. All treatments were used in 2015 and 2016 unless labeled with a single year.

ME	NY	Placement	Compost lbs N at Planting	Bloodmeal lbs N at Planting	Side-dress lbs N Mid-Season	Total N Applied	Treatment Label
X	X	Band	0	0	0	0	Band (0:0:0)
X	X	Band	0	0	40	40	Band (0:0:40)
X	X	Band	0	40	0	40	Band (0:40:0)
X	X	Band	0	40	40	80	Band (0:40:40)
X	X	Broadcast	0	40	0	40	Broadcast (0:40:0)
X	X	Broadcast	0	40	40	80	Broadcast (0:40:40)
2016		Band	0	80	0	80	Band (0:80:0)
2016		Band	0	80	40	120	Band (0:80:40)
X		Band	40	0	0	40	Band (40:0:0)
X		Band	40	0	40	80	Band (40:0:40)
X		Broadcast	40	0	0	40	Broadcast (40:0:0)
X		Broadcast	40	0	40	80	Broadcast (40:0:40)
X	X	Band	80	0	0	80	Band (80:0:0)
X	X	Band	80	0	40	120	Band (80:0:40)
X	X	Broadcast	80	0	0	80	Broadcast (80:0:0)
X	X	Broadcast	80	0	40	120	Broadcast (80:0:40)
X	X	Band	80	40	0	120	Band (80:40:0)
X	X	Band	80	40	40	160	Band (80:40:40)
X	X	Broadcast	80	40	0	120	Broadcast (80:40:0)
X	X	Broadcast	80	40	40	160	Broadcast (80:40:40)
X		Band	120	0	0	120	Band (120:0:0)
X		Band	120	0	40	160	Band (120:0:40)
X		Broadcast	120	0	0	120	Broadcast (120:0:0)
X		Broadcast	120	0	40	160	Broadcast (120:0:40)

Statistical Analysis

Statistical Analysis System (SAS Studio, SAS Institute, Cary NC) was used to complete the statistical analysis at all sites for this experiment. Boxplot graphs were created for all response variables for each site and year. Extreme outliers were identified by data points displayed above the maximum or below the minimum value of the box plot. This data was either corrected if there had been obvious mistakes in the data entry or removed from the data set all together. Due to the unbalanced design of the experiment, the General Linear Model Procedure was used to run an ANOVA at $P<.05$ on all the treatments. Individual comparisons were performed using contrasts for fruit number, weight and dry stem weight. Petiole data was analyzed at all sites for %NO_3-N, additionally %P was analyzed in Maine. ANOVA at $P\leq .05$ and a Tukey's HSD mean separation was used to determine differences in these petiole nutrient levels between the treatments. The data from both years and all sites was analyzed separately due to the alternation of fields with different initial amounts of fertility, as well as the vastly different growing seasons which occurred between the two years.

To test the assumptions of ANOVA, the residuals were plotted on a fitted-line graph and a Shapiro Wilk's test at an alpha value of $P\leq .05$ was used to test for normality. To test the equality of the variance residuals were graphed to look for acceptable distribution and a more rigorous Levene's test was performed. In both years, data modified to correct extreme outliers was found to be normally distributed with equal variances; meeting the assumptions of ANOVA in Maine. Data from Freeville, NY was found to meet these assumptions without further adjustment. A square transformation was used on the 2016 petiole data from Riverhead and one treatment was removed due to extreme outliers. This made the data fit a normal distribution with equal variances meeting the assumptions for the ANOVA.

Experimental Design: Monmouth ME

This field study was conducted at the University of Maine Agricultural and Forestry Experiment Station: Highmoor Farm in Monmouth, Maine during the 2015 and 2016 growing seasons. In both

years, the soil type was a Woodbridge very stony fine sandy loam. The experiment was designed as a randomized complete block to control variation in both fields due to the slope.

Both fields had been in unmanaged sod for more than 10 years before being rototilled in 2014 in preparation for the experiment. Monmouth is situated approximately 15 miles west from the weather station at the airport in Augusta, ME. Monthly temps and precipitation are listed in **TABLE: 2**

Table 2. 2015 and 2016 Growing season weather data for Monmouth ME, Freeville NY and Riverhead NY.

Site	Month	May		June		July		August		September	
	Year	2015	2016	2015	2016	2015	2016	2015	2016	2015	2016
Monmouth, ME	Avg. Temp °F	59	56	61	63	68	70	70	71	65	64
	High Temp °F	86	90	85	84	88	91	89	94	89	90
	Low Temp °F	36	34	41	47	52	52	55	54	37	41
	Precipitation (inches)	1.88	1.48	1.9	3.74	2.77	1.96	1.24	2.31	3.32	1.13
Freeville, NY	Avg. Temp °F	59	54	63	63	66	69	65	70	64	61
	High Temp °F	85	87	86	87	86	91	88	92	89	87
	Low Temp °F	28	26	38	35	42	43	45	45	36	32
	Precipitation (inches)	3.57	1.91	6.72	1.22	4.96	1.93	1.55	5.72	3.54	1.31
Riverhead, NY	Avg. Temp °F	59	52	65	65	73	73	74	73	68	66
	High Temp °F	82	77	87	86	94	97	91	93	88	91
	Low Temp °F	30	28	41	42	51	50	50	47	44	35
	Precipitation (inches)	0.87	2.68	3.49	1.4	1.06	4.19	1.6	1.01	2.79	2.4

In both years, the fields were planted into a cover crop of common oats (*Avena sativa).* The 2014 planting of oats failed to germinate well and essentially provided no cover for the winter of 2014-2015. This left little plant residue in the field at the start of the 2015 growing season. The 2015 oat cover established well with a dense planting however, the oats failed to grow to an adequate height before cooler winter temperatures arrived which reduced biomass. Furthermore, the winter of 2015-2016 had a less than normal snow pack which prevented the oats from laying down under the snow's

weight. The short standing oats allowed sunlight to penetrate onto the soil surface. This provided good conditions for weeds to germinate, establish and be protected from surface machine cultivation available on farm. To mitigate this problem, a shallow rototill at the depth of approximately two inches was used when the ground could be worked in the spring of 2016.

Soil tests were taken prior to planting. The 2015 field contained low levels of phosphorus and potassium. Consequently, rock phosphate (0-3-0) was applied at a rate of 1000 lbs·acre^{-1}. Potassium was applied as potassium sulfate (0-0-50) at a rate of 250 lbs·acre^{-1}. Both fertilizers were applied 19 June. A soil test of the field used in 2016 revealed adequate fertility and no additional adjustments where needed.

In both years, Honey Bear acorn squash (*Curcurbita pepo* 'Honey Bear') was grown as the test crop. Each plot consisted of three 36" wide beds 72" on center. Honey bear was transplanted at 36" in-row spacing. Data was collected only from the center row.

The experiment consisted of 22 treatments in 2015 and 24 in 2016, (**Table 1)**. The combination of treatments created a range of total nitrogen applied from 40, 80, 120 and 160 lbs·acre^{-1} of N with 0 lbs·acre^{-1} of N as the control. Due to space and practicality, treatments only included combinations that we were interested in testing which created an unbalanced design.

In both years compost used was made at Highmoor farm from a mixture of animal bedding, manure, apple pomace, and culled chickens. Analysis for all sites is listed below in **Table 3.** In 2015 and 2016 pre-plant bloodmeal fertilizer and compost were applied by banding or broadcasting. Banding involved placing a narrow strip of the amendment, approximately 12 inches wide, in the center of the bed where the squash would be planted. broadcasting involved placing the material over the entire planting bed between the wheel tracks. However, in both cases the same volume was applied regardless of the distribution pattern. This caused banded applications to have a higher concentration of materials due to the reduction of area where the materials were applied. Compost and bloodmeal

fertilizer were applied by total N rate. Compost was applied at 40, 80 and 120 lbs·acre^{-1} of N. Pre-plant bloodmeal (13-0-0) was applied at 40 lbs·acre^{-1} of N in both years. In 2016 two additional treatments included pre-plant bloodmeal applied at 80 lbs·acre^{-1} of N.

Table 3. Compost analysis for Monmouth, ME; Freeville and Riverhead NY 2015 and 2016.

Maine Soil Testing Lab Compost Analysis	Monmouth, ME 2015	Monmouth, ME 2016	Freeville, NY 2015	Freeville, NY 2016	Riverhead, NY 2015	Riverhead, NY 2016
pH	6.9	7	7.1	7.2	7.3	7.3
Bulk Density (lbs·yd^3)	830	840	1030	940	840	1150
Conductivity (mmhos·cm^{-1})	1.5	3.5	2.6	5.2	1.8	5.9
C:N Ratio	23.6	19.9	15.4	17.5	22.8	14.8
Organic Matter % (dry basis)	68	63	38	46.4	41.1	33.7
Total N (%)	.36	0.44	0.41	0.46	0.47	0.63
Total P (%)	.21	0.35	0.12	0.13	0.05	0.1
Total K (%)	.09	0.28	0.19	0.35	0.1	0.58

In 2015 and 2016 pre-plant bloodmeal fertilizer and compost were applied by banding or broadcasting. Banding involved placing a narrow strip of the amendment, approximately 12 inches wide, in the center of the bed where the squash would be planted. broadcasting involved placing the material over the entire planting bed between the wheel tracks. However, in both cases the same volume was applied regardless of the distribution pattern. This caused banded applications to have a higher concentration of materials due to the reduction of area where the materials were applied. Compost and bloodmeal fertilizer were applied by total N rate. Compost was applied at 40, 80 and 120 lbs·acre^{-1} of N. Pre-plant bloodmeal (13-0-0) was applied at 40 lbs·acre^{-1} of N in both years. In 2016 two additional treatments included pre-plant bloodmeal applied at 80 lbs·acre^{-1} of N.

Some treatments received a side-dress blood meal application of 40 lbs·acre^{-1} of N. Timing of side-dressing was based on the phenological indicator of first flower as suggested by the New England Vegetable Management Guide, 2016-2017. This occurred on 23 July and 14 July in 2015 and 2016 respectively. Side-dressing was applied manually by shaking the fertilizer out of a bucket in a banding

strip under the established plants. In both years the side-dress fertilizer was not incorporated. In 2015 the side-dressed fertilizer was covered by soil thrown from a hillside cultivator (Hillside Cultivator Company, Model CS; Lititz, Pennsylvania, US) and in 2016 side-dress fertilizer was applied before a rain event.

Both pre-plant bloodmeal and compost were applied shortly before strip tillage each year. In 2015 bloodmeal application occurred on 19 June and compost application started on 19 June and finished on 22 June. In 2016 compost was applied on 3 June and bloodmeal was applied on 6 June. Strip tillage was done with a 1-shank Yeoman plow (Market Farm Equipment; Friedens, Pennsylvania, US) shortly before transplanting.

Previously, ‘Honey Bear’ was seeded in 50 cell trays (T.O. Plastics, PL-50; Clearwater, Minnesota, US) filled with media (Sun Gro #1 Natural and Organic; Agawam, Massachusetts, US) and grown in a greenhouse until the seedlings were hardened off in a high tunnel. The plants were then transplanted approximately three weeks after on 25 June and 8 June in 2015 and 2016, respectively. In 2015 the squash seedlings were fertilized once with fish emulsion (2-4-1).

Minimal work was needed to maintain the plots throughout both growing seasons. In 2015 weeds were for the most part controlled mechanically with a hillside cultivator. This implement straddles the crop row and uses angled disks and spider tines for shallow disturbance. Cultivations took place on 7 and 9 July and. Additionally, hoeing was used to control weeds in-row between plants on 27 July. In 2016 the shallow roto-till of two inches previously mentioned was used to control early emergent weeds. Hillside cultivation was not used during 2016 due to the slope of the field and moist conditions that caused the cultivator to drift towards the plants. Instead a shallow power harrow mounted on a walk behind tractor (BCS, Model 732gx11; Portland, Oregon, US) at a depth of two inches was used on 15 July. The perimeter around the experiment was maintained by clean cultivation.

In both years, striped cucumber beetles (*Acalymma vittatum*) were controlled on the squash using pyrethrin at 4.5 oz·acre^{-1} (Pyganic EC5.0^{OG}). In 2015 applications were made 9 and 29 July. Additionally, the application on 9 July also included mineral oil at 3qt·100 gal^{-1} (JMS Stylet-Oil^{OG}) and the application on 29 July included copper hydroxyl chloride at 0.5 lbs·acre^{-1} (Badge X2®); both to prevent powdery mildew (*Podosphaera xanthii*) (*Erysiphe cichoracearum*). In 2016 Pyganic was used at the same rate on 25 June, 6 and 23 July. Powdery mildew appeared late, after the crop had matured and was not controlled.

As part of the crop rotation cover crops were over seeded in 2015 and 2016. In 2015 oats (*Avena sativa*) at 100 lbs·acre^{-1} and field peas (*Pisum* sativum) at 50·lbs·acre^{-1} were broadcasted over the squash plants in mid-August. In 2016, only oats at 100 lbs·acre^{-1} were applied.

In 2015 petiole samples were taken in late July after the side-dress had been applied for all treatments. On 28 July a powerful thunderstorm produced significant hail that damaged the plants and fruit. Petiole samples were taken again in early August and this second petiole set was used. In 2016 petiole samples were only taken from the banded plots before side-dressing on 12 July and ten days after on 22 July. The later samples were used for this thesis.

Harvest began on 13 October and 3 October in 2015 and 2016, respectively. In both years, data collection at harvest was identical. The fruit number and fruit yield were recorded for individual plants in the center data rows. The stem weight was recorded for each individual plant. This involved severing the stem of the plant from the root system at the soil line. All remaining leaves were removed since earlier senesced squash leaves could not be accounted for and the remaining stem was dried and weighed.

Results 2015, Monmouth ME: Fruit Number, Fruit Yield and Stem Dry Weight

In 2015, fruit number ($P < 0.001$), fruit yield ($P < 0.001$) and biomass ($P < 0.001$) had highly significant differences among treatments in the overall F-test. **Figures 1, 2, and 3**, respectively. Contrasts

were used to compare treatments to one another and significant differences were found (**Table 4).** The control (0:0:0) produced significantly lower fruit number (P<0.001) and weight (P<0.001) compared to the compost treatments (40:0:0), (80:0:0) and (120:0:0). Banded pre-plant fertilizer (0:40:0) produced significantly lower fruit number (P<0.001) and fruit yield (P<0.001) than banded compost (40:0:0) (80:0:0) (120:0:0). Broadcasted pre-plant fertilizer (0:40:0) produced significantly lower fruit number (P<0.001) and fruit yield (P<0.001) than broadcasted compost (40:0:0) (80:0:0) (120:0:0). No differences in fruit number or weight were detected when considering banding or broadcasting of pre-plant fertilizer at the 40 lbs·acre^{-1} of N rate or compost at 40 and 120 lbs·acre^{-1} of N rate. There was a significant decrease (P=0.016) in fruit number with the banded compost compared to the broadcasted compost both applied at a rate of 80 lbs·acre^{-1} (80:0:0) but there was no difference in fruit weight. Furthermore, no differences in fruit number and weight were detected between the differing rates of compost. Compost at 80 lbs·acre^{-1} of N (80:0:0) produced significantly greater fruit numbers (P<0.001) and weight (P<0.001) than a combination pre-plant and side-dressed fertilizer totaling to 80 lbs·acre^{-1} of N (0:40:40), both without considering placement.

Adding a side-dress of 40 lbs·acre^{-1} of N to pre-plant fertilizer rates of 40 lbs·acre^{-1} of N and compost rates of 40, 80 and 120 lbs·acre^{-1} of N did not increase fruit number or fruit yield in this year of the experiment. When comparing both the side-dress only treatment (0:0:40) and the pre-plant fertilizer with side-dress (0:40:40) to the control (0:0:0) neither one was significantly different for fruit number and weight **(Table 4)**.

Stem dry weight had fewer significant differences found compared to fruit number and weight. **(Table 4)**. The control had significantly lower biomass than all treatments which received compost (40:0:0), (80:0:0) and (120:0:0) (P<0.001). Banded pre-plant fertilizer did not differ significantly from banded compost; however, broadcasted fertilizer was significantly lower (P=.002) than broadcasted compost. Compost applied at 80 lbs·acre^{-1} of N (80:0:0) did produce a significantly higher (P=0.01)

amount of biomass compare to the same total N rate applied as a combination of pre-plant and side-dress fertilizer (0:40:40). Other comparisons were found to be non-significant, but there was an increasing stem weight trend with the addition of compost to the treatments.

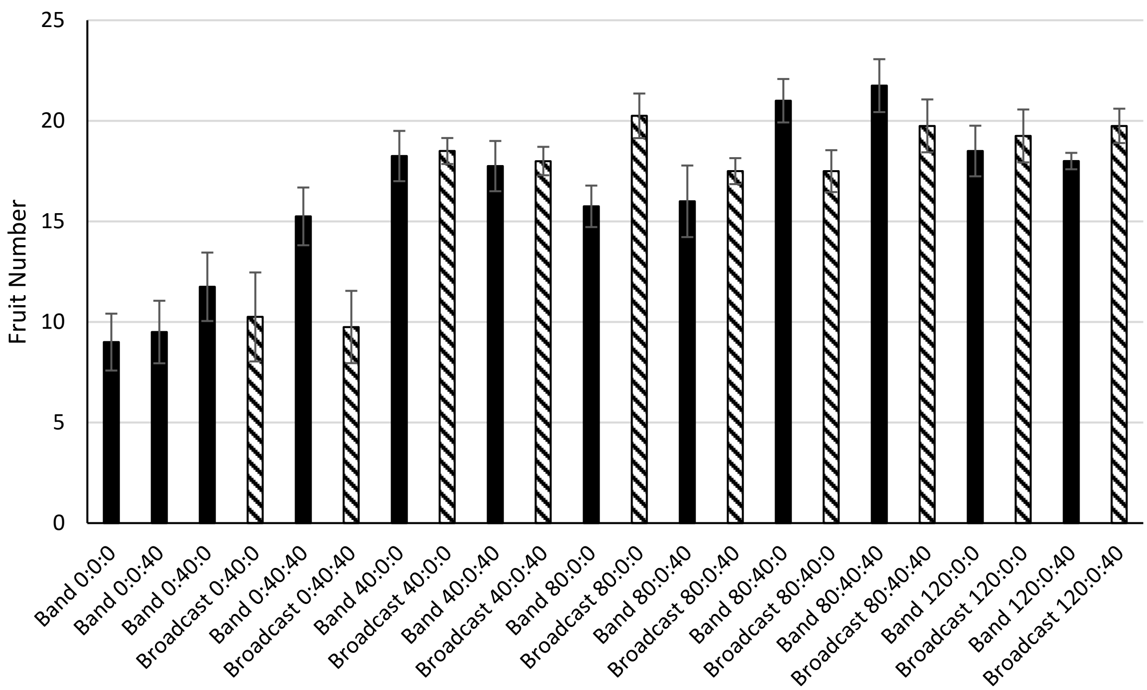

Figure 1. Comparison of mean fruit number harvested from plots amended with differing rates of N from compost : pre-plant bloodmeal : side-dressed bloodmeal applied by banding or broadcasting Monmouth, ME 2015.

Total lbs·acre^{-1} of N obtained by summing values given in the proportions i.e. 80:40:40 = 160 Total lbs·acre^{-1} of N. Vertical bars represent +/- standard error.

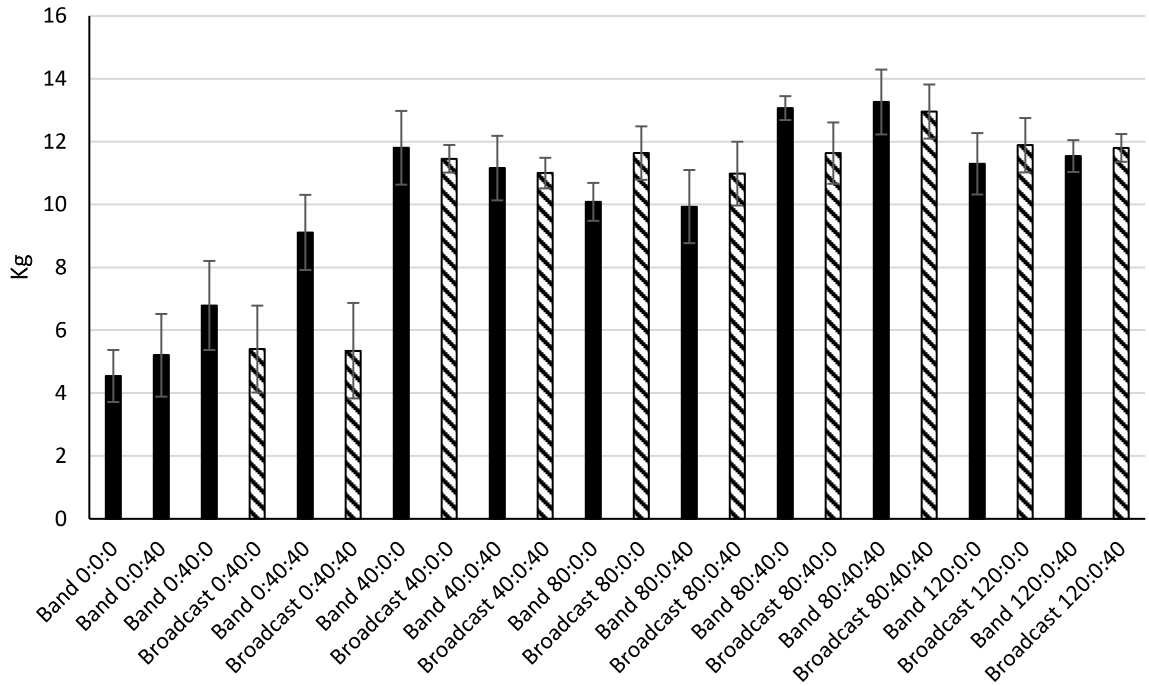

Figure 2. Comparison of mean fruit yield harvested from plots amended with differing rates of N from compost : pre-plant bloodmeal : side-dressed bloodmeal applied by banding or broadcasting Monmouth, ME 2015.

Total lbs·acre^{-1} of N obtained by summing values given in the proportions i.e. 80:40:40 = 160 Total lbs·acre^{-1} of N. Vertical bars represent +/- standard error.

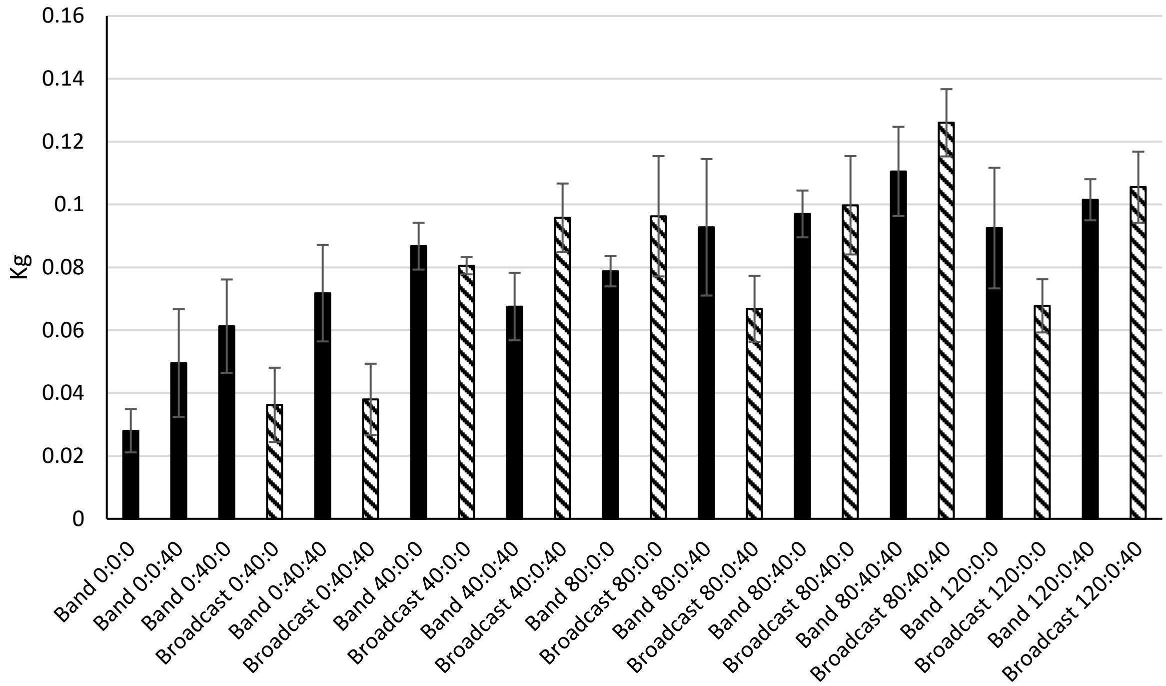

Figure 3. Comparison of mean dried stem weight taken from 4 plants at harvest from plots amended with differing rates of N from compost : pre-plant bloodmeal : side-dressed bloodmeal applied by banding or broadcasting Monmouth, ME 2015.

Total lbs·acre^{-1} of N obtained by summing values given in the proportions i.e. 80:40:40 = 160 Total lbs·acre^{-1} of N. Vertical bars represent +/- standard error.

Table 4. Treatment comparisons for squash fruit number, fruit yield and dry stem weight from plots amended with differing rates of N from compost : pre-plant bloodmeal : side-dressed bloodmeal applied by banding or broadcasting Monmouth, ME 2015.

Total lbs·acre^{-1} of N obtained by summing values given in the proportions i.e. 80:40:40 = 160 Total lbs·acre^{-1} of N. $F_{1,63}$ = 3.99.

Comparison	Fruit Number		Fruit Yield		Dry Stem Weight	
	F Value	Pr > F	F Value	Pr > F	F Value	Pr > F
(0:0:0) vs (0:40:40)	0.69	0.410	1.06	0.308	2.15	0.148
(0:0:0) vs (40:0:0) (80:0:0) (120:0:0)	**46.01**	<0.001	**47.17**	<0.001	**17.64**	<0.001
(40:0:0) vs (80:0:0) (120:0:0)	0.00	0.955	0.26	0.613	0.00	0.986
(0:40:0) vs (0:40:40)	1.36	0.248	1.53	0.221	0.25	0.620
(40:0:0) vs (40:0:40)	0.15	0.699	0.36	0.551	0.03	0.871
(80:0:0) vs (80:0:40)	0.95	0.335	0.19	0.663	0.40	0.531
(80:0:0) vs (0:40:40)	**18.31**	<0.001	**15.60**	<0.001	**7.05**	0.010
(80:40:0) vs (80:40:40)	1.36	0.248	0.68	0.411	2.62	0.111
(120:0:0) vs (120:0:40)	0.00	1.000	0.01	0.932	3.62	0.062
Band (40:0:0) vs Broad (40:0:0)	0.02	0.891	0.07	0.789	0.13	0.720
Band (80:0:0) vs Broad (80:0:0)	6.13	0.016	1.42	0.238	1.01	0.318
Band (120:0:0) vs Broad (120:0:0)	0.17	0.681	0.21	0.651	2.03	0.159
Band (0:40:0) vs Broad (0:40:0)	0.68	0.412	1.14	0.291	2.07	0.155
Band (40:0:0) (80:0:0) (120:0:0) vs Band (0:40:0)	**15.01**	<0.001	**16.23**	<0.001	3.04	0.086
Broad (40:0:0) (80:0:0) (120:0:0) vs Broad (0:40:0)	**37.46**	<0.001	**34.77**	<0.001	**10.17**	0.002
Band (80:40:0) vs Broad (80:40:0)	3.71	0.059	1.21	0.276	0.03	0.875

2015 Petiole Analysis: %NO_3-N

In 2015 there were highly significant differences ($P<0.0001$) between treatments for %NO_3-N in petiole samples. Treatments that received only bloodmeal as supplemental nitrogen had the highest mean %NO_3-N detected in squash petioles. Plants that received compost had lower mean %NO_3-N concentrations in their petioles compared to squash that received only bloodmeal even if they received pre-plant or side-dressed N as well (**Figure 4)**.

Significant differences were found between the highest %NO_3-N concentrations from treatments: broadcasted (0:40:40), banded (0:40:40), banded (0:0:40), broadcasted (0:40:0) and the lowest %NO_3-N concentration from treatments: banded (40:0:0), broadcasted (80:40:0), banded (80:40:0), broadcasted (120:0:0), banded (120:0:40), banded (80:0:0), broadcasted (80:0:0), banded (120:0:0) (**Table 5)**. Plots with higher %NO_3-N levels in squash petioles had lower fruit number and yield in 2015. Nitrogen likely was not the limiting factor because plots with lower %NO_3-N in petiole samples produced greater fruit number and weight.

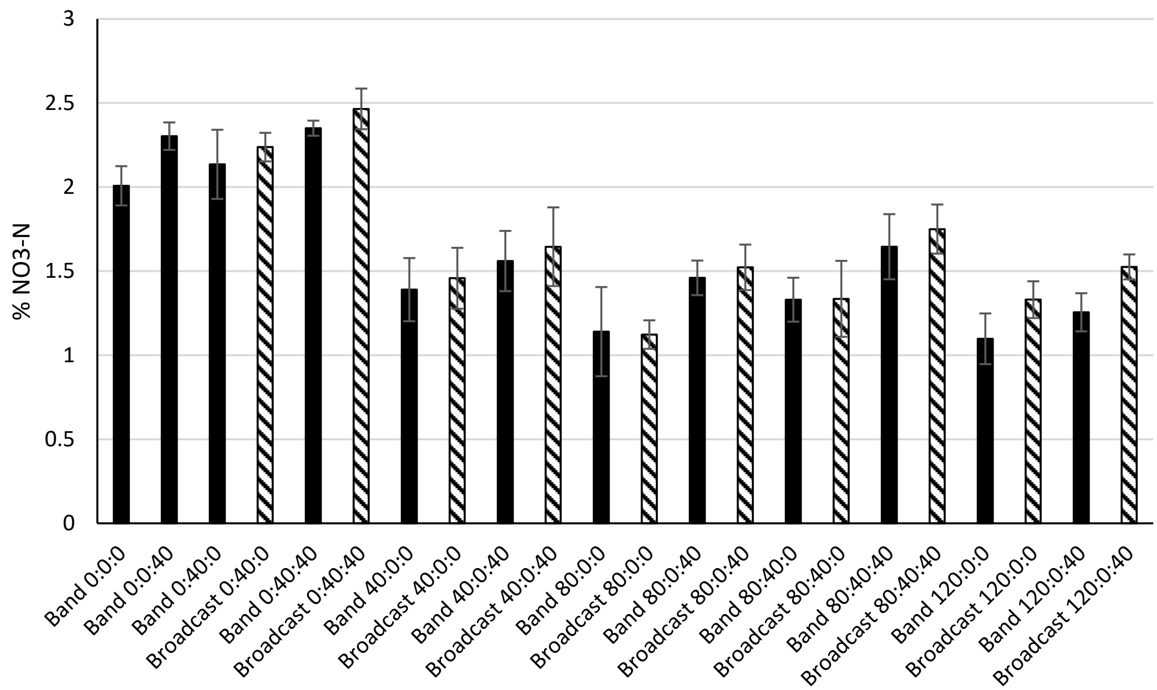

Figure 4. Comparison of post side-dress mean dried petiole %NO_3-N from plots amended with differing rates of N from compost : pre-plant bloodmeal : side-dressed bloodmeal applied by banding or broadcasting Monmouth, ME 2015.

Total lbs·acre^{-1} of N obtained by summing values given in the proportions i.e. 80:40:40 = 160 Total lbs·acre^{-1} of N. Vertical bars represent +/- standard error.

Table 5. Mean %NO_3-N in dried squash petioles taken two weeks after side-dressing from plots amended with differing rates of N from compost : pre-plant bloodmeal : side-dressed bloodmeal applied by banding or broadcasting Monmouth, ME 2015.

Total lbs·acre^{-1} of N obtained by summing values given in the proportions i.e. 80:40:40 = 160 Total lbs·acre^{-1}

Application	Mean %NO_3-N	[z]Tukey's HSD test at $P \leq .05$
Broadcast (0:40:40)	2.47	A
Band (0:40:40)	2.35	A B
Band (0:0:40)	2.30	A B C
Broadcast (0:40:0)	2.24	A B C D
Band (0:40:0)	2.14	A B C D E
Band (0:0:0)	2.01	A B C D E F
Broadcast (80:40:40)	1.75	A B C D E F G
Broadcast (40:0:40)	1.65	B C D E F G
Band (80:40:40)	1.65	B C D E F G
Band (40:0:40)	1.56	B C D E F G
Broadcast (120:0:40)	1.53	C D E F G
Broadcast (80:0:40)	1.52	C D E F G
Band (80:0:40)	1.46	D E F G
Broadcast (40:0:0)	1.46	D E F G
Band (40:0:0)	1.39	E F G
Broadcast (80:40:0)	1.34	F G
Band (80:40:0)	1.33	F G
Broadcast (120:0:0)	1.33	F G
Band (120:0:40)	1.26	F G
Band (80:0:0)	1.14	G
Broadcast (80:0:0)	1.12	G
Band (120:0:0)	1.10	G

[z]Means followed by the same letter are not significantly different.

2015 Petiole Analysis: %Phosphorus

Squash petioles were found to have significantly different amounts of phosphorus when comparing treatments (**Table 6, Figure 5)**. All treatments that contained compost had significantly higher amounts of P in the petioles than treatments that received bloodmeal fertilizer alone; except for broadcasted compost applied at 40 lbs·acre^{-1} (40:0:0). This treatment was not significantly higher than the combination of banded pre-plant and side-dress bloodmeal applied at 40lbs of lbs·acre^{-1} each (0:40:40), even though the mean % of P was found to be higher in the compost treatment. Comparisons between banded and broadcasted compost treatments at equal rates revealed no significant differences in mean %P between the two application methods for compost. P was likely a limiting factor because a pre-planting soil test revealed low soil P levels. The sufficient range for petiole %P in cucurbits is .30-.40% (Hochmuth & Hanlon, 1999). Based on the range, treatments that did not receive compost had %P levels that were low or deficient in P.

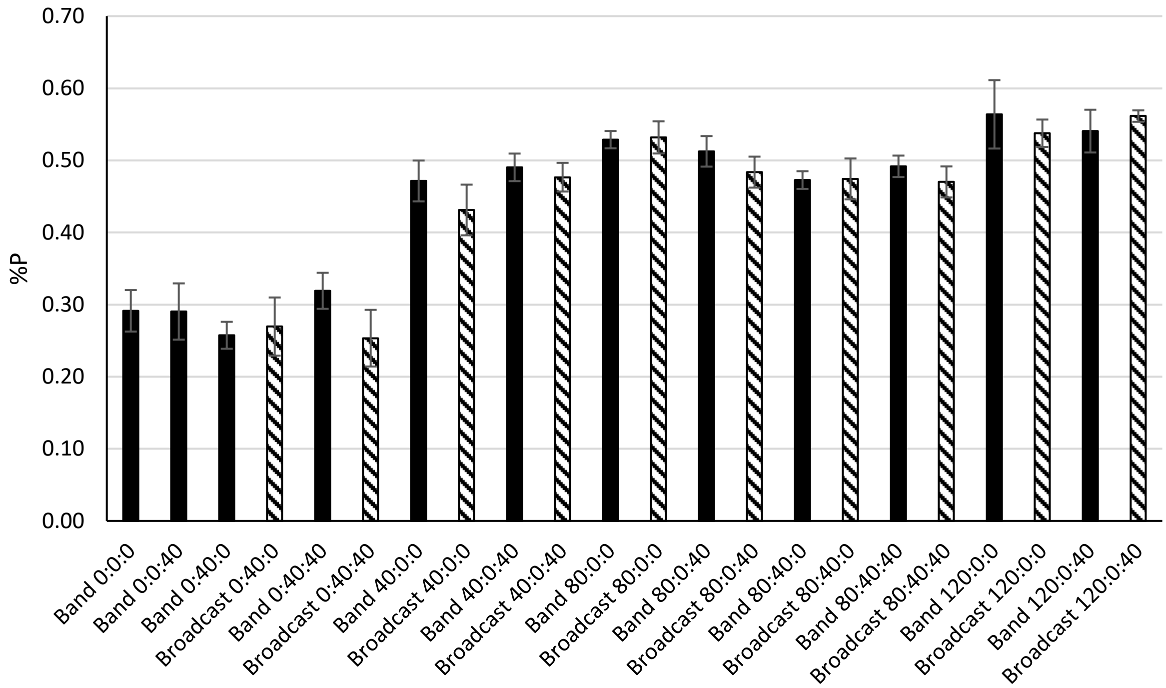

Figure 5. Comparison of mid-season mean dried petiole %P from plots amended with differing rates of N from compost : pre-plant bloodmeal : side-dressed bloodmeal applied by banding or broadcasting Monmouth, ME 2015.

Total lbs·acre^{-1} of N obtained by summing values given in the proportions i.e. 80:40:40 = 160 Total lbs·acre^{-1} of N. Vertical bars represent +/- standard error.

Table 6. Mean %P in dried squash petioles taken two weeks after side-dressing from plots amended with differing rates of N from compost : pre-plant bloodmeal : side-dressed bloodmeal applied by banding or broadcasting Monmouth, ME 2015.

Total lbs·acre^{-1} of N obtained by summing values given in the proportions i.e. 80:40:40 = 160 Total lbs·acre^{-1}

Application	**Mean %P**	**[z]Tukey''s HSD test at P ≤ .05**
Band (120:0:0)	0.564	A
Broadcast (120:0:40)	0.561	A
Band (120:0:40)	0.541	A
Broadcast (120:0:0)	0.538	A
Broadcast (80:0:0)	0.532	A
Band (80:0:0)	0.529	A
Band (80:0:40)	0.512	A
Band (80:40:40)	0.492	A
Band (40:0:40)	0.490	A
Broadcast (80:0:40)	0.484	A
Broadcast (40:0:40)	0.477	A
Broadcast (80:40:0)	0.474	A
Band (80:40:0)	0.473	A
Band (40:0:0)	0.471	A
Broadcast (80:40:40)	0.470	A
Broadcast (40:0:0)	0.431	A B
Band (0:40:40)	0.319	B C
Band (0:0:0)	0.291	C
Band (0:0:40)	0.290	C
Broadcast (0:40:0)	0.269	C
Band (0:40:0)	0.257	C
Broadcast (0:40:40)	0.253	C

[z]Means followed by the same letter are not significantly different.

Results 2016 Monmouth ME: Fruit Number, Yield and Stem Dry Weight

In 2016 fruit number (P <0.1651), fruit yield (P <0.3879) and dry stem weight (P <0.7525) were all non-significant based on the overall F-test. Contrasts were used to compare treatments to one another; however, no significant differences were found (**Figures 6, 7, and 8, Table 7).**

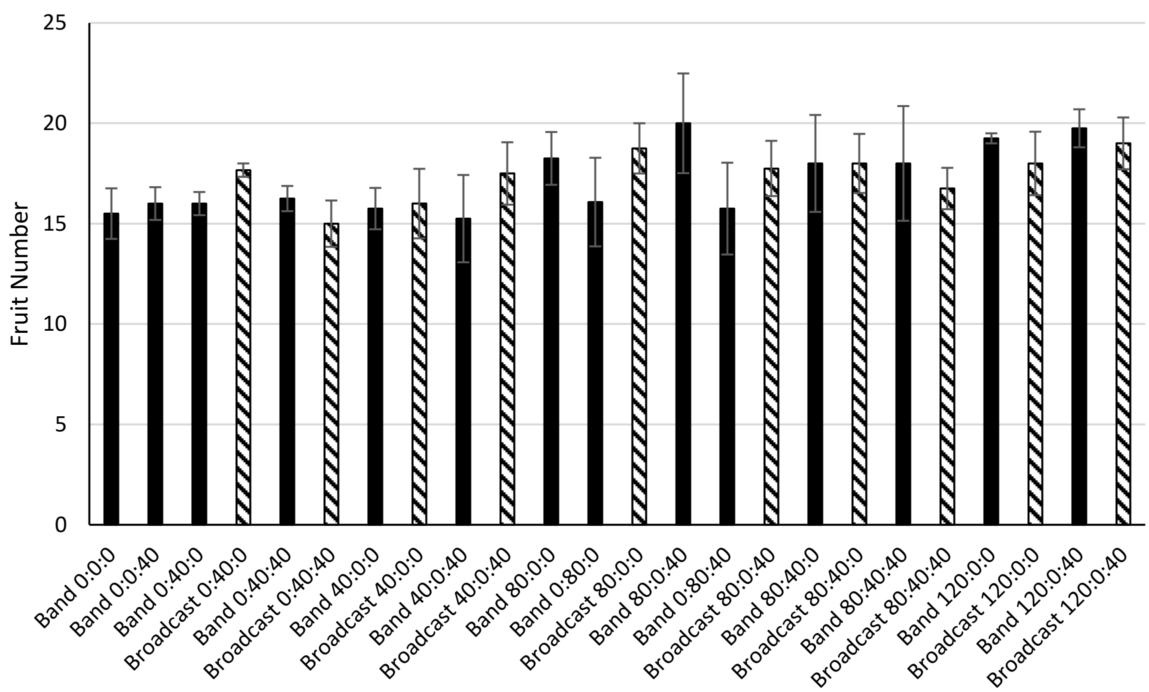

Figure 6. Comparison of mean fruit number harvested from plots amended with differing rates of N from compost : pre-plant bloodmeal : side-dressed bloodmeal applied by banding or broadcasting Monmouth, ME 2016.

Total lbs·acre^{-1} of N obtained by summing values given in the proportions i.e. 80:40:40 = 160 Total lbs·acre^{-1} of N. Vertical bars represent +/- standard error.

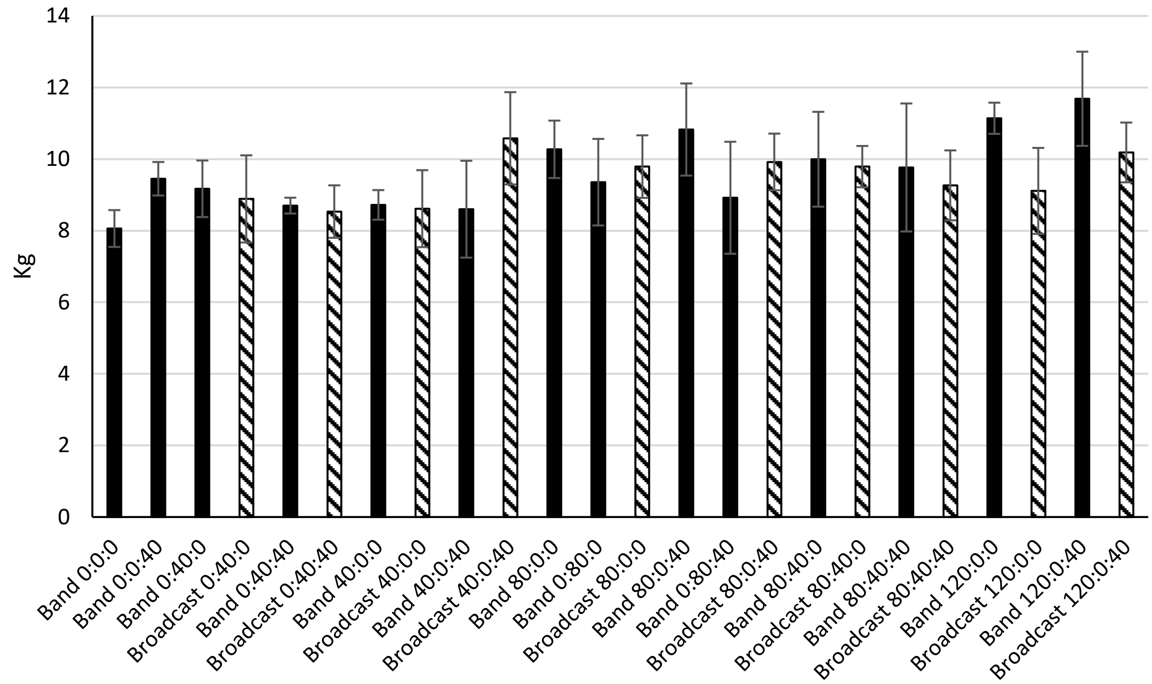

Figure 7. Comparison of mean fruit yield harvested from plots amended with differing rates of N from compost : pre-plant bloodmeal : side-dressed bloodmeal applied by banding or broadcasting Monmouth, ME 2016.

Total lbs·acre^{-1} of N obtained by summing values given in the proportions i.e. 80:40:40 = 160 Total lbs·acre^{-1} of N. Vertical bars represent +/- standard error.

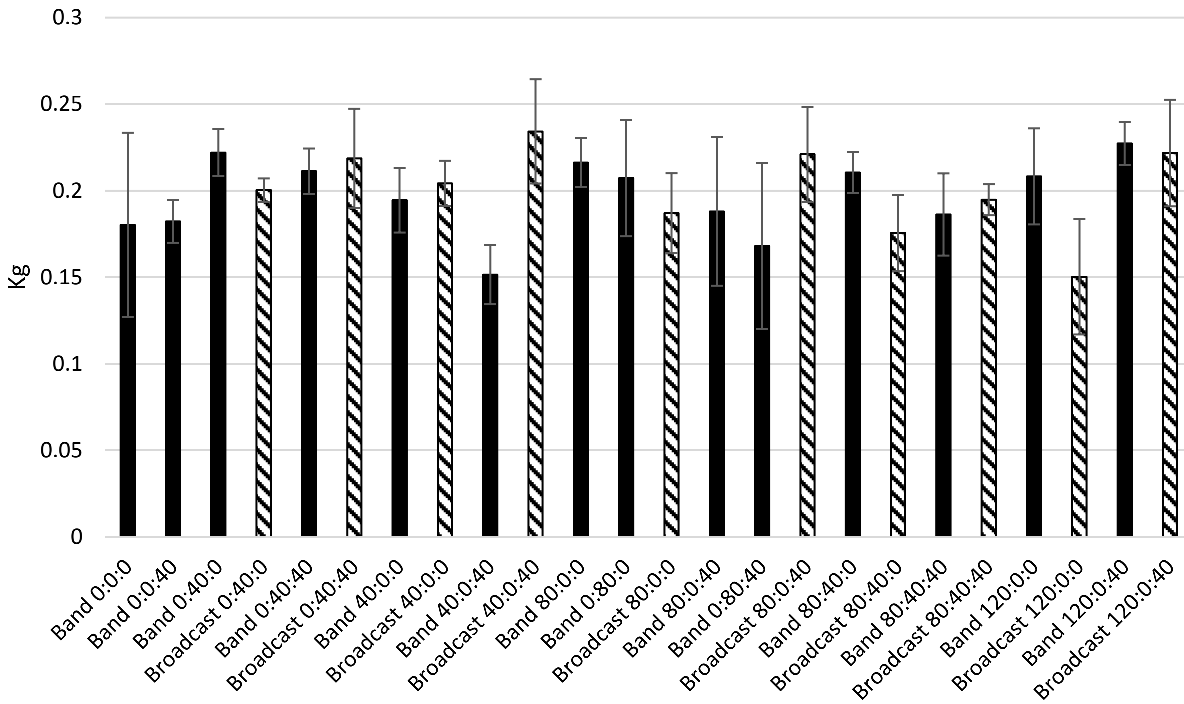

Figure 8. Comparison of mean dried stem weight taken from 4 plants at harvest from plots amended with differing rates of N from compost : pre-plant bloodmeal : side-dressed bloodmeal applied by banding or broadcasting Monmouth, ME 2016.

Total lbs·acre^{-1} of N obtained by summing values given in the proportions i.e. 80:40:40 = 160 Total lbs·acre^{-1} of N. Vertical bars represent +/- standard error.

Table 7. Treatment comparisons for squash fruit number, fruit yield and dry stem weight from plots amended with differing rates of N from compost : pre-plant bloodmeal : side-dressed bloodmeal applied by banding or broadcasting Monmouth, ME 2016.

Total lbs·acre-1 of N obtained by summing values given in the proportions i.e. 80:40:40 = 160 Total lbs·acre-1 of N. $F_{1,67} = 3.98$

Comparison	Fruit Number		Fruit Yield		Dry Stem Weight	
	F Value	Pr > F	F Value	Pr > F	F Value	Pr > F
(0:0:0) vs (0:40:40)	0.29	0.589	1.04	0.312	0.26	0.610
(0:0:0) vs (40:0:0) (80:0:0) (120:0:0)	1.82	0.182	2.10	0.152	0.21	0.647
(40:0:0) vs (80:0:0)	3.12	0.082	1.90	0.173	0.01	0.933
(40:0:0) vs (120:0:0)	3.42	0.069	2.17	0.146	0.58	0.450
(80:0:0) vs (120:0:0)	0.01	0.933	0.01	0.925	0.71	0.402
(0:40:0) vs (0:40:40)	0.50	0.483	0.09	0.762	0.02	0.880
(40:0:0) vs (40:0:40)	0.11	0.738	0.87	0.355	0.06	0.807
(80:0:0) vs (80:0:40)	0.06	0.802	0.12	0.731	0.01	0.914
(80:40:0) vs (80:40:40)	0.18	0.676	0.15	0.704	0.01	0.925
(120:0:0) vs (120:0:40)	0.25	0.616	0.67	0.416	2.92	0.092
Band (40:0:0) vs Broad (40:0:0)	0.01	0.906	0.01	0.940	0.07	0.796
Band (80:0:0) vs Broad (80:0:0)	0.06	0.813	0.12	0.732	0.61	0.438
Band (120:0:0) vs Broad (120:0:0)	0.35	0.554	2.10	0.152	2.39	0.127
Band (0:40:0) vs Broad (0:40:0)	0.63	0.429	0.02	0.879	0.33	0.569
Band (0:80:0) vs Band (80:0:0)	1.07	0.305	0.43	0.515	0.06	0.811
Band (0:80:0) vs Band (0:40:40)	0.15	0.696	0.29	0.592	2.21	0.142
Broad (0:40:40) vs Band (80:0:0)	0.46	0.500	0.77	0.385	0.52	0.474
Band (0:80:40) vs Band (120:0:0)	2.77	0.101	2.51	0.118	1.15	0.287
Broad (0:80:0) vs (80:0:0)	1.07	0.305	0.43	0.515	0.06	0.811
Band (40:0:0) (80:0:0) (120:0:0) vs Band (0:40:0)	1.04	0.312	0.58	0.447	0.26	0.610
Broad (40:0:0) (80:0:0) (120:0:0) vs Broad (0:40:0)	0.01	0.905	0.03	0.856	0.28	0.597
Band (80:40:0) vs Broad (80:40:0)	0.00	1.000	0.02	0.884	0.87	0.354

2016 Petiole Analysis %NO_3-N

In 2016 there were highly significant differences ($P<.0019$) between treatments for %NO_3-N in petiole samples. Treatments that received only bloodmeal as supplemental nitrogen had the highest mean %NO_3-N detected in squash petioles. Plants that received compost had lower mean %NO_3-N concentrations in their petioles compared to squash that received a bloodmeal alone even if they also received pre-plant or side-dressed N as well **(Figure 9)**.

Significant differences were found between the highest %NO_3-N concentration in the banded (0:80:40) treatment and the lowest %NO_3-N concentrations in the banded (80:0:40), banded (80:0:0), banded (80:40:0) and banded (120:0:40) treatments **(Table 8)**.

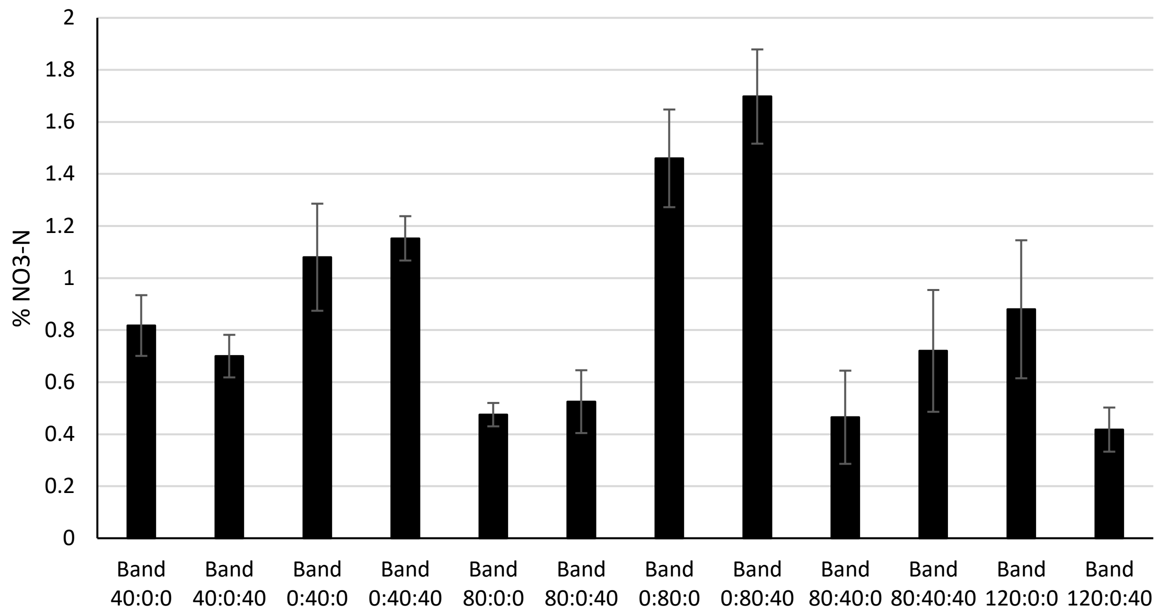

Figure 9. Comparison of post side-dress mean dried petiole %NO3-N from plots amended with differing rates of N from compost : pre-plant bloodmeal : side-dressed bloodmeal applied by banding or broadcasting Monmouth, ME 2016.

Total lbs·acre^{-1} of N obtained by summing values given in the proportions i.e. 80:40:40 = 160 Total lbs·acre^{-1} of N. Vertical bars represent +/- standard error.

Table 8. Mean %NO_3-N in dried squash petioles taken two weeks after side-dressing from plots amended with differing rates of N from compost : pre-plant bloodmeal : side-dressed bloodmeal applied by banding or broadcasting Monmouth, ME 2016.

Total lbs·acre^{-1} of N obtained by summing values given in the proportions i.e. 80:40:40 = 160 Total lbs·acre^{-1}

Application	**Mean** %NO_3-N	[1]**Tukey's HSD test at P ≤ .05**
Band (0:80:40)	1.698	A
Band (0:80:0)	1.460	A B
Band (0:40:40)	1.153	A B
Band (0:40:0)	1.080	A B
Band (120:0:0)	0.880	A B
Band (40:0:0)	0.818	A B
Band (80:40:40)	0.720	A B
Band (40:0:40)	0.700	A B
Band (80:0:40)	0.525	B
Band (80:0:0)	0.475	B
Band (80:40:0)	0.465	B
Band (120:0:40)	0.418	B

Means followed by the same letter are not significantly different.

2016 Petiole Analysis: % Phosphorus

In 2016 squash petioles did not have significantly different amounts of phosphorus when comparing treatments. Furthermore, %P in the petioles where all found to be at satisfactory levels between treatments (Hochmuth & Hanlon, 1999) (**Figure 10, Table 9).**

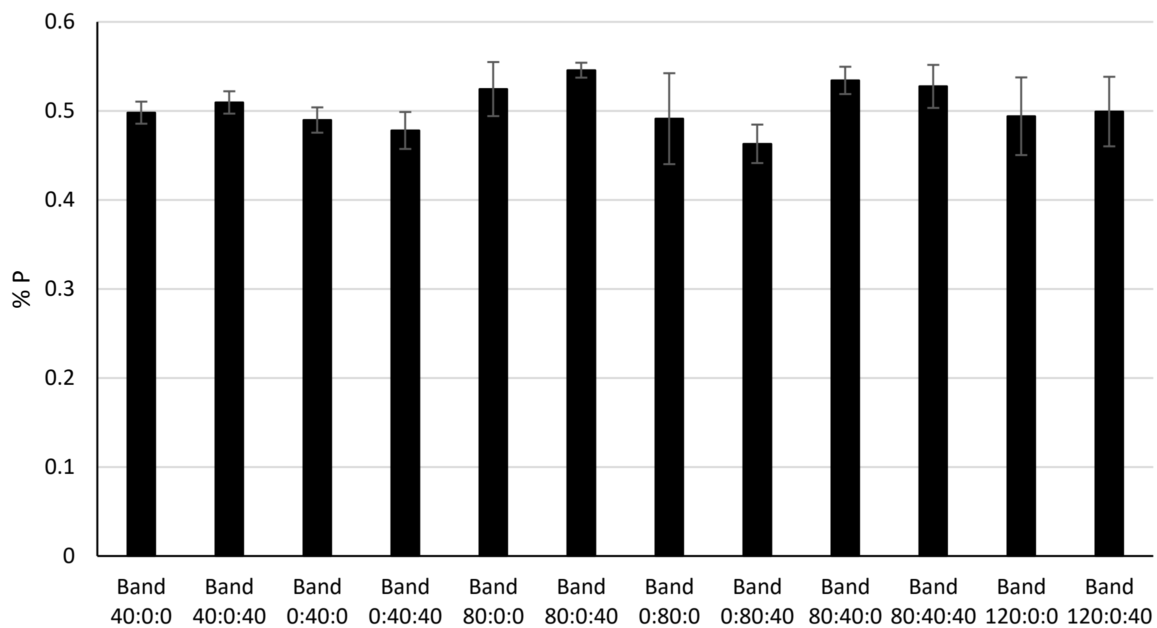

Figure 10. Comparison of mid-season mean dried petiole %P from plots amended with differing rates of N from compost : pre-plant bloodmeal : side-dressed bloodmeal applied by banding or broadcasting Monmouth, ME 2016.

Total lbs·acre^{-1} of N obtained by summing values given in the proportions i.e. 80:40:40 = 160 Total lbs·acre^{-1} of N. Vertical bars represent +/- standard error.

Table 9. Mean %P in dried squash petioles taken two weeks after side-dressing from plots amended with differing rates of N from compost : pre-plant bloodmeal : side-dressed bloodmeal applied by banding or broadcasting Monmouth, ME 2016.

Total lbs·acre^{-1} of N obtained by summing values given in the proportions i.e. 80:40:40 = 160 Total lbs·acre^{-1}

Application	Mean %P	Tukey's HSD test at P ≤ .05
Band (80:0:40)	0.546	A
Band (80:40:0)	0.534	A
Band (80:40:40)	0.528	A
Band (80:0:0)	0.525	A
Band (40:0:40)	0.510	A
Band (120:0:40)	0.499	A
Band (40:0:0)	0.498	A
Band (120:0:0)	0.494	A
Band (0:80:0)	0.491	A
Band (0:40:0)	0.490	A
Band (40:40:40)	0.478	A
Band (0:80:40)	0.463	A

Means followed by the same letter are not significantly different

Discussion: Monmouth ME

Yields

The New England Vegetable Management Guide 2016-2017, list good yields of smaller bush type winter squash varieties in the range of 5-7 tons·acre^{-1}. In 2015 and 2016 plant density was lower than recommended production practices. Yields adjusted for this lower density using the average fruit number and weights per plant ranged from approximately 3.5-6.5 tons·acre^{-1}. In 2015 most plots when averaged by treatment produced yields that fell within this recommended range. However, the control (0:0:0), had the lowest yields and produced only 3.02 tons·acre^{-1}. The highest yielding treatment was the combination of compost, pre-plant bloodmeal, and side-dressed bloodmeal (80:40:40) at 8.82 tons·acre^{-1}.

In 2016 there were no significant differences (**Figure 6, 7 and 8**) in yield between any of the treatments and all treatments produced yields that fell within the recommended range listed above. The variation in total yields in 2016 was lower between each treatment. The lowest yielding treatment contained only pre-plant blood meal (0:40:0) and produced 4.25 tons^{-1}, while the highest yielding treatment included compost and side-dressed bloodmeal (120:0:40) produced 7.77 tons acre^{-1}.

Fertilizer and Compost

Fertilizer rate and timing is crucial in efficient fertilizer use. The goal being to supply the crop with the least amount of additional nutrients to receive the greatest amount of marketable yield. Under high crop N demand, organic fertilizers can provide adequate nitrogen and promote desirable yields (Gaskell and Smith, 2007). Bloodmeal has been shown to have a high rate of nitrogen mineralization and therefore is considered a fast-acting source of organic N. (Hartz and Johnstone, 2006). However, if timing of the available N doesn't line up with crop demand then the nitrogen will continue to move through the nitrogen cycle (Van Eerd, 2010; Buwalda and Freeman, 1986; Mohammad 2004; Havlin et al., 1999; Maathuis, 2009). The New England Vegetable Management Guide, (2016-2017) demonstrates the crop nitrogen uptake curve where little crop N uptake

corresponds with slow early season growth. N uptake dramatically increases as the plant grows throughout the season. Growth as well as N uptake, levels off as crops reach maturity.

A high rate of available N supplied by an organic N fertilizer early in the season may no longer be in an available form when crop need is there. Furthermore, N in an available form may be both converted to an unavailable form or be readily lost to another aspect of the nitrogen cycle. Hartz and Johnstone's (2006) findings report that the greatest amount of N mineralization from organic fertilizers, such as bloodmeal, occurs within the first two weeks after application regardless of environmental factors such as temperature. However, temperature, as well as moisture, plays a critical role in the mineralization process because it is a driving force behind the soil microbial community. Considering this and the crop nitrogen uptake curve, it is plausible to think that the lack of response to pre-plant bloodmeal fertilizer may be due to mineralization of N at a time where N wasn't efficiently taken up by the crop. However this is unlikely, because petiole %NO_3-N levels were higher for all treatments with pre-plant bloodmeal.

Another consideration is that N was not our most limiting nutrient in 2015. This was supported by the analytical results from our petiole samples. Available information on ideal %NO_3-N in dried petiole samples was not found for *Cucurbita pepo.* In its absence, melon (*Cucumis melo*) %NO_3-N levels were used. Adequate %NO_3-N ranges from .08 to 1.5% (Spectrum Technologies INC., 2009), Based on this range, petioles from 2015 show that there is adequate %NO_3-N in all treatments **(Figure 4)**.

This would explain why there was no response to bloodmeal but a response to treatments containing compost. Compost in an environment with typical mineralization would provide roughly 20% of the total N applied. However, even at the highest compost rate of 120 $lbs \cdot acre^{-1}$ of N the amount of N really being supplied would roughly be 50% of the N supplied by bloodmeal at a rate of 40 $lbs \cdot acre^{-1}$ of N (Gale et al., 2006). Since there was no crop response to higher N availably from bloodmeal it is improbable that low N supplied by compost would promote a response. Compost contains P and K which

is available at higher levels compared to N, it is likely that the addition of one of these plant nutrients from the compost increased yields. (Cooperband et. al., 2002; Preusch et. al., 2002).

Pre-planting soil K was sufficient both years and petiole K amounts were not significantly different within each year, (data is not shown). On the other hand, soil tests revealed low levels of phosphorus in the field used in 2015. When comparing bloodmeal to compost in 2015, all treatments with compost had significantly higher fruit number, fruit weight, and dry stem weight compared to equal N rates of bloodmeal alone. Petiole %P levels were much higher for nearly all the treatments containing compost in 2015 **(Figure 5)**. Sufficient range of petiole %P in cucurbits is .30-.40% (Hochmuth & Hanlon, 1999). Treatments without compost all contained low amounts of P some below desired levels, while all treatments with compost contained optimum or high rates.

Visual signs of phosphorus deficiency in cucurbits is the loss of green hue leading to dispersed chlorotic areas and eventually necrosis (Carmona et. al., 2015). While these typical deficiency symptoms were not seen in the field, there were obvious visual differences in size during the early growing season and P availability is a factor to consider. Phosphorus is critical to plant establishment, growth and development due to its involvement in many energy-dependent plant processes. Plants deficient in P at a young age may not respond to later P applications and may continue to display stunted growth later in development (Grant et. al., 2001). P is structurally important for plants in the formation of nucleic acids, coenzymes, phosphoproteins and phospholipids (Grant et. al., 2001). Furthermore, phosphorus deficiency has been shown to slow down photosynthesis in plants (Plesniar et. al, 1994).

There were no significant differences between bloodmeal rates and compost rates in 2016. Soil in this year contained nearly optimum nutrient levels prior to planting. The underlying potential nutrient availability likely inhibited us from seeing differences between experimental treatments for fruit number, fruit yield and dry stem weight. Testing for %NO_3-N and %P in 2016 squash petioles reveled no significant differences and showed adequate %NO_3-N and %P levels **(Figures 9 and 10)**.

Side-dressing

Side-dressing had no effect on fruit number, fruit yield or dried stem weight in 2015 (**Figures 1, 2 and 3,)** or in 2016 **(Figures 6, 7 and 8)**. This was seen in both years when comparing the side-dress only treatment (0:0:40) to the control and the pre-plant fertilizer treatment, (0:0:0) and (0:40:0) respectively. Recent literature and current guidelines suggests that a combination of compost and bloodmeal would have a synergistic effect that could increase yields. Season-long nutrient demands could be better met by combining fertilizer and compost. This would provide an N component when plant growth and N need has peaked with a source of long-term N and available P in early growth. However, adding side-dressed bloodmeal or a combination of side-dressed and pre-plant bloodmeal to compost at 40, 80, or 120 lbs·acre^{-1} of N, did not increase yields in anyway in our experiments during either year, when compared to compost alone (Gaskell and Smith, 2007) (Hartz and Johnstone, 2006) (Evanylo. et al. 2008) (Khalilian and Sullivan, et al. 2002) (The New England Vegetable Management Guide, 2016-2017);

The lack of response to side-dressing does raise questions when considering fertilizer efficiency and effectiveness of organic fertilizers to deliver mid-season nitrogen. In 2015 a severe hail producing thunderstorm struck Highmoor farm a few days after the application of side-dressed bloodmeal. Bloodmeal was applied on the top of the soil and without incorporation it was exposed to the elements where it could have been washed away. This could have influenced the potential effect side-dressed bloodmeal had on squash yields. Mineralized nitrogen from the bloodmeal may also have been flushed out of the field in this heavy rain storm because of the negative charge of nitrate. The 2016 growing season was unusually dry. The lack of sufficient rain fall could have left more nitrogen in the soil than usual, creating an abundance of nitrogen. Another possibility in 2016, is that the dry year hampered the soil microbial community from mineralizing the later season application of bloodmeal. However, to prevent that issue, we applied the side-dressed bloodmeal before a rain event. Additionally, even though the year was drier than normal, water did not appear to be a limiting factor based on our yields.

Considering the crop N uptake curve (The New England Vegetable Management Guide, 2016-2017) and the lag time between application and availability of organic fertilizers, another scenario could be that our application timing is off and ineffective. While these influences could have potentially altered the crop response to our side-dressed bloodmeal, we likely saw no difference because N was not limiting in either year.

Banding or Broadcasting Bloodmeal and Compost

Banding or concentrating the rate of nutrients near the root zone is a strategy to deliver nutrients more efficiently to the crop. This technique is used prior to planting and to apply side-dress fertilizers mid-season (Khalilian and Sullivan, et al. 2002; New England Vegetable Management Guide, 2016-2017). Shapiro et. al. (2016) saw increased grain yields and greater plant nitrogen uptake with banding a conventional fertilizer over broadcasting. Buwalda et. al. (1987) found that yield increased with increasing widths of localized P and K fertilizer up to a certain point of 0.25 meters, after which the increase in width had no further increase in yield.

By banding fertilizer or compost, nutrient demands may be met by lowering the per acre amount due to the smaller application area and therefore a lower relative application rate. In this experiment compost amounts were not changed between the banding and broadcasting of identical rates. This led to the banding application being applied at a higher concentration then the same rate applied as a broadcast. This is because the same volume was applied in treatments with the same compost rate over different areas. When comparing these delivery patterns at like rates no differences were seen in fruit number, weight, or dry stem weight between both years at the 40 lbs·acre^{-1} of N pre-plant bloodmeal treatment (40:0:0) or the 40 and 120 lbs·acre^{-1} of N supplied by compost (40:0:0), (120:0:0) and the 80 lbs·acre^{-1} of N supplied by compost (80:0:0) in 2016. Partial incorporation of the compost by the yeoman plow might be a possible reason for the lack of differences between banding and broadcasting compost at the 40, 120 lbs·acre^{-1} of N in 2015 and 80 lbs·acre^{-1} in 2016.

Another possibility is the low amount of plant available nitrogen in the initial compost application and the subsequent slow release of nitrogen through the mineralization process. Readily usable nitrogen is in the inorganic form of ammonium or nitrate. Ammonium can be rapidly converted to nitrate. Nitrate having a negative charge is transient in the soil water solution. (Gaskell and Smith, 2007; Maathuis, 2009). Perhaps taking this into consideration placement of nitrogen is less important when the actual difference in soil coverage between treatments is small, such as the case in this experiment where broadcasting width differed by 24" in total compared to banding width.

In 2015 the 80 lbs·acre^{-1} of N from compost alone did have a significant difference between banding and broadcasting. Broadcasting (80:0:0) produced a greater amount of fruit with a mean roughly 25% greater than the banded treatment average. There is no obvious explanation for this in our data except that it may be a product of random chance. Mixed results have been found in past research with compost utilization (Khalilian and Sullivan, et al. 2002; Parish, Bracy and McCoy, 2008; Manuck 2006; Shapiro et. al. 2016). In our research banded compost caused a higher relative concentration of compost to be incorporated by the yeoman plow. Higher concentrations of banded and broadcasted compost were not seen to have a negative effect in other treatments when we increased the compost volume to 120 lbs·acre^{-1} (120:0:0). Compost can be highly variable and perhaps the compost that was put in these plots tied up N through a higher amount of carbon. Although, this is unlikely because it was not seen anywhere else within this experiment or on other projects where the same compost was used during the same time frame.

Experimental Design: Freeville, NY

This experiment was conducted at Cornell's Homer C. Thompson Vegetable Research Farm in Freeville, NY in the 2015 and 2016 growing seasons. In both years the soil type was a Howard gravelly loam. Freeville is located approximately 12 miles north east of the weather station in Ithaca NY. Weather

data for Freeville is listed in **(Table 2).** In both years of the experiment reduced tillage went in following plowing to simulate a transition into conservation tillage from conventional tillage methods. Starting in September 2014 a previous wheat crop (*Triticum sp.*) was incorporated through moldboard plowing and then disking and cultipacking were used to establish a seed bed. Oats (*Avena sativa)* and peas (*Pisum sativum*) were then planted at 100 and 50lbs·acre^{-1} respectively. In August of 2015 a second field sown with wheat was plowed in preparation for the 2016 experiment.

In the spring of 2015 and 2016, shallow cultivation with a field cultivator (Perfecta II; Kalida, Ohio, US) was done to limit early-season weed growth. In each year 'Honey Bear' acorn squash (*Cucurbita pepo*) was used as the test crop. Each plot consisted of three 36" beds 60" on center. Seeding was completed on 27 May in 2015 and 26 May in 2016. Approximately 3 weeks later, squash was transplanted with an 18-inch in-row spacing on 18 June and 15 June in 2015 and 2016, respectively. Transplanting followed fourteen treatment applications of banded and broadcasted compost at 80 lbs·acre^{-1} of N and pre-plant fertilizer at 40 lbs·acre^{-1} of N. Additionally, side-dressing at a rate of 40 lbs·acre^{-1} of N occurred in mid-July based on flower initiation in both years **(Table 1)**. These 14 core treatments were also used at Highmoor and Riverside Long Island. Seven selected treatments of interest were sampled prior to side-dress on July 13th both years. These were used to compare mid-season %$N0_3$-N in petiole samples. The experiment was set up as a random complete block design with four replicates and was carried out in 2015 and 2016. Compost used in this experiment was created at the Homer C. Thompson Vegetable Research Farm. This compost was analyzed at University of Maine Analytical and Soil Testing Lab **(Table 3)**.

Weed management was carried out through mechanical between-row cultivation and manual hand weeding between plants within rows. In both years, row cover was used to control striped cucumber beetle (*Acalymma vittatum*) and was removed at flowering. In 2015, squash was sprayed three times on 6, 13 and 31 August to control powdery mildew (*Podosphaera xanthii, Erysiphe cichoracearum*).

In 2016 chemical control using sulfur at 5 lbs·acre^{-1} (Microthiol Disperss) on 15 and 30 August and *Bacillus amyloliquefaciens* strain D747 at 2 qt·acre^{-1} (Double Nickle) on 23 August were used to control powdery mildew. Striped cucumber beetle was also controlled in 2016 using a kaolin at 25 lbs·acre^{-1} (Surround WP^{OG}), and pyrethrin at 4.5 oz·acre+-1 (Pyganic EC5.0^{OG}) combination.

Fall harvest started on September 18th in 2015. The 2016 harvest was completed on September 28th. Data was taken only from the center row. Fruit yield, fruit number and dry stem weight data were gathered.

Results 2015, Freeville, NY: Fruit Number, Fruit Yield and Stem Dry Weight

The overall F Test for fruit number was non-significant (P = 0.3292) in 2015, but significant differences among the treatments were found for both fruit yield (P = 0.0099) and dry stem weight (P= 0.0288). Contrasts were used to compare specific treatments to one another. While the overall F test showed no significance, individual comparisons for fruit number revealed that there was a significantly lower fruit number, yield and dry stem weight for broadcasted compost (80:0:0) compared with broadcasted compost with the addition of pre-plant and side-dressed bloodmeal (80:40:40) (P = 0.030) (P=0.015)(P=0.016)**(Figure 11, Table 10)**.

Banded fertilizer (0:40:0) produced significantly higher fruit yield then broadcasted fertilizer (0:40:0) (P=0.014). Side-dressed fertilizer alone (0:0:40) produced significantly lower fruit yield then banded pre-plant fertilizer (0:40:0) (P=0.045). The combination of banded pre-plant and side-dress fertilizer (0:40:40) produced significantly greater fruit yield then strictly banded compost (80:0:0) (P=0.018), even though the same total N was applied. A combination of banded compost (80:0:40) and side-dressed bloodmeal was significantly lower when compared to the broadcasted (80:0:40) treatment (P=0.039). There was also a difference in fruit yield between banded compost (80:0:0) and broadcasted compost with the addition of pre-plant and side-dressed bloodmeal (80:40:40) (P= 0.015), where the combined broadcasted application sources led to greater squash fruit weights. Significantly

increased fruit weights were found when adding banded pre-plant bloodmeal to banded compost (80:40:0) (P=.005) and when combining banded bloodmeal, side-dressed fertilizer and banded compost (80:40:40) (P=.006) when compared to banded compost alone (80:0:0). Significant differences were not found when looking at a similar combination comparing broadcasted compost (80:0:0) to broadcasted compost with side-dressed bloodmeal (80:0:40). **(Figure 12, Table 10)**.

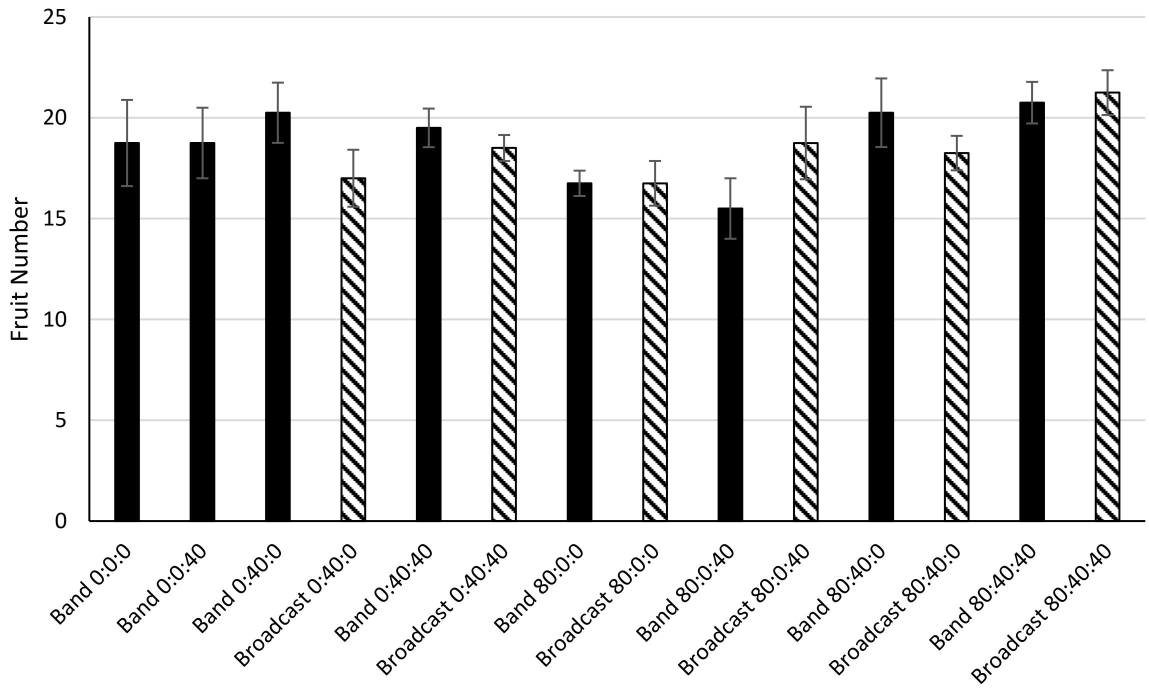

Figure 11. Comparison of mean fruit number harvested from plots amended with differing rates of N from compost : pre-plant bloodmeal : side-dressed bloodmeal applied by banding or broadcasting Freeville, NY 2015.

Total lbs·acre^{-1} of N obtained by summing values given in the proportions i.e. 80:40:40 = 160 Total lbs·acre^{-1} of N. Vertical bars represent +/- standard error.

Table 10. Treatment comparisons for squash fruit number, fruit yield and dry stem weight from plots amended with differing rates of N from compost : pre-plant bloodmeal : side-dressed bloodmeal applied by banding or broadcasting Freeville, NY 2015.

Total lbs·acre^{-1} of N obtained by summing values given in the proportions i.e. 80:40:40 = 160 Total lbs·acre^{-1} of N. $F_{1,39}$ = 4.09.

Comparison	Fruit Number		Fruit Weight		Dry Stem Weight	
	F Value	Pr > F	F Value	Pr > F	F Value	Pr > F
(0:40:0) vs (0:0:40)	0.56	0.458	**4.29**	0.045	0.63	0.432
Band (0:40:0) vs Broad (0:40:0)	2.64	0.112	**6.70**	0.014	0.12	0.734
Band (80:0:0) vs Broad (80:0:0)	0.00	1.000	0.50	0.483	0.36	0.551
Band (80:0:0) vs Band (0:40:40)	1.89	0.177	**6.12**	0.018	**6.19**	0.017
Broad (80:0:0) vs Broad (0:40:40)	0.76	0.387	0.67	0.417	1.12	0.298
Band (80:40:0) vs Broad (80:40:0)	1.00	0.324	1.12	0.296	0.48	0.493
Band (80:0:40) vs Broad (80:0:40)	2.64	0.112	**4.54**	0.039	1.63	0.210
Broad (80:0:0) vs Broad (80:0:40)	1.00	0.324	0.30	0.586	0.06	0.806
Band (0:40:40) vs Broad (0:40:40)	0.25	0.620	0.89	0.351	0.69	0.412
Band (80:0:0) vs Band (80:40:0)	3.06	0.088	**8.82**	0.005	3.1	0.086
Band (80:0:0) vs Band (80:40:40)	4.00	0.053	**8.50**	0.006	**4.19**	0.048
Band (80:0:0) vs Broad (80:40:40)	**5.06**	0.030	**6.53**	0.015	**6.29**	0.016
Broad (80:0:40) vs Broad (80:40:40)	1.56	0.219	1.68	0.202	2.75	0.105

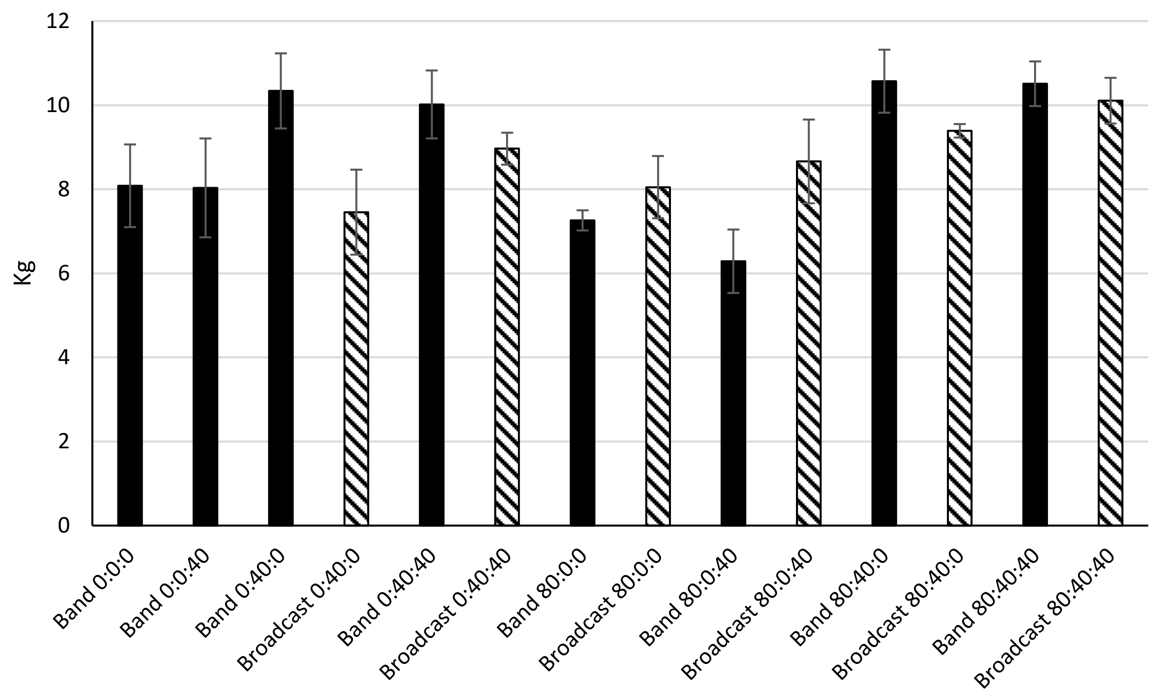

Figure 12. Comparison of mean weight harvested from plots amended with differing rates of N from compost : pre-plant bloodmeal : side-dressed bloodmeal applied by banding or broadcasting Freeville, NY 2015.

Total lbs·acre^{-1} of N obtained by summing values given in the proportions i.e. 80:40:40 = 160 Total lbs·acre^{-1} of N. Vertical bars represent +/- standard error.

Individual contrasts revealed that squash plants receiving banded pre-plant bloodmeal and side-dressed blood meal (0:40:40) produced greater dry stem weight then banded compost alone (80:0:0) (P=0.017). Stem weight was also greater when combining broadcasted pre-plant bloodmeal, side-dressed bloodmeal and broadcasted compost (80:40:40) when compared to just banded compost alone (80:0:0) (P=0.016). Likewise, greater stem weights were produced when adding both banded pre-plant bloodmeal and side-dressed blood meal to banded compost (80:40:40), compared to banding

compost alone (80:0:0), (P=0.048). However, when not including the additional side-dress (80:40:0) the stem weights were not significantly different **(Figure 13, Table 10)**.

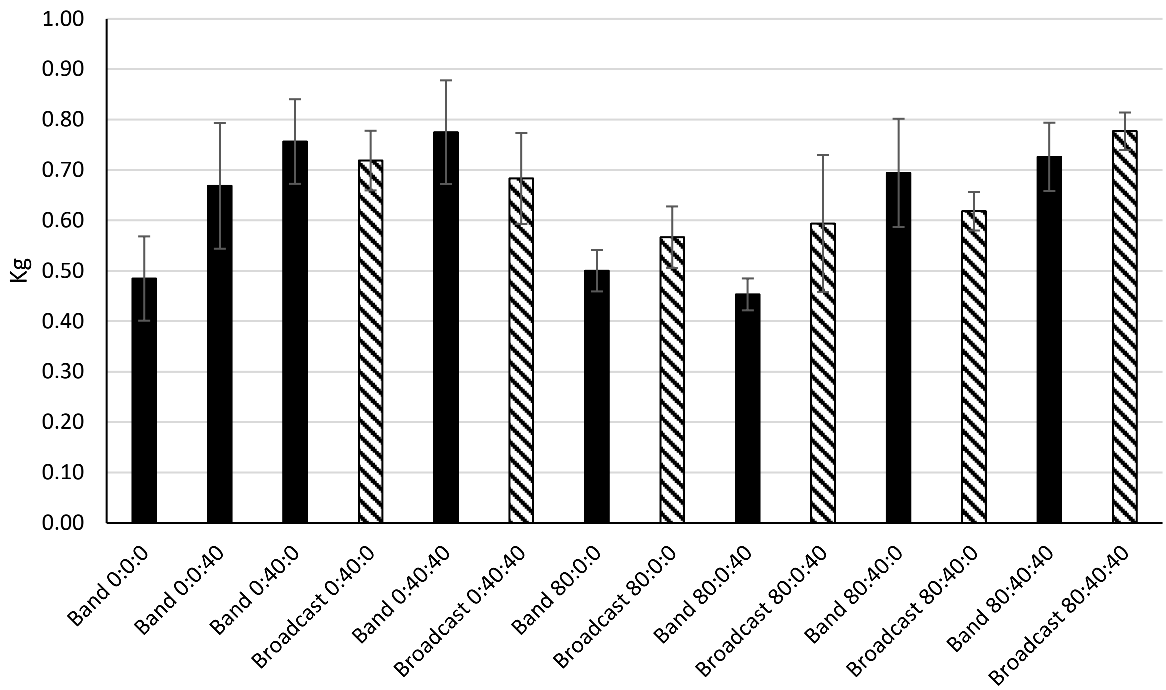

Figure 13. Comparison of mean dried stem weight taken from 6 plants at harvest from plots amended with differing rates of N from compost : pre-plant bloodmeal : side-dressed bloodmeal applied by banding or broadcasting Freeville, NY 2015.

Total lbs·acre^{-1} of N obtained by summing values given in the proportions i.e. 80:40:40 = 160 Total lbs·acre^{-1} of N. Vertical bars represent +/- standard error.

2015 Petiole Analysis %NO_3-N

Petiole samples were taken from 7 treatments of interest. Significant differences were found among the treatments in the overall F-Test (P<.0001). A mean separation using Tukey's HSD at P=.05 was used. Generally, treatments that contained pre-plant bloodmeal fertilizer had a higher %NO_3-N in their dried petiole samples, the exception to this was the broadcasted (80:40:40) treatment. Specifically, banded (0:40:40) had the higher mean %NO_3-N levels than the broadcasted (80:40:40), banded (0:0:40),

broadcasted (80:0:40) and banded (80:0:40) treatments. Banded (80:40:40) had significantly higher %NO_3-N levels then banded (0:0:40), broadcasted (80:0:40) and banded (80:0:40) **(Figure 14, Table 11)**.

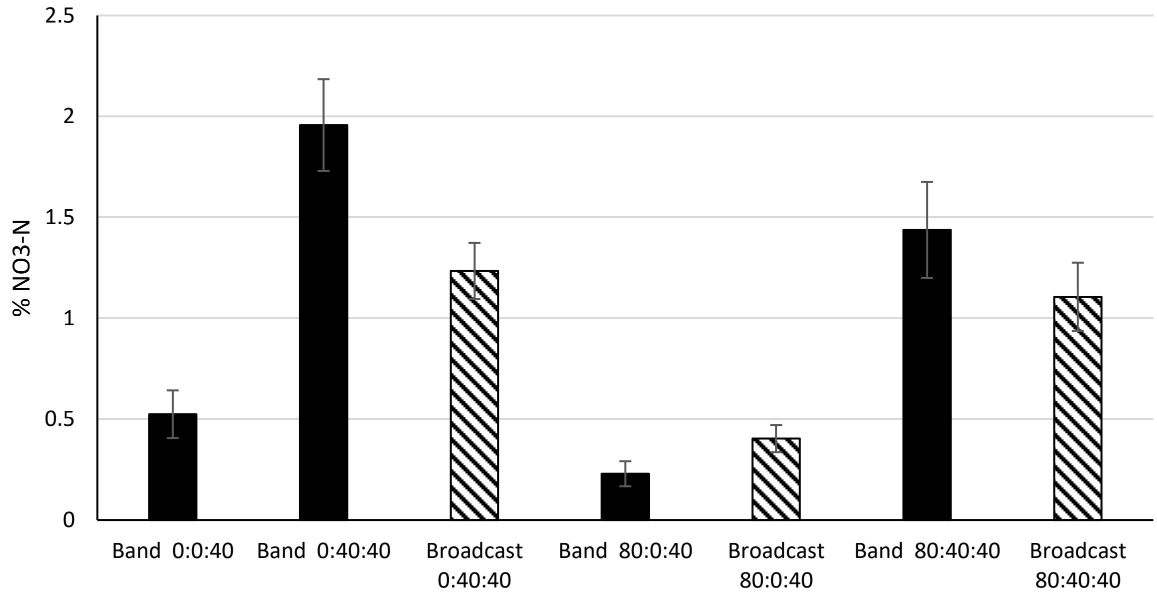

Figure 14. Comparison of mid-season mean dried petiole %NO_3-N from plots amended with differing rates of N from compost : pre-plant bloodmeal : side-dressed bloodmeal applied by banding or broadcasting Freeville, NY 2015.

Total lbs·acre^{-1} of N obtained by summing values given in the proportions i.e. 80:40:40 = 160 Total lbs·acre^{-1} of N. Vertical bars represent +/- standard error.

Table 11. Mean $\%NO_3$-N in dried squash petioles taken at flowering from plots amended with differing rates of N from compost : pre-plant bloodmeal : side-dressed bloodmeal applied by banding or broadcasting Riverhead, NY 2015 and 2016.

Total lbs·acre^{-1} of N obtained by summing values given in the proportions i.e. 80:40:40 = 160 Total lbs·acre^{-1}

2015			2016		
Application	**Mean $\%NO_3$-N**	**Tukey's HSD test at P ≤ .05**	**Application**	**Mean $\%NO_3$-N**	**Tukey's HSD test at P ≤ .05**
Band (0:40:40)	1.9565	A	Broadcast (80:40:40)	1.560	A
Band (80:40:40)	1.4373	AB	Band (80:40:40)	1.563	A
Broadcast (0:40:40)	1.2342	ABC	Band (80:0:40)	1.549	A
Broadcast (80:40:40)	1.1055	BCD	Broadcast (0:40:40)	1.506	A
Band (0:0:40)	0.5240	C D E	Band (0:40:40)	1.449	A
Broadcast (80:0:40)	0.4036	DE	Broadcast (80:0:40)	1.295	A
Band (80:0:40)	0.2292	E	Band (0:0:40)	1.250	A

Means followed by the same letter are not significantly different

Results 2016: Freeville, NY Fruit Number, Fruit Yield and Dry Stem Weight

In 2016 the overall F-test in the ANOVA detected no significant differences for fruit number (P=0.6469), fruit yield (P=0.9691) or dry stem weight (P=0.1008). Further comparisons using orthogonal contrasts found no significant differences between any of the treatments. **(Figures 15, 16 and 17, Table 12)**.

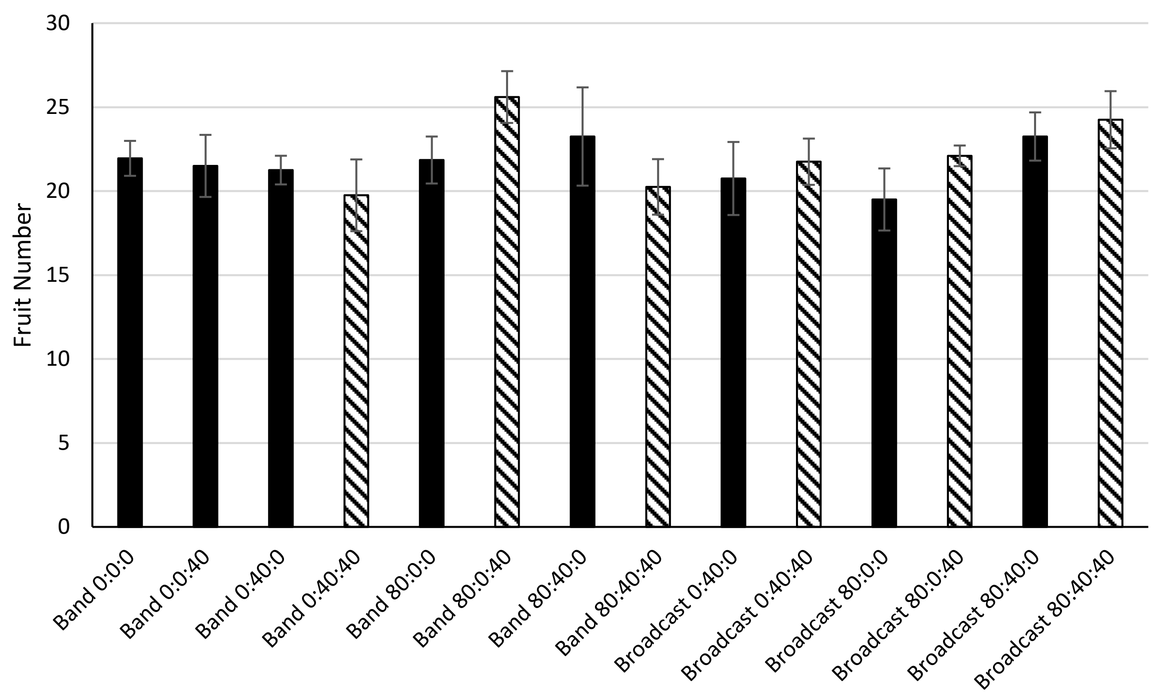

Figure 15. Comparison of mean fruit number harvested from plots amended with differing rates of N from compost : pre-plant bloodmeal : side-dressed bloodmeal applied by banding or broadcasting Freeville, NY 2016.

Total lbs·acre^{-1} of N obtained by summing values given in the proportions i.e. 80:40:40 = 160 Total lbs·acre^{-1} of N. Vertical bars represent +/- standard error.

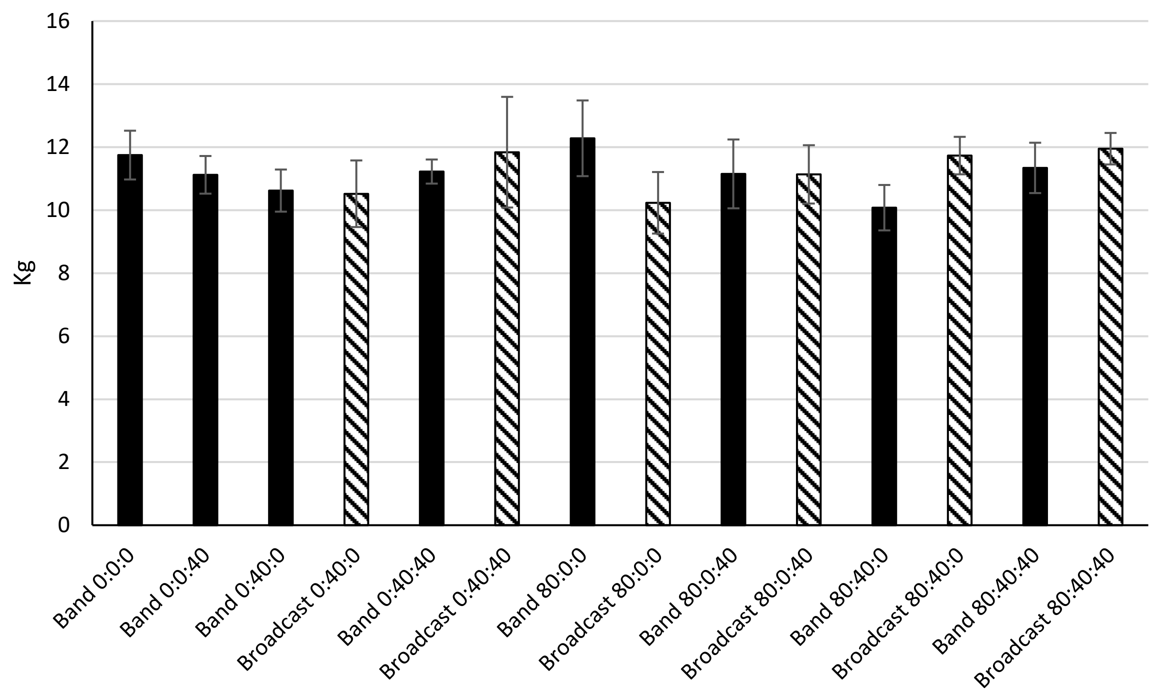

Figure 16. Comparison of mean weight harvested from plots amended with differing rates of N from compost : pre-plant bloodmeal : side-dressed bloodmeal applied by banding or broadcasting Freeville, NY 2016.

Total lbs·acre^{-1} of N obtained by summing values given in the proportions i.e. 80:40:40 = 160 Total lbs·acre^{-1} of N. Vertical bars represent +/- standard error.

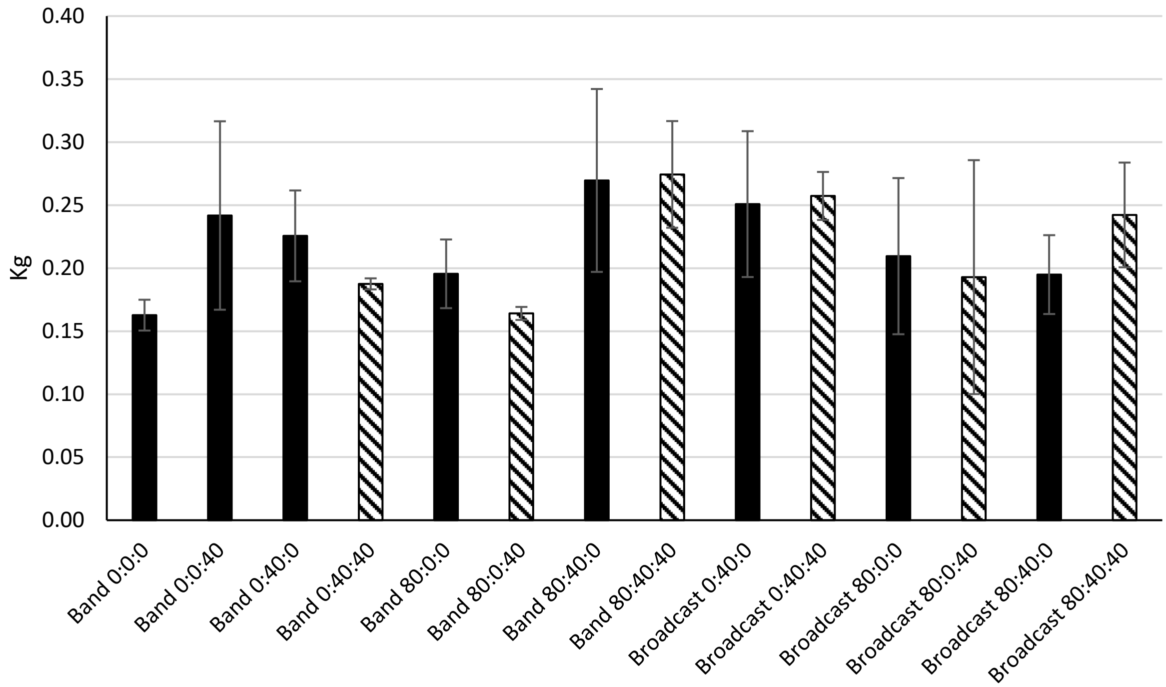

Figure 17. Comparison of mean dried stem weight taken at 6 plants from harvest from plots amended with differing rates of N from compost : pre-plant bloodmeal : side-dressed bloodmeal applied by banding or broadcasting Freeville, NY 2016.

Total lbs·acre^{-1} of N obtained by summing values given in the proportions i.e. 80:40:40 = 160 Total lbs·acre^{-1} of N. Vertical bars represent +/- standard error.

Table 12. Treatment comparisons for squash fruit number, fruit yield and dry stem weight from plots amended with differing rates of N from compost : pre-plant bloodmeal : side-dressed bloodmeal applied by banding or broadcasting Freeville, NY 2016.

Total lbs·acre^{-1} of N obtained by summing values given in the proportions i.e. 80:40:40 = 160 Total lbs·acre^{-1} of N. $F_{1,39}$ = 4.09.

Comparison	Fruit Number		Fruit Weight		Dry Stem Weight	
	F Value	Pr > F	F Value	Pr > F	F Value	Pr > F
(0:40:0) vs (0:0:40)	0.01	0.920	0.14	0.713	0.08	0.781
Band (0:40:0) vs Broad (0:40:0)	0.04	0.841	0.15	0.697	0.19	0.665
Band (80:0:0) vs Broad (80:0:0)	0.90	0.349	0.72	0.401	0.06	0.810
Band (80:0:0) vs Band (0:40:40)	0.72	0.402	0.27	0.605	0.02	0.891
Broad (80:0:0) vs Broad (0:40:40)	0.83	0.369	0.61	0.438	0.69	0.413
Band (80:40:0) vs Broad (80:40:0)	0.00	1.000	0.48	0.490	1.68	0.203
Band (80:0:40) vs Broad (80:0:40)	2.00	0.166	0.01	0.937	0.55	0.462
Broad (80:0:0) vs Broad (80:0:40)	1.10	0.300	1.50	0.228	0.01	0.938
Band (0:40:40) vs Broad (0:40:40)	0.65	0.424	0.21	0.651	1.46	0.234
Band (80:0:0) vs Band (80:40:0)	0.32	0.575	0.61	0.439	1.65	0.207
Band (80:0:0) vs Band (80:40:40)	0.42	0.522	0.54	0.467	1.87	0.180
Band (80:0:0) vs Broad (80:40:40)	0.94	0.339	0.29	0.594	0.66	0.423
Broad (80:0:40) vs Broad (80:40:40)	0.75	0.391	0.03	0.872	0.20	0.660

2016 Petiole Analysis NO3-N

In the 2016 petiole data, significance was found in the overall F-test (P=0.0191). However, this difference was attributed to a difference between blocks in the design (P=0.0058). No differences were found among the treatments for %NO_3-N (P=0.1590) **(Figure 18 and Table 11)**.

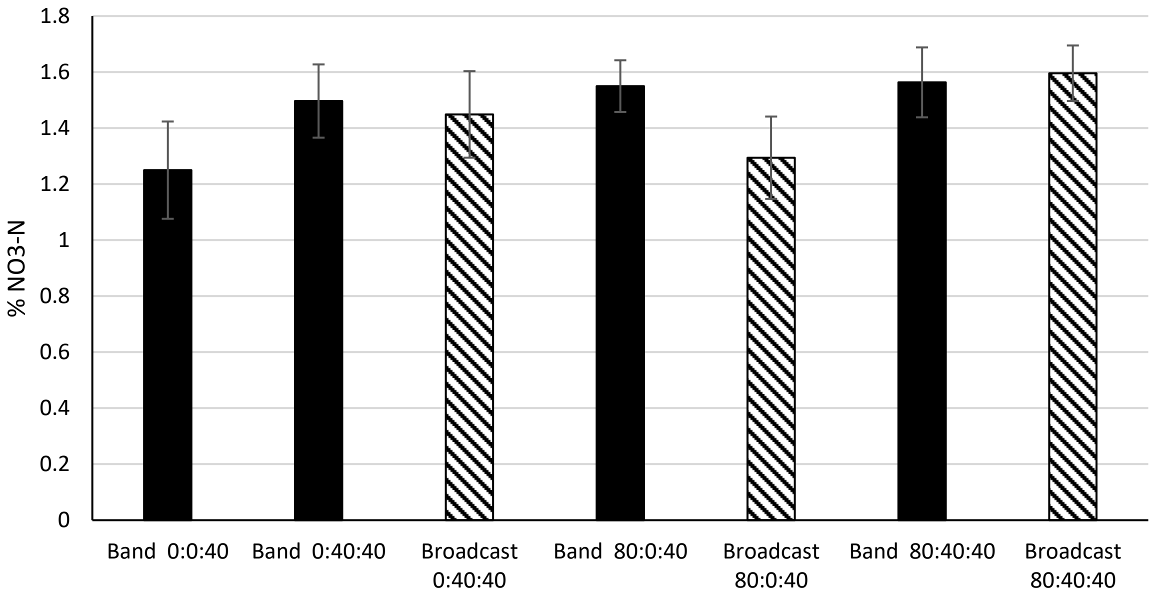

Figure 18. Comparison of mid-season mean dried petiole % NO3-N from plots amended with differing rates of N from compost : pre-plant bloodmeal : side-dressed bloodmeal applied by banding or broadcasting Freeville, NY 2016.

Total lbs·acre^{-1} of N obtained by summing values given in the proportions i.e. 80:40:40 = 160 Total lbs·acre^{-1} of N. Vertical bars represent +/- standard error.

Discussion: Freeville, NY

Yields

The New England Vegetable Management Guide 2016-2017, list good yields of smaller bush type winter squash varieties in the range of 5-7 tons of fruit acre^{-1}. In 2015 and 2016 plant density was at the tightest recommended spacing for smaller bush winter squash. In both years all plots produced yields that fell within that range regardless of the treatments. There were yield differences between the treatments although they were not always significant. The lowest yielding plot mean during 2015 was the banded compost with side-dress treatment (80:0:40) with an average yield of 6.69 tons acre^{-1}. The

highest yielding plot was the combination of compost and pre-plant bloodmeal (80:40:0) at 11.25 tons acre^{-1}.

There were no significant differences in yield between any of the treatments during 2016. However, all treatments in 2016 also produced yields that exceeded The New England Vegetable Management Guides recommendations. The variation in total yields was lower between treatments in the 2016 growing season. The lowest yielding treatment contained only broadcasted compost (80:0:0) and produced 10.73 tons acre^{-1}. The highest yielding treatment included banded compost and pre-plant bloodmeal (120/40/0) but produced an average of 13.08 tons acre^{-1}

Fertilizer and Compost

Fertilizer rate and timing is crucial in efficient fertilizer use. The goal being to supply the crop with the least amount of additional nutrients to receive the greatest amount of marketable yield. Under high crop N demand, organic fertilizers can provide adequate nitrogen and promote desirable yields (Gaskell and Smith, 2007). Bloodmeal has been shown to have a high rate of nitrogen mineralization and therefore is considered a fast-acting source of organic N. (Hartz and Johnstone, 2006). However, if timing of the available N doesn't line up with crop demand then the nitrogen will continue to move through the nitrogen cycle (Van Eerd, 2010; Buwalda and Freeman, 1986; Mohammad 2004; Havlin et al., 1999; Maathuis, 2009). The New England Vegetable Management Guide, (2016-2017) demonstrates the crop nitrogen uptake curve where little crop N uptake corresponds with slow early season growth. N uptake dramatically increases as the plant grows throughout the season. Growth as well as N uptake, levels off as crops reach maturity.

A high rate of available N supplied by an organic N fertilizer early in the season may no longer be in an available form when crop need is there. Furthermore, N in an available form may be converted to an unavailable form or be readily lost to another aspect of the nitrogen cycle. Hartz and Johnstone's, (2006) findings report that the greatest amount of N mineralization from organic fertilizers, such as

bloodmeal, occurs within the first two weeks after application regardless of environmental factors such as temperature. However, temperature and moisture play a critical role in the mineralization process because they are a driving force behind the soil microbial community.

When comparing bloodmeal to compost in 2015, all treatments that contained pre-plant bloodmeal fertilizer had a higher mean fruit number then the treatments that contained only compost, side-dressed bloodmeal or a combination of the two **(Figure 11)**. However, this general trend was only found to be significantly different between banded compost alone (80:0:0) and a combination of broadcasted compost with pre-plant and side-dressed bloodmeal (80:40:40) **(Table 10)**. More significant differences were found for fruit yield and dry stem weight in 2015 when comparing compost to bloodmeal **(Table 10)**. Treatments that contain pre-plant bloodmeal had greater fruit yield and dry stem weight then treatments without. This response to pre-plant bloodmeal suggests that there was a deficit of N in the soil, bloodmeal was better at supplying nitrogen for crop growth than compost and early fertilizer placement increased yields. However, these differences were not repeated in 2016 **(Table 12).**

Available information on ideal %NO_3-N in dried petiole samples was not found for *Cucurbita pepo.* In its absence, melon, *Cucumis melo,* NO3-N % levels were used. Adequate %NO_3-N ranges from .08 to 1.5% (Spectrum Technologies INC., 2009), petioles from 2015 show that only treatments that received pre-plant fertilizer contained adequate %NO_3-N for plant growth (**Figure 18**).

Increased nitrogen levels have been shown to increase fruit size in cucurbits (Mohammad, 2004; Heidari and Mohammad, 2012). Ahmad et. al., 2007 found that plant size increases in cucurbits with the addition of higher nitrogen levels. Considering the low amounts of N in the petiole samples, it's possible that nitrogen was deficient in the plots not receiving pre-plant bloodmeal in 2015. Soil tests results prior to the 2015 growing season show sub-optimal organic matter amounts which support that hypothesis.

Although compost was applied at double the total N rate of the bloodmeal, the available N sourced from compost did not provide enough nitrogen to the plants causing lower yields and smaller amounts of biomass at harvest. Based on Gale, et al. (2006) findings of PAN, actual available N from this compost would have been roughly 16 lbs·acre^{-1} of N. This rate is far lower than N from the applied bloodmeal and the N recommendation for winter squash (Rynk, 1992; New England Vegetable Management Guide, 2016-2017). Another possibility, is that compost could be contributing a negative effect to plant growth through a high C:N ratio, the presence of residual herbicide or high amounts of organic acids. The compost source was tested for toxicity and results showed there was a possibility of a slight toxic effect on squash in the laboratory. Separate analytical results showed a low soluble salt content which would not have a negative effect on squash growth and a low C:N ratio (15.4:1), which is considered to be good for faster nitrogen release **(Table 3).**

The 2016 experiment didn't reveal any differences between compost and fertilizer applications for fruit number, fruit yield or dry stem weight **(Table 12)**. Petiole %NO_3-N samples all contained adequate amounts of nitrogen **(Figure 18)**. The most likely possibility is that background fertility levels were high in the field used in 2016. Sufficient soil nitrogen could support plant growth therefore causing no response to the additional bloodmeal or mineralized N from compost. Soil tests showed that organic matter levels exceeded 6% for most of the blocks used in 2016. Levels this high could provide over 65 lbs·acre^{-1} of N per year for crop growth (Erich).

Side-dressing

Side-dressing had no effect on fruit number, fruit yield or dry stem weight in 2015 **(Figures 11, 12 and 13)** or in 2016 **(Figures 15, 16 and 17)**. This was seen in each year when comparing the side-dress only treatment (0:0:40) to the control and the pre-plant fertilizer treatment, (0:0:0) and (0:40:0) respectively. This was also seen with adding side-dressed N to pre-plant N treatments of bloodmeal at

40 lbs·acre^{-1} of N, compost at 80 lbs·acre^{-1} of N and a combination of pre-plant fertilizer, compost and side-dressing.

Recent literature and current guidelines suggests that a combination of compost and bloodmeal would have a synergistic effect that could increase yields. Season-long nutrient demands could be better met by combining fertilizer and compost. This would supply N during early growth and when plant growth and N need has peaked, with a source of long-term N and available P. Yields were increased when combing pre-plant fertilizer with compost. This was also seen when adding side-dressed bloodmeal to pre-plant compost and bloodmeal. However, additional mid-season bloodmeal without pre-plant bloodmeal did not increase yields in our experiments during either year. This was likely because compost provide little N and bloodmeal in this combination was not applied when plants needed it early on. (Gaskell and Smith, 2007) (Hartz and Johnstone, 2006) (Evanylo. et al. 2008) (Khalilian and Sullivan, et al. 2002) (The New England Vegetable Management Guide, 2016-2017);

Considering the petiole samples were taken prior to side-dress bloodmeal application, the results from the analysis do not reflect N uptake from the additional mid-season N. When reviewing %NO_3-N levels in the 2015 squash petioles samples; the sample that received bloodmeal solely as a side-dress (0:0:40) at this point is the same as the control treatment, which was not sampled. This treatment, understandably had lower %NO_3-N levels than other treatments but was like treatments that had received only compost. This suggests that compost was not supplying N that was being incorporated into the tissues of the petioles. However, all were still above the .08 %NO_3-N threshold levels for required nitrogen (Spectrum Technologies INC., 2009) **(Figure 14)**. In 2016 petiole %NO_3-N levels were all above 1% for all treatments and were not significantly different from one another **(Table 18).** As a result, the addition of mid-season bloodmeal had no effect on fruit number, fruit yield or plant growth **(Figures 15, 16 and 17)**. The lack of response to side-dressing does raise questions when considering fertilizer efficiency and effectiveness of organic fertilizers to deliver mid-season nitrogen.

Furthermore, the 2015 petiole samples support the notion that compost is not a reliable nitrogen fertilizer even though it has been shown to provide sufficient fertility compared to other sources in multiple crops (Evanylo. et al., 2008; N. Khalilian and Sullivan, et al., 2002; Eghball and Powers, 1999).

Banding or Broadcasting Bloodmeal and Compost

Banding or concentrating the rate of nutrients near the root zone is a strategy to deliver nutrients more efficiently to the crop. This technique is used prior to planting and to apply side-dress fertilizers mid-season (Khalilian and Sullivan, et al. 2002; New England Vegetable Management Guide, 2016-2017). Shapiro et. al. (2016) saw increased grain yields and greater plant nitrogen uptake with banding a conventional fertilizer over broadcasting. Buwalda et. al. (1987) found that yield increased with increasing widths of localized P and K fertilizer up to a certain point of 0.25 meters, after which the increase in width had no further increase in yield.

By banding fertilizer or compost, nutrient demands can be met by lowering the per acre amount due to the smaller application area and therefore a lower relative application rate. In this experiment compost amounts where not changed when comparing banding and broadcasting of identical rates. This led to the banding application being applied at a higher concentration than the broadcasting rate because the same volume was applied in both treatments over different areas.

Compost rates and pre-plant bloodmeal were applied by banding or broadcasting at similar rates. No differences were seen in fruit number or dry stem weight in either year when comparing banded fertilizer (0:40:0) to broadcasted fertilizer (0:40:0) or banded compost (80:0:0) to broadcasted compost (80:0:0) **(Tables 10 and 12)**. In 2015 fruit yield was greater when banding pre-plant bloodmeal compared to broadcasting. This is likely due to an increase in bloodmeal incorporation that created higher N availability which produced bigger fruit (Mohammad, 2004; Heidari and Mohammad, 2012). However, this was not duplicated in 2016 **(Table 10 and 12).** Banding compost with side-dress bloodmeal did produce lower yields than broadcast compost with side-dress bloodmeal in 2015. This

also could be due to greater incorporation of the banded compost which had a negative effect on plant growth in these plots, either by tying up N in a N deficit soil or introducing some kind of phytotoxic effect. Mixed results have been found in past research as well (Khalilian and Sullivan, et al. 2002; Parish, Bracy and McCoy, 2008; Manuck 2006; Shapiro et. al. 2016).

When comparing banding and broadcasting of compost at 80 lbs·acre^{-1} we found no difference. Low amounts of plant available nitrogen in the initial compost application and the subsequent slow release of nitrogen through the mineralization process is a possible reason. Plant available nitrogen is in the inorganic form of ammonium or nitrate. Ammonium can be rapidly converted to nitrate. Nitrate having a negative charge can be transient in the soil water solution. (Gaskell and Smith, 2007; Maathuis, 2009). Perhaps taking this into consideration placement of an organic source of nitrogen is less important when the actual difference in soil coverage between treatments is small, such as the case in this experiment where broadcasting width did not differ greatly from banding widths.

Experimental Design: Riverhead, NY

Adapted from: Investigation of Nitrogen Fertility Management Practices in Organic Reduced Tillage Winter Squash (Unpublished Report); Margaret T. McGrath and Zachary F. Sexton

This experiment was conducted at Cornell's Long Island Horticultural Research & Extension Center in Riverhead, NY in the 2015 and 2016 growing seasons. Riverhead is located on the north and easterly side of Long Island. Weather data for Riverhead was gathered from the Gabreski airport in West Hampton NY about 5 miles away and is listed in **Table 2 f**or both years of the experiment.

Fall-planted cover crops of oats (*Avena sativa)* and peas (*Pisum* sativum) were drilled into a disked field prior to each experiment year at rates of 100 and 50 lbs·acre^{-1} respectively. Additional disking was used to control early-season weeds before treatments were applied.

The experiment was set up as a randomized complete block with four replications. Soil type was a Haven sandy loam. A total of 14 treatments were applied in early June that consisted of banding and

broadcasting compost at 80 lbs·acre^{-1} of N and blood meal fertilizer (13-0-0) at 40 lbs·acre^{-1} of N coupled with a mid-season side-dress application of bloodmeal fertilizer for some treatments **(Table 1).** Compost and pre-plant fertilizer were applied between 4 June and 9 June in 2015 and between 2 and 3 June in 2016. Compost was analyzed by the University of Maine Analytical and Soil Testing Lab **(Table 3).** The onset of flowering was used as an indicator for side-dress application, and side-dressed bloodmeal was applied in mid-July during both years at 40 lbs·acre^{-1} of N. At the time of side-dressing petiole samples were taken from selected treatments, dried then tested for %NO_3-N. Similar treatments were carried out in Freeville, New York and Monmouth, Maine. Pre-plant compost and bloodmeal were shallowly incorporated with a field cultivator (Perfecta II; Kalida, Ohio, U.S). Strip tillage was preformed using a Unverferth zone builder (Kalida, Ohio, U.S).

Seeding of 'Honey Bear' acorn squash (*Cucurbita pepo*) was completed 1 June 2015 and 25 May 2016. Transplanting occurred on 19 June and 14 June in 2015 and 2016, respectively. During both years the plots consisted of three 36" beds that were 66" on center. Plant spacing was 18" in 2015 and 24" in 2016. The center row was used for data collection. Weed management was carried out through mechanical cultivation between rows until the machinery could no longer fit. After that time, hand weeding was done between plants within rows. Irrigation when needed was applied overhead early-on after planting; later, drip irrigation was installed.

In 2016 powdery mildew (*Podosphaera xanthii, Erysiphe cichoracearum*) was controlled using *Bacillus amyloliquefaciens* strain D747 at 2 qt·acre^{-1} (Double Nickle) and Extract of *Reynoutria sachalinensis* at 2 qt acre^{-1} (Regalia) on 15 and 26 July and 4 August. Powdery mildew was targeted again using sulfur at 5 lbs·acre^{-1} (Microthiol Disperss) on 26 and 31 August and 10 September. Spray records were not available for 2015.

Fall harvest occurred between 20 and 22 September in 2015 and between 21 and 26 September in the 2016 growing season. Fruit yield and number data were gathered, squash stems were cut off at the soil line then dried and weighed for dry stem weight.

Results 2015 Riverhead, NY: Fruit Number, Fruit Weight and Dry Stem Weight

The overall F Test for fruit number (P = 0.2144), fruit yield (P=0.0855) and biomass (P=0.1454) was non-significant. Contrasts were used to compare treatments to one another. These individual comparisons found few significant treatment effects on fruit number, fruit weight, and dry stem weight. Fruit number was shown to be significantly greater in treatments with either banded or broadcasted compost, pre-plant bloodmeal and side-dressed bloodmeal (80:40:40) compared to banded compost alone (80:0:0) (P=0.012, P=0.028 respectively) **(Table 13, Figure 19)**.

Banding compost (80:0:0) also produced significantly lower fruit yield than both combinations of broadcasted or banded compost, pre-plant bloodmeal and mid-season bloodmeal (P=0.021, P=0.004 respectively) **(Table 13, Figure 20)**. Pre-plant blood meal (0:40:0) produced significantly greater dry stem weight compared to mid-season side-dress bloodmeal (0/0/40/) at the same rate (P=0.004) **(Table 13, Figure 21)**.

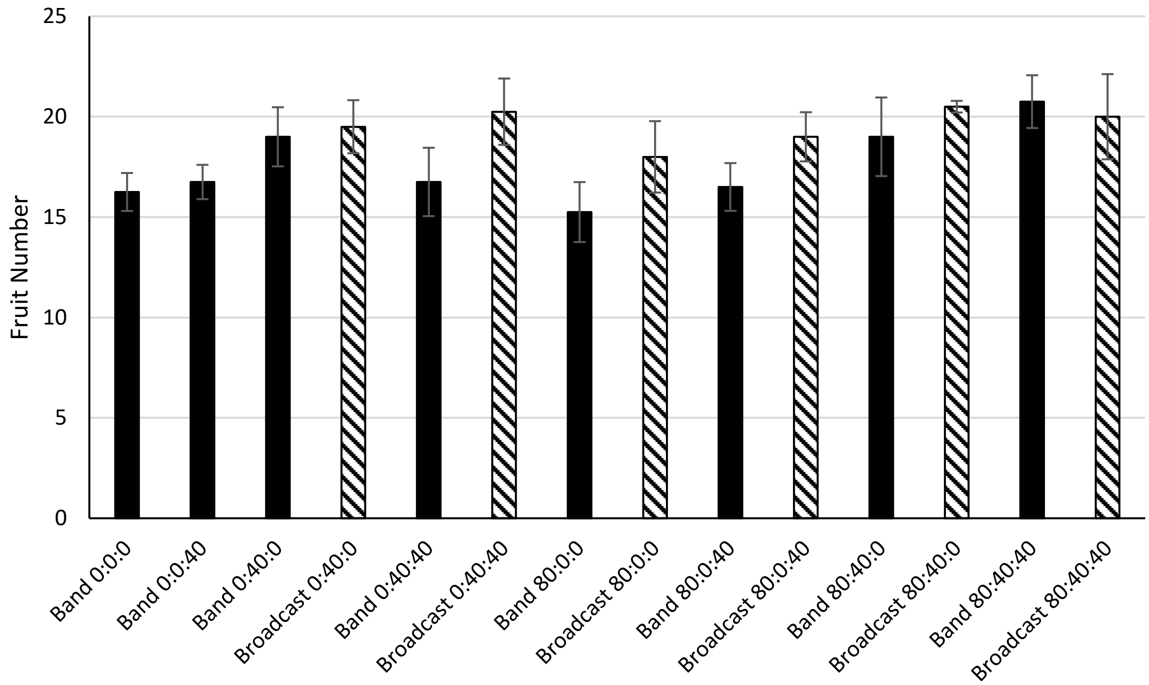

Figure 19. Comparison of mean fruit number harvested from plots amended with differing rates of N from compost : pre-plant bloodmeal : side-dressed bloodmeal applied by banding or broadcasting Riverhead, NY 2015.

Total lbs·acre^{-1} of N obtained by summing values given in the proportions i.e. 80:40:40 = 160 Total lbs·acre^{-1} of N. Vertical bars represent +/- standard error.

Table 13. Treatment comparisons for squash fruit number, fruit yield and dry stem weight from plots amended with differing rates of N from compost : pre-plant bloodmeal : side-dressed bloodmeal applied by banding or broadcasting Riverhead, NY 2015.

Total lbs·acre^{-1} of N obtained by summing values given in the proportions i.e. 80:40:40 = 160 Total lbs·acre^{-1} of N. $F_{1,39}$ = 4.09.

Comparison	Fruit Number		Fruit Yield		Dry Stem Weight	
	F Value	Pr > F	F Value	Pr > F	F Value	Pr > F
(0:40:0) vs (0:0:40)	1.17	0.285	3.44	0.071	**9.29**	0.004
Band (0:40:0) vs Broad (0:40:0)	0.06	0.811	0.06	0.810	0.90	0.350
Band (80:0:0) vs Broad (80:0:0)	1.75	0.193	1.52	0.226	0.01	0.917
Band (80:0:0) vs Band (0:40:40)	0.52	0.474	0.49	0.490	0.22	0.639
Broad (80:0:0) vs Broad (0:40:40)	1.17	0.285	1.93	0.173	0.18	0.676
Band (80:40:0) vs Broad (80:40:0)	0.52	0.474	0.43	0.515	0.07	0.794
Band (80:0:40) vs Broad (80:0:40)	1.45	0.236	1.10	0.301	1.11	0.300
Broad (80:0:0) vs Broad (80:0:40)	0.23	0.633	0.68	0.414	1.00	0.324
Band (0:40:40) vs Broad (0:40:40)	2.84	0.100	3.69	0.062	0.00	0.958
Band (80:0:0) vs Band (80:40:0)	3.26	0.079	3.06	0.088	0.14	0.715
Band (80:0:0) vs Band (80:40:40)	**7.02**	0.012	**9.49**	0.004	1.11	0.300
Band (80:0:0) vs Broad (80:40:40)	**5.23**	0.028	**5.75**	0.021	0.90	0.350
Broad (80:0:40) vs Broad (80:40:40)	0.23	0.633	0.12	0.735	0.00	0.958

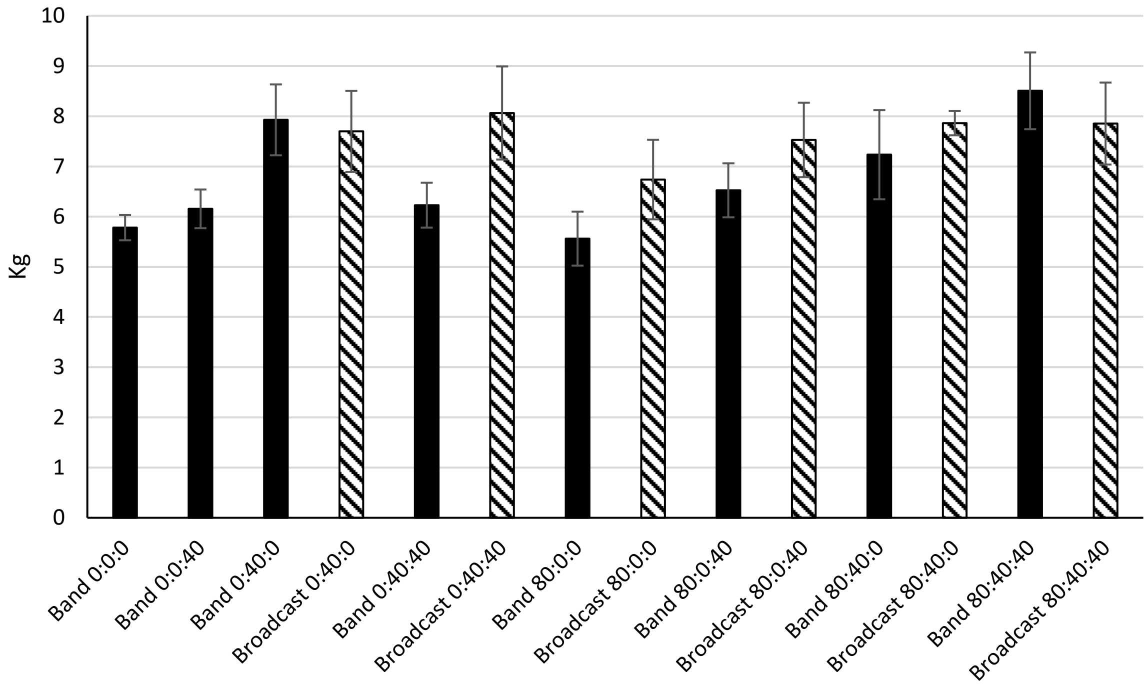

Figure 20. Comparison of mean weight harvested from plots amended with differing rates of N from compost : pre-plant bloodmeal : side-dressed bloodmeal applied by banding or broadcasting Riverhead, NY 2015.

Total lbs·acre^{-1} of N obtained by summing values given in the proportions i.e. 80:40:40 = 160 Total lbs·acre^{-1} of N. Vertical bars represent +/- standard error.

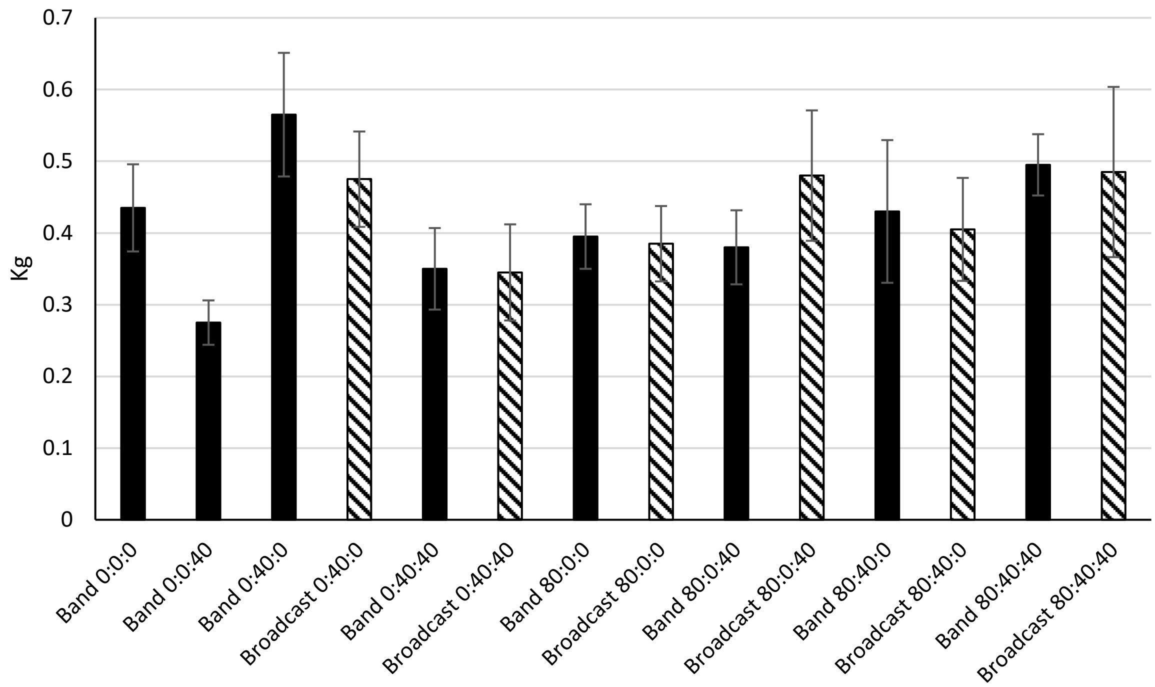

Figure 21. Comparison of mean dried stem weight taken from 2 plants at harvest from plots amended with differing rates of N from compost : pre-plant bloodmeal : side-dressed bloodmeal applied by banding or broadcasting Riverhead, NY 2015.

Total lbs·acre^{-1} of N obtained by summing values given in the proportions i.e. 80:40:40 = 160 Total lbs·acre^{-1} of N. Vertical bars represent +/- standard error.

2015 Petiole Analysis NO3-N

Petiole samples were taken from 7 treatments of interest. Initially the data failed to meet the assumptions for ANOVA. Transformations on the data also were unable to fit the petiole %NO_3-N data to a normal distribution or to obtain equal variance. The banded pre-plant and side-dress treatment (0:40:40) had a large amount of variation and one extremely high value, this treatment was pulled from the 2015 analysis. A square transformation was used on the remaining data to meet the assumptions of ANOVA. Significance was found in the overall F-Test (P<.0012) at P=.05. A mean separation using Tukey's HSD at P=.05 was used. Generally, treatments that contained pre-plant bloodmeal fertilizer had a higher mean %NO_3-N in their dried petiole samples, although only the banded (80:40:40) combination of compost, pre-plant bloodmeal and side-dressed blood meal was significantly different from the rest **(Figure 22, Table 14)**.

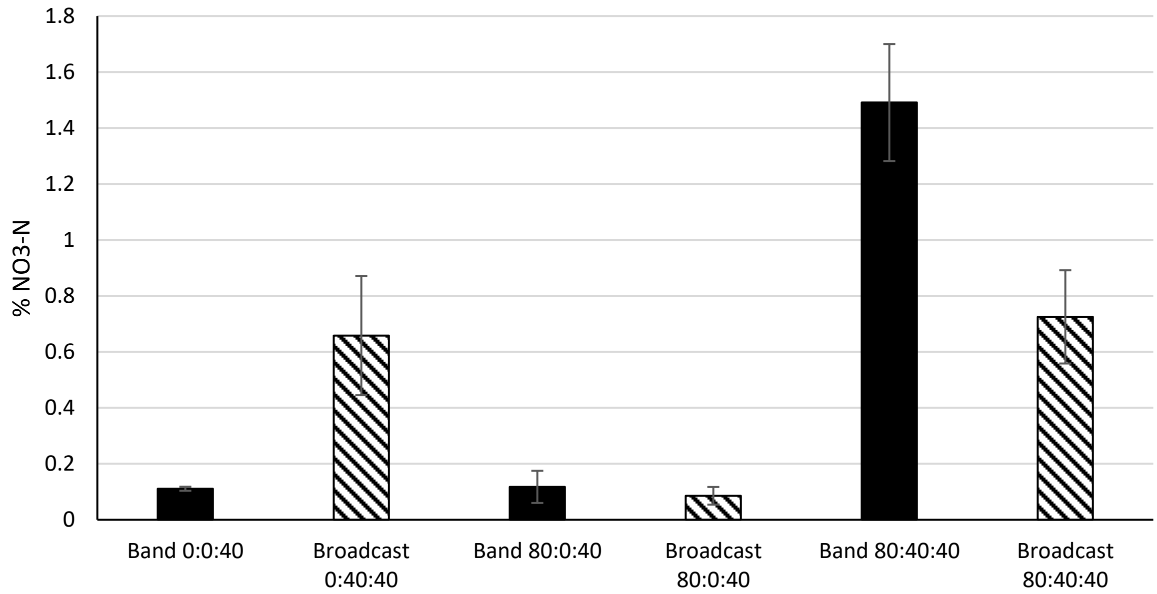

Figure 22. Comparison of mid-season mean dried petiole %NO3-N from plots amended with differing rates of N from compost : pre-plant bloodmeal : side-dressed bloodmeal applied by banding or broadcasting Riverhead, NY 2015.

Total lbs·acre^{-1} of N obtained by summing values given in the proportions i.e. 80:40:40 = 160 Total lbs·acre^{-1} of N. Vertical bars represent +/- standard error.

Table 14. Mean %NO_3-N in dried squash petioles taken at flowering from plots amended with differing rates of N from compost : pre-plant bloodmeal : side-dressed bloodmeal applied by banding or broadcasting Freeville, NY 2015 and 2016.

Total lbs·acre^{-1} of N obtained by summing values given in the proportions i.e. 80:40:40 = 160 Total lbs·acre^{-1}

2015			**2016**		
Application	**Mean** %NO_3-N	[z]**Tukey's HSD test at P ≤ .05**	**Application**	**Mean** %NO_3-N	[z]**Tukey's HSD test at P ≤ .05**
Band (80:40:40)	1.49	A	Band (0:40:40)	2.56	A
Broadcast (80:40:40)	0.72	B	Broadcast (0:40:40)	2.46	A
Broadcast (0:40:40)	0.66	B	Band (80:40:40)	2.45	A
Band (80:0:40)	0.12	B	Broadcast (80:40:40)	2.42	A
Band (0:0:40)	0.11	B	Band (80:0:40)	2.02	A
Broadcast (80:0:40)	0.09	B	Band (0:0:40)	1.81	A
			Broadcast (80:0:40)	1.79	A

[z]Means followed by the same letter are not significantly different

Results 2016 Riverhead, NY: Fruit Number, Fruit Yield and Dry Stem Weight

In 2016 Phytophthora limited the amount of plants in some plots causing large variations in harvest data. To account for the low number of plants, fruit number and fruit yield were averaged by plant then multiplied to represent a plot containing 6 plants. Dry biomass data was only collected for 2 plants per plot. Two adjacent plots in the design had extreme outliers in the original data, these data points were removed from this analysis.

The overall F Test for fruit number (P = 0.4102), fruit yield (P=0.4486) and biomass (P=0.5080) was non-significant **(Figure 23, 24 and 25)**. Contrasts of interest were used to compare treatments to one another. Further contrasts found no significances for all response variables **(Table 15)**.

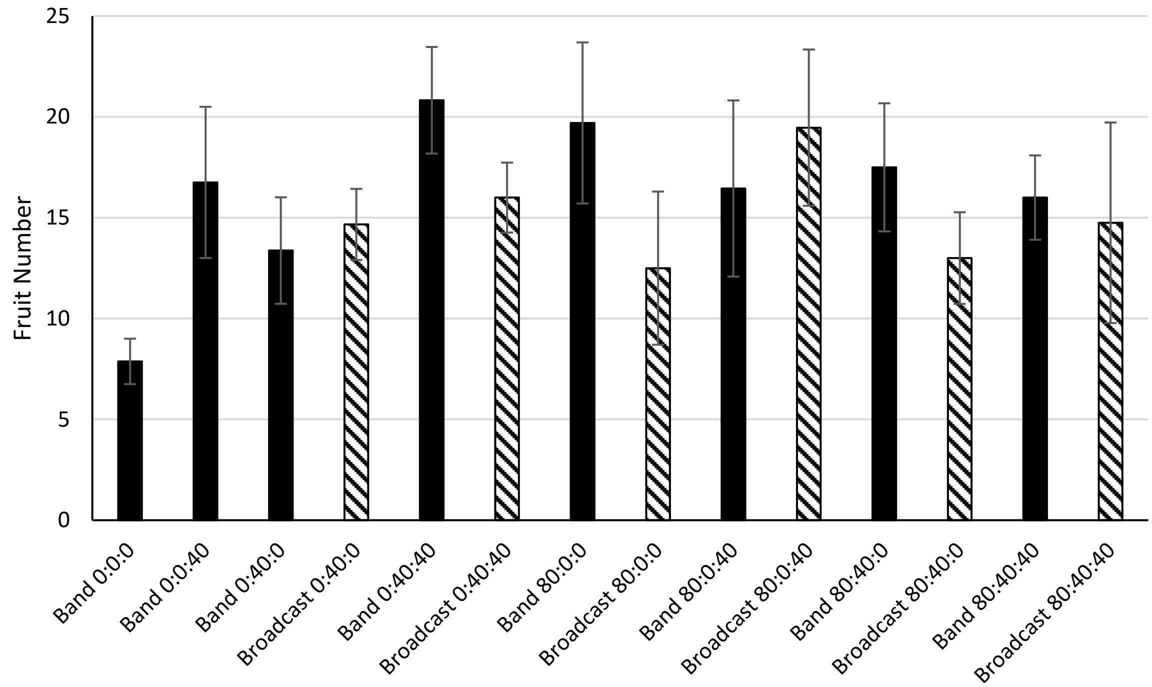

Figure 23. Comparison of mean fruit number harvested from plots amended with differing rates of N from compost : pre-plant bloodmeal : side-dressed bloodmeal applied by banding or broadcasting Riverhead, NY 2016.

Total lbs·acre^{-1} of N obtained by summing values given in the proportions i.e. 80:40:40 = 160 Total lbs·acre^{-1} of N. Vertical bars represent +/- standard error.

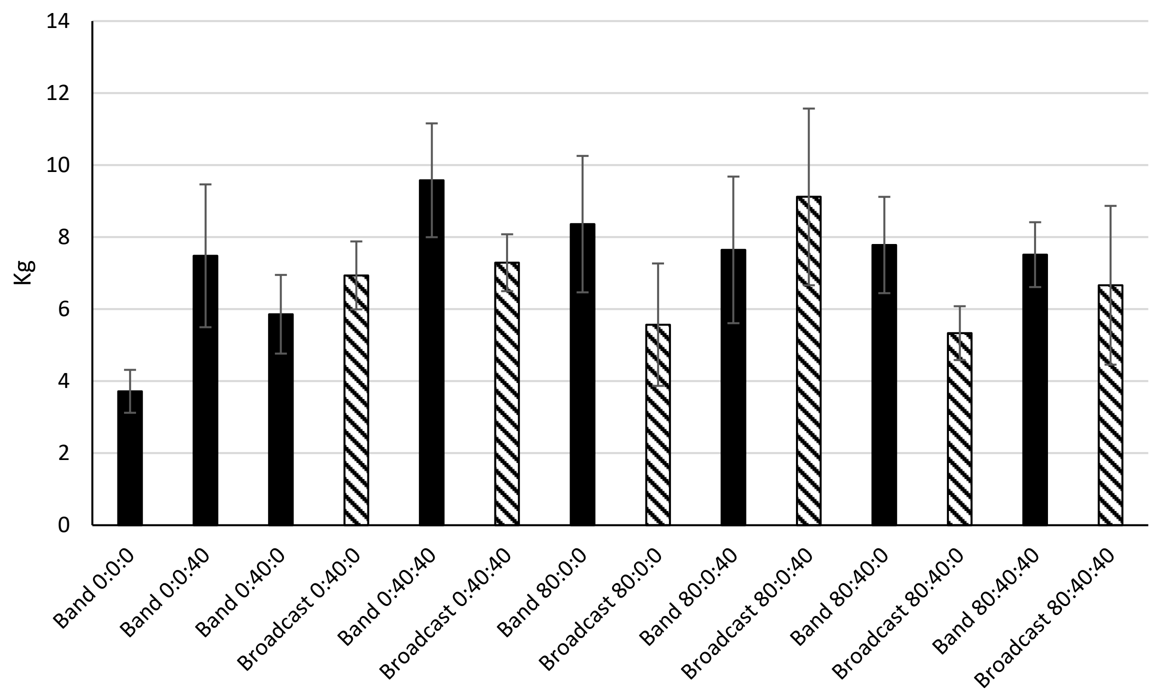

Figure 24. Comparison of mean weight harvested from plots amended with differing rates of N from compost : pre-plant bloodmeal : side-dressed bloodmeal applied by banding or broadcasting Riverhead, NY 2016.

Total lbs·acre^{-1} of N obtained by summing values given in the proportions i.e. 80:40:40 = 160 Total lbs·acre^{-1} of N. Vertical bars represent +/- standard error.

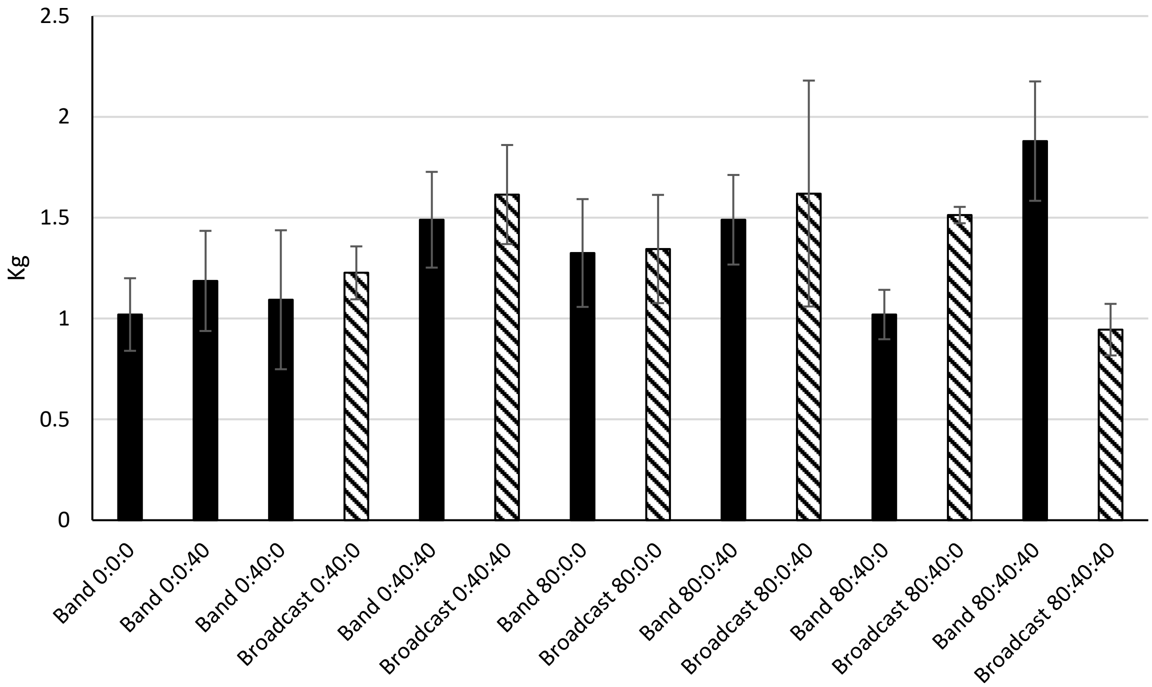

Figure 25. Comparison of mean dried stem weight taken from 2 plants at harvest from plots amended with differing rates of N from compost : pre-plant bloodmeal : side-dressed bloodmeal applied by banding or broadcasting Riverhead, NY 2016.

Total lbs·acre^{-1} of N obtained by summing values given in the proportions i.e. 80:40:40 = 160 Total lbs·acre^{-1} of N. Vertical bars represent +/- standard error.

Table 15. Treatment comparisons for squash fruit number, fruit yield and dry stem weight from plots amended with differing rates of N from compost : pre-plant bloodmeal : side-dressed bloodmeal applied by banding or broadcasting Riverhead, NY 2016.

Total lbs·acre^{-1} of N obtained by summing values given in the proportions i.e. 80:40:40 = 160 Total lbs·acre^{-1} of N. $F_{1,39}$ = 4.09.

Comparison	Fruit Number		Fruit Weight		Dry Stem Weight	
	F Value	Pr > F	F Value	Pr > F	F Value	Pr > F
(0:40:0) vs (0:0:40)	0.56	0.458	0.58	0.453	0.06	0.815
Band (0:40:0) vs Broad (0:40:0)	0.16	0.688	0.37	0.546	0.17	0.680
Band (80:0:0) vs Broad (80:0:0)	0.01	0.926	0.22	0.641	0.79	0.381
Band (80:0:0) vs Band (0:40:40)	0.06	0.804	0.32	0.573	0.23	0.634
Broad (80:0:0) vs Broad (0:40:40)	0.60	0.442	0.65	0.427	0.62	0.438
Band (80:40:0) vs Broad (80:40:0)	1.00	0.324	1.31	0.260	1.76	0.194
Band (80:0:40) vs Broad (80:0:40)	0.57	0.453	0.61	0.442	0.20	0.658
Broad (80:0:0) vs Broad (80:0:40)	2.45	0.126	2.79	0.103	0.70	0.410
Band (0:40:40) vs Broad (0:40:40)	1.15	0.291	1.14	0.292	0.13	0.718
Band (80:0:0) vs Band (80:40:0)	0.24	0.628	0.07	0.788	0.79	0.381
Band (80:0:0) vs Band (80:40:40)	0.68	0.416	0.16	0.694	1.81	0.188
Band (80:0:0) vs Broad (80:40:40)	1.21	0.279	0.63	0.433	1.22	0.277
Broad (80:0:40) vs Broad (80:40:40)	1.22	0.276	1.44	0.238	3.64	0.066

2016 Petiole Analysis NO3-N

In 2016 Petiole samples were taken from 7 treatments of interest. Data was found to have no significant differences in %NO_3-N levels (P=.1946) between any of the treatments **(Figure 26, Table 14).**

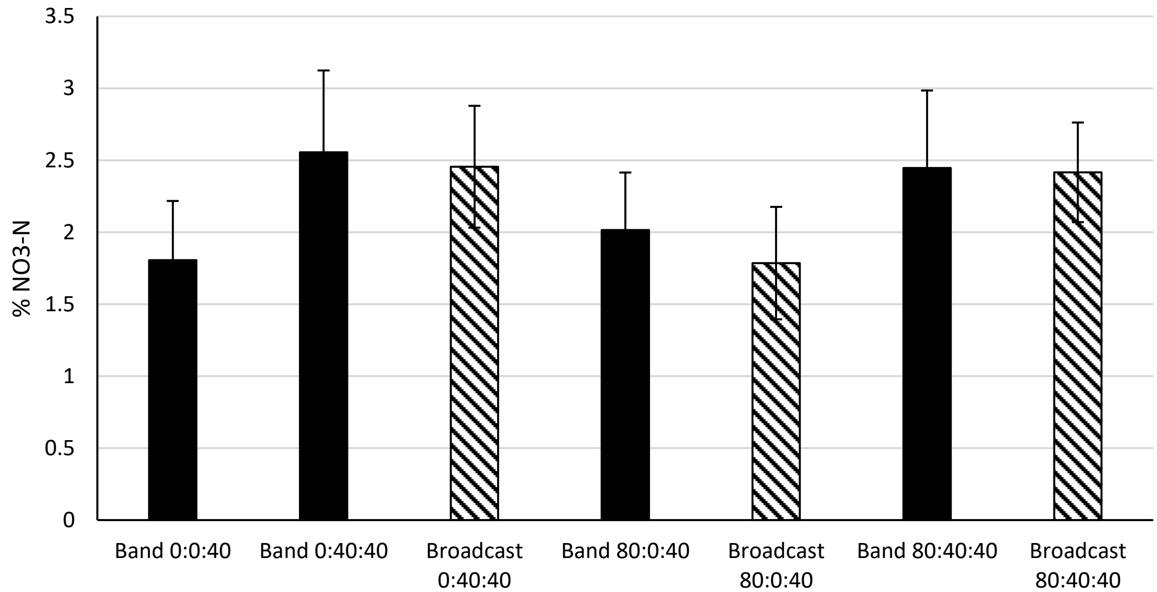

Figure 26. Comparison of mid-season mean dried petiole %NO3-N from plots amended with differing rates of N from compost : pre-plant bloodmeal : side-dressed bloodmeal applied by banding or broadcasting Riverhead, NY 2016.

Total lbs·acre^{-1} of N obtained by summing values given in the proportions i.e. 80:40:40 = 160 Total lbs·acre^{-1} of N. Vertical bars represent +/- standard error.

Discussion: Riverhead, NY

Yields

The New England Vegetable Management Guide 2016-2017, lists good yields of smaller bush type winter squash varieties in the range of 5-7 tons of fruit acre^{-1}. In 2015 plant density was at the tightest recommended spacing for smaller bush style winter squash at 18" per plant. In 2016 plot size was increased and plant spacing was 24" inches between plants. In 2015 all plots produced acceptable yields regardless of the treatments, based on the recommendation. There were yield differences between the treatments that produced the highest and lowest yields. In 2015 the mean lowest yielding plot was the banded compost treatment (80:0:0) with an average yield of 5.92 tons acre^{-1}. The highest yielding plot was the combination of banded compost, pre-plant bloodmeal and side-dressed bloodmeal (80:40:40) at 9.05 tons acre^{-1}.

In 2016 there were no significant differences in yield between any of the treatments. Treatments in 2016 varied considerably, most likely due to plant mortality by Phytophthora. The variation in total yields was higher between treatments in the 2016 growing season. The lowest yielding treatment was the control (0:0:0) which produced 3.95 tons acre^{-1}. the highest yielding treatment included pre-plant and side-dressed bloodmeal (0:40:40), which produced an average of 10.19 tons acre^{-1}.

Fertilizer and Compost

Fertilizer rate and timing is crucial in efficient fertilizer use. The goal being to supply the crop with the least amount of additional nutrients to receive the greatest amount of marketable yield. Under high crop N demand, organic fertilizers can provide adequate nitrogen and promote desirable yields (Gaskell and Smith, 2007). Bloodmeal has been shown to have a high rate of nitrogen mineralization and therefore is considered a fast-acting source of organic N. (Hartz and Johnstone, 2006). However, if timing of the available N doesn't line up with crop demand then the nitrogen will

continue to move through the nitrogen cycle (Van Eerd, 2010; Buwalda and Freeman, 1986; Mohammad 2004; Havlin et al., 1999; Maathuis, 2009). The New England Vegetable Management Guide, (2016-2017) demonstrates the crop nitrogen uptake curve where little crop N uptake corresponds with slow early season growth. N uptake dramatically increases as the plant grows throughout the season. Growth as well as N uptake, levels off as crops reach maturity.

A high rate of available N supplied by an organic N fertilizer early in the season may no longer be in an available form when crop need is there. Furthermore, N in an available form may be both converted to an unavailable form or be readily lost to another aspect of the nitrogen cycle. Hartz and Johnstone's, (2006) findings report that the greatest amount of N mineralization from organic fertilizers, such as bloodmeal, occurs within the first two weeks after application regardless of environmental factors such as temperature. However, temperature and moisture play a critical role in the mineralization process because they are a driving force behind the soil microbial community.

When comparing yields through contrasts in 2015, treatments that contained banded or broadcasted compost, pre-plant bloodmeal and side-dress bloodmeal (80:40:40) each had higher mean yields then the treatments that contained only banded compost (80:0:0) **(Table 13)**. The availability of N sourced from compost alone likely did not provide enough nitrogen to the plants causing lesser fruit sets with lower yields at harvest compared to treatments with compost, pre-plant and side-dressed bloodmeal. Based on Gale, et al. (2006) findings of PAN, available N from this compost would have been roughly 16 lbs·acre^{-1} of N. This rate is far lower than the N recommendation for winter squash, where the combination of all sources closely matched the 100 lbs·acre^{-1} of N recommendation (Rynk, 1992; New England Vegetable Management Guide, 2016-2017).

In 2016 there were no differences between any of the response variables **(Figure 23, 24 and 25)**. However, due to high rates of plant mortality the data that was analyzed was a calculation of what would be produced if plants had survived based on average weights of the plants that were left in the plot. This

might not accurately reflect responses to nutrient treatments because plant density was decreased which most likely affected competition for nutrients.

Available information on ideal %NO_3-N in dried petiole samples was not found for *Cucurbita pepo.* In its absence, melon *Cucumis melo,* NO3-N % levels were used. Adequate %NO_3-N ranges from .08 to 1.5% (Spectrum Technologies INC., 2009), petioles from 2015 show that only treatments that received banded pre-plant fertilizer contained adequate %NO_3-N for plant growth **(Figure 22)**. However, considering the petiole samples were taken prior to side-dress bloodmeal application, the results from the analysis do not reflect N uptake from the additional mid-season N. When reviewing NO3-N levels in the 2015 squash petioles samples; the sample that received bloodmeal solely as a side-dress (0:0:40) at this point is the same as the control treatment, which was not sampled. Being so, this treatment has similar %NO_3-N levels as treatments with compost and without pre-plant bloodmeal, suggesting that compost is not supplying available N **(Figure 22)**. The low amounts of N found in the petiole samples, reflects soil test results prior to the 2015 growing season which showed very low organic matter and NO3-N.

The 2016 petiole NO3-N samples all contained high amounts of nitrogen **(Figure 26)**. One possibility is that background fertility levels were high in the field used in 2016 leading to sufficient nitrogen for plant growth and a lack of response to the additional bloodmeal or compost. Previously compost studies had been carried out in some portions of the field. To create greater uniformity throughout the field, compost was applied prior to the treatments in spots were compost had not been applied in the past. This could have contributed to background fertility if compost was able to supply nitrogen for plant growth despite typically lower availability compared to fertilizer (Rynk, 1992; New England Vegetable Management Guide, 2016-2017). Compost has been shown to provide sufficient fertility compared to other sources in multiple crops (Evanylo. et al., 2008; N. Khalilian and Sullivan, et

al., 2002; Eghball and Powers, 1999). Furthermore; the compost used in Riverhead NY had a low C:N ratio of 14.8:1, which would promote a faster release of N from compared to a higher C:N ratio.

Side-dressing

In 2015, Side-dressed bloodmeal added to either banded or broadcasted pre-plant compost and bloodmeal (80:40:40) produced significantly higher fruit set and fruit yield than banded or broadcasted compost alone (80:0:0). Timing of bloodmeal was only significantly different for dry stem weight, where pre-plant (0:40:0) produced more biomass then side-dress alone (0:0:40).

Recent literature and current guidelines suggests that combinations of compost and bloodmeal would have a synergistic effect that could increase yields. Season-long nutrient demands could be better met by combining fertilizer and compost. This would provide N when plant growth and N need has peaked with a source of long-term N and available P in early growth (Gaskell and Smith, 2007; Hartz and Johnstone, 2006; Evanylo. et al. 2008; Khalilian and Sullivan, et al. 2002; The New England Vegetable Management Guide, 2016-2017). This was reflected for fruit yield and number in the 2015 experiment. While banded compost (80:0:0) was not significantly different from banded pre-plant bloodmeal and side-dressed fertilizer (0:40:40), banded compost with pre-plant bloodmeal (80:40:0) or banded compost with side-dressed bloodmeal (80:0:40) the combination of the three (80:40:40) created significantly greater yields. **(Figure 19 and 20)**. Similar results were not found in **(2016 Figure 23 and 24)**.

In 2016 petiole %NO_3-N levels were high for all treatments, including the side-dress treatment which at the time of sampling had no added N. Adding additional mid-season bloodmeal had no effect on fruit number, fruit yield or plant growth **(Figure 23, 24 and 25)**. The lack of response to side-dressing does raise questions when considering fertilizer efficiency and effectiveness of organic fertilizers to deliver mid-season nitrogen.

Banding or Broadcasting Bloodmeal and Compost

Banding or concentrating the rate of nutrients near the root zone is a strategy to deliver nutrients more efficiently to the crop. This technique is used prior to planting and to apply side-dress fertilizers mid-season (Khalilian and Sullivan, et al. 2002; New England Vegetable Management Guide, 2016-2017). Shapiro et. al. (2016) saw increased grain yields and greater plant nitrogen uptake with banding a conventional fertilizer over broadcasting. Buwalda et. al. (1987) found that yield increased with increasing widths of localized P and K fertilizer up to a certain point of 0.25 meters, after which the increase in width had no further increase in yield.

By banding fertilizer or compost, nutrient demands can be met by lowering the per acre amount due to the smaller application area and therefore a lower relative application rate. In this experiment compost amounts where not changed between the banding or broadcasting of identical rates. This led to the banding application being applied at a higher concentration then the broadcasting rate because the same volume was applied in both treatments over different areas.

Compost rates and pre-plant bloodmeal were applied by banding or broadcasting at similar rates. No differences were seen in 2015 or 2016 for fruit number, fruit yield or dry stem weight when comparing banded fertilizer (0:40:0) to broadcasted fertilizer (0:40:0) or banded compost (40:0:0) to broadcasted compost (40:0:0). It is reasonable to speculate that banding the compost or bloodmeal would allow for more accurate delivery of nutrients to the rhizosphere of the plant. However, mixed results have been found in past research (Khalilian and Sullivan, et al. 2002; Parish, Bracy and McCoy, 2008; Manuck 2006; Shapiro et. al. 2016). In conventional tillage compost and fertilizer would have been fully incorporated, while in this experiment the yeoman plow reduced incorporation. This might be a possible reason for the lack of a difference between the two.

Another possibility is the low amount of plant available nitrogen in the initial compost application and the subsequent slow release of nitrogen through the mineralization process. Plant

available nitrogen is in the inorganic form of ammonium or nitrate. Ammonium can be rapidly converted to nitrate. Nitrate having a negative charge can be transient in the soil water solution. (Gaskell and Smith, 2007; Maathuis, 2009). Perhaps taking this into consideration placement of an organic source of nitrogen is less important when the delivery of inorganic N relies on the mineralization process and the actual difference in soil coverage between treatments is small, such as the case in this experiment where broadcasting width did not differ greatly than banding widths.

CONCLUSION

The findings of this multi-site two-year experiment shed light on the effectiveness and uncertainty of organic fertility sources, specifically in a small-scale, reduced-till system. Although significant differences were not repeatable between years at any site. Our results reinforced the need for a multifaceted approach for nutrient management to optimize rates; using soil tests, accurate delivery of nutrients and promoting soil health.

Compost utilization is popular among farmers, especially organic farmers who often view it as an alternative source of nitrogen for crops. Compost does contain nitrogen; however, to view it as a reliable nitrogen fertilizer is a misconception because PAN is influenced heavily by the compost characteristics, soil environment and microbial community. Furthermore, targeting high N rates using compost can lead to excess phosphorus loads. While 20% of total N may be available within the season; 50-90% of P and nearly all the K will also be available. (Gale, et al. 2006; Evanylo, et al., 2008; D'Hose, et. al. 2016). Compost can provide many other benefits to the soil and ultimately plant growth (Weber et al., 2007; Khalilian and Sullivan, et al., 2002; Rivenshield and Bassuk, 2007;Evanylo. et al. 2008). This was observed in Maine in 2015 where treatments containing compost produced greater fruit numbers and weights, most likely caused by increased available P during early growth. The inability of compost to supply sufficient N to crops was shown in 2015 at both Cornell sites were nitrogen was limiting and the addition of bloodmeal produced higher fruit numbers and fruit yield compared to compost alone. Petiole analysis further supported this and %NO_3-N levels were higher in all treatments that received bloodmeal compared to compost at all sites.

Organic nitrogen fertilizers have been shown to benefit plant growth where nitrogen was limiting (Hartz and Johnstone, 2006; Gaskell and Smith, 2007). This experiment could not detect a significantly different response in yield with bloodmeal application in Maine. This may be due to sufficient nitrogen supplied by the soil or may be due to poor application time and nutrient loss in the lag time between

availability and plant uptake. However, pre-plant bloodmeal was found to produce the greatest yields in Freeville, N.Y. in 2015, where soil organic matter levels were low, and N was limiting. Chance et al. (1999) also found that higher amounts of early-season NO_3^- encourage squash yields. The experiment in Riverhead, N.Y also produced greater yields in the 2015 growing season with the addition of pre-plant and side-dressed bloodmeal to compost. However, when comparing yields from plots treated with compost to plots treated with bloodmeal at similar rates there was no difference.

Placement of the bloodmeal and compost was found to have significant effects in Freeville during 2015. Banded compost produced lower fruit weights while banded fertilizer increased fruit weights. Banding the materials puts them in line with the Yeoman plow and causes them to be mixed into the soil. This created higher yields with bloodmeal because soil N was low. However, better incorporation near the rooting zone of compost had a negative effect, even though compost analysis did not detect traits that would limit plant growth. This finding supports the unreliability of compost as a fertility source. There was a significant difference when adding compost in Maine, but there was no yield difference when comparing banding or broadcasting at equal rates.

Interesting responses to timing were seen when N was limiting, such as in Freeville 2015. Early-season bloodmeal applications were more effective than side-dress applications for yield, but increased fruit numbers were observed only when adding a pre-plant and a side-dress application to compost. Likewise, in Riverhead yield and fruit number were increased only when adding a combination of compost, pre-plant and side-dressed bloodmeal.

Regardless of the site the findings in the first year of the experiment were not duplicated in the second year. Furthermore, field studies using sources that supply nutrients in an organic form, like compost and organic fertilizers lack control because of the high amount of influence environmental factors have on the mineralization process. However, field studies are practical in their relation to actual farming. Being so, further research may be needed to more accurately match product availability with

plant uptake and to adjust side-dress fertilizer recommendations in field settings. This may be carried out in a field that has been depleted of nutrients in some way. Then crop responses to the amendments could be detected better due to lower influences from background fertility. Throughout the growing season soil tests could be conducted to monitor nutrient levels and microbial activity. At the same time, plant tissue samples could be taken to monitor uptake. This data could then be used to explore availability and uptake over time.

There were many comparisons made in this study that were not significantly different. The importance of this is that we often may be overapplying materials and nutrients even in organic agriculture; when sustainable farming strives to prevent this. In some instances, in this experiment the control plot had no statistical difference from additional bloodmeal or compost. Higher rates do not increasingly lead to higher returns if the need for those nutrients is absent or other environmental factors limit the response. This experiment involves reducing both soil disturbance and optimizing fertility rates. Managing soil health may reduce the need for additional nutrients in some cases. Likely, by increasing organic matter and promoting soil biodiversity that plays a role in the N mineralization process. Ultimately, greater precision will lead to greater efficiency although, this is challenging with organic products because of the many factors that influence the availability of N.

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