THE RESPONSE OF BASIL (OCIMUM BASILICUM L.) TO CHICKEN MANURE,
COMPOST AND UREA APPLICATIONS

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I would like to acknowledge my committee members for their help and guidance over the course of this project.

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ABSTRACT

Once essential components of agriculture, organic amendments are regaining importance in the management of agricultural soil fertility. Three experiments were conducted at the University of Hawaii Waimanalo Experiment Station to determine the effect chicken manure, compost and urea applications have on the yield, nutrient status and sensory quality of basil. Yield of basil plants receiving applications of either chicken manure at 5 t ha\(^{-1}\) or compost applications at 23 t ha\(^{-1}\) were comparable or greater than plants to which recommended rates of synthetic fertilizer (urea) had been applied. Although higher rates of compost (90 t ha\(^{-1}\)) generally increased yield over the lower rates, N use efficiency was determined to be greatest at the lower rates of compost application. Tissue N and sap nitrate-N levels were increased with organic amendment applications. Tissue N levels of 4.5-4.8 were associated with highest yields. Sap nitrate-N was well correlated with tissue N levels at 65 days after transplanting. Sap nitrate-N levels varied with cultivar, while tissue N did not. Nitrate-N levels were not affected by compost applications, but were increased with applications of urea. Compost applications increased soil organic matter over the control and urea treatments, while soil pH was lowest in the urea plots. Although low in all treatments after 5 years of annual fertilizer applications, soil salinity was slightly higher in the treatment receiving high rates (90 t ha\(^{-1}\)) of a manure-based compost. In one experiment, fresh basil aroma intensity increased with fertilizer applications.
Compost was therefore determined to be a very valuable resource for Hawaii vegetable growers.
# TABLE OF CONTENTS

<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acknowledgements</td>
<td>iii</td>
</tr>
<tr>
<td>Abstract</td>
<td>iv</td>
</tr>
<tr>
<td>List of Tables</td>
<td>v</td>
</tr>
<tr>
<td>List of Figures</td>
<td>ix</td>
</tr>
<tr>
<td>Chapter 1: Introduction</td>
<td>1</td>
</tr>
<tr>
<td>Chapter 2: Literature Review</td>
<td>4</td>
</tr>
<tr>
<td>Introduction</td>
<td>4</td>
</tr>
<tr>
<td>Compost Applications Effects on Vegetable Yield</td>
<td>4</td>
</tr>
<tr>
<td>Poultry Manure Effects on Vegetable Yield</td>
<td>11</td>
</tr>
<tr>
<td>Basil</td>
<td>15</td>
</tr>
<tr>
<td>Plant Nutrient Status</td>
<td>18</td>
</tr>
<tr>
<td>Nematode Control with Compost and Chicken Manure Applications</td>
<td>21</td>
</tr>
<tr>
<td><em>Fusarium</em> wilt Control with Compost Applications</td>
<td>24</td>
</tr>
<tr>
<td>Sensory Quality of Fresh Basil</td>
<td>28</td>
</tr>
<tr>
<td>Literature Cited</td>
<td>33</td>
</tr>
<tr>
<td>Chapter 3: Basil Yield and Tissue Levels in Response to Poultry Manure and Urea Applications</td>
<td>47</td>
</tr>
<tr>
<td>Abstract</td>
<td>47</td>
</tr>
<tr>
<td>Introduction</td>
<td>48</td>
</tr>
<tr>
<td>Materials and Methods</td>
<td>49</td>
</tr>
<tr>
<td>Results</td>
<td>52</td>
</tr>
<tr>
<td>Discussion and Conclusions</td>
<td>52</td>
</tr>
<tr>
<td>Literature Cited</td>
<td>55</td>
</tr>
<tr>
<td>Chapter 4: Effects of Compost Applications on Basil Yield, Tissue Nitrogen Concentration and Sap NO$_3^-$-N Levels</td>
<td>66</td>
</tr>
<tr>
<td>Abstract</td>
<td>66</td>
</tr>
<tr>
<td>Introduction</td>
<td>67</td>
</tr>
<tr>
<td>Materials and Methods</td>
<td>69</td>
</tr>
<tr>
<td>Results and Discussion</td>
<td>73</td>
</tr>
<tr>
<td>References Cited</td>
<td>78</td>
</tr>
<tr>
<td>Chapter 5: Basil Yield and Soil Quality As Affected By Compost and Urea Applications</td>
<td>99</td>
</tr>
<tr>
<td>Abstract</td>
<td>99</td>
</tr>
<tr>
<td>Introduction</td>
<td>100</td>
</tr>
<tr>
<td>Materials and Methods</td>
<td>102</td>
</tr>
<tr>
<td>Results and Discussion</td>
<td>106</td>
</tr>
<tr>
<td>Conclusions</td>
<td>110</td>
</tr>
<tr>
<td>Literature Cited</td>
<td>111</td>
</tr>
<tr>
<td>Chapter 6: Effects of Compost and Synthetic Fertilizer Applications On the Aroma and Flavor Intensity of Basil</td>
<td>126</td>
</tr>
<tr>
<td>Abstract</td>
<td>126</td>
</tr>
<tr>
<td>Introduction</td>
<td>127</td>
</tr>
<tr>
<td>Materials and Methods</td>
<td>128</td>
</tr>
<tr>
<td>Results</td>
<td>131</td>
</tr>
</tbody>
</table>
# LIST OF TABLES

<table>
<thead>
<tr>
<th>Table</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>3.1</td>
<td>60</td>
</tr>
<tr>
<td>3.2</td>
<td>61</td>
</tr>
<tr>
<td>3.3</td>
<td>62</td>
</tr>
<tr>
<td>3.4</td>
<td>63</td>
</tr>
<tr>
<td>4.1</td>
<td>81</td>
</tr>
<tr>
<td>4.2</td>
<td>87</td>
</tr>
<tr>
<td>4.3</td>
<td>88</td>
</tr>
<tr>
<td>4.4</td>
<td>89</td>
</tr>
<tr>
<td>4.5</td>
<td>90</td>
</tr>
<tr>
<td>4.6</td>
<td>91</td>
</tr>
<tr>
<td>5.1</td>
<td>115</td>
</tr>
<tr>
<td>5.2</td>
<td>115</td>
</tr>
<tr>
<td>5.3</td>
<td>123</td>
</tr>
<tr>
<td>5.4</td>
<td>124</td>
</tr>
<tr>
<td>5.5</td>
<td>125</td>
</tr>
<tr>
<td>5.6</td>
<td>126</td>
</tr>
</tbody>
</table>
## LIST OF FIGURES

<table>
<thead>
<tr>
<th>Figure</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>3.1</td>
<td>Effect of Chicken Manure and Urea Application on Mean Cumulative Yield of Basil</td>
</tr>
<tr>
<td>3.2</td>
<td>Effect of Poultry Manure and Synthetic Fertilizer on Final Plant Weight</td>
</tr>
<tr>
<td>3.3</td>
<td>Effect of Poultry Manure and Synthetic Fertilizer Treatment on Mean Tissue Nitrogen Concentration</td>
</tr>
<tr>
<td>3.4</td>
<td>Tissue Nitrogen Relative to Basil Yield</td>
</tr>
<tr>
<td>3.5</td>
<td>Effect of Poultry Manure Application on Soil Organic Carbon Content</td>
</tr>
<tr>
<td>4.1</td>
<td>Effect of Compost Rates and Urea Applications on Mean Cumulative Yield By Treatment</td>
</tr>
<tr>
<td>4.2</td>
<td>Mean Cumulative Yield of Cultivars By Treatment</td>
</tr>
<tr>
<td>4.3</td>
<td>Effect of Fertilizer Treatments on Soil Organic Carbon Content</td>
</tr>
<tr>
<td>4.4</td>
<td>Effect of Treatment on Root Gall Index Scores of Cultivars</td>
</tr>
<tr>
<td>4.5</td>
<td>Effect of Treatment on Root Health Index Scores Basil Cultivar ‘UH’</td>
</tr>
<tr>
<td>4.6</td>
<td>Total Nitrogen Concentration of Basil Leaves Relative To Stem Sap Nitrate-N</td>
</tr>
<tr>
<td>4.7</td>
<td>Total Nitrogen Concentration of UH Basil Leaves Relative to Stem Sap Nitrate-N</td>
</tr>
<tr>
<td>4.8</td>
<td>Total Nitrogen Concentration of SWEET Basil Leaves Relative to Stem Sap Nitrate-N</td>
</tr>
<tr>
<td>4.9</td>
<td>Total Nitrogen Concentration of THAI Basil Leaves Relative to Stem Sap Nitrate-N</td>
</tr>
<tr>
<td>4.10</td>
<td>Yield of Cultivar SWEET Relative to Stem Sap Nitrate-N Concentration</td>
</tr>
</tbody>
</table>
4.11 Yield of Cultivar UH Relative to Stem Sap Nitrate-N Concentration
...........................................................................................................97

4.12 Yield of Cultivar UH Relative to Tissue N Concentration
..................................................................................................................98

5.1 Effect of Several Compost and Synthetic Fertilizer Treatments on Yield
.......................................................................................................................116

5.2 Effect of Several Compost and Synthetic Fertilizer Treatments on Yield Response of Cultivars to Treatment
..........................................................................................................................117

5.3 Effect of Treatment on Stem Sap Nitrate-N of Basil
.................................................................................................................................118

5.4 Effect of Several Compost and Synthetic Fertilizer Treatments on Total Nitrogen Content of Basil Leaves
........................................................................................................................119

5.5 Mean Plant Health Index of Cultivar UH As Affected By Treatment
..........................................................................................................................120

5.6 Percent of the Total Number of ‘Thai’ Plants exhibiting Symptoms of Fusarium Wilt Relative to the NH4+-N:NO3- N Ratio In the Soil
...............................................................................................................................121

5.7 Mean Soil NH4+ N and NO3- N Levels of Treatments Over Time
.................................................................................................................................122

6.1 Score Sheet Used By Panelists In the First Sensory Evaluation of Basil, Fall 1998
.................................................................................................................................141

6.2 Score Sheet Used By Panelists In the Second Sensory Evaluation of Basil, Spring 1999
.................................................................................................................................142

7.1 Effect of Treatments on Cumulative Yield of ‘Sweet’
.................................................................................................................................160

7.2 Effect of Treatments on Cumulative Yield of ‘Thai’
.................................................................................................................................161

7.3 Effect of Treatments on Cumulative Yield of ‘UH’
.................................................................................................................................162

7.4 Yield Trend of ‘UH’ Over Time, Fall 1998
.................................................................................................................................163

7.5 Yield Trend of ‘UH’ Over Time, Fall 1998 and Spring 1999
.................................................................................................................................164

7.6 Mean Plant Parasitic Nematode Levels By Treatment
.................................................................................................................................165

7.7 Root Gall Index by Treatment for Two Experiments
.................................................................................................................................166
7.8 Mean Gall and Root Health Index Scores of 'UH'...............................167
7.9 Effect of Fertilizer Application on Soil Organic Carbon Content..........168
CHAPTER 1

INTRODUCTION

Prior to the nineteenth century, fresh and composted manure were among the primary tools employed to maintain agricultural soil fertility (Martin and Gershuny, 1992). In the mid 1800’s, Justus von Liebig and others proposed that mineral salts replace organic amendments as the source of essential plant nutrients needed for agricultural production (Brock, 1997). This new emphasis on chemistry, and the industrialization of agriculture in America and Europe through the first half of the 20th century, brought with it a reduced emphasis on the use of manure and organic matter to sustain soil fertility (Howard, 1943).

Application of organic amendments such as compost and chicken manure have been demonstrated to be effective tools to manage soil fertility in vegetable production (Roe, 1998; Verma, 1995). These amendments not only supply essential plant nutrients to a crop, but by virtue of their organic fraction can improve the nutrient holding capacity of soils, nutrient availability, beneficial soil micro organism activity, soil structure, and plant growth in acid soils (Marchensini et al., 1988; Woomer et al. 1994; Marcus et al., 1995; Hue and Sobieszczyk, 1999). In addition to these effects on crop production, utilization of chicken manure and compost in vegetable systems in Hawaii provides an opportunity to reduce the amount of inputs (i.e. fertilizers) needed to be brought into the State. Maximum use of locally available resources is an integral part of sustainable vegetable production in the tropics (Valenzuela, 2000), and composting provides an opportunity to recycle materials that would otherwise add to the amount of
waste needing disposal. In fact, recycling is one of the primary reasons cited by growers for substituting organic fertilizers for their synthetic counterparts (Wallace, 1994)

Basil is an important crop in Hawaii (HASS 1999) that has shown positive yield response to applications of locally produced compost (Valenzuela et al. 1999). However, rate recommendations are not available for organic fertilization of basil in the tropics. Chicken manure and compost have been used to effectively control root-knot nematodes and disease caused by *Fusarium oxysporum* (Coosemans, 1982; Chindo and Kahn, 1990, Raj and Kapoor, 1997), both of which are major constraints to basil production in Hawaii. No detailed information is available on the response of these pests to compost and other fertilizer applications in a basil production system under Hawaii conditions. Also, no information is available on the effects of fertilization on the nutrient status of basil, nor have critical N levels been determined specifically for this crop. There is evidence that fertilization may affect the sensory quality of fresh-market basil (Alder et al. 1989), but no studies have yet been conducted to evaluate the impact that changes in nutritional regime may have on the taste or aroma of this herb.

Thus, the objectives of this project were:

1. To evaluate the effects of available organic and synthetic fertilizers on the yield of basil produced under field conditions in Hawaii.
2. To evaluate the effects of organic and synthetic fertilizers on important soil qualities.
3. To determine the potential of sap nitrate analysis using a portable nitrate ion selective electrode to diagnose the nitrogen status of basil.

4. To evaluate the potential of organic fertilizer use as a pest control measure in basil produced under field conditions.

5. To evaluate the sensory quality of fresh sweet basil as affected by organic and synthetic fertilizer applications.
CHAPTER 2
LITERATURE REVIEW

Introduction

Much work has been conducted on the use of compost and chicken manure as a soil amendment in vegetable production. The literature pertaining to basil as an important agricultural crop, the potential for fertilization practices to influence the sensory quality of fresh produce, and the use of rapid sap nitrate analysis to manage the fertilization of vegetable crops is similarly extensive. This review of the literature focuses on the following topics:

1. The effects of compost applications on vegetable yield
2. The effects of chicken manure applications on vegetable yield
3. Basil as an important agricultural crop
4. Rapid analysis of petiole sap NO$_3^-$ to determine crop nutrient status
5. Nematode control with compost and chicken manure applications
6. Fusarium wilt control with compost applications
7. The potential of fertilization to affect the sensory quality of fresh basil

Compost Application Effects on Vegetable Yield

Compost Quality and nutrient value

A major obstacle to the development of universal recommendations for the use of compost in vegetable production is the considerable variation in quality of commercially available composts (Hue et al, 1995; Ozores-Hampton, 1998; Roe, 1998). The concepts of maturity and stability are frequently associated with
compost quality, and used interchangeably (Hue, 1997). Standards in Canada designate compost of adequate maturity for vegetable production if it has a C:N ratio $\leq 25:1$, it does not inhibit the germination of radish or cress seed, and if the microbial activity within the compost is low (Composting Council of Canada, 1998). Ozores-Hampton et al. (1998) define a mature compost as one which is not phytotoxic, and which does not immobilize soil N. Use of an immature municipal solid waste compost negatively affected cucumber seed germination and seedling development (Sainz et al, 1998); further composting eliminated phytotoxicity of the product. Adverse effects of immature compost on vegetable production were also observed by Kostewicz (1993), who reported a negative linear correlation between pole bean yield and application rates (0, 25, 50, 100 t ha$^{-1}$) of an immature, unscreened, wood based compost, most likely due to nitrogen immobilization.

Nitrogen content and availability are often the most important criteria vegetable growers are interested in when the primary goal of compost applications is increased crop yield. Most of the nitrogen will be in organic form and therefore subject to release over time by microbial degradation. High soil moisture, high temperatures, and aerobic conditions facilitate rapid conversion of organic N to plant available mineral form by soil microorganisms (Tisdale et al. 1993). As a result, N release rates may be expected to be higher in the tropics than in temperate regions (Woomer, et al., 1994). Compost stability refers to the potential for a compost to release, or mineralize, its organic N and is frequently measured by the ratio of total organic carbon to
organic nitrogen (C:N) (Hue and Liu, 1995; Ozares-Hampton et al., 1998). A C:N ratio <25:1 is usually necessary for any mineralization of N, with a C:N ratio <15 indicating high N availability (Bezdicek and Fauci, 1997). For example, first year N mineralization of a compost with a high N concentration and low C:N ratio may be as high as 50% (Buchanan and Gliessman, 1991). General N mineralization estimates developed for the continental U.S. are 10% the first year, 5% the second year, and 2-3% the third year (Compost Council, 1996), and those for the tropics are 15, 5, 3 and 3% for the 1st, 2nd, 3rd, and 4th year after application, respectively (Hue, 1997). Erbertseder et al. (1996) found the ratio of organic carbon to total nitrogen C:N (total) of the compost solid phase to accurately predict the N release rate of a compost as measured by N uptake in oat seedlings. N availability increased with decreasing C:N ratio. However, these workers found that using C:N (total) to compare nitrogen availability between composts was only useful when composts originated from similar feedstocks. This may explain the findings of Hue et al. (1995), who observed the C:N (total) ratio of the solid phase to be a poor indicator of compost stability when applied to a group of composts varying in parent material.

Application of compost to meet crop N needs results in the addition of considerable amounts of other nutrients. Estimates of compost P availability from Washington State University is 5-15%, while almost all compost K is plant available (Bezdicek and Fauci, 1997). Additions of 11 t ha\(^{-1}\) of a chicken manure based compost significantly increased soil P and K, and shoot P concentrations in peppers with respect to those grown in synthetic fertilizer plots that received
149, 0, 93 kg ha\(^{-1}\) of N, P, K, respectively (Douds et al., 1997). A review of several long-term studies on the effect of compost applications on rice yield demonstrated that the positive yield response observed was primarily due to nitrogen effects, although continued applications increased plant available soil P and K levels by 35 and 113% respectively (Kumazawa, 1984). Sainz et al. (1998) also found compost applications to increase soil and plant tissue concentrations of P, K, and micronutrients. In another study, tissue N, P, Mn and Cu levels of bean increased with increasing compost applications (Browaldh, 1992).

**Compost effects on soil quality**

Compost applications may affect soil properties important in vegetable production, such as pH, organic matter content, CEC and salinity. For example, applications of ammonium sulfate were found to significantly increase soil acidity, while low rates of compost applied with synthetic N appeared to buffer soil pH (Buchanan and Gliessman, 1991). The same study showed compost applications of 30 t ha\(^{-1}\) to significantly raise soil pH with respect to plots receiving either synthetic fertilizer or no amendment. Sainz et al. (1998) observed that application of compost to a slightly acid soil raised the pH from 6.5 to 7.2. In Hawaii, soil salinity as well as pH increased with increasing rates of chicken manure-and-wood-chip-based compost applications (Silva et al., 1995.). Bevacqua and Mellano (1994) reported a decrease in soil pH from 7.7 to 7.4 with applications of compost, while soil organic matter, nutrient concentration, and salinity increased compared to the control. In Thailand, soil CEC increased
after 9 years of compost applications in flooded rice production, but soil pH and organic carbon content was little affected (Songmuang et al., 1984).

**Compost applications affect microbial activity**

Compost applications affect plant growth by influencing soil microorganism populations. For example, applications of chicken litter-based compost increased mycorrhizal colonization, and compost additions increased the number of mycorrhiza spores over levels in soil receiving synthetic fertilizer or raw dairy manure (Douds et al., 1997). Applications of composted stable manure (0.3% P) to pepper reduced mycorrhiza root colonization with increased rates up to the maximum applied 300 dry t ha\(^{-1}\) (Brechelt 1989). In another study, compost applications increased extractable P and decreased root colonization by mycorrhiza (Sainz et al., 1998). In Australia, Sivapalan et al. (1993) found soil fungi, total bacteria, and actinomycete populations to be significantly higher in plots receiving 120 t ha\(^{-1}\) than those receiving 80 t ha\(^{-1}\) of compost. They also found that microbial populations, particularly those of *Trichoderma* and *Penicillium*, were higher in soil receiving a chicken manure based compost as the sole source of crop nutrients than those in synthetic fertilizer plots. In a pot trial with tomatoes, additions of manure based composts did not stimulate total soil microorganism populations in the rhizosphere with respect to a control receiving no amendment. However, the compost treatments did increase the percentage of phytopathogen antagonists (de Brito Alvarez et al., 1995). In other work, compost applications to contaminated soil improved plant growth, enhanced microbial
activity, and resulted in degradation of persistent soil pesticides with respect to unamended soil (Liu and Cole, 1996).

**Compost application rates associated with increased crop yields**

Compost Application rates of 10-60 t ha\(^{-1}\), on a dry weight basis, are generally recommended for vegetable production, although applications as low as 7 t ha\(^{-1}\) have shown positive effects on vegetable yields (Compost Council, 1996; Roe, 1998).

In Hawaii, a chicken manure and wood-chips compost treatment increased corn biomass production up to a rate of 50 t ha\(^{-1}\), with yield decreasing at higher rates (Silva et al., 1995). Other workers reported that applications of 11 t ha\(^{-1}\) dry weight compost increased azuki bean yields over 112 kg ha\(^{-1}\) synthetic N and control treatments (Robinson 1983). Lettuce and onion yields were increased with compost applications of 37 and 74 t ha\(^{-1}\) over a control treatment (Bevacqua and Mellano, 1994). Lettuce yields in this experiment were higher with the highest compost application rate, while onion yields were not different between the two compost application rates. The same study found stand establishment of lettuce and onion to increase with sewage sludge compost applications of when compared to controls, with no significant difference between rates. Also with lettuce, Stopes et al. (1989) reported a yield increase in response to application of composted farm yard manure (.9% N), with highest lettuce yields obtained at the highest rate of application of 18 dry t ha\(^{-1}\). Yield at this rate was not different than that obtained with 160 kg ha\(^{-1}\) synthetic N. Other studies have
shown similar results. For example, when a manure based compost was applied to cabbage and carrot to provide 300 and 170 kg ha\(^{-1}\) N respectively, crop yields and tissue N levels were the same as those obtained in synthetically fertilized plots receiving the same N rate (Warman and Havard 1997). This ability of compost to meet all plant nutrient needs previously met with synthetic fertilizers was also reported in rice (Inoko, 1984). However, crops may differ in their response to fertilizer type. Chu and Wong (1987) investigated the yield response of carrot, tomato and Chinese cabbage to compost applications between 0-150 t ha\(^{-1}\), and an application of a 15-9-15 fertilizer at 2 t ha\(^{-1}\). Optimum carrot yields were obtained with 50 t ha\(^{-1}\) compost, while the highest tomato and Chinese cabbage yields were observed in the synthetic fertilizer treatment. In this experiment, cabbage leaf yield was not increased with compost applications, while tomato plant biomass increased at a much higher rate than did fruit yield in the compost treatments. Yields of bitter eggplant (Solanum aethiopicum) plants receiving 20 t ha\(^{-1}\) of composted wood chips were 750% higher than those receiving no amendment (Seck and Lo, 1998).

In addition to the application rate, the method of application may also effect plant response to compost applications. Plant response to compost applications may be greater, for example, when the compost is incorporated into the soil than with surface application of compost. Compost incorporation to a depth of 15 cm is recommended by the Compost Council (1996). McSorley and Gallaher (1995) found that incorporation of compost at 269 t ha\(^{-1}\) was more
effective in increasing squash and okra yield than surface applications at the same rate.

Despite the positive effects compost has on the yield of food crops, the low nutrient concentration and high cost of composts relative to synthetic fertilizers makes it impractical to consider compost as a complete replacement for mineral fertilizers in conventional systems (Buchanan and Gliessman, 1991; Bittenbender et al., 1998). However, they may be used in conjunction with each other to increase soil organic matter, and reduce loss of inorganic N from the agroecosystem.

Buchanan and Gliessman (1991) observed that applying 3 t ha$^{-1}$ compost plus 75 kg ha$^{-1}$ synthetic N improved N use efficiency of broccoli, probably due to the compost serving as both a sink and a subsequent source for inorganic N. It was also observed that when 15-21 t ha$^{-1}$ of compost was applied with synthetic N at rates greater than 170 kg ha$^{-1}$, there was an increase in rice yield that could not be obtained with synthetic N alone (Kumazawa, 1984). Again, the likely explanation for this apparently synergistic effect is the immobilization and subsequent mineralization by compost microbial activity of excess synthetic N that would otherwise be lost to the crop.
Poultry manure effects on vegetable yield

Introduction

With over 500,000 layers in the state, poultry manure represents a significant potential source of plant nutrients to Hawaii vegetable growers (HASS, 2000). As with other organic fertilizers, no crop specific recommendations are available to Hawaii vegetable growers who want to incorporate poultry manure into their fertility program. Currently, the University of Hawaii recommends thoroughly composting animal manure to ensure destruction of any human pathogens it may contain (LeaMaster et al., 1998).

Poultry manure as a source of plant nutrients

Poultry manure generally has a higher total N concentration and lower C:N ratio than composites resulting in a relatively quick release of plant available N (Parnes, 1990). A portion of the total N in poultry manure is organic, and release rates are therefore generally slower than with synthetic fertilizers (Goh and Vityakon, 1983). Approximately 30-50% of total N in poultry manure becomes available over to a crop following application (Castellano and Pratt, 1981; Hue, 1997). Vegetable yield increases in response to poultry manure applications are frequently attributed to N effects (Hochmuth et al. 1993; Hue and Sobieszczuk, 1999). However, poultry manure contains a wide range of plant nutrients, and is also considered a good source of Mg and Ca (Mengbo et al. 1997). In fact, P levels in both soils and plant tissues have been shown to significantly increase.
with poultry manure applications, and may actually lead to excessive P levels in soils not deficient in that nutrient (Cheung and Wong, 1983; Browaldh, 1992; Hue and Sobiezczyk, 1999).

**Poultry manure affects soil quality**

Poultry manure applications can affect soil properties. Poultry litter applications of 4.8, 9.5 and 19.0 t ha\(^{-1}\) increased soil pH over a control and synthetic fertilizer treatment, but showed no significant difference in this effect between manure application rates (Brown et al., 1993). In another study, poultry manure applied at rates above 10 t ha\(^{-1}\) raised soil pH (Opara and Asiegbu, 1996). Similarly, Cheung and Wong (1983) observed poultry manure increased cabbage yield, and raised soil pH and OC content. Surface application of poultry manure also effectively increased soil pH and decreased plant available aluminum (Hue and Licudine, 1999). Mian and Rodriguez-Kabana (1982) found a positive linear relationship between application rates of poultry manure, and increasing soil pH. Soil quality may also be negatively affected by applications of chicken manure. Increased soil salinity was speculated to be the cause of significantly more tipburn of cabbage observed in plots receiving poultry manure than in those receiving synthetic fertilizer (Hochmuth et al, 1993). However, in an earlier study Goh and Vityakon (1983) reported that manure applications did not alter soil salinity or pH levels, while ammonium sulfate and urea increased salinity and lowered pH.
Effects on soil microbial activity

Soil microorganism activity may also be affected by poultry manure applications. Doran et al. (1988) found no effect of synthetic fertilizers on soil microbial populations, but found that incorporation of organic amendments including manure enhanced soil microorganism levels. Chicken manure applications at three rates (1x, 2x and 3x) increased common bean biomass and rhizobial infection (Browaldh, 1992). Bean biomass in this experiment was similar for all three manure treatments and root nodule dry weight significantly higher in the 3x treatment than in the lower rates.

Application rates associated with increased vegetable yield

General poultry manure application rate recommendations of 7-23 t ha\(^{-1}\) have been made in the past for Hawaii home-gardeners (McCall, 1974). Oikeh and Asiegbu (1992) observed an increase in tomato yield with applications of 10 t ha\(^{-1}\) dry weight chicken manure over plants receiving no amendment or synthetic fertilizer at 150 kg ha\(^{-1}\) N, with yield decreasing at manure rates of 20 and 30 t ha\(^{-1}\). In northern Florida, highest marketable yields in cabbage were obtained with 19 t ha\(^{-1}\) chicken manure, and were statistically similar to yields obtained with 130 kg ha\(^{-1}\) synthetic N (Hochmuth et al. 1993). Kogbe (1980) found no increase in yield of *Celosia* sp. (a West African leafy vegetable) with chicken manure applications lower than 20 t ha\(^{-1}\), with highest yields obtained at 20 or 40 t ha\(^{-1}\). This response to manure applications was found to be cultivar dependant.
Warman (1990) found no yield response in tomato, cabbage, or cauliflower to applications of chicken manure at 10 t ha$^{-1}$. Opara and Asiegbu (1996) reported a linear increase in West African eggplant (*Solanum* sp.) yield with increased rate of poultry manure application of 0-20 t ha$^{-1}$. Yield of strawberries increased with increased rate of chicken manure application between 0-12 t ha$^{-1}$, while lettuce yield was not significantly affected by additions of manure or synthetic fertilizer (Rubeiz et al., 1998). Yield response of vegetables to poultry manure applications varies with crop and location; it is therefore important to conduct yield response trials on a crop by crop basis in the region the commodity is to produced.

### Basil

*Ocimum basilicum* is one of the best known of ~160 *Ocimum* species, all of which are commonly referred to as basil (Sobti and Pushpangadan, 1977). *O. basilicum* is an important crop world wide grown for its fresh and dry herb, and the essential oil which is used as a food additive and in cosmetics (Prakesh, 1990). There are literally dozens of forms of *O. basilicum* which are classified based on plant morphology, pigmentation, and/or chemical composition of the essential oil (Simon et al., 1990; Prakesh, 1990; Small, 1997). Rindels (1997) classifies several distinct types of *O. basilicum* as subspecies; types having distinct scents of cinnamon, lemon, or licorice are given the designation *O. basilicum odoratum*, and dwarf varieties are *O. basilicum minimum*. 
Reproduction

*O. basilicum* (basil) is a tetraploid (2n=48) (Sobti and Pushpangadan, 1977; Ryding, 1994). Forms within the species are interfertile, although differences in flower morphology may prevent natural outcrossing (Darrah, 1974; Sobti and Pushpangadan, 1977; Nation et al., 1992). Basil is open-pollinated (OP) with honey bees being the most common pollinators (Darrah, 1974; Nation et al., 1992). Darrah (1974) found reduced seed set in manually selfed plants compared to OP plants, but no differences in germination rate, percentage, seedling growth or other indications of inbreeding depression were observed.

Importance in Hawaii

Sweet and Asian basil are the commercially important varieties in Hawaii. 850 tons of basil were produced in the state in 1998 for a total farm-gate value of $2.7 million, making it by far the most important herb crop grown in the state (HASS, 1999). Sweet basil accounted for 70% of the total locally produced basil, and had a higher farm-gate value that the Asian type.

Cultural requirements

Basil is either direct seeded or transplanted, and may be propagated by cuttings. Most varieties germinate in 4-6 days and initiate flowering 14 weeks after germination (Darrah, 1974).
Spacing is dependent on cultural practices. Multiple row beds are commonly used with 60-90 cm row spacing and plants within a row 15-60 cm apart; spacing for single-harvest operations is generally less dense than that for a planting harvested over an extended period of time (Hamasaki et al., 1994). Fertilizer recommendations for basil production in Hawaii are 135 kg ha\(^{-1}\) each N, P\(_2\)O\(_5\), K\(_2\)O as a preplant application when plants are grown in soils deficient in these nutrients, plus a sidedress of N at 22-34 kg ha\(^{-1}\) following the first harvest (Hamasaki et al., 1994). These recommendations are similar to those made for the temperate U.S. (Davis, 1997). Recommendations for India are similar in total amount of nutrients applied, but differ in that the preplant application is reduced by one third, and the balance is applied as several split applications over the crop lifecycle (Gulat and Duhan, 1972). A complete fertilizer applied at 120-100-100 kg ha\(^{-1}\) N-P\(_2\)O\(_5\)-K\(_2\)O was found to be optimum for basil production on a nutrient poor sandy soil (Wahab and Hornol, 1982). Tesi et al. (1995) found basil to be sensitive to high rates of fertilizer, with plant growth reduced with increasing rate of soluble fertilizer between 1-5 g/l applied to plants growing in a peat potting mix. Excess N fertilizer will reportedly reduce the postharvest quality of basil (Hamasaki et al., 1994; Davis, 1997). No difference in yield response was observed between ammonium and nitrate N sources by Tesi et al. (1995), and they reported better plant response with a 1-1-2 than a 1-1-1 fertilizer ratio. Tesi (1997) observed that plant growth and leaf nitrate content increased with increased N applied at rates of 0-80 kg ha\(^{-1}\). Gupta and Shah (1989) found B,
Cu and Mn foliar sprays to increase yield of field-grown basil. Levels of these nutrients in the soil and other soil information were not reported.

There are no rate recommendations for organic fertilization of basil. In Hawaii, Valenzuela et al. (1999) recorded commercially acceptable basil yields with applications of 25 t ha\(^{-1}\) of compost, with yields from compost plots not being significantly different from those receiving 110 kg ha\(^{-1}\) of synthetic N. When using an organic source of nutrients for basil fertilization, the reduced rate of nutrient release from organic materials must be taken into account. For example, Aflatuni (1993) found 34% greater yields in basil fertilized with synthetic fertilizer than plants given compost to supply an equivalent amount of total N.

Zidan and Al-Zahrani (1994) report basil to be moderately tolerant to salinity. A pH range of 4.3-8.2 is reported to be acceptable for basil (Simon et al. 1984), while the optimum range is 6.0-7.5 (Hamasaki et al., 1994). In Hawaii, harvested shoots are 10-15 cm long and consist of 2-4 pairs of true leaves (Hamasaki et al. 1994).

**Plant Nutrient Status**

Determination of nutrient concentrations in plant tissues is an important tool to manage a crop fertility program (IFA, 1992). Tissue nutrient concentrations may be used to diagnose the nutrient status of a plant at the time of sampling, estimate the potential for a crop to reach optimum yield, and to time fertilizer applications (Coltman, 1988; Smith and Lonegran, 1997). Plant age, genotype,
type of tissues sampled, and environmental conditions affect tissue nutrient concentrations in vegetables, and need to be considered when determining or using critical ranges to determine the nutrient status of vegetables (Mills and Jones, 1996; Huett et al. 1997). Scaife (1988) maintains that directly relating tissue nutrient levels to yield is inherently flawed because the relationship between the two parameters is not necessarily one of cause and effect.

Nitrogen is the plant nutrient required in largest quantities, and N deficiency is often a limiting factor in vegetable production (Marschner, 1995). Much work has been done to establish sufficiency ranges for total N, and more recently sap nitrate-N evaluations have been conducted for various vegetable crops (Hochmuth, 1994; Smith and Lonegran, 1997). Sap nitrate-N as measured by a quick test method such as merkoquat (Merk) test strips or a hand-held nitrate ion selective electrode can be an effective way for a grower to determine the nutrient status of a crop in the field (Hochmuth, 1999; Huett and White, 1992). Not only are results obtained more quickly, but sap nitrate-N levels may be a better indicator than total tissue N of plant nutrient availability in the soil. For example, petiole sap nitrate-N concentrations as measured with Merck test strips were more sensitive, but more variable (higher CV), than total tissue N to nitrogen fertilizer applications (Huett and Rose, 1989). Olsen and Lyons (1994) similarly reported that sap nitrate-N in pepper showed greater change than tissue N concentrations in response to fertilizer applications. Sap nitrate-N concentrations were found to be better correlated than total tissue N with nitrogen application
rates (Prasad and Spiers, 1985). Warnke (1996) found petiole sap nitrate-N to increase with increased rate of N fertilizer in carrot.

Results from rapid analysis of sap nitrate-N which can be conducted in the field have been shown be reliable when compared with laboratory results. Work done with cabbages and tomatoes showed that sap nitrate-N concentrations measured with a Merck test strip were significantly correlated with laboratory results (Prasad and Spiers, 1984; Huett and Rose, 1989). In Hawaii, the monitoring of petiole sap nitrate-N levels using Merck strips was used to effectively manage N fertilization of greenhouse tomatoes, but required frequent sampling (Coltman, 1988).

Use of a nitrate ion selective electrode is another method for rapid sap nitrate-N analysis. Results between test strips and nitrate selective electrodes have been found to be similar (Scaife and Stevens 1983). Kubota et al. (1996) found broccoli petiole nitrate-N measurements taken with a portable Cardy nitrate ion meter to correlate well with previously developed critical ranges for sap nitrate-N. Hartz et al. (1994) also found determinations of sap nitrate-N using a portable nitrate meter to be highly correlated with measurements made with conventional lab techniques in a wide variety of vegetables.

Rapid sap nitrate-N analysis has been proposed to be a potentially valuable tool for growers to use in managing the nutrient status of their crop. In fact, critical ranges of petiole sap nitrate-N concentrations have been determined for a number of vegetables including broccoli, carrots, lettuce, collard, cucumber, melons, squash, pepper, potato, tomato, and eggplant (Hochmuth, 1994;
Warnke, 1996; Huett et al., 1997). However, some studies with sap analysis for nutrient calibrations have also shown inconsistent reports. For example, Beverly (1994) found tomato petiole sap nitrate-N as measured with a portable meter to be highly variable and not correlated with either nitrogen applications or plant dry weight.

Some studies have shown that sap nitrate-N measures can be more variable than other techniques to determine crop N status (Beverly, 1994; Huett and Rose, 1989). No differences were found between sap measurements taken immediately after sampling and those taken up to 16 h after sampling if petioles without leaves were stored on ice in sealed plastic bags (Hochmuth 1994). Internal crop factors may also contribute to the observed variability in sap nitrate concentrations. For instance, Scaife and Stevens (1983) found significant differences in concentrations between individual cabbage plants of the same cultivar, and between tissue location within a plant, but there was no effect of time of day on sap nitrate-N concentrations. Therefore, while it has been shown to be a potentially useful tool to determine plant nutrient status, the wide variability of results obtained with rapid sap nitrate-N analysis demonstrates the importance of conducting research under field conditions before making recommendations to growers.
Nematode control with compost and chicken manure applications

Introduction

Root-knot nematodes (*Meloidogyne* spp.) are serious pests of vegetable crops world-wide (Johnson, 1998). In Hawaii, nematodes are a major limiting factor in basil production, with *M. incognita* and *M. javanica* being the primary pests (Hamasaki et al., 1994). In addition to directly affecting a crop’s ability to develop normally, nematodes can interact with other phytopathogenic organisms to create a disease complex that may have more devastating effects than either pathogen individually (Webster, 1985). Effects of organic amendments on nematode populations varies with nematode species and type of amendment, and organic amendments play a relatively minor role in an integrated nematode management program (Miller, 1977; Duncan and Noling, 1998). Application of organic amendments may affect nematode populations and their virulence towards a host crop by improving plant vigor and thereby increasing resistance to attack, by promoting soil microorganism populations which may compete with or be antagonistic towards parasitic nematodes, or by containing nematicidal compounds (Coosemans, 1982).
Nematode suppression with chicken manure

Several reports have documented nematode suppression with poultry manure applications. For example, *M. incognita* levels and root galls on tomato were reduced with the application of chicken manure at 2 t ha$^{-1}$, and continued to decline with increased application rates (Chindo and Kahn, 1990). This effect was attributed to nematicidal properties in the manure; researchers found that a solution of 4% manure in water inhibited hatching in over 99% of exposed eggs, and killed all juveniles after 12 h exposure. Babatola (1989) found chicken manure rates as low as 1 t ha$^{-1}$ to decrease *Meloidogyne* and *Helicotylenacus* populations and to reduce root galling of tomato. Mian and Rodriguez-Kabana (1982) found chicken manure incorporated into potting soil at 1% by volume to reduce root galling of squash caused by *M. arenaria* and observed the decline in galling to be associated with a corresponding increase in soil microbial levels as determined by urease activity.

Nematode suppression with compost

Work done with compost has shown it to effectively suppress some plant parasitic nematodes. In one study, leaf mold composts applied at 20 t ha$^{-1}$ reduced *Pratylenchus penetrans* populations with respect to a control receiving no compost or nematicide, while nematicide applications gave the highest and most consistent level of control (Miller 1977). Coosemans (1982) observed that compost mixed with soil at 10% by volume resulted in the lowest levels of root galling in lettuce by *M. hapla* and the highest levels of soil microbial activity. Both
higher and lower rates of compost incorporation (0, 5, 15, 20%) resulted in higher galling incidence and lower microorganism activity. This study indicates that there may be a relatively narrow range of compost application rate within which nematode levels are effectively suppressed, with rates outside this range ineffective in supressing nematodes. Application of 18 t ha$^{-1}$ compost caused no significant yield improvement in nematode infested citrus (Tarjan, 1977). Also, McSorley and Gallaher (1995) found M. incognita densities in okra and squash to be unaffected by very high compost application rates (269 t ha$^{-1}$).

**Fusarium wilt control with compost applications**

The various formae specialis of *Fusarium oxysporum* cause significant losses in vegetable production globally, particularly in the tropics (Roberts and Boothroyd, 1972). *F. oxysporum* f. sp. basilici causes a disease in basil that seriously limits production around the world (Wick and Haviland, 1992, Gamliel et al., 1996). In Hawaii, *F. oxysporum* is a major pest of basil which effects almost all commercial production areas in the state, and for which there is no chemical control registered for use on the crop (Hamasaki et al., 1994; Uchida et al., 1996).

A number of different cultural practices are available as useful tools in an integrated *Fusarium* management program for basil. These include heat treatment to sterilize seed (Davis, 1997), use of tolerant varieties (CTAHR, 1996; Ruveni et al., 1998; Hamasaki unpubl. data), manipulation of microorganisms.
antagonistic to the fungus (Minuto et al., 1995), and application of composts to suppress the disease (Raviv et al., 1998).

The potential of compost to suppress plant diseases has received much attention. While the use of compost in controlling *Fusarium* wilt of field grown basil is promising, extensive work has not yet been conducted. Raviv et al. (1998) showed that composts suppressed the disease in greenhouse produced transplants. Severity of visual symptoms of basil seedlings grown in 100% compost was lower than those grown in peat. The suppressive effect was found to be biological as determined by a loss of suppressiveness when the compost was autoclaved.

Compost applications have been shown to effectively reduce disease severity caused by numerous other plant pathogens, and this suppressive effect is generally associated with soil microbial activity (Huber et al., 1966; Cheung and Hoitink, 1990; Hardy and Sivasithamparam, 1991; Hoitink and Grebus, 1996; Kim et al., 1997). Serra-Wittling et al. (1996) showed that the addition of compost increased a soil’s suppressiveness to *Fusarium* wilt, and the investigators determined that this was caused by competition for nutrients by the total microflora population with the pathogen (general suppression). They also showed soil microflora to be more suppressive of Fusarium than the compost microflora, and suggested that suppressiveness of compost is due to its acting as a nutrient rich substrate for colonization by soil borne, antagonistic organisms. In another study, the severity of *Fusarium* wilt of tomato was reduced with compost application, and corresponded with an increase in total soil microflora
population (Raj and Kapoor, 1997). Amir et al (1993) found soils high in organic matter to be significantly more suppressive to *F. oxysporum* than those with low organic matter, despite the fact that the soil with higher organic matter also had a larger population of the pathogen. These workers proposed that the beneficial nature of a soil high in organic matter to the general microflora resulted in more intense competition for nutrients resulting in survival of the pathogen inoculum, but inhibiting germination of the propagules. Suppression of *Fusarium* may also be associated with specific organisms. For example, Alvarez (1995) reported that compost application affected species composition of the soil microflora populations, favoring antagonists to *Fusarium* (Psuedomonas sp.), but did not stimulate an increase in the total microbial population. Also demonstrating specific antagonism of bacteria to *Fusarium*, Tsuge et al (1995) isolated the bacteria *B. subtilis* from Bark compost and found it to produce substances suppressive to *Fusarium oxysporum*. Bacteria are not the only biological control agents with potential to suppress *Fusarium*. Minuto et al (1993) found that seed treatment of basil with isolates of two antagonistic fungi significantly reduced the number of infected plants. The biological antagonism afforded by compost may be environmentally dependent, however. For example, Pera et al (1987) found that fully composted poplar bark containing *Bacillus pseudomonas* antagonistic to *Fusarium* increased resistance to *Fusarium* wilt in carnations in green house experiments, but had no effect in field trials.
In addition to the biological soil fraction, soil chemical properties, particularly pH, play a role in determining the severity of *Fusarium*. For example, Scher et al (1980) eliminated the effectiveness of a soil suppressive to *F. oxysporum* by reducing the pH from 8 to 6. In Italy, Melloni et al. (1995) reported cucumber seeds planted in Fusarium infested soil, amended with compost, had a higher germination rate than seeds planted in the same soil without compost; the beneficial effect was associated with higher pH in compost amended soil.

Disease suppressiveness is dependent on compost quality. High salt content, and rapid N release (i.e. high N, low C:N ratio) in compost can negate suppressiveness (Hoitink and Grebus, 1994). The severity of *Fusarium* root rot on bean was observed to increase with increasing soil inorganic N (Lewis and Papavizas, 1977). Schmidt (1972) found *F. solani* pathogenecity in pea to increase as the C:N ratio of incorporated plant residues decreased. Chef et al. (1983) found fully composted tree bark to suppress Fusarium wilt in chrysanthemum and Flax, with hardwood bark being more suppressive than pine bark and immature compost less suppressive than mature compost. The authors concluded that the higher carbon content in the hardwood compost provided better nutrition for microorganisms and resulted in the highest level of suppression.

The rate of nitrification of soil ammonium also plays a role in disease suppression and is affected by the type of organic amendment applied as demonstrated by Kirpichenko (1975) who found that the pathogenicity of F.
oxysporum was greater on media with ammonium than with nitrate.

Amendments which stimulate nitrification of soil ammonium are likely to suppress soil pathogens, while amendments inhibiting or slowing nitrification may increase disease severity (Watson and Huber, 1970). Use of nitrate rather than ammonium fertilizers is recommend for control of Fusarium (Agrios, 1993). For example, F. oxysporum in tomato was less severe when plants were supplied with nitrate-N compared to ammonium-N (Woltz and Jones, 1973).

Therefore, the usefulness of compost to suppress Fusarium wilt of crops varies, and is dependant in part on the chemical and biological quality of compost to be used.

**Sensory Quality of Fresh Basil**

**Introduction**

Sensory quality of fresh produce is an important factor for consumers in making purchasing decisions (Misra and Huang, 1991), and any cultural practice which alters the sensory quality of produce may affect its marketability. Little attention has been given to the sensory attributes of fresh basil, although much work has been done on the composition of basil essential oil due to its importance as an additive in food, toiletries and cosmetics (Parry, 1921; Charles and Simon, 1990; Prakesh, 1990). It is from this oil that the fresh herb gets its characteristic odor and flavor (Simon et al., 1990; Sheen et al, 1991).
Potential for fertilization to affect basil quality

Environmental effects on basil essential oil content and composition have been well documented (Simon and Reiss-Bubenhiem, 1987). Ichimura et al. (1995) found essential oil concentrations in basil to be higher in summer than spring. Nitrogen fertilizer was found to affect essential oil content in sweet basil increasing with increased N to an optimum level, then decreasing with higher N rates (Youssef et al., 1998); these workers observed that the treatments producing the highest herb yield also produced the highest concentration of essential oil. Nitrogen and potassium fertilizers decreased the levels of eugenol in tomato (Wright and Harris, 1985); eugenol is a major constituent of basil essential oil (Sheen, 1991; Prakesh, 1990). Alder et al. (1989) found the form of N applied to affect both the content and composition of basil oil.

Cultural methods which cause changes in basil essential oil content and composition thus have the potential to also affect the aroma and taste of the fresh product. However, analysis of chemical composition has limitations as a tool in predicting sensory quality of fresh produce (Johnson et al. 1998; Meilgaard et al. 1987). Direct panel evaluation of possible fertilizer effects on the aroma and taste of fresh basil leaves is therefore necessary to evaluate the potential of fertilization to affect fresh basil quality.
Evaluation of taste and aroma of fresh basil

Qualifying taste and aroma of basil is difficult because the sensory quality attributes of fresh basil have not been thoroughly described, nor have specific procedures been developed for evaluating the aroma and taste of fresh basil. Lacking specific guidelines, objective measurements can only be made on the intensity of aroma and taste. Paakokonen et al. (1990) evaluated taste and aroma intensity of both dried and fresh basil with 12 trained sensory panelists who scored samples ‘weak’ to ‘strong’ on a linear scale, and found both taste and aroma intensity of dried basil to be stronger than that of fresh samples. The basil samples were blended into a medium of mash potato.

Fertilization affects quality of other vegetables

Fertilization rate can affect the taste and aroma of agricultural products, possibly as a result of changes in the chemical composition of the commodity. Spinach fertilized with organic N sources were observed to have no differences in flavor to spinach receiving similar rates of mineral nitrogen (Magna et al., 1976). The same study did report a difference in flavor between leaves from plants receiving low and high rates of nitrogen, and found these differences to correspond with increased concentration of volatile compounds in the leaves with the higher N rate. This suggests that some differences in taste and other qualities between organic and conventional produce may be detected due to variability in the amount of nutrients available to the crop between different fertilizer regimes.
Organic fertilizers such as manures and compost generally have lower nutrient concentrations than mineral fertilizers (Roe, 1995). Plant availability of nutrients in organic fertilizers varies; generally, lower levels of soluble nutrients are immediately available to a crop when using organic fertilizers when compared with mineral fertilizers (Brinton, 1985). In kiwifruit, taste panelists could distinguish between fruit from fertilized and unfertilized trees, with scores for sourness correlating well with titratable acidity (Gorini, 1990). Haglund et al. (1997) found tomatoes from plants grown in a "nutrient rich" substrate containing 25% compost by volume to have lower sugar content and pH, and higher scores for acidity than those grown in a "nutrient-poor" substrate containing no compost. Also in tomato, nitrogen and potassium fertilization increased both short chain carbonyls and unacceptable flavor (Wright and Harris, 1985). The authors suggest that the higher scores for unacceptability may be due to nitrogen fertilization increasing short-chain carbonyl production to a level high enough to mask compounds contributing to desirable flavor in tomato. When Jia et al. (1999) doubled the rate of fertilizer in peaches, fruits from trees receiving the higher rates were less sweet and had lower aroma scores than fruit from trees receiving lower fertilizer rates. These sensory scores corresponded with lower sugar, and decreased concentration of the main volatile constituents of peach aroma in fruit from highly fertilized trees. In corn, Wong et al. (1995) found nitrogen fertilization to increase levels of S-methylmethionine, the precursor to dimethyl sulfide, a compound responsible for sweet corn aroma.
The change in sensory quality of vegetables affected by fertilization are usually attributed to an N effect. For example, in kohlrabi N had the leading role in altering chemical components most affecting taste and aroma (Fischer, 1992). In another study, Wong et al. (1995) found nitrogen to be more important than sulfur for the production of dimethyl sulfide, which contains no nitrogen. However, changes in chemical composition does not necessarily equate to a change in sensory quality. Applications of potassium sulfate decreased the pH of pear fruits, but had no effect on scores for flavor or firmness (Johnson et al., 1998). Also, Vieira et al. (1998) found nitrogen applications to have no effect on leaf taste or texture. Although N applications did increase leaf nitrate levels, leaf volatiles were not reported in this study.

Although it is possible that fertilization may alter the chemical composition of basil, and therefore the sensory quality of the fresh herb, direct panel evaluation would be necessary to determine any changes fertilization affected in the taste and aroma intensity of fresh basil.
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CHAPTER 3
BASIL YIELD AND TISSUE N LEVELS IN RESPONSE TO
POULTRY MANURE AND UREA APPLICATIONS

Abstract

An experiment was conducted at the University of Hawaii Waimanalo Experiment station organic farming plots to determine the yield response of basil cv. UH to applications of chicken manure, and to evaluate possible residual N effects from urea applied to previous crops in the same location. The experiment was arranged in a randomized complete block (RCB) design. The four treatments, replicated four times, were: poultry manure applied at 5 t ha\(^{-1}\) wet weight in plots which had previously received urea plus compost applications; poultry manure applied at 5 t ha\(^{-1}\) wet weight in plots having received compost +no synthetic fertilizer; 100 kg ha\(^{-1}\) N applied as urea ; and an unamended control with no previous history of amendment applications. The chicken manure was applied 7 days after basil transplanting (DAT) and incorporated to a depth of 3 cm. The urea was applied in two equal split applications at 12 and 43 DAT. Six weekly harvests were taken beginning 28 DAT. Leaf tissue was analyzed for total N concentration at 35 and 55 DAT. Soil organic carbon (OC) content and nematode levels were determined at 75 DAT. All fertilizer treatments significantly increased basil yield over the control and there was no significant difference between yield in the organic and synthetic fertilizer treatments. Poultry manure applications increased tissue N concentrations over those in the control, and leaf N concentration was positively correlated with yield at both sampling
dates. Greater plant weights and tissue N concentrations in the CM5(urea) treatment indicated a likely residual N effect from previous urea applications. Fertilizer treatments had no significant effect on soil organic carbon content or nematode levels.

**Introduction**

Poultry manure is an organic fertilizer which has proven effective in enhancing the yield of vegetable crops. In regions of the world where high costs and unavailability makes the widespread use of synthetic fertilizers impractical, poultry manure is a valuable alternative source of crop nutrients (Kogbe, 1980).

In Hawaii, agricultural use of waste products such as poultry manure recycles a material which would otherwise need disposal, and reduces the reliance of local farmers on expensive, imported fertilizers. Numerous vegetables have shown a positive yield response to poultry manure applications (Cheung and Wong, 1983; Mbagwu, 1985; Rubiez et al., 1998). The positive yield response from chicken manure treatments is attributed to increased nitrogen nutrition as indicated by increased N concentration in plant tissues (Hochmuth et al, 1993; Opara and Asiegbu, 1996). In addition to its value as an organic N source, poultry manure has also been shown to increase soil organic matter content and to effectively reduce root knot nematode populations and root galling in vegetables (Cheung and Wong, 1983; Babatola, 1989; Chindo and Khan, 1990).

Synthetic fertilization of basil has been investigated to a very limited extent. Fertilizer recommendations for basil production in Hawaii are 135 kg ha$^{-1}$ each
N, P\textsubscript{2}O\textsubscript{5}, K\textsubscript{2}O as a preplant application when plants are grown in soils deficient in these nutrients, plus sidedress applications of N at 22-34 kg ha\textsuperscript{-1} following the first harvest (Hamasaki et al., 1994). These recommendations are similar to those made for the temperate U.S. (Davis, 1997). However, as with other organic fertilizers, no crop specific recommendations are available to Hawaii vegetable growers who want to incorporate poultry manure into their fertility program. In the past, general poultry manure application rate recommendations of 7-23 t ha\textsuperscript{-1} have been made for Hawaii home-gardeners (McCall, 1974). This experiment was thus conducted to determine the response of basil to moderate rates of poultry manure and urea applications under tropical conditions, and was part of a long-term organic farming project established in 1993 to evaluate the effect of organic and synthetic fertilizers on long term soil quality, crop yields and other production factors.

**Materials and Methods**

**Site Description**

The experiment was conducted at the University of Hawaii’s Waimanalo Experiment Station on Oahu. Soil at the station is a silt clay (Mollisol, Waialua series). Mean monthly temperature range at the station is 22-27 C, and mean annual rainfall range is 500-800 mm.
Experimental Design

Four treatments replicated four times were arranged in a randomized complete block design. Each treatment consisted of a 1 m by 12 m bed. The field was blocked according to a slope and fertility gradient.

The treatments were:
1. Control: No amendment.
2. CM5(urea): Locally obtained, aged chicken manure applied at 5 t ha\(^{-1}\) fresh weight in beds with a 5 year history of both compost and urea annual applications (25 t ha\(^{-1}\) + 100 kg ha\(^{-1}\) respectively)
3. CM5: Locally obtained, aged chicken manure applied at 5 t ha\(^{-1}\) fresh weight in beds with a history of compost applications (25 t ha\(^{-1}\)) annually
4. Urea: 100 kg ha\(^{-1}\) nitrogen applied as urea in beds with a 5 year history of synthetic N applications

The chicken manure was applied between rows 7 days after transplanting (DAT) and incorporated with a hand rake to a depth of 3 cm. The urea was sidedressed in two equal split applications at 12 and 43 DAT. The crop was drip irrigated and hand weeded as needed. No pesticides were applied to the crop.

Planting and Harvest

Seeds of a Fusarium tolerant sweet basil variety developed by the University of Hawaii were planted in Speedling\textsuperscript{®} trays in early April, 1998. Seven week-old seedlings were transplanted in double rows spaced 30 cm apart on 28
May, 1998. Six weekly harvests were taken beginning 28 DAT. Harvested materials consisted of 10-15 cm long shoots with 3-4 nodes per shoot. Weight of harvested materials for an entire plot were recorded, and grams per plant values calculated based on the number of plants in each plot. Final plant weights were determined following the final harvest at 75 DAT.

**Tissue Sampling**

The most recently fully expanded leaf pair from 10 shoots in each replication were taken 35 and 55 DAT. Samples were analyzed for N (total), P, K, Ca, Mg, Na, Mn, Fe, Cu, Zn and B by the UH Agricultural Diagnostic Service Center.

**Analysis of Chicken Manure and Soil**

Prior to application, the chicken manure was analyzed for pH, organic carbon, P, K, Ca, and Mg. The pH was determined using a saturated paste. Organic carbon content was measured by a modified Wakely-Black method. The modified Truog procedure was used to determine available P. Exchangeable Ca, Mg and K were determined with a NH₄Oac, pH 7 extract, and an atomic absorption spectrophotometer.

Soil organic matter was determined from samples taken at a depth of 15 cm immediately after the last harvest (75 DAT). Nematode counts were taken at the same time from rhizosphere soil samples at a depth of 15 cm.
Statistical Analysis

The data was analyzed with the GLM procedure (SAS® version 6.1). Duncan’s New Multiple Range Test was conducted with the corresponding error term for each variable.

Results

Yields in the fertilizer treatments were similar to each other and higher than the control (Fig. 3.1). Final plant weights were greatest in the urea and CM5 (urea) plots and lowest in the control (Fig. 3.2). Mean tissue N levels across dates were greater in the CM5(urea) treatment compared to the control (Fig. 3.3). There was no significant treatment by date interaction. Tissue N levels were positively correlated with crop yields obtained at both sampling dates (Fig. 3.4). A trend was observed toward greater organic matter levels in the chicken manure plots compared to the control and urea plots, but the differences were not statistically significant (Fig. 3.5). Nematode populations were not significantly affected by treatment, with very low counts in all plots (see the General Discussion section, Chapter 7).

Discussion and Conclusions

Application of 5 t ha⁻¹ of poultry manure increased cumulative basil yield by ~39% with respect to the control, and produced yields similar to those
obtained with 100 kg ha$^{-1}$ synthetic N. This follows the findings of Ospara and Asiegbu (1996), Cheung et al. (1983) and Browaldh (1992) who observed poultry manure applications to increase yield of *Solanum* sp., Chinese cabbage and bean biomass, respectively. This increase in yield is due to a nitrogen effect. Addition of both the organic and synthetic fertilizers increased tissue N levels, which were positively correlated with yield (Fig. 3.4). Lowest yields were associated with tissue N concentrations below 4.5%.

Higher cumulative yield (11%) and higher total tissue N levels were observed in the CM5(urea) plots than in the CM5 plots (Figs. 3.1 & 3.3), despite identical fertilizer applications to the two treatments in this experiment. This would indicate a residual N effect from previous urea applications in the CM5(urea) plots. The estimated amount of N removed from each treatment is listed in Table 3.4. During the crop cycle plants in the CM5 and CM5(urea) removed 17 and 26 kg ha$^{-1}$ more N, respectively, than the control plants from the system. This difference of 9 kg ha$^{-1}$ between the two chicken manure treatments may be the amount of residual N contributed from previous urea applications. Residual plant available N remaining from previous compost applications may also be estimated from data listed in Table 3.4. Over the course of the crop cycle, plants in plots with chicken manure estimated to supply 25 kg ha$^{-1}$ plant available N removed the same amount of N as plants supplied with 89 kg ha$^{-1}$ of synthetic N. Therefore, the residual plant available N remaining from previous compost applications may be as great as 64 kg ha$^{-1}$. However, N equivalent from the control must also be taken into account. Early in the crop cycle, this amounts to
25 kg ha\(^{-1}\) compared with 33 kg ha\(^{-1}\) from the chicken manure plots, with an estimated 8 kg ha\(^{-1}\) supplied by previous compost applications. This number decreases over the crop cycle as the N equivalent of the control increases over time indicating a source of N available to the control plants. The high rate of N removal from plots receiving 0 N compared those receiving 100 kg ha\(^{-1}\) may be due to greater microbial activity in the control plots; it is possible that microbial activity may be inhibited by acidic and/or high soil nutrient conditions resulting from the application of both synthetic and organic fertilizers. Vigorous basil plants producing good yields removed between 62-72 kg ha\(^{-1}\) N from the system over a 75 day cycle (Table 3.4).

The poultry manure (11% OC) did not significantly increase soil organic matter content when applied at 5 t ha\(^{-1}\) on a wet weight basis. Assuming a moisture content of 30-50%, the amount of organic carbon added to the soil with this application of chicken manure is 275-385 kg ha\(^{-1}\).

Poultry manure applications did not significantly affect final nematode counts in this experiment, although Babatola (1989), and Chindo and Khan (1990) have reported poultry manure to reduce nematode levels in vegetable production systems at rates of 1 and 2 t ha\(^{-1}\), respectively.
Literature Cited


Figure 3.1. Effect of chicken manure and urea applications on the mean cumulative yield of basil. Values are means of four replications. Means designated by the same letter are not significantly different at P<0.05 as determined by Duncan’s New Multiple Range test. CM5= chicken manure applied at 5 t ha$^{-1}$ in plots with a history of 10 t ha annual compost applications. CM5(urea)= chicken manure applied at 5 t ha$^{-1}$ in plots with a history of 10 t ha annual compost applications plus urea. Urea= 100 kg N ha$^{-1}$ applied as urea in plots with of a history of annual urea applications of 100-300 kg N ha$^{-1}$. Control= no amendment.
Figure 3.2. Effect of poultry manure and synthetic fertilizer treatments on final plant weight. Weight of above ground plant parts were determined after final harvest, 75 days after transplanting. Values are means of all plants in four replications. Means designated by the same letter are not significantly different at $P<0.05$ as determined by Duncan’s New Multiple Range test.
Figure 3.3. Effect of poultry manure and synthetic fertilizer treatments on mean tissue nitrogen concentration of most recently matured leaves. Values are means of four replications and two sample dates (35 and 55 days after transplanting). Means designated by the same letter are not significantly different at P<0.05 as determined by Duncan's New Multiple Range test.
Table 3.1. Selected Soil Chemical Properties at 1/15/98, four months prior to basil transplanting, and of chicken manure applied in this experiment. Soil samples were composites of four replications.

<table>
<thead>
<tr>
<th>Treatment</th>
<th>OC (%)</th>
<th>pH</th>
<th>EC (dS m⁻¹)</th>
<th>P</th>
<th>K</th>
<th>Ca</th>
<th>Mg</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
<td>2.3</td>
<td>7.0</td>
<td>0.1</td>
<td>319</td>
<td>420</td>
<td>4700</td>
<td>1100</td>
</tr>
<tr>
<td>Comp</td>
<td>2.3</td>
<td>6.7</td>
<td>0.1</td>
<td>91</td>
<td>460</td>
<td>4525</td>
<td>1100</td>
</tr>
<tr>
<td>MOA</td>
<td>2.3</td>
<td>7.4</td>
<td>0.2</td>
<td>240</td>
<td>460</td>
<td>4700</td>
<td>1200</td>
</tr>
<tr>
<td>Urea</td>
<td>2.4</td>
<td>6.8</td>
<td>0.1</td>
<td>395</td>
<td>540</td>
<td>4600</td>
<td>1100</td>
</tr>
<tr>
<td>Chicken Manure</td>
<td>11.5</td>
<td>8.1</td>
<td>----</td>
<td>3498</td>
<td>24420</td>
<td>6330</td>
<td>2258</td>
</tr>
</tbody>
</table>

¹ Organic carbon  
² Electrical conductivity  
²² Not determined
Table 3.2. Effect of poultry manure and synthetic fertilizer treatments on mean nutrient concentration of most recently matured basil leaf (UH) grown in four treatments at 55 DAT. Values obtained from a composite sample of four replications.

<table>
<thead>
<tr>
<th>Treatment</th>
<th>P</th>
<th>K</th>
<th>Ca</th>
<th>Mg</th>
<th>Na</th>
<th>Mn</th>
<th>Fe</th>
<th>Cu</th>
<th>Zn</th>
<th>B</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
<td>0.53</td>
<td>2.34</td>
<td>2.42</td>
<td>0.71</td>
<td>0.07</td>
<td>57</td>
<td>229</td>
<td>18</td>
<td>43</td>
<td>22</td>
</tr>
<tr>
<td>CM5(urea)</td>
<td>0.48</td>
<td>2.88</td>
<td>2.57</td>
<td>0.72</td>
<td>0.02</td>
<td>84</td>
<td>353</td>
<td>18</td>
<td>50</td>
<td>25</td>
</tr>
<tr>
<td>CM5</td>
<td>0.54</td>
<td>2.48</td>
<td>2.36</td>
<td>0.66</td>
<td>0</td>
<td>67</td>
<td>252</td>
<td>17</td>
<td>41</td>
<td>24</td>
</tr>
<tr>
<td>Urea</td>
<td>0.47</td>
<td>2.69</td>
<td>2.2</td>
<td>0.67</td>
<td>0.01</td>
<td>67</td>
<td>268</td>
<td>19</td>
<td>41</td>
<td>22</td>
</tr>
<tr>
<td>Treatment</td>
<td>Cumulative Yield (kg ha(^{-1}))</td>
<td>Yield as % over control</td>
<td>N applied (kg ha(^{-1}))</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>---------------</td>
<td>-----------------------------------</td>
<td>-------------------------</td>
<td>-----------------------------</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Control</td>
<td>8361</td>
<td></td>
<td>0</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CM5</td>
<td>10935</td>
<td>31</td>
<td>50(^{\gamma})</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CM5(urea)</td>
<td>12007</td>
<td>44</td>
<td>50</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Urea</td>
<td>12434</td>
<td>49</td>
<td>100</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

\(^{\gamma}\) Total N supplied by 5 t ha\(^{-1}\) of chicken manure based on an assumed moisture and total N content of 50% and 2%, respectively.
Table 3.4. Effect of poultry manure and synthetic fertilizer treatments on N use of basil at 35, 55 and 75 days after transplanting (DAT). Values are means of four replications. CM5= chicken manure applied at 5 t ha\(^{-1}\) in plots with a history of 25 t ha annual compost applications. CM5(urea)= chicken manure applied at 5 t ha\(^{-1}\) in plots with a history of 25 t ha annual compost applications plus urea. Urea= 100 kg N ha\(^{-1}\) applied as urea in plots with of a history of annual urea applications of 100-300 kg N ha\(^{-1}\). Control= no amendment.

<table>
<thead>
<tr>
<th>Date</th>
<th>Treatment</th>
<th>Cumulative yield (kg ha(^{-1}))(^{v})</th>
<th>Biomass</th>
<th>N removed (kg ha(^{-1})) (^{w})</th>
<th>N equivalent (^{x})</th>
<th>N applied (kg ha(^{-1}))</th>
</tr>
</thead>
<tbody>
<tr>
<td>35 DAT</td>
<td>control</td>
<td>549</td>
<td>55</td>
<td>3</td>
<td>25</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>CM5</td>
<td>1166</td>
<td>117</td>
<td>7</td>
<td>58</td>
<td>25 (^{y})</td>
</tr>
<tr>
<td></td>
<td>CM5(urea)</td>
<td>1578</td>
<td>158</td>
<td>9</td>
<td>75</td>
<td>25</td>
</tr>
<tr>
<td></td>
<td>urea</td>
<td>1098</td>
<td>110</td>
<td>6</td>
<td>50</td>
<td>50</td>
</tr>
<tr>
<td>55 DAT</td>
<td>control</td>
<td>4254</td>
<td>425</td>
<td>23</td>
<td>61</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>CM5</td>
<td>6037</td>
<td>604</td>
<td>34</td>
<td>89</td>
<td>25</td>
</tr>
<tr>
<td></td>
<td>CM5(urea)</td>
<td>6449</td>
<td>645</td>
<td>38</td>
<td>100</td>
<td>25</td>
</tr>
<tr>
<td></td>
<td>urea</td>
<td>6449</td>
<td>645</td>
<td>38</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>75 DAT</td>
<td>control</td>
<td>8361</td>
<td>836</td>
<td>45</td>
<td>64</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>CM5</td>
<td>10935</td>
<td>1094</td>
<td>62</td>
<td>89</td>
<td>25</td>
</tr>
<tr>
<td></td>
<td>CM5(urea)</td>
<td>12007</td>
<td>1201</td>
<td>71</td>
<td>100</td>
<td>25</td>
</tr>
<tr>
<td></td>
<td>urea</td>
<td>12434</td>
<td>1243</td>
<td>70</td>
<td>100</td>
<td>100</td>
</tr>
</tbody>
</table>

\(^{v}\)Cumulative yield at sampling date.  
\(^{w}\)N removed from the fertilized crop (kg ha\(^{-1}\)) calculated by multiplying biomass by mean tissue content of each treatment.  
\(^{x}\)N equivalent is the N removed from the treatment divided by the N removed by urea plots then multiplied by the amount of N applied as urea at sample date. Assumes 100% plant availability of synthetic N.  
\(^{y}\)Plant available N from manure estimated at 50% total N supplied by 5 t ha\(^{-1}\) of chicken manure based on an assumed moisture and total N content of 50% and 2%, respectively.  
\(^{z}\)Tissue levels are means of those from 35 and 55 DAT sampling dates.
Figure 3.4. Tissue N concentration relative to basil yield at 35 and 55 days after transplanting.

\[ y = 76.54x - 302.53 \]

\[ R^2 = 0.20 \]
Figure 3.5. Effect of poultry manure applications on soil organic carbon content (%). Soil samples were taken immediately following the last basil harvest, 75 days after transplanting. Values are means of four replications. Means designated by the same letter are not significantly different at P<0.05 using Duncan’s New Multiple Range test. CM5= chicken manure applied at 5 t ha\(^{-1}\) in plots with a history of 10 t ha annual compost applications. CM5(urea)= chicken manure applied at 5 t ha\(^{-1}\) in plots with a history of 10 t ha annual compost applications plus urea. Urea= 100 kg N ha\(^{-1}\) applied as urea in plots with of a history of annual urea applications of 100-300 kg N ha\(^{-1}\). Control= no amendment.
CHAPTER 4

EFFECTS OF COMPOST APPLICATIONS ON BASIL YIELD, TISSUE N CONCENTRATION AND SAP NO₃⁻ LEVELS

Abstract

A field trial was conducted at the University of Hawaii Waimanalo Experiment Station to determine the effects of compost (0.3% N) and urea applications on basil production and nutrient status. The experiment was arranged as a split split plot with fertilizer treatments as the main plots, cultivars as sub plots, and harvest dates as sub sub plots. The three cultivars were ‘Sweet Italian’, ‘UH’ and ‘Thai Siam Queen’. The four treatments replicated four times were: 110 kg ha⁻¹ synthetic N, compost applied at 45 t ha⁻¹, compost applied at 180 t ha⁻¹, and a control receiving no amendments. The compost was applied 7 days prior transplanting and incorporated with a roto-tiller to a depth of 15 cm. Graviota 16-16-16 fertilizer supplying 30 kg ha⁻¹ N was applied at transplanting. The remaining 80 kg ha⁻¹ N was applied as urea in two equal split applications 35 and 73 DAT. Eight weekly harvests were taken beginning 30 DAT. The most recently matured leaves of 10 marketable shoots per replication were sent to the University of Hawaii Agricultural Diagnostic Service Center (ADSC) for analysis of total N at 37, 65 and 100 DAT. Sap nitrate concentration was determined at the same sampling dates from marketable shoots with a nitrate ion selective electrode. Application of 45 t ha⁻¹ of a low nutrient compost increased basil yield in all varieties by an average of 38% over the control.
Highest yields were obtained with ‘Sweet’, the only variety to remain relatively pest-free during the crop cycle. ‘UH’ was determined to be more susceptible to root-knot nematode attack and associated root rot than the other two cultivars, while ‘Thai’ was more susceptible to Fusarium wilt. Sap nitrate levels were more sensitive to fertilizer treatment and were a slightly better indicator of plant nutrient status than total tissue N levels. Mean sap nitrate levels varied with cultivar, emphasizing the need for critical range determinations to be done at the cultivar level. Urea applications increased plant nitrate levels with respect to the control while compost applications did not.

Introduction

The positive yield response observed in vegetable crops in response to compost applications is often attributed to factors other than the direct contribution of essential nutrients provided by composts. Applications of chicken litter-based compost increased mycorrhizal colonization of corn roots, and additions of compost increased the number of mycorrhizal spores over levels in soil receiving synthetic fertilizer or raw dairy manure alone (Douds et al., 1997). Sivapalan et al. (1993) found that microbial populations, particularly those of *Trichoderma* and *Penicillium*, were higher in soil receiving a chicken manure based compost as the sole source of crop nutrients than those in synthetic fertilizer plots. Also, application of organic amendments may suppress nematode populations and their virulence towards a host crop by improving crop vigor,
promoting antagonistic soil microbes, or by containing nematicidal compounds (Coosemans, 1982). Similarly, compost applications have been shown to effectively reduce disease severity caused by numerous other plant pathogens, and this suppressive effect is generally associated with microbial activity (Huber et al., 1966; Cheung and Hoitink, 1990; Hardy and Sivasithamparam, 1991; Hoitink and Grebus, 1996; Kim et al., 1997). For example, Serra-Wittling (1996) showed that the addition of compost increased a soil’s suppressiveness to Fusarium wilt in flax.

An organic source of plant nutrients, compost may also be used to increase the level of plant available nutrients in the soil, and to increase the concentrations of essential elements in crop tissues (Browaldh, 1992; Hue et al., 1994; Douds et al., 1997; Sainz et al., 1998). Analysis of nutrient concentrations in crop tissues is an important tool for fertility management in vegetable systems, but little crop specific information is available for growers in the tropics (Fox and Valenzuela, 1992). Work has been conducted to establish sufficiency ranges for total N, and more recently sap nitrate-N for various vegetable crops in the sub-tropics (Hochmuth, 1994). Critical nutrient ranges have not been established for basil (Mills and Jones, 1996; Huett et al., 1997). Sap nitrate-N as measured by a quick test method such a hand-held nitrate ion selective electrode can be an effective way for a grower to determine the nutrient status of a crop in the field (Huett and White, 1992; Hochmuth, 1999). Not only are results obtained quickly, but sap nitrate-N levels may be a better indicator than total tissue N of nitrogen.
availability. Petiole sap nitrate-N concentrations as measured with Merck test strips were more sensitive but more variable (higher CV) than total tissue N to nitrogen fertilizer applications (Huett and Rose, 1989). Olsen and Lyons (1994) reported that sap nitrate-N in pepper was more closely related than tissue N concentrations to fertilizer applications. Sap nitrate-N concentrations were found to be better correlated than total tissue N with nitrogen application rates (Prasad and Spiers, 1985). Warnke (1996) found petiole sap nitrate-N to increase with increased rate of N fertilizer in carrot.

This experiment was conducted as part of a long-term organic farming project initiated in 1993. This replicated trial was established to evaluate the effect of organic and synthetic fertilizers on long term soil quality, crop yields and other production factors. Specific objectives of this experiment were to:

1. Determine the effect of various application rates of a low nutrient compost on yield, N status, and plant health of three basil varieties.
2. Determine the effect of compost applications on soil organic matter.
3. Determine the feasibility of using a portable, hand-held nitrate selective electrode to diagnose the nitrogen status of different basil cultivars.

**Materials and Methods**

**Experimental Design**

The experiment was arranged as a split split-plot with treatments as the main plot cultivars as the sub plot and harvest dates as the sub sub plots. Work
was conducted in the same location as described in chapter 3, without any changes in bed arrangement.

The treatments were:

1. Control: No amendments were applied to these plots.

2. C45: On-farm produced compost applied at 45 t ha\(^{-1}\) fresh weight in beds with a history of annual compost and urea applications (25 t ha\(^{-1}\) + 100 kg ha\(^{-1}\) respectively)

3. CM180: On-farm produced compost applied at 180 t ha\(^{-1}\) fresh weight in beds with a history of annual compost applications (25 t ha\(^{-1}\)).

4. Urea: 110 kg ha\(^{-1}\) nitrogen applied as urea and 16-16-16 as Graviota fertilizer.

The relatively high rates of compost were selected based on the low nutrient and organic carbon content of the compost (Table 1.). The compost was applied 7 days prior transplanting and incorporated with a roto-tiller to a depth of 15 cm.

30 kg ha\(^{-1}\) N was applied as Graviota 16-16-16 complete fertilizer at transplanting. The remaining 80 kg ha\(^{-1}\) N was applied as urea in two equal split applications 35 and 73 DAT.

The varieties used in this experiment were:

'Sweet Italian' Italian type commercially grown in Hawaii. Obtained from Fukuda Seed Store (Honolulu, HI 96817).

'UH' Italian type, Fusarium resistant variety developed by the University of Hawaii. Obtained from the UH seed program.

'Thai Siam Queen' Commercial Asian variety. Obtained from Fukuda Seed.
Planting and Harvest

Seeds of the three basil cultivars were planted in Speedling® trays in early June, 1998. Seven week-old seedlings were transplanted at a 30 x 43 cm spacing in double rows on 10 August, 1998. Eight weekly harvests were taken beginning 9 September, 30 DAT. Harvested materials consisted of 10-15 cm long shoots with 3-4 nodes. Weight of harvested materials for an entire plot were recorded, and grams per plant values calculated based on the number of plants in each plot.

The crop was drip irrigated and hand weeded as needed, and no pesticides or other inputs were used in the plots.

Tissue Sampling and Sap Nitrate Analysis

The most recently fully expanded leaf pair from 10 shoots per replication were collected at 37, 65 and 100 DAT for total N analysis. Sap nitrate-N content was measured using a Cardy sap nitrate meter (Horiba Instruments Inc., Irvine, CA), also at 37, 65 and 100 DAT. Stems were harvested between 9-11 am at all dates from the same side of the row. Samples were stored in sealed plastic bags in a cooler with ice until analysis in the lab. Stem portions between the first and third node from the apex were obtained from 10 marketable shoots in each replication and leaves removed. Stems were macerated with a mortar and pestle and sap extracted with a garlic press.
Analysis of Compost and Soil

The sample of the compost used was sent to the ADSC for analysis (as soil) of pH, organic carbon, P, K, Ca, and Mg. The pH was determined using a saturated paste. Organic carbon content was measured using a modified Walkley-Black method. The Olsen method was used to measure available P. Exchangeable Ca, Mg and K levels were extracted with NH$_4$OAc, pH 7 and measured with an atomic absorption spectrophotometer.

Soil organic matter was determined from samples taken at a depth of 15 cm. immediately after plant removal (120 DAT). Nematode counts were taken at the same time from rhizosphere soil samples at a depth of 15 cm.

Plant Root Indexes

Roots of all plants in each replication were rated visually for severity of galling caused by root-knot nematode infestation, and overall root health 120 DAT using the following index:

<table>
<thead>
<tr>
<th>Galling</th>
<th>Root Health</th>
</tr>
</thead>
<tbody>
<tr>
<td>1= 0-20% of roots galled</td>
<td>1= very poor (81-100% rot)</td>
</tr>
<tr>
<td>2= 21-40% of roots galled</td>
<td>2= poor (61-80% rot)</td>
</tr>
<tr>
<td>3= 41-60% of roots galled</td>
<td>3= fair (41-60% rot)</td>
</tr>
<tr>
<td>4= 61-80% of roots galled</td>
<td>4= good (21-40% rot)</td>
</tr>
<tr>
<td>5= 81-100% of roots galled</td>
<td>5= excellent (0-20% rot)</td>
</tr>
</tbody>
</table>
**Statistical Analysis**

The data was analyzed with a proc GLM procedure (SAS version 6.1). Duncan’s New Multiple Range Test was conducted with the corresponding error term for each variable.

**Results and Discussion**

The fertilizer treatments had a significant effect on yield at \( P < 0.07 \). Differences between yield of cultivars were highly significant (\( P < 0.01 \)). There was no significant cultivar by treatment interaction (\( P = 0.56 \)) as tested by the error b (Little and Small, 1978). Figure 4.1 shows the mean cumulative yield of the treatments across cultivars, with yield from the lower rate of compost 40% and 15% greater than those from the control and urea plots respectively. A trend for higher yields with increased rate of compost application was observed in cvs. Sweet and Thai, but not in UH (Fig. 4.2, Table 4.3). The trend for lower yields in the urea treatment compared to the compost treatments was more apparent in ‘Thai’ (Fig. 4.2, Table 4.3). Soil organic carbon levels were higher in the compost plots than in the control, but were not affected by the rate of compost application (Fig. 4.3). Root galling as a result of nematode attack was highest in c180 for all cultivars (Fig. 4.4). Decline associated with heavy nematode infestation (Hamasaki et al. 1994) was observed only in ‘UH’, and associated with moderate to severe levels of root rot in this treatment (Fig. 4.5). Root knot nematodes (*Meloidogyne* sp) were the predominant plant parasitic nematode species in the
rhizosphere (80%). Spiral and Reniform nematodes were also identified in rhizosphere soil. Although not significantly affected by fertilizer treatments, nematode levels in the root zone of ‘UH’ in c180 (487 per L of soil) were over twice those in the other treatments. This implies an environment favoring nematode populations with the higher applications of compost, probably due to an initial stimulation of root growth in that treatment. Of the three cultivars, only ‘UH’ had a significant difference in root health between treatments (fig. 4.5). This implies that ‘UH’ is more susceptible than ‘Thai’ or ‘Sweet’ to reduced yields resulting from root knot nematode infestation. Increased root rot as a result of nematode attack has been observed previously with applications of municipal waste compost in tomato (Duncan and Noling, 1998).

Fertilizer treatments affected sap nitrate-N levels at P<0.1, and differences between cultivars were highly significant. Cultivar differences in tissue nitrate levels in response to fertilizer treatments were also observed in pumpkin and endive (Swaider et al, 1991; Reinik et al., 1994). The effect of genotype on sap nitrate-N levels must therefore be considered when determining critical ranges of a crop. Although tissue N levels were increased with fertilizer applications, there was no difference between cultivars in mean tissue N concentrations (Table 4.2). Urea applications significantly increased sap nitrate levels with respect to the control, while compost applications did not (Table 4.2). This increase in sap nitrate-N over the compost treatments observed in the urea plots did not correspond with an increase in yield. This observation agrees with the findings of others. For example, Smith and Hadley (1989) have shown inorganic fertilizer to
increase nitrate levels in lettuce leaves, while applications of compost contributed very little or no nitrate to tissues. In another study, Dominguez et al (1984) found lettuce grown with compost to contain 10% less nitrates than that grown with inorganic fertilizers. Excessive nitrate in the diet is known to increase the risk of such health problems as cancer and inhibited oxygen transport by blood, and it has been estimated that nitrates from vegetable can contribute to more that 80% of total dietary nitrates (Lyons et al, 1994; Huarte-Mendicoa, et al 1996).

There was no significant treatment by cultivar interaction for sap nitrate-N as tested with the error b, nor were there interactions between sample date and treatment or cultivar. Sap nitrate levels were more sensitive than total tissue N concentration to fertilizer application. This is in agreement with similar observations made by Huett and Rose (1989). Measurements obtained with the Cardy meter were positively correlated with results from total tissue N analysis at 65 DAT across all cultivars, although correlation is improved when considered by cultivar, as would be expected by the genotypic differences observed in sap nitrate levels (Fig 4.6-9). Sap nitrate levels of ‘Sweet’ and both sap nitrate and tissue N concentrations of ‘UH’ were correlated with yield at 65 DAT (Fig. 4.10-12). Yields decreased to below 857 kg ha\(^{-1}\) at sampling date with increasing sap nitrate-N levels above 800 mg L\(^{-1}\) in both cultivars. As in Chapter 3, lowest yields (643 kg ha\(^{-1}\) at sampling date) of 'UH' were associated with tissue N levels lower than 4.5%. Neither total tissue N or sap nitrate concentrations in ‘Thai’ were significantly correlated with yield at any sample date.
N removal data is listed in Tables 4.4-6. N removed by crops producing the highest yields was 67-71 kg ha\(^{-1}\) over 120 days. This is similar to previous estimations of 62-70 kg ha\(^{-1}\) N removed by basil over a 75 day crop cycle (Chapter 3). Disease incidence affected N uptake in ‘UH’. This cultivar removed 26 kg ha\(^{-1}\) N from the control compared to 48, 42 and kg ha\(^{-1}\) removed by ‘Sweet’ and ‘Thai’, respectively. The fact that this was due to the root rot observed in ‘UH’ in this experiment is indicated by the removal of 45 kg ha\(^{-1}\) N by healthy ‘UH’ plants in the previous experiment (Chapter 3). Estimation of residual plant available N from previous compost applications is discussed relative to the other experiments in Chapter 7. It is unlikely that the yield response of basil to fertilizer applications in this experiment is simply an N effect. Increased soil organic matter in the soil, plant nutrients other than N contained in the compost, and an interaction between fertilizer treatments and pest incidence may also have contributed to the additional crop yield observed in the compost plots.

Conclusions

Application of 45 t ha\(^{-1}\) of a low nutrient compost increased basil yield with respect to the control in all three cultivars. Very high rates of compost applied to compensate for the low nutrient content did not result in the expected yield increase over the yield obtained from the lower rate of compost. This may have been due to phytotoxicity resulting from excess N and/or a higher incidence of root galling in the c180 treatment. Relative nitrogen use efficiency was greatest in plots receiving 45 t ha\(^{-1}\) compost (See General Discussion Chapter). Low
rates of compost combined with moderate applications of synthetic fertilizer is likely to be the most efficient fertilization regime for basil, as observed previously by Valenzuela et al. (1999) with basil in the same location. Highest yields were obtained with ‘Sweet’, the only variety to remain relatively pest-free during the crop cycle. N removed by crops producing the highest yields was 67-71 kg ha\(^{-1}\) over 120 days. ‘UH’ was determined to be more susceptible to root-knot nematode attack and associated root rot than the other two cultivars, while ‘Thai’ was more susceptible to Fusarium wilt. It was therefore determined possible to grow disease tolerant basil cultivars organically.

Values obtained with rapid analysis of stem sap nitrate levels using a portable hand-held nitrate ion selective electrode were positively correlated with total tissue N values obtained from a professional plant diagnostic service provider. Sap nitrate levels were more sensitive to fertilizer treatment and were a slightly better indicator of plant nutrient status than total tissue N levels. This indicates the potential of sap nitrate-N analysis as a useful tool in management of crop nutrition. However, mean sap nitrate levels varied with cultivar, emphasizing the need for critical range determinations to be done at the cultivar level. Urea applications increased plant nitrate levels with respect to the control while compost applications did not, indicating that compost may be used as a fertilizer to lower nitrate levels in vegetables.
Literature Cited:


Table 4.1. Selected chemical properties of the compost applied.

<table>
<thead>
<tr>
<th></th>
<th>OC</th>
<th>pH</th>
<th>P</th>
<th>K</th>
<th>Mg</th>
<th>Ca</th>
</tr>
</thead>
<tbody>
<tr>
<td>Compost</td>
<td>4%</td>
<td>7.2</td>
<td>141 ppm</td>
<td>1316 ppm</td>
<td>1166 ppm</td>
<td>8174 ppm</td>
</tr>
</tbody>
</table>
Figure 4.1. The effect of compost rates and urea applications on the mean cumulative yield of basil by treatment. Values are means of four replications and three cultivars. Means designated by the same letter are not significantly different at P<0.05 as determined by Duncan’s New Multiple Range test. C45= compost applied at 45 t ha\(^{-1}\) in plots with a history of compost applications. C180= compost applied at 180 t ha\(^{-1}\) in plots with a history of compost applications plus urea. Urea= 110 kg ha\(^{-1}\) N applied as urea in plots with a history of annual urea applications of 100-300 kg ha\(^{-1}\) N. Control= no amendment.
Figure 4.2. The effect of compost rates and urea applications on the mean cumulative yield of cultivars by treatment. Values are means of four replications. C45= compost applied at 45 t ha\(^{-1}\) in plots with a history of compost applications. C180= compost applied at 180 t ha\(^{-1}\) in plots with a history of compost applications plus urea. Urea= 110 kg ha\(^{-1}\) N applied as urea in plots with a history of annual urea applications of 100-300 kg ha\(^{-1}\) N. Control= no amendment.
Figure 4.3. Effect of fertilizer treatments on soil organic carbon content, 120 days after transplanting. Values are means of four replications. Mean values designated by the same letter are not significantly different at $P<0.05$ as determined by Duncan’s New Multiple Range Test.
Figure 4.4. Effect of treatment on root gall index scores of cultivars, 120 DAT. Values are means of four replications. Root Gall Index: 1= 0-20% of roots galled, 2= 21-40% of roots galled, 3= 41-60% of roots galled, 4= 61-80% of roots galled, 5= 81-100% of roots galled.
Figure 4.5. Effect of treatment on root health index scores of basil cv. UH, 120 DAT. Values are means of four replications. Root health index: 1= very poor (81-100% rot), 2= poor (61-80% rot), 3= fair (41-60% rot), 4= good (21-40% rot).
Table 4.2. Mean sap nitrate and tissue N concentrations and mean standard error by cultivar and treatment.

<table>
<thead>
<tr>
<th>Sap Nitrate-N (mg L⁻¹)</th>
<th>Treatment</th>
<th>Sweet</th>
<th>Thai</th>
<th>UH</th>
<th>Mean (treatment)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
<td>748 ± 110</td>
<td>470 ± 82</td>
<td>820 ± 125</td>
<td>679 ± 67</td>
<td></td>
</tr>
<tr>
<td>C45</td>
<td>764 ± 105</td>
<td>540 ± 102</td>
<td>946 ± 101</td>
<td>750 ± 66</td>
<td></td>
</tr>
<tr>
<td>C180</td>
<td>691 ± 127</td>
<td>549 ± 95</td>
<td>858 ± 126</td>
<td>699 ± 70</td>
<td></td>
</tr>
<tr>
<td>Urea</td>
<td>981 ± 87</td>
<td>701 ± 103</td>
<td>1098 ± 117</td>
<td>927 ± 67</td>
<td></td>
</tr>
<tr>
<td>Mean (cultivar)</td>
<td>795 ± 55</td>
<td>565 ± 48</td>
<td>930 ± 59</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Tissue N (%)</th>
<th>Treatment</th>
<th>Sweet</th>
<th>Thai</th>
<th>UH</th>
<th>Mean (treatment)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
<td>4.36 ± 0.09</td>
<td>4.40 ± 0.07</td>
<td>4.30 ± 0.09</td>
<td>4.36 ± 0.05</td>
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</tr>
<tr>
<td>C45</td>
<td>4.59 ± 0.10</td>
<td>4.48 ± 0.07</td>
<td>4.47 ± 0.10</td>
<td>4.51 ± 0.05</td>
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</tr>
<tr>
<td>C180</td>
<td>4.46 ± 0.09</td>
<td>4.43 ± 0.09</td>
<td>4.42 ± 0.12</td>
<td>4.43 ± 0.06</td>
<td></td>
</tr>
<tr>
<td>Urea</td>
<td>4.60 ± 0.04</td>
<td>4.68 ± 0.10</td>
<td>4.49 ± 0.10</td>
<td>4.59 ± 0.05</td>
<td></td>
</tr>
<tr>
<td>Mean (cultivar)</td>
<td>4.50 ± 0.04</td>
<td>4.50 ± 0.04</td>
<td>4.42 ± 0.05</td>
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<td></td>
</tr>
</tbody>
</table>
Table 4.3. Effect of compost and synthetic N on relative yield increase of fertilizer treatments over control.

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Sweet</th>
<th>Cumulative Yield (kg ha(^{-1}))</th>
<th>Yield increase over control (kg ha(^{-1}))</th>
<th>Yield increase over control (%)</th>
</tr>
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<tbody>
<tr>
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<td>3295</td>
<td>38</td>
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<td>38</td>
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<td>4393</td>
<td>50</td>
<td></td>
</tr>
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<td>38</td>
<td></td>
</tr>
<tr>
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<td>C180</td>
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<td>1921</td>
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<td></td>
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<tr>
<td>Urea</td>
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<td>23</td>
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<td>1922</td>
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Table 4.4. Effect of compost and synthetic fertilizer treatment on N use of basil cv. Sweet Italian, at 37, 65 and 100 days after transplanting (DAT). Values are means of four replications. C45= compost applied at 45 t ha⁻¹ in plots with a history of compost applications. C180= compost applied at 180 t ha⁻¹ in plots with a history of compost applications plus urea. Urea= 110 kg ha⁻¹ N applied as urea in plots with a history of annual urea applications of 100-300 kg ha⁻¹ N. Control= no amendment.

<table>
<thead>
<tr>
<th>Date</th>
<th>Treatment</th>
<th>Cumulative yield (kg ha⁻¹)</th>
<th>Biomass (kg ha⁻¹)</th>
<th>N removed (kg ha⁻¹)</th>
<th>N equivalent</th>
<th>N applied (kg ha⁻¹)</th>
</tr>
</thead>
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<tr>
<td>37 DAT</td>
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<td>12075</td>
<td>1207</td>
<td>67</td>
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<td>110</td>
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</tbody>
</table>

wa Cumulative yield at sampling date.
xb N removed from the fertilized crop (kg ha⁻¹) calculated by multiplying biomass by mean tissue content of each treatment.
yc N equivalent is the N removed from the treatment divided by the N removed by urea plots then multiplied by the amount of N applied as urea at sample date. Assumes 100% plant availability of synthetic N.
zd Plant available N from compost estimated at 25% total N supplied by compost based on an assumed moisture and total N content of 30% and 0.3%, respectively.
Table 4.5. Effect of compost and synthetic fertilizer treatment on N use of basil cv. UH, at 37, 65 and 100 days after transplanting (DAT). Values are means of four replications. C45 = compost applied at 45 t ha\(^{-1}\) in plots with a history of compost applications. C180 = compost applied at 180 t ha\(^{-1}\) in plots with a history of compost applications plus urea. Urea = 110 kg ha\(^{-1}\) N applied as urea in plots with a history of annual urea applications of 100–300 kg ha\(^{-1}\) N. Control = no amendment.

<table>
<thead>
<tr>
<th>Date</th>
<th>Treatment</th>
<th>Cumulative yield (kg ha(^{-1}))</th>
<th>Biomass (kg ha(^{-1}))</th>
<th>N removed (kg ha(^{-1}))</th>
<th>N equivalent</th>
<th>N applied (kg ha(^{-1}))</th>
</tr>
</thead>
<tbody>
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<td>576</td>
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<td>6863</td>
<td>686</td>
<td>35</td>
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</tbody>
</table>

\(^a\)Cumulative yield at sampling date.

\(^b\)N removed from the fertilized crop (kg ha\(^{-1}\)) calculated by multiplying biomass by mean tissue content of each treatment.

\(^c\)N equivalent is the N removed from the treatment divided by the N removed by urea plots then multiplied by the amount of N applied as urea at sample date. Assumes 100% plant availability of synthetic N.

\(^d\)Plant available N from manure estimated at 25% total N supplied by compost based on an assumed moisture and total N content of 30% and 0.3%, respectively.
Table 4.6. Effect of compost and synthetic fertilizer treatment on N use of basil cv. Thai, at 37, 65 and 100 days after transplanting (DAT). Values are means of four replications. C45 = compost applied at 45 t ha\(^{-1}\) in plots with a history of compost applications. C180 = compost applied at 180 t ha\(^{-1}\) in plots with a history of compost applications plus urea. Urea = 110 kg ha\(^{-1}\) N applied as urea in plots with a history of annual urea applications of 100-300 kg ha\(^{-1}\) N. Control = no amendment.

<table>
<thead>
<tr>
<th>Date</th>
<th>Treatment</th>
<th>Cumulative yield (kg ha(^{-1})) (^w)</th>
<th>Biomass (kg ha(^{-1})) (^x)</th>
<th>N removed (kg ha(^{-1})) (^x)</th>
<th>N equivalent (^y)</th>
<th>N applied (kg ha(^{-1})) (^y)</th>
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<td>851</td>
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</table>

\(^w\)Cumulative yield at sampling date.

\(^x\)N removed from the fertilized crop (kg ha\(^{-1}\)) calculated by multiplying biomass by mean tissue content of each treatment.

\(^y\)N equivalent is the N removed from the treatment divided by the N removed by urea plots then multiplied by the amount of N applied as urea at sample date. Assumes 100% plant availability of synthetic N.

\(^z\)Plant available N from manure estimated at 25% total N supplied by compost based on an assumed moisture and total N content of 30% and 0.3%, respectively.
Figure 4.6. Total nitrogen concentration of most recently matured basil leaves relative to stem sap nitrate-N, 65 days after transplanting. Each value represents the mean of 20 leaves for tissue N analysis and 10 stem portions for sap nitrate-N determination from each cultivar in a single replication.
Figure 4.7. Total nitrogen concentration of most recently matured UH basil leaves relative to stem sap nitrate-N, 65 days after transplanting. Each sample consisted of 20 leaves for total N analysis, and 10 stem portions for sap nitrate-N determination.
Figure 4.8. Total nitrogen concentration of most recently matured SWEET basil leaves relative to sap nitrate-N, 65 days after transplanting. Each sample consisted of 20 leaves for total N analysis, and 10 stem portions for sap nitrate-N determination.

\[ y = 0.0017x - 0.00000070x^2 + 3.73 \]

\[ r^2 = 0.39 \quad P<0.05 \]
Figure 4.9. Total nitrogen concentration of most recently matured THAI basil leaves relative to stem sap nitrate-N, 65 days after transplanting. Each sample consisted of 20 leaves for total N analysis, and 10 stem portions for sap nitrate-N determination.

\[
y = 0.0010 x + 4.33
\]

\[
r^2 = 0.41 \quad P<0.01
\]
Figure 4.10. Yield of cv. SWEET relative to stem sap nitrate-N concentration, 65 days after transplanting. Each value represents a sample from a single replication consisting of 10 stem portions.

![Graph showing the relationship between yield and sap nitrate-N concentration]

\[ y = -0.30x + 763.76 \]

\[ r^2 = 0.25 \quad P<0.05 \]
Figure 4.11. Yield of cv. UH relative to stem sap nitrate-N concentration, 65 days after transplanting. Each value represents a sample from a single replication consisting of 10 stem portions.

\[ y = 1.28x - 0.00083x^2 - 10.5 \]

\[ r^2 = 0.42 \quad P<0.05 \]
Figure 4.12. Yield of cv. UH relative to total nitrogen concentration of the most recently matured leaves, 65 days after transplanting. Each value represents a sample from each replication consisting of 20 most recently matured leaves.
CHAPTER 5
BASIL YIELD AND SOIL QUALITY AS AFFECTED BY COMPOST AND UREA APPLICATIONS

Abstract

A field trial was conducted at the University of Hawaii Waimanalo experiment station to determine the effects of compost and urea applications on the marketable yield of three basil cultivars, ‘Sweet Italian’, ‘UH’, and ‘Siam Queen’. The experiment was arranged in a split split-plot design with fertilizer treatments as the main plots, cultivars as the sub-plots, and harvest dates as the sub sub-plots. The four treatments, replicated four times, were 230 kg ha\(^{-1}\) N applied as urea, compost applied at 23 t ha\(^{-1}\), compost applied at 90 t ha\(^{-1}\), and a control receiving no amendment. The chicken manure/woodchip-based compost contained 1.2% N on a dry weight basis and 30% moisture. Compost was incorporated to a depth of 15 cm one week prior to transplanting basil seedlings. Urea was applied in six split applications. Twelve weekly harvests were taken beginning 45 days after transplanting. Soil pH, organic carbon (OC), electrical conductivity (EC), and nematode levels were determined at the end of the harvest period. Fertilizer treatment, cultivar, and harvest date had significant effects on yield. The cultivar by fertilizer treatment interaction was not significant with respect to yield. Highest yields were obtained with 90 t ha\(^{-1}\) compost. Cumulative yields from the 23 t ha\(^{-1}\) compost treatment were comparable to that from the urea plots. Lowest yield for ‘Siam Queen’ was recorded in the urea treatment and corresponded with a high incidence of wilt disease caused by
*Fusarium oxysporum*. Compost applications significantly increased OC content and EC compared to the other treatments, while soil pH was significantly lower in the urea plots. There was no significant treatment effect on rhizosphere nematode levels, with populations high in all treatments. Relatively low yields in the urea plots were attributed to high disease incidence and associated with high levels of soil N late in the crop cycle, and a reduction in soil pH.

**Introduction**

Compost use as the primary means to provide essential nutrients to vegetable crops is an effective way to sustain and build soil fertility as well as a valuable waste management strategy. Chicken manure contains many plant nutrients and has proven to be an effective fertilizer for vegetables, with the added potential of improving soil physical and chemical characteristics (Cheung and Wong, 1983; Hue and Licudine, 1999). However, there are some health risks associated with untreated manure, which are minimized or eliminated by composting (Strauch, 1996; LeaMaster et al., 1998). Composting as described throughout this paper refers to the controlled microbial degradation of organic residues to produce temperatures (40-55°C) high enough to kill pathogens and weed seeds (Zibilske, 1999). Other wastes, such as woodchips, may be combined with manure to produce a valuable organic amendment. A chicken manure and wood-chips based compost increased corn biomass production up to a rate of 50 t ha\(^{-1}\), with yield decreasing at higher rates (Silva et al., 1995). Stopes et al. (1989) reported increased lettuce yields in response to composted FYM (0.9% N) applications, with highest yields obtained at the highest
application rate of 18 dry t ha\(^{-1}\). Yield at this rate was not different from that obtained with 160 kg ha\(^{-1}\) synthetic N. When a manure based compost was applied to cabbages and carrots to provide 300 and 170 kg ha\(^{-1}\) N respectively, crop yields and tissue N levels were the same as those obtained in synthetically fertilized plots receiving the equivalent N rates (Warman and Havard 1997). In addition to yield benefits compost applications may also improve or maintain soil quality, contributing directly and indirectly to improved crop growth (Bevaqua and Mellano, 1994). Compost has also effectively suppressed numerous plant pathogens, with the suppressive effect generally associated with microbial activity (Huber et al, 1966; Hoitink, 1980; Cheung and Hoitink, 1990; Hardy and Sivasithamparam, 1991).

Due to relatively low nutrient content and increased labor involved with application, composts are generally more expensive than synthetic nutrient sources. Its use in large quantities can be justified, however, when applied to high value crops, when additional objectives of the grower are to recycle on-farm wastes, build soil organic matter and control plant disease, or in cropping situations where the use of synthetic fertilizers are not an option (i.e. certified organic systems) (Buchanan and Gliessman, 1993; Serra-Wittling, 1996). Basil is an important crop in Hawaii with a 1998 total farm-gate value of $2.7 million, but there are currently no fertilizer recommendations available to growers wishing to grow this crop organically in the state (Hamasaki et al, 1994; HASS, 1999). In Hawaii, compost applied at 25 t ha\(^{-1}\) increased basil yield with respect to unfertilized plants, and produce yields similar to those obtained with
100 kg ha\(^{-1}\) synthetic N (Valenzuela et al., 1999). However, information on the response of basil to higher rates of compost is not available.

This experiment was thus conducted to determine the yield response of three basil cultivars to compost and urea applications, and the effect of fertilizer type and rate on soil quality and pest incidence.

**Materials and Methods**

**Experimental Design**

The experiment was arranged as a split split-plot with fertilizer treatments as the main plot, cultivars as the sub-plot and harvest date as the sub sub-plot. This was the third of three consecutive experiments conducted in the same field plots to determine the response of basil to organic fertilization in the tropics. The first experiment was conducted in the Spring, 1998, with basil in the field for 75 days. The second basil planting was in the field for 120 days. Work was conducted as described in Chapter 4, without any changes in bed arrangement or varieties used. However, the location of cultivars within the beds was re-randomized.

The treatments were:

1. Control: No amendment
2. C23: Compost applied at 23 t ha\(^{-1}\) in beds previously receiving 90 t ha\(^{-1}\) compost.
3. C90: Compost applied at 90 t ha\(^{-1}\) in beds previously receiving 180 t ha\(^{-1}\).
4. Urea: 230 kg ha\(^{-1}\) N applied as urea

The compost was applied 7 days prior to transplanting and incorporated with a roto-tiller to a depth of 15 cm.

34 kg ha\(^{-1}\) N was applied as urea at 13 DAT. The remaining urea was applied in 5 split applications 2 weeks apart beginning at the time of first harvest, 45 DAT

Planting and Harvest

Seeds of the three basil cultivars were planted at the University of Hawaii Magoon Greenhouse in 200 cell Speedling® trays 25 January, 1999. Seven week-old seedlings were transplanted in double row beds at a distance of 45 cm between plants in the row, and 60 cm between rows on 3 March, 1999. Twelve weekly harvests were taken beginning 45 DAT. Harvested materials consisted of 10-15 cm long shoots with 3-4 nodes. Weight of harvested materials for an entire plot were recorded, and grams per plant values determined based on the number of plants in each plot.

The crop was drip irrigated as needed, and no pesticides or other inputs were used in the plots.

Tissue N and Sap Nitrate-N Analysis

The most recently fully expanded leaf pair from 10 shoots per replication were collected at 70, 113 and 135 DAT for total N analysis. Sap nitrate-N content was measured using a Cardy sap nitrate meter (Horiba Instruments Inc.,
Irvine, CA) at 70 DAT. Stems were harvested between 9-11 am at all dates from the same side of the row. Samples were stored in a cooler with ice until analysis in the lab. Stem portions between the first and third node from the apex were obtained from 10 marketable shoots in each replication and leaves removed. Stems were macerated with a mortar and pestle and sap extracted with a garlic press.

**Analysis of Compost**

Locally obtained aged chicken manure and wood chips (2 : 3 by volume) were composted in piles for ten weeks. Piles were turned weekly, and moisture content maintained at approximately 50%. A sample of the compost was analyzed at the University of Hawaii Agricultural Diagnostic Service Center prior to application. Electrical conductivity was determined on a slurry of 50 g compost and 50 ml of water. Organic carbon content and pH were determined as previously described for soil in Chapter 4. Results of the analyses are given in Table 1.

**Soil Analysis**

Soil samples of two replications were taken to a depth of 15 cm and analyzed for NO$_3$-N and NH$_4^+$-N prior to compost application, then again at 22, 74, 96, and 103 days after compost application. Organic carbon content, electrical conductivity and pH of each replication was conducted on samples obtained at 15 cm at 175 DAT. Composite samples of four replications were
analyzed for extractable nutrients (Table 2). The nutrient analysis was conducted as described previously in Chapter 4.

**Pest and Disease Levels**

The number of plants exhibiting symptoms of disease caused by *Fusarium oxysporum* were counted 52 DAT.

Plants of ‘UH’ were visually rated for severity of decline 150 DAT on a scale of 1-5, where: 1=dead; 2=severe decline; 3=moderate decline; 4=little decline; 5=healthy

Roots of all varieties were rated for severity of galling, and overall root health using the following indexes:

**Galling**, where: 1= 0-20% of roots galled, 2= 21-40% of roots galled, 3= 41-60% of roots galled, 4= 61-80% of roots galled, 5= 81-100% of roots galled.

**Root Health**, where: 1= very poor (81-100% rot), 2= poor (61-80% rot), 3= fair (41-60% rot), 4= good (21-40% rot), 5=excellent (0-20% rot)

Nematode counts were taken made from rhizosphere soil samples collected at a depth of 15 cm 175 DAT.

**Statistical Analysis**

The data was analyzed with a proc GLM procedure (SAS version 6.1). Means separation was done using Duncan’s New Multiple Range test.
Results and Discussion

Fertilizer treatment and genotype both significantly affected mean yields (P<0.01), but there was no significant cultivar by treatment interaction. Mean cumulative yields for each fertilizer treatment are shown in Figure 5.1. Individual cultivar response is shown in Figure 2. Compost applications increased yield with respect to the control, and applications of 90 t ha\(^{-1}\) resulted in the highest yields; at 30% moisture, 90 t ha\(^{-1}\) corresponds to the highest recommended compost application rate for vegetable production of 60 dry t ha\(^{-1}\) (Compost Council, 1996). Tables 5.1 and 5.2 list the results of the compost and soil nutrient analysis.

Yields from c90 treatment were 30 and 80% higher than c23 and control plots respectively across cultivars. Yield response of the cultivars differed slightly with respect to treatment (Figure. 5.2). Statistical analysis had shown no significant treatment by cultivar interaction, and may have not been sensitive enough to pick up slight differences. The effect of the high compost application rate on cumulative yield was most pronounced in ‘Sweet’. Yield response of each cultivar with respect to the control is given in Table 5.3. Only in ‘Sweet’ did the magnitude of increase in compost rate (4x) matched that of increased yield over the control. Table 5.3. lists the cumulative yield of cultivars by treatment and the yield difference between fertilizer treatments and the control. Tissue levels were taken only from cv ‘UH’.
Tissue N and sap nitrate-N levels were highest in the C90 treatment. The estimated N removed from each treatment is listed in Table 5.4. A total of 78 kg ha$^{-1}$ N was removed by the highest yielding treatment in this experiment. As in the previous experiment, disease levels affected the N uptake of ‘UH’. The lack of difference between in N equivalents of the two compost rates at later sample dates corresponded to high amounts of root rot (i.e. low root health) and plant decline in the C90 treatment. The high N equivalents in control and compost treatments relative to the urea treatment corresponds with the highest levels of rot and plant decline observed in the urea plots over the compost and control treatments (Figure 5.5, Table 5.5). Estimation of residual plant available N from previous compost applications is discussed relative to the other experiments in Chapter 7.

All plants of cultivar ‘UH’ exhibited mild to severe symptoms of decline attributed to root-knot nematode infestation. Symptom severity was significantly affected by treatment, being greatest in the urea treatments, followed by c90 (Figure 5.5). Root galling was most severe in the urea and c90 treatments as well, as was the severity of root rot indicated by the low root health index scores (Table 5.5). Root gall index scores were highest and root health index scores lowest for ‘UH’. This cultivar is apparently more susceptible to nematode attack than either ‘Thai’ or ‘Sweet’. While no fungal pathogen was isolated from the vascular system of ‘UH’ plants exhibiting severe symptoms of decline, it is possible that resistance to fusarium broke down as a result of nematode
infestation, or that some other nematode by pathogen interaction had adverse effects on plant growth.

Fusarium wilt was observed in ‘Thai’ and ‘Sweet’ but not in ‘UH’, with 42%, 21%, and 0% of plants exhibiting symptoms of infection, respectively. Although symptomatic plants were observed in all treatments of ‘Sweet’, the effect on yield of this cultivar was observed to be minimal. No symptoms of the disease were observed in the resistant cultivar, ‘UH’. Lowest cumulative yields for ‘Thai’ (2942 kg ha\(^{-1}\)) were obtained in the urea treatment and corresponded with high levels of disease incidence (58% of plants infected by 52 DAT) compared with the other treatments (<35% of total plants infected by 52 DAT). The severity of symptoms caused by \(F. \text{oxysporum}\) was not rated. Soil analysis of two replications showed that \(\text{NH}_4^+\) was the predominant form of mineral N in the urea treatment, while \(\text{NO}_3^-\) predominated in the soil of the other three treatments (data not shown). N supplied as \(\text{NH}_4^+\) has been shown to increase the pathogenicity of Fusarium spp with respect to \(\text{NO}_3^-\) N applications (Woltz and Jones, 1973; Kirpichenko, 1975). This effect is associated with a decrease in soil pH resulting from the release of \(\text{H}^+\) from plant roots when absorbing \(\text{NH}_4^+\) (Agrios, 1988; Marschner, 1995). The percentage of plants exhibiting symptoms of Fusarium wilt was positively correlated with the ratio of ammonium to nitrate-N in the soil (Fig. 5.6), with ammonium to nitrate-N ratios highest in the urea treatment. Soil pH levels were significantly lower in the urea treatment with respect to the compost treatments and control (Table 7). Scher et al. (1980) eliminated the effectiveness of a soil suppressive to Fusarium wilt by decreasing the soil pH from 8.0 to 6.0.
The high \( \text{NH}_4^+ : \text{NO}_3^- \) ratio observed in the urea treatments may also be responsible for the relatively low yields of all varieties in this treatment, despite the addition of 230 kg ha\(^{-1}\) N. Alder et al. (1995) found basil stem and petiole yields to be lower when supplied with ammonium nitrogen than when given nitrate-N. Another reason for the poor yield response to split urea applications may be reduced synchrony of N availability with plant requirements. Most N in the urea plots was available late in the crop cycle (Fig. 5.7). High soil nitrate levels early in the development of broccoli corresponded to higher final yields (Buchanan and Gliessman, 1991), and was attributed to the ability of the crop to store N in its tissues to be translocated as needed.

Compost (pH 6.5) applications did not significantly affect soil pH. While compost may increase the pH of acid soils (Buchanan and Gliessman, 1991; Silva et al., 1995; Sainz et al., 1998), effects are usually negligible on neutral or basic soils (Compost Council, 1996). Bevaqua and Mellano (1994) reported a reduction in pH of a basic soil (7.7) with applications of a slightly acid compost. Soil salinity levels in all treatments were extremely low, although EC in c90 was significantly higher than the other treatments (Table 5.6). This was the fifth year of compost and urea applications. The compost used in this experiment had a relatively high salt content (EC = 23 dS\(^{-1}\)); repeated applications of compost with similar levels may increase soil salinity to concentrations negatively affecting
Compost applications of 23 and 90 t ha$^{-1}$ increased soil organic carbon content 15 and 35% over the control and urea plots, respectively. Increased soil organic matter benefits plant growth by improving soil structure and nutrient holding capacity, and by buffering the soil pH (Buchanan and Gleissman, 1991; Woomer et al, 1994). Although four times as much compost, and therefore organic carbon, was applied in c90 than c23, the resulting increase in soil OC with the higher rate of application was little more than twice that of the lower rate over the control. This disproportionate increase in soil OC may indicate an increase in microbial activity resulting in increased OC mineralization at the higher rate of compost application. Research has shown compost applications to enhance microbial activity (Siviplan et al., 1993; Liu and Cole, 1996; Raj and Kapoor, 1997). Since soil organic matter is decomposed by microbial activity in the soil (Tisdale et al., 1993), the higher rate of compost application possibly stimulated soil microbial populations, thereby increasing the rate of OC decomposition.

**Conclusions**

Results from this experiment indicates that composts may be used as the sole external source of essential nutrients to grow basil. Applications of a chicken manure and wood chips based compost increased basil yield, sap nitrate
levels, mineral N in the soil, and soil organic matter over the control. Yields obtained were significantly higher with 90 t ha$^{-1}$ than those receiving either 23 t ha$^{-1}$ compost or 230 kg ha$^{-1}$ synthetic N. This effect was likely due to a combination of improved plant nutrition and an increase in soil organic matter. Relatively low yields in the urea plots were associated with high disease incidence, high levels of soil N late in the crop cycle (Fig. 5.7), and a reduction in soil pH. Final nematode levels were not affected by treatments; however, plant damage as a result of nematode attack was highest in the plots receiving urea and compost at 90 t ha$^{-1}$. The data indicates that cultivar UH is highly susceptible to nematode attack. Fusarium incidence in cv. Thai was positively correlated with the ratio of ammonium to nitrate in the soil, and associated with a decrease in the soil pH.

Selection of disease tolerant and potentially high yielding basil cultivars such as ‘Sweet Italian’ is important to help ensure maximum yield response to compost applications.
Literature Cited


Table 5.1. Selected chemical properties of the compost used in this experiment.

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<th>C:N</th>
<th>pH</th>
<th>EC (mmhos cm)</th>
<th>N (%)</th>
<th>P (%)</th>
<th>K (%)</th>
<th>Ca (%)</th>
<th>Mg (%)</th>
<th>Na (%)</th>
<th>Mn (ppm)</th>
<th>Fe (ppm)</th>
<th>Cu (ppm)</th>
<th>Zn (ppm)</th>
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</table>

Table 5.2. Selected chemical properties of treatment soil prior to compost application (Feb. 1999), and 182 days after application (Aug. 1999) of compost.

<table>
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<th>Treatment</th>
<th>OC (%)</th>
<th>pH</th>
<th>EC (dS m⁻¹)</th>
<th>P (mg L⁻¹)</th>
<th>K (mg L⁻¹)</th>
<th>Ca (mg L⁻¹)</th>
<th>Mg (mg L⁻¹)</th>
<th>Mn (ppm)</th>
<th>Fe (ppm)</th>
<th>Cu (ppm)</th>
<th>Zn (ppm)</th>
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Figure 5.1. Effect of several compost and synthetic fertilizer treatments on mean cumulative basil yield. Values are means of four replications and three cultivars. Means designated with the same letter are not significantly different at $p<0.05$ according to Duncan’s New Multiple Range Test. Control= No amendment, C23= Compost applied at 23 t ha$^{-1}$ in beds previously receiving 45 t ha$^{-1}$ compost, C90= Compost applied at 90 t ha$^{-1}$ in beds previously receiving 180 t ha$^{-1}$, Urea=230 kg t ha$^{-1}$ N applied as urea.
Figure 5.2. Effect of several compost and synthetic fertilizer treatments on mean cumulative yield response of cultivars to treatment. Values are means of four replications, and means within cultivars designated with the same letter are not significantly different at $P<0.05$ according to Duncans’ New Multiple Range Test. Control= No amendment, C23= Compost applied at 23 t ha$^{-1}$ in beds previously receiving 90 t ha$^{-1}$ compost, C90= Compost applied at 90 t ha$^{-1}$ in beds previously receiving 180 t ha$^{-1}$, Urea=230 kg t ha$^{-1}$ N applied as urea.
Figure 5.3. Effect of several compost and synthetic fertilizer treatment on stem sap nitrate-N of basil, 50 days after transplanting. Values are means of samples consisting of 10 stem portions from three cultivars and four replications. Means designated with the same letter are not significantly different at $P<.05$ as determined using Duncan's New Multiple Range Test. Control= No amendment, C23= Compost applied at 23 t ha$^{-1}$ in beds previously receiving 90 t ha$^{-1}$ compost, C90= Compost applied at 90 t ha$^{-1}$ in beds previously receiving 180 t ha$^{-1}$, Urea=230 kg t ha$^{-1}$ N applied as urea.
Figure 5.4. Effect of several compost and synthetic fertilizer treatments on total nitrogen content of most recently matured basil leaves, 50 days after transplanting. Values are means of samples consisting of 20 most recently matured leaves from three cultivars and four replications. Means designated with the same letter are not significantly different at P<.05 as determined using Duncan’s New Multiple Range Test. Control= No amendment, C23= Compost applied at 23 t ha\(^{-1}\) in beds previously receiving 90 t ha\(^{-1}\) compost, C90= Compost applied at 90 t ha\(^{-1}\) in beds previously receiving 180 t ha\(^{-1}\), Urea=230 kg t ha\(^{-1}\) N applied as urea.
Figure 5.5. Mean plant health index of cv. UH as affected by treatment at 150 DAT. 1=Dead 2=Severe decline 3=Moderate decline 4=Mild decline 5=No decline. Mean values designated by the same letter are not significantly different at P<0.05 as determined using Duncan’s New Multiple Range Test. Control= No amendment, C23= Compost applied at 23 t ha⁻¹ in beds previously receiving 90 t ha⁻¹ compost, C90= Compost applied at 90 t ha⁻¹ in beds previously receiving 180 t ha⁻¹, Urea=230 kg t ha⁻¹ N applied as urea.
Figure 5.6. Percent of the total number of ‘Thai’ plants exhibiting symptoms of Fusarium wilt relative to the \( \text{NH}_4^+ : \text{NO}_3^- \) ratio in the soil. Each value represents the mean of two replications.

\[
y = -24.66x^2 + 98.74x + 7.00
\]

\[
 r^2 = 0.77 \quad P<0.05
\]
Figure 5.7. Mean soil NH4+ N and NO3- N levels of treatments over time (days after compost application, DAC). Urea applications were made 0, 29, 80, 92 and 106 DAC. Values are means of two replications.
Table 5.3. Effect of compost and synthetic fertilizer treatment on relative cumulative yield increase of fertilizer treatments over control.

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Cumulative Yield (kg ha(^{-1}))</th>
<th>Yield as % over control</th>
<th>N applied (kg ha(^{-1}))</th>
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<td><strong>Thai</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>control</td>
<td>5274</td>
<td></td>
<td>0</td>
</tr>
<tr>
<td>c23</td>
<td>9967</td>
<td>89</td>
<td>193</td>
</tr>
<tr>
<td>c90</td>
<td>12688</td>
<td>141</td>
<td>756</td>
</tr>
<tr>
<td>Urea</td>
<td>2942</td>
<td>-56</td>
<td>230</td>
</tr>
</tbody>
</table>
Table 5.4. Effect of fertilizer treatments on N use of basil cv. UH at 70, 113 and 145 days after transplanting (DAT). Values are means of four replications. Control= No amendment, C23= Compost applied at 23 t ha\(^{-1}\) in beds previously receiving 90 t ha\(^{-1}\) compost, C90= Compost applied at 90 t ha\(^{-1}\) in beds previously receiving 180 t ha\(^{-1}\), Urea=230 kg t ha\(^{-1}\) N applied as urea.

<table>
<thead>
<tr>
<th>Date</th>
<th>Treatment</th>
<th>Cumulative yield (kg ha(^{-1}))(^w)</th>
<th>Biomass (kg ha(^{-1}))</th>
<th>N removed (kg ha(^{-1}))(^x)</th>
<th>N equivalent(^y)</th>
<th>N applied (kg ha(^{-1}))</th>
</tr>
</thead>
<tbody>
<tr>
<td>70 DAT</td>
<td>control</td>
<td>347</td>
<td>35</td>
<td>1</td>
<td>107</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>C23</td>
<td>669</td>
<td>67</td>
<td>2</td>
<td>199</td>
<td>48</td>
</tr>
<tr>
<td></td>
<td>C90</td>
<td>1533</td>
<td>153</td>
<td>6</td>
<td>502</td>
<td>193</td>
</tr>
<tr>
<td></td>
<td>Urea</td>
<td>394</td>
<td>39</td>
<td>1</td>
<td>110</td>
<td>110</td>
</tr>
<tr>
<td></td>
<td>113 DAT</td>
<td>control</td>
<td>5283</td>
<td>528</td>
<td>143</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>C23</td>
<td>9230</td>
<td>923</td>
<td>34</td>
<td>258</td>
<td>48</td>
</tr>
<tr>
<td></td>
<td>C90</td>
<td>13417</td>
<td>1342</td>
<td>50</td>
<td>375</td>
<td>193</td>
</tr>
<tr>
<td></td>
<td>Urea</td>
<td>7969</td>
<td>797</td>
<td>31</td>
<td>230</td>
<td>230</td>
</tr>
<tr>
<td></td>
<td>145 DAT</td>
<td>control</td>
<td>10330</td>
<td>1033</td>
<td>45</td>
<td>209</td>
</tr>
<tr>
<td></td>
<td>C23</td>
<td>15919</td>
<td>1592</td>
<td>69</td>
<td>322</td>
<td>48</td>
</tr>
<tr>
<td></td>
<td>C90</td>
<td>19197</td>
<td>1920</td>
<td>78</td>
<td>367</td>
<td>193</td>
</tr>
<tr>
<td></td>
<td>Urea</td>
<td>12405</td>
<td>1240</td>
<td>49</td>
<td>230</td>
<td>230</td>
</tr>
</tbody>
</table>

\(^w\)Cumulative yield at sampling date.
\(^x\)N removed from the fertilized crop (kg ha\(^{-1}\)) calculated by multiplying biomass by mean tissue content of each treatment.
\(^y\)N equivalent is the N removed from the treatment divided by the N removed by urea plots then multiplied by the amount of N applied as urea at sample date. Assumes 100% plant availability of synthetic N.
\(^z\)Plant available N from manure estimated at 25% total N supplied by compost based on an assumed moisture and total N content of 30% and 1.2%, respectively.
Table 5.5. Root Gall and Root Health Index scores by treatment and cultivar. Root Gall Index: 1= 0-20% of roots galled, 2= 21-40% of roots galled, 3= 41-60% of roots galled, 4= 61-80% of roots galled, 5= 81-100% of roots galled. Root Health Index: 1= very poor (81-100% rot), 2= poor (61-80% rot), 3= fair (41-60% rot), 4= good (21-40% rot).

<table>
<thead>
<tr>
<th>Gall Index</th>
<th>Treatment</th>
<th>Sweet</th>
<th>Thai</th>
<th>UH</th>
<th>Mean (treatment)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>control</td>
<td>3.3 ± 0.2</td>
<td>2.3 ± 0.4</td>
<td>3.7 ± 0.2</td>
<td>3.3 ± 0.2</td>
</tr>
<tr>
<td></td>
<td>c23</td>
<td>3.9 ± 0.2</td>
<td>3.7 ± 0.3</td>
<td>3.7 ± 0.2</td>
<td>3.8 ± 0.1</td>
</tr>
<tr>
<td></td>
<td>c90</td>
<td>4.1 ± 0.2</td>
<td>4.2 ± 02</td>
<td>4.9 ± 0.3</td>
<td>4.5 ± 0.1</td>
</tr>
<tr>
<td></td>
<td>urea</td>
<td>4.8 ± 0.1</td>
<td>5.0 ± 0.0</td>
<td>4.7 ± 0.1</td>
<td>4.7 ± 0.1</td>
</tr>
<tr>
<td></td>
<td>Mean (cultivar)</td>
<td>4.0 ± 0.1</td>
<td>3.5 ± 0.2</td>
<td>4.3 ± 0.1</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Root Health Index</th>
<th>Treatment</th>
<th>Sweet</th>
<th>Thai</th>
<th>UH</th>
<th>Mean (treatment)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>control</td>
<td>3.7 ± 0.2</td>
<td>4.1 ± 0.3</td>
<td>2.9 ± 0.2</td>
<td>3.4 ± 0.1</td>
</tr>
<tr>
<td></td>
<td>c23</td>
<td>3.5 ± 0.2</td>
<td>3.2 ± 0.2</td>
<td>2.9 ± 0.2</td>
<td>3.2 ± 0.1</td>
</tr>
<tr>
<td></td>
<td>c90</td>
<td>3.2 ± 0.2</td>
<td>2.5 ± 0.2</td>
<td>1.6 ± 0.1</td>
<td>2.4 ± 0.1</td>
</tr>
<tr>
<td></td>
<td>urea</td>
<td>3.4 ± 0.2</td>
<td>3.0 ± 0.0</td>
<td>1.8 ± 0.1</td>
<td>2.3 ± 0.1</td>
</tr>
<tr>
<td></td>
<td>Mean (cultivar)</td>
<td>3.5 ± 0.1</td>
<td>3.2 ± 0.1</td>
<td>2.3 ± 0.1</td>
<td></td>
</tr>
</tbody>
</table>
CHAPTER 6
EFFECTS OF COMPOST AND SYNTHETIC FERTILIZER APPLICATIONS ON THE AROMA AND FLAVOR INTENSITY OF BASIL

Abstract

The sensory quality of fresh basil was evaluated in two experiments to determine if compost or synthetic fertilizer applications affected flavor and aroma intensity. The four treatments in the first experiment, arranged in a randomized complete block design with four replications, were: compost applied at 45 t ha\(^{-1}\); compost applied at 180 t ha\(^{-1}\); synthetic N applied at 110 kg ha\(^{-1}\); and a control receiving no amendment. In the second experiment, the compost applications were reduced by half and the synthetic fertilizer rate was doubled. Different basil cultivars were used for each experiment. Other methodology remained the same for both experiments. Leaves from the first four nodes of young shoots were used in the evaluations. Twelve trained panel members scored samples of three leaves from each treatment for aroma and flavor intensity using a linear scale, converted to a scale of 0-10 where 0 = much less intense than a reference sample (control), and 10 = much more intense than the reference. Significant differences between treatments in aroma intensity were found in the first experiment. Aroma scores were highest in samples from the compost and synthetic fertilizer treatments, and lowest in those from the control. Scores for aroma from the compost and synthetic fertilizer treatments were similar to each
other. Aroma intensity increased with increased rate of compost application. The increase in aroma intensity was possibly due to enhanced essential oil production in fertilized plants. No significant correlation was found between aroma intensity and plant tissue N content, sap NO$_3^-$ levels, or yield. No significant difference between treatments was found in flavor intensity in the first experiment, nor was there any significant treatment effect on flavor or aroma intensity in the second experiment. Fertilization may alter the post harvest quality of fresh basil and possible effects on product quality should be taken into account when making nutrient management decisions.

**Introduction**

Sensory quality of fresh produce is an important factor for consumers in making purchasing decisions (Misra and Huang, 1991). Sweet basil is a high value crop which is grown for the fresh market in Hawaii (Hamasaki et al., 1994), and any change in cultural practice which affects the quality of fresh basil may also affect its marketability. Basil is an herb frequently grown in Hawaii without the use of chemical fertilizers. Popular claims that organic fertilization improves the quality of fresh produce with respect to synthetic sources of plant nutrients are largely unfounded (Rader et al. 1985; Jeong et al., 1996; Woese et al., 1997). No studies have been conducted to determine the effect of fertilizer type and rate on the flavor or aroma of sweet basil. However, previous work has shown both type and rate of fertilizer to affect the content and composition of basil essential oil, the source of the herb's characteristic aroma and flavor (Alder et al, 1989; Simon et al, 1990; Youssef et al, 1998).
Thus, the objectives of this study on the sensory quality of fresh basil were to:

1) Generate information to qualify attributes of fresh basil flavor and aroma;
2) Determine if fertilization can affect the flavor and aroma intensity of fresh basil leaves;
3) Determine if a difference in aroma and flavor intensity can be detected between plants fertilized with compost compared to synthetic fertilizer.

**Materials and Methods**

Panel 1

Basil cv. Sweet Italian plants were grown in the Fall of 1998 under the conditions described in chapter 4 of this text. The treatments were: a control receiving no amendment; compost at 45 t ha\(^{-1}\); compost at 180 t ha\(^{-1}\); and synthetic N at 110 t ha\(^{-1}\). Seedlings were transplanted 10 August, 1999. The first application of synthetic fertilizer was as Gaviota 16-16-16 containing one third of nitrogen and all the P and K to be received. The remaining N was applied in two additional split applications of urea. The last application occurred 2 weeks prior to the taste panel evaluation. All the compost was applied one week prior to transplanting, 13 weeks before the panel evaluation. Plants were harvested nine times over a period of twelve weeks. Sensory evaluation was conducted 12 weeks after transplanting.
Shoots with 3-4 nodes were removed approximately six inches from the apex. These were placed in plastic bags and stored at approximately 20 C. Samples were removed from field blocks one and two for preparation and testing less than 24 and 48 hours respectively. Immediately following panel testing of block two, blocks three and four were harvested in the same manner.

Twelve panel members were trained for an hour on methods of evaluation. A modified difference from a reference test was used. Scoresheets were pre-labeled with panelist identification numbers and divided into two sections (Fig. 1). The top section was used to score aroma, the bottom to score taste. Each section contained four lines with anchor marks 10 cm apart; in the center of each line, 5 cm from either anchor, was a mark indicating the pre-determined score of the reference sample. Each line was preceded by a randomly selected 3-digit number corresponding with a labeled sample. Tests were conducted over four consecutive days, treatments within a single block being evaluated each day. Each panelist was given a reference sample, and a sample from each treatment. Presentation order was randomized. The reference sample was from the control treatment. Samples consisted of three leaves removed from their stems and rinsed with deionized water. Leaves within a sample were from the same treatment and block, but not necessarily from the same plant.

When evaluating for aroma intensity, panelists first macerated all the leaves in the reference, inhaling at close proximity to determine aroma intensity. The same was done for each of the four other samples, referring as needed to the reference sample. For taste intensity, all three leaves in a sample were chewed
at their proximal ends; water and unsalted crackers were provided between samples. Samples were scored for perceived aroma or taste intensity as compared to that of the reference. If intensity was identical to the reference, a mark was made at the center tick of the score line. If intensity was perceived to be less than the reference, a mark was made at an appropriate distance from the center tick; increasing distance from this center tick corresponded to a decrease in intensity. If intensity was perceived to be greater than the reference, a mark was made at an appropriate distance from the center tick; increasing distance from this center tick corresponded to an increase in intensity.

Using a ruler, sample scores were converted to a numerical value based on their distance from the left anchor mark; for example, a mark 3.4 cm from the left anchor was given a score of 3.4. An increase in the numerical score indicates an increase in intensity. Data was analyzed using the GLM procedure in SAS.

Panel 2

The plants were grown in the field as described in Chapter 5. Seven week-old seedlings were transplanted on 3 March, 1999. The variety used was ‘UH’ due to the leaf shape uniformity compared with that of ‘Sweet Italian’. This morphological uniformity was considered beneficial to minimize perceived variation by panelists due to leaf size and shape, and possible genetic variation as indicated by the variable morphology. The treatments were: a control receiving no amendment; compost at 23 t ha$^{-1}$; compost at 90 t ha$^{-1}$; and
synthetic N at 230 kg ha\(^{-1}\). Synthetic fertilizer treatment was applied as urea at 230 kg ha\(^{-1}\) in split applications. The last application was received 2 weeks before sensory evaluation.

Plants were harvested 12 times over twelve weeks. The sensory evaluation was conducted 20 weeks after transplanting. This second sensory panel was analyzed in the same way as the first.

**Results**

The fertilizer treatments significantly affected fresh basil aroma intensity, but not flavor intensity (Table 6.1). Aroma intensity was 20% higher in the treatments receiving compost and synthetic fertilizer than in the control (Table 6.2). Table 6.2 also shows a similar trend in flavor for increased intensity (7%) with fertilization compared to the control. This corresponded to a 7% increase in tissue N levels with fertilization; no significant correlation between flavor intensity and tissue N levels were found, however. Aroma intensity increased by 6% with the higher rate of compost application as compared to the lower rate. There was no difference in aroma intensity scores between the highest rate of compost application and the synthetic fertilizer treatment. Highest aroma scores were observed in the same treatments where higher tissue N and yield were recorded. However, no significant correlation was found between aroma score and tissue N concentration, sap nitrate levels, or yield in the compost and synthetic fertilizer treatments. Panelists noted variations in leaf size, shape, and color. Descriptive terms used by panelists are listed in tables 6.4 and 6.5. Aroma descriptors were
more negative in the C180 and urea plots than in the control and c45 plots (Table 6.3), while flavor descriptors were most positive in the c45 treatment (Table 6.4).

Analysis of variance and data from panel two is shown in Tables 6.5 & 6.6. No significant difference was found in taste or aroma intensity between any of the treatments. However, there was a trend for decreased flavor with increased fertilization, which was accompanied by a corresponding decrease in tissue N levels (Table 6.6). Scores for flavor were not significantly correlated with tissue N levels. Plants that samples were taken from were seriously affected by a decline related to nematode infestation and resulting root rot. As a result, some samples were small and/or chlorotic. Panelists noted variations in leaf size.

Discussion

Results from panel 1 indicate that fertilization may affect the sensory quality of basil. The increase of intensity with increasing amounts of compost, and the lack of intensity difference between the compost and synthetic fertilizer treatments indicate that nutrient availability plays a role in determining aroma intensity. The aromatic compounds found in basil are primarily terpenes and other hydrocarbons (Prakesh, 1992; Bettelheim and March, 1998; C. S. Tang, personal communication). Fertilization may increase the concentration of volatiles in basil due to increased enzyme activity in the fertilized plant (Youssef 1998). Some descriptors (sweet, minty, grassy, green, fresh) used
independently by panelists to qualify aroma follow those used by Sheen et al. (1991) to describe the aroma of individual basil oil constituents. This supports the suggestion that aroma changes resulting from fertilization may be due to changes in the essential oil content and composition. Aroma intensity scores from the c180 and urea treatments were the same. However, the marked difference between the number, type and frequency of terms used to describe the aroma of samples from the c180 and urea plots (Table 6.3) may indicate a quality difference between the two treatments not best measured by intensity. Panelists generally associated an increase in intensity with a decrease in desirability (Tables 6.3 and 6.4, personal communication). Positive, negative and neutral values assigned to the descriptors indicate that the aroma of samples from the urea plots may have been less desirable than that of samples from c180, while aroma from the c45 treatment was most desirable of all the fertilizer plots (Table 6.3). Data listed in Table 6.4 also indicates that the lower rate of fertilizer produced basil with the most desirable flavor. Therefore, lower rates of N fertilizer may increase fresh basil quality. Similarly, basil fertilized with compost may be of higher quality than that fertilized with urea. Cumulative yields obtained from the c45 plots were similar to that obtained with the higher rate of compost and synthetic fertilizer (Table 6.2). Therefore, 45 t ha\(^{-1}\) of compost may be the best of the fertilizer treatments, producing good yields of high quality fresh basil.

The lack of significance between flavor scores may be due to the inadequacy of measuring flavor intensity to account for the complexity of this quality. As shown in table 6.5, terms used to describe the flavor of basil involve a
mix of aromatic (e.g. anise, clove), gustatory (e.g. bitter, sour), and chemical (e.g. astringent) sensations (Meilgaard et al., 1989). Evaluations of fresh basil flavor may therefore be better conducted by focusing on specific qualities, such as bitterness.

Results from panel 2 cannot be directly compared to those from panel 1, as the experimental conditions were different (i.e. different compost quality an rate, and different cultivars). Failure to find a significant difference between treatments may indicate that there was no treatment effect on sensory quality in this experiment. However, severe root rot and the resulting plant decline observed in the variety 'UH' (data not shown) in the second experiment is likely to have confounded any possible treatment effects.

Conclusions

Results from one of the two experiments indicate that fertilization can affect the sensory quality of fresh basil leaves. Aroma intensity increased with the rate of fertilization in the first experiment. Changes in aroma intensity were the same for the compost and synthetic fertilizer treatments, although some aroma quality characteristics possibly affected by nutrient source may not be best measured by overall aroma intensity. Intensity may not be an adequate measure of fresh basil flavor; evaluating a specific taste quality (e.g. bitterness) is likely to be more appropriate. Results from two separate experiments varied, and may reflect the influence of environmental and genotypic factors. Growers should be
aware that cultural practices may affect the postharvest quality of basil.

Increased fertilization of basil may result in increased aroma intensity of the fresh product, which was a characteristic considered undesirable by some evaluators.

**Literature Cited**


Florida.

Rader, J. S., R. H. Walser, C. F. Williams, and T. D. Davis. 1985. Organic and
conventional peach production and economics. Biological Agriculture and
Horticulture. 2:215-222.

found in the essential oil of *Ocimum basilicum* L. with sensory evaluation and

press, Portland, OR.

and conventionally grown foods- results of a review of the relevant literature. J.

basil green ruffles (*Ocimum basilicum* L.) to nitrogen fertilization in different soil
Table 6.1. Analysis of variance for aroma and flavor intensity of fresh basil leaves in Fall, 1998

<table>
<thead>
<tr>
<th>Source</th>
<th>df</th>
<th>Aroma Intensity</th>
<th>Taste Intensity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Treatment</td>
<td>3</td>
<td>*</td>
<td>ns</td>
</tr>
<tr>
<td>block (field)</td>
<td>3</td>
<td>ns</td>
<td>ns</td>
</tr>
<tr>
<td>Judge</td>
<td>11</td>
<td>**</td>
<td>**</td>
</tr>
<tr>
<td>Treatment*block</td>
<td>9</td>
<td>ns</td>
<td>ns</td>
</tr>
<tr>
<td>Treatment*judge</td>
<td>33</td>
<td>ns</td>
<td>ns</td>
</tr>
<tr>
<td>Error</td>
<td>124</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*ns, **Nonsignificant or significant at P<0.05, 0.01, respectively

Table 6.2. Effect of fertilizer treatments on sensory scores of 1st panel. Corresponding tissue nutrient levels and yield are also listed. Values within a column having the same letter are not significantly different from each other at P<0.05 as determined by Duncan's New Multiple Range Test.

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Flavor score</th>
<th>Aroma score</th>
<th>Mean Tissue Nitrogen(%)</th>
<th>Mean Sap Nitrate-N (mg L⁻¹)</th>
<th>Yield (kg ha⁻¹) at Sample Date</th>
<th>Total Yield (kg ha⁻¹)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
<td>5.4a</td>
<td>4.4b</td>
<td>4.3c</td>
<td>715b</td>
<td>1647a</td>
<td>8785b</td>
</tr>
<tr>
<td>C45</td>
<td>5.8a</td>
<td>5.0ab</td>
<td>4.6a</td>
<td>735b</td>
<td>2265a</td>
<td>12080a</td>
</tr>
<tr>
<td>C180</td>
<td>5.8a</td>
<td>5.3a</td>
<td>4.5b</td>
<td>671b</td>
<td>2162a</td>
<td>13178a</td>
</tr>
<tr>
<td>Synthetic</td>
<td>5.7a</td>
<td>5.3a</td>
<td>4.6a</td>
<td>954a</td>
<td>2368a</td>
<td>12080a</td>
</tr>
</tbody>
</table>
Table 6.3. Descriptors used independently by panelists to qualify fresh basil aroma, panel 1. Frequency of usage for each treatment in parentheses.

<table>
<thead>
<tr>
<th></th>
<th>Control</th>
<th>C45</th>
<th>C180</th>
<th>Urea</th>
</tr>
</thead>
<tbody>
<tr>
<td>light/fresh</td>
<td>(2)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>green</td>
<td>(1)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>clove</td>
<td>(1)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>light/pleasant</td>
<td>(1)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>wintergreen</td>
<td>(1)</td>
<td></td>
<td>sweet (2)</td>
<td>sweet (4)</td>
</tr>
<tr>
<td>grassy</td>
<td>(1)</td>
<td></td>
<td>licorice (2)</td>
<td>clove (3)</td>
</tr>
<tr>
<td>best</td>
<td>(1)</td>
<td></td>
<td>green (1)</td>
<td>anise (1)</td>
</tr>
<tr>
<td>minty</td>
<td>(1)</td>
<td></td>
<td>medicinal (1)</td>
<td>leafy (1)</td>
</tr>
<tr>
<td>best</td>
<td>(1)</td>
<td></td>
<td>medicinal (1)</td>
<td></td>
</tr>
<tr>
<td>worst</td>
<td>(1)</td>
<td></td>
<td>worst (1)</td>
<td></td>
</tr>
</tbody>
</table>

-1, -2, +, +2, 0 Assumed to be negative, strongly negative, positive, strongly positive, and neutral qualities, respectively.

\( ^a \) The sum of the above quality designations within the treatment.
Table 6.4. Terms used independently by panelists to qualify fresh basil flavor, panel 1. Frequency of usage for each treatment in parentheses

<table>
<thead>
<tr>
<th>Term</th>
<th>Control</th>
<th>C45</th>
<th>C180</th>
<th>Urea</th>
</tr>
</thead>
<tbody>
<tr>
<td>bitter (2)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>sweet (2)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>grassy (1)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>medicinal/wintergreen (1)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>licorice (1)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>minty (1)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>strong/unpleasant (1)</td>
<td>-2</td>
<td>0</td>
<td>-2</td>
<td>-6</td>
</tr>
<tr>
<td>pleasant (1)</td>
<td>+</td>
<td>0</td>
<td>+2</td>
<td>-6</td>
</tr>
</tbody>
</table>

-3<sup>a</sup>  0  -6  -6

<sup>a</sup> -2, +, +2, 0 Assumed to be negative, strongly negative, positive, strongly positive, and neutral qualities, respectively.

<sup>a</sup> The sum of the above quality designations within the treatment.
Table 6.5. Analysis of variance for aroma and flavor intensity of fresh basil leaves in Spring, 1999.

<table>
<thead>
<tr>
<th>Source</th>
<th>df</th>
<th>Aroma Intensity</th>
<th>Taste Intensity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Treatment</td>
<td>3</td>
<td>ns</td>
<td>ns</td>
</tr>
<tr>
<td>block (field)</td>
<td>3</td>
<td>*</td>
<td>ns</td>
</tr>
<tr>
<td>Judge</td>
<td>11</td>
<td>**</td>
<td>**</td>
</tr>
<tr>
<td>Treatment*block</td>
<td>9</td>
<td>ns</td>
<td>ns</td>
</tr>
<tr>
<td>Treatment*judge</td>
<td>33</td>
<td>ns</td>
<td>ns</td>
</tr>
<tr>
<td>Error</td>
<td>124</td>
<td>ns, *, **</td>
<td>Nonsignificant of significant at P&lt;0.05, 0.01, respectively</td>
</tr>
</tbody>
</table>

Table 6.6. Effect of fertilizer treatments on 1st panel sensory scores. Corresponding tissue nutrient levels and yield are also listed. Values within a column having the same letter are not significantly different from each other at P=0.05 as determined by Duncan’s multiple range test.

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Flavor score</th>
<th>Aroma score</th>
<th>Mean Tissue Nitrogen(%)</th>
<th>Mean Sap Nitrate-N (ppm)</th>
<th>Yield (kg ha) at Sample Date</th>
<th>Total Yield (kg ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
<td>4.9a</td>
<td>4.6a</td>
<td>3.6a</td>
<td>443a</td>
<td>1600</td>
<td>10338b</td>
</tr>
<tr>
<td>C-25</td>
<td>4.9a</td>
<td>4.9a</td>
<td>3.6a</td>
<td>553a</td>
<td>2100</td>
<td>15932ab</td>
</tr>
<tr>
<td>C-100</td>
<td>4.8a</td>
<td>4.6a</td>
<td>3.4a</td>
<td>350a</td>
<td>1300</td>
<td>19210a</td>
</tr>
<tr>
<td>Synthetic</td>
<td>4.6a</td>
<td>4.9a</td>
<td>3.3a</td>
<td>418a</td>
<td>1400</td>
<td>12396ab</td>
</tr>
</tbody>
</table>
Figure 6.1. Scoresheet used by panelists in the first sensory evaluation of basil, Fall 1998.
Figure 6.2. Scoresheet used by panelists in the second sensory evaluation of basil, Summer 1999.
CHAPTER 7
GENERAL DISCUSSION

Introduction

Three experiments were conducted at the The University of Hawaii Waimanalo experiment station between April, 1998 and December, 1999 to evaluate the response of basil to applications of locally available organic and synthetic fertilizers.

The first experiment (Chapter 3) was conducted in the Spring of 1998. The treatments were: a control receiving no amendment; locally obtained, aged chicken manure applied at 5 t ha\(^{-1}\) fresh weight in beds with a five year history of both annual compost and urea applications (25 t ha\(^{-1}\) + 100 kg ha\(^{-1}\) respectively); locally obtained, aged chicken manure applied at 5 t ha\(^{-1}\) fresh weight in beds with a history of annual compost applications (25 t ha\(^{-1}\)); 100 kg ha\(^{-1}\) nitrogen applied as urea in plots with a five year history of annual urea applications. Data collected in this experiment included marketable yield and tissue N levels.

The second experiment (Chapter 4) was conducted in the same location and immediately following the first. The treatments for this experiment were: a control receiving no amendment; on-farm produced compost applied at 45 t ha\(^{-1}\) fresh weight in beds with a history of both compost and urea applications (25 t ha\(^{-1}\) + 100 kg ha\(^{-1}\) respectively) annually; the same compost applied at 180 t ha\(^{-1}\) fresh weight in beds with a history of annual compost applications (25 t ha\(^{-1}\)); 110
kg ha\(^{-1}\) nitrogen applied as urea. Data collected included marketable yield, tissue N and sap nitrate-N levels, nematode counts and organic carbon levels in the soil, galling and health indexes of plant roots, and sensory panel scores for fresh leaf taste and aroma intensity. Immediately following this experiment, sunnhemp (\textit{Crotolaria juncea}) cv. Tropic Sun was planted at a rate of 60 kg ha\(^{-1}\) in an effort to reduce nematode pressure on the next basil crop.

The third experiment (Chapter 5) was conducted in the same location in the Spring, 1999. Treatments for the third experiment were: a control receiving no amendment; on-farm produced compost applied at 23 t ha\(^{-1}\) fresh weight; the same compost applied at 90 t ha\(^{-1}\) fresh weight; 230 kg ha\(^{-1}\) nitrogen applied as urea. Data collected during this experiment included marketable yield, tissue N and sap nitrate-N levels, soil nematode counts, soil organic carbon, salinity and pH levels, galling and health indexes of plant roots, and sensory panel scores for fresh leaf taste and aroma intensity.

The three experiments have previously been discussed individually in this thesis; the purpose of this chapter is to discuss the results of the individual trials as they relate to each other. This general discussion will focus on data from all three experiments pertaining to yield, pest (nematodes and \textit{Fusarium} wilt) incidence, soil quality, plant nutrient status, and fresh basil sensory quality. Future research needs are also discussed.
Yield

Yield of all basil cultivars was increased with compost and chicken manure applications with respect to the control. These results agree with other studies which have shown chicken manure and compost to be effective tools to manage soil fertility in vegetable production (Roe, 1998; Verma, 1995). The magnitude of yield increase varied with cultivar and amendment. This variation was due primarily to a differential response of cultivars to pest pressure.

The N removed by the highest yielding plants in all experiments was 69-78 kg ha$^{-1}$. This indicates that general fertilizer recommendations of 130 kg ha$^{-1}$ N for basil are adequate for good yields. Differences in N uptake between pest-free cultivars was small; highest yielding plants of 'UH' removed 70 kg ha$^{-1}$ N over 75 days, while cv. Sweet removed 71 kg ha$^{-1}$ N in 100 days. However, N uptake was affected by disease incidence; plants of 'UH' exhibiting symptoms of root rot removed 45 kg ha$^{-1}$ N over 100 days. Residual N from previous organic amendment applications was likely available to the crop, and may have been as much as 86 kg ha$^{-1}$ N (Chapter 4). However, control plants receiving no amendment removed as much N as plants receiving 64-80 kg ha$^{-1}$ synthetic N (Chapters 3-5). This indicates a source of N unaccounted for (i.e. improved mycorrhizal associations in the control plots, mineralization of soil organic matter, movement of mineral $\text{NO}_3^-$ from fertilizer plots, etc). It is difficult to estimate the contribution this unaccounted for N source made to the N removed from the fertilizer plots.
In the first experiment, plants were supplied with 25 kg ha\(^{-1}\) plant available N in the CM5 and CM5(urea) treatments and removed 248% and 280%, respectively of that N, while Urea removed 70% of the N supplied as urea. The estimated residual N in the CM5 and CM5(urea) plots remaining from previous compost applications were 37 and 46 kg ha\(^{-1}\) respectively. In the second experiment, plants were supplied with 24 and 95 kg ha\(^{-1}\) in the C45 and C180 plots, respectively. 279% of the N supplied was removed by the C45 treatment, with residual N estimated at 43 kg ha\(^{-1}\). 75% of the N supplied was removed by the c180 treatment, indicating lower N use efficiency for this treatment. Plants in this treatment were disease free. Utilization of supplied compost was higher in both compost treatments than in the urea treatments (61%). Results from the third experiment were similar, with plants receiving the lower rate of compost (23 kg ha\(^{-1}\)) removing a greater percentage of N applied than plants receiving 90 kg ha\(^{-1}\) compost or 230 kg ha\(^{-1}\) synthetic N (144%, 40% and 21%, respectively). Again, the plants receiving the lower compost rate were most efficient in utilizing N supplied, while plants receiving urea were least efficient. 21 kg ha\(^{-1}\) was the estimated amount of residual N available to the plants in the lower rate compost plots. Results from all three experiments indicate that N use efficiency is greatest in plants receiving moderate rates of organic fertilizers. Residual N available to basil plants in the first, second and third experiment were estimated to be 37, 23, and 21 kg ha\(^{-1}\), respectively.

Highest yields were obtained in the cultivar ‘Sweet Italian’. The higher rate of compost applications increased yields of this cultivar above those
obtained with both the lower compost rate and synthetic fertilizer (fig. 7.1).

However, the higher yield per unit of N applied observed in the lower compost rate treatments (Table 7.1) indicates that plants made most efficient use of the N applied in the lower rate of compost. The yield difference between compost rates was greater when compost 2 (1.2% N, 13.3% C) was used than with application of compost 1 (0.3%, 4% C), and is probably due to differences in compost quality, particularly with respect to the N and organic matter content. These two qualities often determine the effectiveness of compost as a fertilizer (Eberseder, 1996; Ozores-Hampton et al., 1998). ‘Sweet’ exhibited no serious pest problems in the field. Yield obtained with synthetic fertilizer applications were similar to those obtained with lower rates of compost applications.

As with the previous cultivar, ‘Thai Siam Queen’ responded well to compost applications (figure 7.2.), with yields being highest at the highest compost application rate, and the difference between rates greatest when the higher N and C compost was used. Yield in the synthetic fertilizer treatment was markedly lower (25-300%) than that from the compost plots (Fig7.2). This difference in yield was associated with a higher incidence of Fusarium disease observed in the urea treatments.

The cultivar UH varied greatest among the varieties with respect to yield response to compost applications (figure 7.3.). This variation was attributed to this cultivar's apparent sensitivity to root knot nematode infestation. The planting established in the Spring 1998 was the first basil planting in this location in years, and the crop was observed to be relatively disease free for the short time (~10
weeks) it remained in the field. Yields obtained with 5 t ha\(^{-1}\) of chicken manure were greater than those in the controls, and similar to those obtained with applications of 100 kg ha\(^{-1}\) of synthetic N as urea. Vigor of UH was markedly reduced in the second and third experiment, most probably due to increased nematode attack. Applications of urea and the higher rate of compost 1 decreased yields with respect to the lower compost 1 rate (fig. 7.3). High applications of compost 2 increased cumulative yield with respect to the other treatments. This effect was due to high yields obtained during the first few weeks of harvest, which then rapidly declined (fig. 7.4). This trend for declining yields with high compost applications was observed with applications of compost 1 as well (fig. 5). The period of initially high yields in the second compost experiment was more likely due to reduced nematode populations resulting from planting Crotolaria juncea ‘Tropic Sun’ between the second and third experiment, than from differences in compost quality. C. juncea has been shown to be a poor host to root knot nematodes (Sipes and Arakaki, 1997). This yield decline was associated with high root galling index scores, and low root health index scores.

**Nematodes**

Final soil plant parasitic nematode levels were low in the first basil planting, but increased in subsequent plantings (fig. 7.6). Treatments were not found to have a significant effect on soil nematodes counts in any experiment. However, the severity of root galling measured using a root gall index was
significantly affect by fertilizer applications. Root galling was greater in plants receiving fertilizer than those from the control plots and the severity of root galling generally increased with increased compost application rate (fig. 7.7). Increased nematode attack in plants receiving higher nutrient levels as indicated by high galling index scores is probably a result of greater initial plant vigor and root growth. ‘UH’ had higher mean galling index scores than ‘Sweet’ or ‘Thai’ and was the only cultivar to exhibit severe symptoms of nematode decline as indicated by low root health associated with high root galling index scores (fig 7.8.). Use of cultivars such as 'Sweet' and 'Thai' which were found to be tolerant to root knot nematodes, was adequate to avoid serious crop losses due to this pest.

**Fusarium**

Disease caused by *Fusarium oxysporum* was observed to affect yield only in ‘Thai’. Yield in the urea treatment was 25-300% lower than that from the compost plots (Fig7.2). Incidence of the disease was greatest in the plots receiving urea (58% of plants infected) and positively related to an increased predominance of NH$_4^+$ to NO$_3^-$ in the soil, and associated with a significantly lower pH value in the urea plots with respect to the other treatments. This supports the findings of others who have reported increased pathogenicity of *Fusarium oxysporum* in response to the addition of NH$_4^+$ or to a reduction in the soil pH (Woltz and Jones, 1978; Scher et al., 1980). Compost applications
probably resulted in indirect suppression of the disease due to a combination of increased plant vigor and maintenance of soil pH.

**Soil quality**

Soil properties prior to and at the completion of the experiment are listed in Table 7.2. The higher rate of compost applications increased soil organic carbon over the course of the three basil plantings, while OC levels were maintained with lower rates of compost, and decreased in the control and urea plots where no organic amendment was added. Removal of organic carbon from the system without returning organic matter to the soil will result in decreasing organic matter levels (Bevaqua and Mellano, 1994). Compost is therefore a fertilizer which can increase soil organic matter relative to synthetic fertilizer treatments. Another interesting trend observed was a decrease in soil K in the urea plots, while soil K increased with the higher rate of compost applications. Although K deficiency was not observed in the urea treatment, it may become necessary to add K fertilizer to replace that removed by the crop. Conversely, the increase in soil K with the application of large amounts of compost indicate the possibility of excess soil nutrient levels when organic amendments are used. Frequent soil samples are therefore important in order to monitor soil nutrient levels when frequently applying compost. Soil analysis in the final experiment demonstrated that soil pH was maintained (i.e. not different from the control) with compost applications. Soil pH was significantly lower in the urea plots than in the
plots receiving compost or no fertilizer. This observation is similar to that of Buchanan and Gleissman (1991) who found applications of ammonium sulfate to significantly reduce soil pH relative to a control and compost treatments. Applications of a chicken manure plus woodchips compost increased soil electrical conductivity (EC), indicating that soil salinity may be a concern with frequent and repeated applications of a manure based compost. Silva et al. (1994) also found soil EC to increase with incorporation of a chicken manure and woodchip based compost.

**Plant tissue N and Sap NO$_3^-$-N concentrations**

Plant tissue N and sap NO$_3^-$-N were increased with applications of compost in these experiments, indicating that improved growth in these treatments was due in part to a N effect. Sap NO$_3^-$-N concentration of basil shoots was found to be a slightly more sensitive indicator of plant nutrient status and more responsive to fertilizer treatment than total N concentration of the most recently matured leaves. These findings agree with those of Huett and Rose (1989) and Olsen and Lyons (1994). Sap nitrate levels were higher in plants receiving urea applications than those grown with compost, without a corresponding increase in yield, indicating that compost may be an effective fertilizer for reducing nitrate levels in vegetables. The best correlations between sap nitrate-N levels, tissue N, and yield occurred 65 days after transplanting. Only in 'UH' was a correlation between tissue N levels and yield observed, with
highest yields corresponding with tissue N levels between 4.5-4.8%. This range is slightly lower than values reported by Youssef et al. (1998), who found maximum yield of basil cv. Green Ruffles to be associated with tissue N levels greater than 4.9%. Sap nitrate-N was correlated with yield in 'UH' and 'Sweet'. Highest yields in 'Sweet' occurred at sap nitrate-N levels below 800 mg L$^{-1}$. Highest yields in 'UH' corresponded to sap nitrate-N levels between 600-900 mg L$^{-1}$. Sap nitrate-N levels were significantly different between cultivars, emphasizing the need for critical range development on a cultivar basis. Levels of other nutrients were found to be adequate for production of leafy vegetables (Tables 7.3 and 7.4).

Sensory quality

Increased aroma intensity of fresh basil was observed with application of fertilizers, with no difference in intensity observed between compost and urea treatments. This effect is likely due at least in part to increased plant vigor and related production of essential oils as a result of fertilization. Flavor intensity was not affected by fertilizer treatment, and it was determined that evaluation of specific qualities such as ‘bitterness’ is probably more appropriate than over-all intensity as an indicator of flavor of fresh basil as affected by fertilization. Descriptors used by panelists indicate lower rates of N fertilizer may increase
fresh basil quality. Similarly, basil fertilized with compost may be of higher quality than that fertilized with urea.

**Concluding Statement**

Basil may be grown organically with compost as the sole fertilizer to produce yields comparable, or exceeding those obtained with recommended synthetic N rates. Compost applied at moderate rates (i.e. 25 t ha\(^{-1}\)) generally resulted in the least disease problems, and the most efficient use of fertilizer N. Results from all three experiments indicate that N use efficiency is greatest in plants receiving moderate rates of organic fertilizers. Residual N available to basil plants in the first, second and third experiment were estimated to be 37, 23, and 21 kg ha\(^{-1}\), respectively.

Cultivar selection for disease resistance and high yields is important for commercial production of basil. With the appropriate cultivar, compost rates as high as 90 t ha\(^{-1}\) may be used to maximize yield. N removal data indicates that the current recommendations of approximately 130 kg ha\(^{-1}\) N is adequate for basil production in Hawaii.

Very little work has been published on the sap nitrate-N or tissue levels of basil, and work to develop critical nutrient ranges for basil should continue. While it would be premature to make grower recommendations based on the observations recorded here, some conclusions may be made. First, sap nitrate-N was positively correlated with tissue N indicating its potential usefulness for
basil growers in fertility management. Also, sap nitrate levels varied with
genotype; further studies should be done on a cultivar by cultivar basis. Finally,
urea applications increased basil nitrate content compared with the control while
compost applications produced high yields and no increase in plant nitrate levels.

Important soil qualities may be affected by fertilizer use. Applications of
urea significantly reduced pH, while compost did not. In fact, compost showed a
trend to increase soil pH. Although all of the pH values recorded here were
within the optimum range for crop growth, it may be possible to apply compost to
acidic tropical soils to improve plant growth and raise soil pH with reduced use of
additional amendments such as lime. After five years of annual fertilizer
applications, salinity levels in all treatment plots were within acceptable range for
plant growth. However, soil salinity was higher in plots receiving the highest
rates of fertilizer, so regular soil testing is recommended to monitor soil EC levels
when applying high rates of compost. Compost applications increased soil
organic matter, while there was a trend for decreased organic matter in the plots
not receiving compost. The increase in soil organic matter was greatest with the
higher rates of compost application. Therefore, while lower rates of compost
may applied for optimum nutrient use efficiency, initial or occasional application
of higher compost rates may be used to increase soil organic matter. Finally,
lower rates of N fertilizer may increase fresh basil quality. Similarly, basil
fertilized with compost may be of higher quality than that fertilized with urea.
Compost use has great potential to improve vegetable production in Hawaii. This project has highlighted the need for increased research in the following areas:

1. Extended field trials to determine the response of vegetable crops to multiple rates (5-6) of compost at various locations in the State.
2. Detailed study of pest population dynamics as affected by fertilizer type and rate of application under field conditions in Hawaii.
3. The potential of compost as a fertilizer to reduce nitrate levels in other leafy vegetables relative to synthetic fertilizer applications.
4. Efficient and inexpensive methods of on-farm compost production to reduce the cost discrepancy between compost and synthetic fertilizers.
5. Continued research to determine the most cost effective and crop use efficient combination of synthetic plus organic fertilizer.
Literature Cited


Table 7.1. Treatment effect on nitrogen use efficiency of basil cv. Sweet in Fall 1998 and Spring 1999. Values are means of four replications. Control= No amendment, C45= compost applied at 45 t ha\(^{-1}\) in plots with a history of compost applications. C180= compost applied at 180 t ha\(^{-1}\) in plots with a history of compost applications plus urea. C23= Compost applied at 23 t ha\(^{-1}\) in beds previously receiving 90 t ha\(^{-1}\) compost, C90= Compost applied at 90 t ha\(^{-1}\) in beds previously receiving 180 t ha\(^{-1}\), Urea=110 and 230 kg t ha\(^{-1}\) N applied as urea for Fall 1998 and Spring 1999, respectively.

<table>
<thead>
<tr>
<th>Date</th>
<th>Treatment</th>
<th>Cumulative Yield (kg ha(^{-1}))</th>
<th>N applied (kg ha(^{-1}))</th>
<th>Yield per unit of N (kg ha(^{-1}))</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fall 1998</td>
<td>control</td>
<td>8785</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td></td>
<td>C45</td>
<td>12080</td>
<td>24</td>
<td>503</td>
</tr>
<tr>
<td></td>
<td>C180</td>
<td>13178</td>
<td>95</td>
<td>139</td>
</tr>
<tr>
<td></td>
<td>urea</td>
<td>12080</td>
<td>110</td>
<td>110</td>
</tr>
<tr>
<td>Spring 1999</td>
<td>control</td>
<td>14825</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td></td>
<td>C23</td>
<td>17711</td>
<td>48</td>
<td>369</td>
</tr>
<tr>
<td></td>
<td>C90</td>
<td>25147</td>
<td>193</td>
<td>130</td>
</tr>
<tr>
<td></td>
<td>urea</td>
<td>16727</td>
<td>230</td>
<td>73</td>
</tr>
</tbody>
</table>
Figure 7.1. Effect of treatments on cumulative yield of ‘Sweet’. Yield for each treatment is represented as percent of that obtained in the control plots. Compost 1 was applied in Fall 1998 and contained 4% and 0.3% total organic carbon and N, respectively. Compost 2 was applied in Spring 1999 and contained 14% and 1.2% total organic C and N, respectively.
Figure 7.2. Effect of treatments on cumulative yield of ‘Thai’. Yield for each treatment is represented as percent of that obtained in the control plots. Compost 1 was applied in Fall 1998 and contained 4% and 0.3% total organic carbon and N, respectively. Compost 2 was applied in Spring 1999 and contained 14% and 1.2% total organic C and N, respectively.
Figure 7.3. Effect of treatments on cumulative yield of ‘Sweet’. Yield for each treatment is represented as percent of that obtained in the control plots. Compost 1 was applied in Fall 1998 and contained 4% and 0.3% total organic carbon and N, respectively. Compost 2 was applied in Spring 1999 and contained 14% and 1.2% total organic C and N, respectively.
Figure 7.4. Yield trend of ‘UH’ over time in Fall ’98. Line equations are: control, $y = -8.17x^2 + 227.96x - 600.96$; C45, $y = -14.71x^2 + 340.72x - 658.15$; C180, $y = -21.04x^2 + 362.17x - 508.42$; urea+, $y = -19.41x^2 + 455.31x - 1641.3$.
Figure 7.5. Yield trend of ‘UH’ over time in Fall '98 (top) and Spring '99. Line equations are: control, \( y = -1.4418x^2 + 119.04x - 352.52 \); C23, \( y = -4.73x^2 + 183.57x - 95.85 \); C90, \( y = -23.91x^2 + 530.76x - 880.29 \); urea, \( y = -28.06x^2 + 745.38x - 3544.20 \).
Figure 7.6. Effect of fertilizer treatment on mean plant parasitic nematode levels at the end of each experiment.

Values are means of four replications.
Figure 7.7. Root Gall Index by treatment for two experiments. Values are means of four replications. Root Gall Index: 1 = 0-20% of roots galled, 2 = 21-40% of roots galled, 3 = 41-60% of roots galled, 4 = 61-80% of roots galled, 5 = 81-100% of roots galled.
Figure 7.8. Mean Gall and Root Health Index scores of ‘UH’. High gall scores correspond with low root health scores in all treatments of both experiments. Root Gall Index: 1= 0-20% of roots galled, 2= 21-40% of roots galled, 3= 41-60% of roots galled, 4= 61-80% of roots galled, 5= 81-100% of roots galled. Root health index: 1= Dead 2= Severe decline 3= Moderate decline 4= Mild decline 5= No decline.
Figure 7.9. Effect of fertilizer applications on soil organic carbon content (%). Values are means of four replications.
Table 7.2. Fertilizer treatment effect on selected chemical properties of treatment soil prior first experiment (Feb. 1999), and immediately following the third (Aug. 1999).

<table>
<thead>
<tr>
<th>Treatment</th>
<th>OC (%)</th>
<th>pH</th>
<th>EC (dS m$^{-1}$)</th>
<th>P (mg L$^{-1}$)</th>
<th>K (mg L$^{-1}$)</th>
<th>Ca (mg L$^{-1}$)</th>
<th>Mg (mg L$^{-1}$)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Jan 1998</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
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<td>7.0</td>
<td>0.1</td>
<td>319</td>
<td>420</td>
<td>4700</td>
<td>1100</td>
</tr>
<tr>
<td>Low compost</td>
<td>2.3</td>
<td>6.7</td>
<td>0.1</td>
<td>91</td>
<td>460</td>
<td>4575</td>
<td>1100</td>
</tr>
<tr>
<td>High compost</td>
<td>2.3</td>
<td>7.4</td>
<td>0.1</td>
<td>240</td>
<td>460</td>
<td>4700</td>
<td>1200</td>
</tr>
<tr>
<td>Urea</td>
<td>2.4</td>
<td>6.8</td>
<td>0.1</td>
<td>395</td>
<td>540</td>
<td>4600</td>
<td>1100</td>
</tr>
<tr>
<td><strong>Aug 1999</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Control</td>
<td>2</td>
<td>7.2</td>
<td>0.27</td>
<td>296</td>
<td>344</td>
<td>5040</td>
<td>1468</td>
</tr>
<tr>
<td>Low compost</td>
<td>2.3</td>
<td>7.4</td>
<td>0.29</td>
<td>120</td>
<td>500</td>
<td>5564</td>
<td>1422</td>
</tr>
<tr>
<td>High compost</td>
<td>2.7</td>
<td>7.5</td>
<td>0.33</td>
<td>152</td>
<td>830</td>
<td>5736</td>
<td>1466</td>
</tr>
<tr>
<td>Urea</td>
<td>2</td>
<td>6.4</td>
<td>0.19</td>
<td>177</td>
<td>192</td>
<td>4380</td>
<td>1346</td>
</tr>
</tbody>
</table>
Table 7.3. Fertilizer effect on tissue nutrient analysis of most recently matured basil leaves 55 days after transplanting (cv. UH). Samples were composites of four replications. CM5= chicken manure applied at 5 t ha\(^{-1}\) in plots with a history of 10 t ha annual compost applications. CM5(urea)= chicken manure applied at 5 t ha\(^{-1}\) in plots with a history of 10 t ha annual compost applications plus urea. Urea= 100 kg N ha\(^{-1}\) applied as urea in plots with a history of annual urea applications of 100-300 kg N ha\(^{-1}\). Control= no amendment.

<table>
<thead>
<tr>
<th>Treatment</th>
<th>P</th>
<th>K</th>
<th>Ca</th>
<th>Mg</th>
<th>Na</th>
<th>Mn</th>
<th>Fe</th>
<th>Cu</th>
<th>Zn</th>
<th>B</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
<td>0.53</td>
<td>2.34</td>
<td>2.42</td>
<td>0.71</td>
<td>0.07</td>
<td>57</td>
<td>229</td>
<td>18</td>
<td>43</td>
<td>22</td>
</tr>
<tr>
<td>CM5(urea)</td>
<td>0.48</td>
<td>2.88</td>
<td>2.57</td>
<td>0.72</td>
<td>0.02</td>
<td>84</td>
<td>353</td>
<td>18</td>
<td>50</td>
<td>25</td>
</tr>
<tr>
<td>CM5</td>
<td>0.54</td>
<td>2.48</td>
<td>2.36</td>
<td>0.66</td>
<td>0</td>
<td>67</td>
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<td>24</td>
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<tr>
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<td>2.69</td>
<td>2.2</td>
<td>0.67</td>
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Table 7.4. Fertilizer effect on tissue nutrient analysis of most recently matured basil leaves 65 days after transplanting (cv. Sweet). Samples were composites of four replications. C45= compost applied at 45 t ha\(^{-1}\) in plots with a history of compost applications. C180= compost applied at 180 t ha\(^{-1}\) in plots with a history of compost applications plus urea. Urea= 110 kg ha\(^{-1}\) N applied as urea in plots with a history of annual urea applications of 100-300 kg ha\(^{-1}\) N. Control= no amendment.

<table>
<thead>
<tr>
<th>Treatment</th>
<th>P</th>
<th>K</th>
<th>Ca%</th>
<th>Mg</th>
<th>Na</th>
<th>Mn</th>
<th>Fe</th>
<th>Cu mg kg(^{-1})</th>
<th>Zn</th>
<th>B</th>
</tr>
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<tbody>
<tr>
<td>Control</td>
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<td>2.67</td>
<td>0.71</td>
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<td>80</td>
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<tr>
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<td>2.78</td>
<td>0.72</td>
<td>0.23</td>
<td>94</td>
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<td>62</td>
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<tr>
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<td>2.71</td>
<td>0.79</td>
<td>0.21</td>
<td>93</td>
<td>775</td>
<td>25</td>
<td>55</td>
<td>28</td>
</tr>
<tr>
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<td>3.37</td>
<td>2.65</td>
<td>0.68</td>
<td>0.28</td>
<td>76</td>
<td>687</td>
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