THE USE OF COTTONSEED MEAL WITH OR WITHOUT SOAPSTOCK OR CANOLA MEAL WITHOUT SOAPSTOCK AS AN ORGANIC FERTILIZER

By

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INTRODUCTION

The world's population has grown from 1.6 billion in the early 1900s to 6.8 billion in 2009 and is projected to increase at a growth rate of about 1.2%, possibly reaching 9 billion in 2050 (FAO, 2008). As population increases so does the need for food and high yield crops. Fertilizers are used to amend the soil and improve crop yields which generate more quantities of food to feed our growing population. According to estimates by the FAO (2008), global use of fertilizers increased from about 31.1 million metric tons in 1961 to 141.2 million metric tons in 2002, this trend will likely continue because of our growing population and increasingly degrading soils.

Plant growth and reproduction are dependent on nutrients. Essential elements are required by all plants to complete their life cycle, can not be substituted by any other element, and are required by all plants (Barker, 2007). Application of fertilizers can help provide supplementary nutrients for crops and can increase yields.

The practice of adding plant and animal residues to soil was first discovered by ancient farmers who understood that decaying material provided benefits for their crops. Fertilizers can provide additional nutrients for plants when the soil is deficient. Population increase led to a necessity for the extensive applications of fertilizer we employ today. Introduction of synthetic fertilizers during the agricultural revolution after the 17^{th} century enabled farmers to improve their soil nutrient content and produce higher

yielding crops. The use of organic fertilizers decreased because of the introduction of synthetic fertilizers. Synthetic fertilizers are often more concentrated, soluble, and easier to apply to large areas of cropland than organic fertilizers. Development of landfills for disposal of waste also made the recycling of organic wastes less desirable since it was cheaper to dispose in landfills than reapply to soils as a nutrient source (Goldstein, 2001). In recent years, consideration for recycling organic residues has increased. Consumers are demanding products grown without the use of chemicals which includes synthetic fertilizers (Goldstein, 2001). Government agencies are also pushing for the redistribution of residues to keep them from accumulating and polluting our environment (Goldstein, 2001).

Environmental issues are growing in importance. We are facing the challenges of cutting carbon dioxide emissions, reducing and recycling waste, and decreasing energy and water use. Application methods for fertilizers, pesticides, and irrigation as well as the process of recycling waste are improving. These improvements are leading to healthier less polluted environments. In a search for alternative fuel sources, oilseed crops are being processed for the production of bio-fuels and production is expected to increase (FAO, 2008). According to the FAO (2008) bio-fuels are promoted because they provide energy security, lower greenhouse gas emissions, and provide economic security to developing countries. By-products of bio-fuel production include seed meal and soapstock. Soapstock is an undesirable chemical compound removed by a chemical reaction during caustic refining (Kuk et al., 2005) and consists of low quality fatty acids (Davis et al., 2002). Cotton (*Gossypium hirsutum* L.) and canola (*Brassica rapa* L.) are two commonly used oilseed crops. Canola and cotton seeds are both grown for the

production of oil for cooking and bio-fuel. The by-products of these seeds must be disposed of, one way is by adding it to feed ration as a protein source for livestock but some feed mills have excess amounts. At high amounts, cottonseed meal can be toxic to cattle if consumed at high rates (Conkling, 2008). Another possibility for disposal is to use cottonseed meal and canola meal for horticultural purposes as a valuable resource to enhance plant growth. A few mills have packaged cottonseed meal and made it available for sale by mass merchandisers. The cottonseed meal is typically sold as a soil conditioner with fertilizer analysis of 6N-1.6P-0.8K ($6N\text{-}2P_2O_5\text{-}2K_20$).

The value of organic fertilizer depends on its rate of mineralization. Decomposition rates of organic material vary depending on environmental conditions and quality of the organic residues. Mineralization is the release of inorganic compounds from organic material and results after microbes feed on the organic material releasing plant available nitrogen (N), phosphorus (P), and other essential elements (Brady and Weil, 2008). Materials with greater nitrogen concentration and low carbon to nitrogen ratios mineralize quickly making them valuable sources of nutrients for plants (Barker and Pilbeam 2007). Compared to other organic materials, cottonseed and canola meal may be good candidates for organic fertilizers. They are high in nutrients and easily soluble compounds that make them ideal for microbial breakdown and release of macro- and micronutrients. Cottonseed meals generally contain 6% to 7% N, 1.3% P, and 1.6% K; have a pH of 6.5, total carbon content of 35% to 45%, and 41% protein. Canola seed meal contains about 5% to 6% N, 0.8% P, and 0.8% K, has a pH of 6.0, total carbon content of 35% to 45%, and 37% protein.

A review of the scientific literature, however, has revealed few articles describing the use of seed meals for horticultural purposes. One study tested the effect of using cottonseed meal in production of salad greens (Gent, 2002) and another study examined the effect of canola (*Brassica napus* L.) meal and mustard (*Brassica juncea* L.) meal on carrot growth (Snyder et al., 2009).

No studies using cottonseed or canola products for landscape purposes have been identified. Such research would provide oil extraction mills with scientific evidence upon which to market cottonseed meal or canola meal, and would provide consumers with better information on uses of these products. Information on application methods and rates and their effect on plant growth and soil fertility would be advantageous as would information on N mineralization from both cottonseed meal and canola meal.

OBJECTIVES

The objectives of this research were to 1) determine the effect of using cottonseed meal and canola meal as organic fertilizers on growth, and visual quality of ornamental plants growing outdoors in native soil, 2) determine the rate of mineralization of inorganic N from cottonseed meal and canola meal, and 3) determine the N, P, and K nutrient partitioning of redbud trees throughout a season and establish the best time to apply fertilizer.

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Chapter II

EFFECT OF CANOLA MEAL OR COTTONSEED MEAL WITH OR WITHOUT SOAPSTOCK ON SOIL FERTILITY AND GROWTH OF MARIGOLD AND REDBUD

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ABSTRACT

*Plants need nitrogen (N) and other nutrients for proper growth and development. Essential nutrients can be supplied by various sources including organic fertilizers. This study was conducted to determine the effect of using cottonseed (*Brassica rapa *L.) or canola meal (*Gossypium hirsutum *L.) as organic fertilizer on growth and ornamental quality of landscape plants. This information can help identify alternative organic fertilizer sources and dispose of excess meal. The effects of incorporating or topdressing with cottonseed meal with or without soapstock, canola meal, urea, or no amendment (control) were investigated using plants of marigold (*Tagetes erecta *L. 'Inca II Gold' or 'Inca II Yellow') and redbud (*Cercis canadensis *L.) in a Norge loam (fine-silty, mixed, thermic Udic Paleustolls) at Stillwater, OK in 2008 and 2009. Fertilizers were applied at a rate based on standard N recommendations for landscape plants (4.9 g* m^{-2} *N) in May. For either species, no differences occurred at* $P \leq 0.05$ *in plant measurements, soil nutrient concentration, or leaf elemental tissue concentration among fertilizer sources or between application methods within fertilizer source in 2008. Soil* NO_3*-N, P, and Fe in*

marigold plots from 2008 to 2009. In 2009, marigolds grown in plots into which cottonseed meal was incorporated were taller than plants in other treatments except the untreated control. Marigolds in plots in which cottonseed meal was topdressed, cottonseed meal with soapstock was incorporated, or commercial fertilizer was topdressed grew less in height than plants in plots with cottonseed meal incorporated or control plots. Shoot dry weights of plants in plots topdressed with cottonseed meal with or without soapstock or urea or control plots were lower than those of plants in any other treatment. Visual ratings of marigold plants receiving a topdress of urea or no treatment were lower than visual ratings of plants in any other treatment. Differences within fertilizer treatments occurred in the redbud soil content of NO_3-N, Ca, Mg, SO_4-S, Fe, B, and Cu from 2008 to 2009. Elemental leaf tissue content of P differed among fertilizer treatments in 2009. The dry weight of redbuds grown in soil incorporated with urea was greater than that of plants in any other treatment. Results indicate that cottonseed and canola meals provide N and other nutrients for the growth of landscape plants.

Keywords: organic fertilizer, nutrient release, *Cercis canadensis*, *Tagetes erecta*

INTRODUCTION

A plant nutrient is a chemical element that is essential for plant growth and reproduction. For an element to be a nutrient the element must be required to complete the plant life cycle and no other element can substitute (Barker and Pilbeam, 2007). Fertilizers replace chemical elements that plants deplete from the soil. For centuries humans have applied manure and other waste products to cropland and used crop rotation to improve plant health and quality.

Fertilizers can come from natural or synthetic sources. In the early 1900s about 90 percent of fertilizers were organic, but due to low cost and efficiency of synthetic fertilizers current usage of organic fertilizer has declined to less than 1 percent of total fertilizer use (Barker and Pilbeam, 2007). Ancient civilizations realized the benefits of decaying plant or animal material. These materials were the first fertilizers used by ancient farmers to increase crop yields. Organic fertilizers come from natural sources of plant and animal residues or ground rock and provide opportunities to recycle and dispose of wastes.

The value of organic fertilizers depends on how effectively they decompose and release nutrients for plant uptake. Environmental conditions and quality of organic residue are two factors that contribute to the breakdown or mineralization of organic materials. Mineralization occurs when organic compounds are released as inorganic forms and made available for plant use (Brady and Weil, 2008). Conducive environmental conditions provide opportunities for plant and animal residues to decompose. Good environmental conditions include soil with a neutral pH, sufficient moisture, good aeration, and warm temperatures (Brady and Weil, 2008). A good organic fertilizer has a low carbon to nitrogen (C/N) ratio, small particle size, and high amounts of easily decomposable compounds such as sugars, starches, cellulose, and proteins (Brady and Weil, 2008). With the right conditions and characteristics, plant residues and animal manures can be food sources for microbial organisms. After organic residues are applied to soil, microbial decomposition stimulates the release of macronutrient and micronutrient ions that are available for plant use (Brady and Weil, 2008). Organic materials used as fertilizer are often applied at a rate based on the N content but they can

also provide other macro- and micronutrients. Since natural fertilizers generally release nutrients slowly, they may provide nutrients throughout the growing season and have less nutrient runoff than synthetic fertilizers (Reich, 2002). Organic soil amendments have been associated with desirable soil properties including greater cation exchange capacity (Lin et al., 1973), improved soil aggregation and pH buffer capacity (Stamatoados et al., 1999), lower bulk density of soils (Parr et al., 1986), and promotion of beneficial microorganisms (Chao et al., 1996). Organic fertilizers and soil amendments generated as by-products have disadvantages that make them difficult to market. For example, organic fertilizers like manure can be hard to package for sale, expensive to transport and apply, and can have wide ranges in nutrient content.

Synthetic fertilizers were developed in the 17th century during the British Agricultural Revolution and production increased quickly after World War I when ammonia and synthetic nitrates for explosives were converted to production of nitrogen-based fertilizers (Bacon, 1995). Synthetic fertilizers are manufactured using chemical methods such as the Haber-Bosch process to create ammonia (Reich, 2002). Many synthetic fertilizers have high nutrient contents and are highly soluble (Reich, 2002). Synthetic fertilizers are relatively inexpensive and easy to apply. Overuse of synthetic fertilizers can cause environmental issues such as nitrate contamination of water sources and overfertilization of soils and crops.

Increased oil prices have contributed to a rise in most agricultural crop prices. Rising oil prices, the desire to provide alternative sources of liquid fuel, and the desire to reduce greenhouse gas emissions has increased demand for production of feedstock crops for bio-fuels (FAO, 2008). High oil prices could also decrease the use of petroleum-based

fertilizers (FAO, 2008); leading to a need for alternative, cheaper fertilizer sources. Increased population, economic growth, agriculture production, prices, and government policy have historically influenced the demand for fertilizer (FAO, 2008). The FAO (2008) estimates that world fertilizer application rates will increase at an annual rate of 1.4% for N, 2% for P, and 2.4% for K until 2011/2012 and then will continue to increase.

Oil is extracted from cotton (*Gossypium hirsutum* L.) seed and canola (*Brassica rapa* L.) seed for cooking purposes. Recently, interest in oil from these seeds for the production of bio-fuels has increased. A hexane extraction method (Zeigler et al., 1982) is used to remove the oil from the seeds. Cottonseed meal and canola meal are byproducts of the oil refining process of cotton seed and canola seed, respectively. Another byproduct of the extraction process is soapstock which is an undesirable chemical compound removed by a chemical reaction during caustic refining (Kuk et al., 2005). Soapstock consists of low quality fatty acids (Davis et al., 2002). Processors add it to meal used for animal feed because of its nutritional value for animal feed and as a means of disposal (Kuk et al., 2005). Cottonseed and canola meal contain about 41% and 36% protein, respectively and add nutritional value for consumption of various livestock (Conkling, 2008).

Cottonseed meal and canola meal both have the potential to provide nutrients for plant uptake. Cottonseed meals generally contain 6% to 7% N, 1.3% P, and 1.6% K; have a pH of 6.5, total carbon content of 35% to 45%, and 41% protein. Canola seed meal contains about 5% to 6% N, 0.8% P, and 0.8% K, has a pH of 6.0, total carbon content of 35% to 45%, and 37% protein. These seed meals contain elemental and organic

compounds (Perez-Maldonado, 2002) that with the right environmental conditions can mineralize to provide plant available nutrients.

RELATED LITERATURE

Research testing cottonseed or canola meal for horticultural purposes is limited. One study tested the use of cottonseed meal in production of salad greens (Gent, 2002) and another study tested canola (*Brassica napus* L.) meal and mustard (*Brassica juncea* L.) meal on carrot growth (Snyder et al., 2009).

Few differences in growth occurred in salad greens due to fertilization, though relative growth rate for lettuce and endive was significantly faster with organic than nitrate-based fertilizer (Gent, 2002). Plants of the eight species grown with cottonseed meal had a greater leaf area than those grown with synthetic fertilizer (Gent, 2002). Similarly, crop quality of carrots was not affected by type of meal, but total fresh market yields were greater than or equal to the untreated control, and Brassicaceae meals increased soil inorganic N and carrot yields while glucosinolate products inhibited microbial N uptake in the short term but not in the long term (Snyder et al., 2009).

Research has shown that seed meals can be effective as biopesticides. Brassicaceae seeds have glucosinolates that are contained until glucosinolate hydrolysis is initiated by the addition of water, the hydrolysis products have been shown to control insects (Elberson et al., 1996), weeds (Brown and Morra, 1995), nematodes (Zasada and Ferriss, 2004), and pathogens (Mazzola et al., 2007).

Using animal and plant by-products as soil amendments provides a means of waste disposal and returns nutrients to the soil. Plant byproducts used as soil amendments include: seed meals, leaf and wood compost, and wood ash; animal by-products include

bone meal, blood meal, feather meal, manure, and sewage sludge (Hall, 1998). Plant and animal byproducts can differ greatly in nutrient content. Manure can be a good source of fertilizer and profit for both livestock and crop producers, though the nutrient content differs widely among operations and animal species.

No studies using cottonseed or canola products for landscape purposes have been identified. Such research would provide oil extraction mills information that may be helpful in marketing cottonseed meal or canola meal. Research would also provide consumers with better information on uses of these products. Information on application methods and rates and their effect on plant growth and soil fertility would be advantageous.

The objective of this research was to determine the effect of using cottonseed meal and canola meal as organic fertilizers on growth, and visual quality of ornamental plants growing outdoors in native soil and on foliar and soil elemental content. The information gained from this research will offer an environmentally friendly way of using cottonseed meal and canola meal for horticultural purposes.

MATERIALS AND METHODS

Marigold 2008. Uniform commercially grown marigold seedling plugs (Park Wholesale Inc., Greenwood, SC) were planted into 10-cm-round pots containing Metromix 702 (Sungro,Vancouver, British Columbia, Canada) on 25 February 2008. The pots were spaced about 30 cm apart on benches in a corrugated polycarbonate covered greenhouse (Oklahoma State University Research Greenhouse, Stillwater, OK) with an average day/night air temperature of 30/15° C, and a maximum photosynthetic photon flux (PPF) of 1500 μmol m^{-2} s^{-1}. Plants were irrigated with 1.9 mm internal diameter

polyethylene microtubes and lead-massed on/off emitters daily as needed and fertilized at each irrigation five days a week with 100 mg L^{-1} of N from 20N-8.7P-16.6K (20N-$20P_2O_5$-$20K_20$ Jack's Professional, Allentown, PA). Plants received soluble trace elements (STEM, Jacks Professional) as a substrate drench at 100 mg L^{-1} every two weeks. On 9 May 2008 marigold plants were removed from the greenhouse and planted in a Norge loam (fine-silty, mixed, thermic Udic Paleustolls) at the Oklahoma State University Botanical Garden, Stillwater, OK.

Prior to planting, the field was rototilled to a depth of 15 cm. Polyethylene edging was installed between treatment plots and extended to a depth of 15 cm. The following treatments were applied on 5 May 2008 at a rate of 4.9 g m^{-2} N:

1) cottonseed meal, incorporated to a depth of about 8 cm,
2) cottonseed meal, topdressed,
3) cottonseed meal with soapstock, incorporated to a depth of about 8 cm,
4) cottonseed meal with soapstock, topdressed,
5) canola meal, incorporated to a depth of about 8 cm,
6) canola meal, topdressed,
7) urea (46N-0P-0K, Agri-Nutrient, Port of Catoosa, OK), incorporated to a depth of about 8 cm,
8) urea (46N-0P-0K), topdressed, and
9) no treatment (control).

The application rate was based on results of preliminary soil tests and on standard recommendations for N fertilizer application to landscape and turf areas. Treatments were applied by hand inside a box frame equal to the dimensions of each plot to ensure

uniform coverage and to eliminate drift. Meal or fertilizer in incorporated treatments was rototilled into the soil to a depth of about 8 cm with a mantis rototiller (Mantis, Hatboro, PA). Four marigold plants were planted in each plot with 30 cm between plants within plots and 1 m between the end of each plot and the first plant to reduce the possibility of plants being affected by nutrient movement between plots. Plants were drip irrigated daily with 16-mm-diameter polyethylene drip tubing and emitters that supply 3.8 L hr^{-1} (Rainbird, Azusa, CA) for eight hours to a depth of 15 to 25cm.

Weeds were controlled with a preemergent application of isoxaben (Gallery 75 Dry Flowable, Dow AgroSciences, Indianapolis, IN) on 19 May 2008 at 250 g ha^{-1} and postemergent sprays of glyphosate (Ranger Pro, Monsanto, St. Louis, MO) at 200 g ha^{-1} on 26 May 2008, 18 June 2008, and 23 July 2008. Spider mites (*Tetranychus urticae* K.) were controlled by spraying avermectin (Avid, Syngenta, Greensboro, NC) at 0.5 ml ai gal^{-1} every two weeks.

Plant height and width (average of width at the widest portion and perpendicular to the widest portion) were determined after planting on 12 May 2008 and at harvest on 4 August 2008. Soil samples were collected to a depth of 15 cm from the field prior to treatment application on 18 April 2008 and from each treatment plot in four replications on 11 August 2008. Soil samples were dried at 100°C for 12 hr and ground to pass through a 2 mm mesh screen then analyzed for NO_3-N (flow-injection analyzer, Lachat QuickChem 8000, Loveland, CO), P, K, Ca, Mg, SO_4-S, Fe, Zn, B, and Cu (inductively coupled plasma (ICP) analyzer, Spectro Ciros, Mahwah, NJ, Soil, Water, and Forage Analytical Laboratory, Oklahoma State University, Stillwater, OK). Mature leaf samples from each treatment in four replications were collected on 21 August 2008, dried at 60° C

for 12 hr and ground to pass through an 1 mm mesh screen, then analyzed for total N (combustion method, Leco TruSpec, St. Joseph, MI), P, K, Ca, Mg, S, Na, Fe, Zn, Cu, and Mn (ICP) by the Soil, Water, and Forage Analytical Laboratory, Oklahoma State University, Stillwater, OK.

Redbud 2008. The experiment described above was repeated with the following exceptions. Two bareroot redbud seedlings, averaging 94 cm tall, were planted 1.5 m apart into holes drilled with a 30 cm diameter augur on 5 May 2008.

Treatments were applied 13 May 2008 after trees were planted to reduce movement of treatments from plot to plot on planting equipment. Trees were irrigated 4 hr every other night by 1.3 cm diameter polyethylene tubing with a 7.6 L hr^{-1} emitter for each tree to an average depth of 70 cm. Thuricide (*Bacillus thuringensis*) was applied until runoff every two weeks at 10 ml ai gal^{-1} to control redbud leaf rollers (*Fascista cercisella* C.). Tree height and trunk diameter (average of two perpendicular measurements) at 15.2 cm above the soil were measured at planting and at harvest.

Marigold 2009. The marigold 2008 experiment described above was repeated with the following exceptions. *Tagetes erecta* 'American Inca II Yellow' plants were planted into 10-cm-round pots on 24 March 2009. On 20 May 2009 the cottonseed meal, canola meal, and urea treatments were reapplied to their respective plots and marigolds were planted in each plot.

Isoxaben was applied on 28 May 2009 for preemergent weed control, and directed sprays of glyphosate were applied on 8 June 2009, 25 June 2009, 13 July 2009, and 30 July 2009 for postemergent weed control. Spider mites were controlled by rotating sprays

of avermectin at 0.5 ml ai gal^{-1} or pyridaben (Sandmite, Gowan, Yuma, AZ) at 1.7 ml ai gal^{-1} to runoff every two weeks.

Height and width were measured at planting on 21 May 2009 and at harvest on 13 August 2009. Plants were visually rated on 6 July 2009 and 13 August 2009 on scale of 1-5 (1= dead, no green or new growth, 2= >50% of plant was chlorotic or necrotic, small size, very little new growth, and little flowering, 3= 25% to 50% of plant exhibited chlorosis or necrosis, new green growth, medium size, and moderate flowering, 4= 15% to 25% of the plant was chlorotic or necrotic, mostly green, vigorous new growth and flowering, large round shape, 5= plant exhibiting <15% chlorosis or necrosis, generally green color throughout, large round shape, and vigorous flowering). On 22 August 2009 above ground portions of marigold plants were severed at the soil line, dried for 24 hr at 55° C, and weighed. Soil samples were collected before planting on 23 April 2009 and 14 August 2009. Leaf samples were collected on 12 August 2009.

Redbud 2009. The redbud 2008 experiment described above was repeated with the following exceptions. Redbud trees were overwintered in the field and treatments were reapplied to their respective plots on 20 May 2009. No thuricide was applied. Trees in four replications were sacrificed for dry weight on 26 and 27 August 2009 (trees were severed at the soil line and separated into leaves and wood). Roots were dug using a tree spade with a diameter and depth of 61 cm and 122 cm, respectively.

Statistics. A randomized complete block design with nine treatments (described above) and ten replications was used. Data were analyzed using PROC MIXED in PC SAS Version 9.1 (SAS Institute, Cary, NC). Differences in treatments were assessed with

a SLICE option in an LSMEANS statement, and if significant, ($P \leq 0.05$) further comparisons were conducted with pair-wise t-tests.

RESULTS

Marigold. No differences among treatments existed for soil pH or content of any nutrient element tested in the soil in 2008 or 2009 (Table 2.1, 2.2, and 2.3). Soil NO_3 -N content was greater in 2009 than in 2008 in plots incorporated with cottonseed meal with soapstock (Table 2.1). Plots in which cottonseed meal or cottonseed meal with soapstock was incorporated increased in soil P content in 2009 compared to 2008 (Table 2.1). Soil Fe concentration was greater in 2009 than in 2008 in plots in which cottonseed meal was incorporated and in plots that were topdressed with canola meal (Table 2.3). Boron concentration in the soil was greater in all treatments in 2009 compared to 2008 (Table 2.3). The soil Cu concentration was lower in plots in which urea was incorporated in 2009 than in 2008 (Table 2.3).

Similarly, no differences among treatments occurred for leaf elemental concentration (Tables 2.4, 2.5, and 2.6). Leaf elemental concentration did not differ between 2008 and 2009 within any fertilizer treatment (Tables 2.4, 2.5, and 2.6).

Plants grown in plots into which cottonseed meal was incorporated were taller than plants in any other treatment, except the control (Table 2.7). Marigolds in plots in which cottonseed meal was topdressed, cottonseed meal with soapstock was incorporated, or urea was topdressed grew less in height than plants in plots with cottonseed meal incorporated or control plots (Table 2.7). Plant growth in width did not differ among treatments (Table 2.7).

Shoot dry weight of the marigold plants grown in soil amended with cottonseed meal incorporated or canola meal applied as a top dress was greater than that of plants in other treatments (Table 2.7). Shoot dry weights of plants in plots topdressed with cottonseed meal with or without soapstock or urea or control plots were lower than those of plants in any other treatment (Table 2.7).

In July, plants in plots topdressed with cottonseed meal had lower visual ratings than plants in plots where cottonseed meal was incorporated or plots topdressed with canola meal (Table 2.7). Visual ratings of marigold plants receiving a top dress of urea or no treatment (control) did not differ, but were lower than visual ratings of plants in any other treatment (Table 2.7). In August, plants in plots topdressed with canola meal had higher visual ratings than those in plots topdressed with cottonseed meal with or without soapstock or those receiving urea by either application method or control plants (Table 2.7).

Redbud. No differences occurred in soil pH or elemental tissue concentration among treatments in 2008 or 2009 (Tables 2.8, 2.9, and 2.10). Soil NO_3-N content was lower in 2009 compared to 2008 in plots incorporated with canola meal (Table 2.8). Soil Ca content was lower in the control plots in 2009 than in 2008 (Table 2.9). Soil Mg content was lower in 2009 compared to 2008 in plots in which cottonseed meal with or without soapstock was incorporated, cottonseed meal with soapstock was topdressed, urea was incorporated, and in the control plots (Table 2.9). Soil SO_4-S content in plots in which cottonseed meal was incorporated or topdressed, cottonseed meal with soapstock was incorporated, and in control plots was lower in 2009 than in 2008 (Table 2.9). The content of Fe increased from 2008 to 2009 in all plots except those that were topdressed

with cottonseed meal with or without soapstock, those incorporated with canola meal, or those topdressed with urea (Table 2.10). Soil B content increased from 2008 to 2009 in all treatments except urea, topdressed (Table 2.10). Soil Cu content decreased from 2008 to 2009 in all treatments except the cottonseed meal with soapstock incorporated and control (Table 2.10).

Similarly, no differences in leaf elemental concentration occurred among fertilizer treatments (Tables 2.11, 2.12, 2.13, and 2.14), except that the percentage of P in plants grown in plots topdressed with cottonseed meal was greater than the P content of plants in all other treatments except those in plots topdressed with cottonseed meal with soapstock (Table 2.11). Phosphorus concentration of plants in plots topdressed with cottonseed meal with soapstock did not differ from that of plants in any other treatment (Table 2.11).

No differences in tree growth in height or width occurred (Table 2.15). Dry weight of the redbud leaves in the plots in which urea was incorporated was greater than that of all other treatments (Table 2.15). Leaf dry weight of plants in plots topdressed with cottonseed meal and in control plots was greater than those of plants in plots into which cottonseed meal with or without soapstock was incorporated or plots topdressed with urea (Table 2.15). Stem dry weight of the trees in plots into which cottonseed meal was topdressed or urea was incorporated was greater than stem dry weight of trees in plots topdressed with urea, but these three treatments did not differ from any other treatment in stem dry weight (Table 2.15). When urea was incorporated, root dry weight was greater than when cottonseed meal was incorporated, cottonseed meal with soapstock was topdressed, canola meal was applied by either method, urea was applied by topdress,

or no treatment was applied (Table 2.15). Similarly, the total dry weight of redbud trees in incorporated urea plots was greater than that of any other treatment and those in plots into which canola meal was incorporated or control plots had greater total dry weights than those in plots topdressed with cottonseed meal with or without soapstock or urea (Table 2.15).

DISCUSSION

Nutrient release from organic material is difficult to predict and nutrient contents in soils can change from year to year depending on environmental conditions. When organic materials like seed meals are added to the soil, the degraded compounds can be immobilized by microbes, removed by plant uptake, volatilized into the atmosphere, or lost by leaching, making it difficult to determine the fate of nutrients (Brady and Weil, 2008). The seed meals used in this study had the appropriate physical characteristics and environmental conditions to decompose and provide plant available macronutrients and micronutrients. Cottonseed meal and canola meal have low C/N ratios, high N content, and contain large amounts of soluble compounds like proteins that microbes readily break down. Environmental conditions during the study that were conducive for mineralization included warm temperatures (Table 2.16), moisture, and soil pH near neutral (pH of marigold and redbud fields prior to treatment were 5.8 and 7.0, respectively). In 2008, large amounts of rainfall (44.7 cm from 1 May to 31 August, Table 2.16) may have contributed to nutrient leaching resulting in few differences among treatments. Tilling the soil prior to treatment application and planting may have stimulated an adequate release of N from organic matter for plant growth without additional fertilizer.

Prior to planting in both seasons, soil tests revealed that the soil in both fields was deficient in N, P, and K for lawn and garden applications (Zhang and Raun, 2006; Barker and Pilbeam, 2007). At the end of both growing seasons the results of soil tests suggested that both fields were deficient in N and P, and the redbud field was deficient in K. Though soil tests suggested insufficiency of some nutrients, none of the plants in either species displayed plant nutrient deficiency or toxicity symptoms and plant nutrient concentrations appeared adequate (Barker and Pilbeam, 2007). For example, sufficiency levels of N for herbaceous bedding plants and woody landscape trees were 2.8% to 5.6% N and 1.9% to 2.6% N, respectively (Barker and Pilbeam, 2007).

Shoot dry weight of marigold plants in any incorporated treatment was greater than when the materials were topdressed or the untreated control suggesting that incorporation of materials may have facilitated nutrient release and resulted in plant uptake or topdressed materials were lost by runoff or wind erosion (Table 2.7). Quality ratings of marigolds in plots treated with seed meals regardless of treatment method or in plots incorporated with urea were similar suggesting that more N and other nutrients were available for plant uptake compared to those plots in which urea was topdressed or control plots (Table 2.7).

Redbud total dry weights were similar among the topdressed and incorporated organic fertilizers (Table 2.15), suggesting that both application methods could be effective. The weight of trees in plots where urea was incorporated was greater than that of trees where urea was topdressed suggesting that topdressing commercial nitrate fertilizer is not as effective as incorporation. Since urea is highly soluble and quickly dissolved, topdressed urea likely ran off the soil surface or was lost to volatilization

creating less opportunity for soil and plants to accumulate N compared to the plots amended with seed meal. The location of fertilizer and organic residues play a role in decomposition rates and plant nutrient availability. Materials applied as surface applications are slower to decompose than those that are incorporated and surface applied materials are more susceptible to temperature extremes, drying, and loss of nutrients by runoff or volatilization (Brady and Weil, 2008). Incorporated materials are in contact more intimately with soil moisture and microbes which enable them to decompose and release nutrients more efficiently than topdressed materials (Brady and Weil, 2008). Nitrogen and other nutrients from the seed meal treatments were released slower than the urea and may have given the plants a prolonged opportunity to absorb the nutrients produced by mineralization, which demonstrated better visual quality in the marigold and greater weights for both species than the plots topdressed with urea or no treatment.

The results of this study are similar to Gent (2002) and Snyder et al. (2009) who found that soil amended with seed meals did not affect plant growth or quality. The visual quality of marigold or redbud species in the current study was not affected by organic or commercial fertilizer. The greater leaf P in redbuds in plots topdressed with cottonseed meal (Table 2.11) were similar to Gent's (2002) findings that leaf concentration of P and in salad greens was greater with organic than synthetic nitrate fertilizer. The elemental content of some of the treatment plots changed from the 2008 to 2009 season. Changes in elemental content often occur due to the environment and the addition of materials. In marigold plots cottonseed meal without soapstock incorporated was mineralized and increased the nutrient content of NO_3-N and P. Soil Cu content decreased where urea was incorporated. Boron is released by mineralization and increased in all treatments likely

due to wet conditions. Soil concentration of Fe and B in the redbud field increased while NO_3-N, Mg, SO_4-S, Ca, and Cu decreased (Tables 2.8, 2.9, and 2.10). These changes may have occurred as a result of wet conditions, leaching, microbial decomposition, mineralization, volatilization, plant uptake, or plant loss.

In summary, minimal differences occurred in the growth of plants, soil nutrient content, and leaf elemental tissue content from plots amended with cottonseed meal, canola meal, or commercial fertilizer. Seed meals can provide macro- and micronutrients for plant growth and likely release nutrients more slowly than commercial fertilizers because microbial action is needed to turn organic material into plant available nutrients. Incorporation of fertilizers may reduce nutrient loss and enhance seed meal decomposition compared to topdressing (Brady and Weil, 2008). Topdressed materials decompose and release nutrients but more time may be required than when that same material is incorporated. Cottonseed meal and canola seed meal have good potential to release nutrients, benefiting the soil and plants.

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Table 2.1. Soil pH, NO_3-N, P, and K for marigold plots fertilized with cottonseed meal with or without soapstock, canola meal, or urea applied as a topdress or incorporated and control (no treatment). n=4.

	pH		NO_3-N (mg kg^{-1})		P (mg kg^{-1})		K (mg kg^{-1})	
Treatment	2008	2009	2008	2009	2008	2009	2008	2009
Cottonseed meal, incorporated	5.6	5.5	5.82	13.7	12.6	21.3*[(1)]	161.8	172.4
Cottonseed meal, topdressed	5.7	5.5	7.08	13.8	12.6	18.6	171.6	184.6
Cottonseed meal with soapstock, incorporated	5.7	5.6	3.79	15.8*	14.3	22.2*	193.4	199.9
Cottonseed meal with soapstock, topdressed	5.7	5.6	4.68	10.4	15.1	21.4	182.8	188.9
Canola meal, incorporated	5.6	5.5	7.59	9.10	18.1	22.5	174.4	174.3
Canola meal, topdressed	5.6	5.5	8.72	9.86	18.9	24.3	196.1	201.4
Urea, incorporated	5.4	5.5	10.6	17.2	14.6	20.8	180.3	172.4
Urea, topdressed	5.7	5.6	7.08	8.60	16.4	22.0	173.9	175.6
Control, no treatment	5.7	5.7	7.59	7.96	17.5	23.3	203.4	209.4

[(1)]*Denotes a significant difference between years at $P \leq 0.05$.

Table 2.2. Soil Mg, Ca, and SO_4-S for marigold plots fertilized with cottonseed meal with or without soapstock, canola meal, or urea applied as a topdress or incorporated and control (no treatment). n=4.

	Ca (mg kg^{-1})		Mg (mg kg^{-1})		SO_4 -S (mg kg^{-1})	
Treatment	2008	2009	2008	2009	2008	2009
Cottonseed meal, incorporated	1043	1131	240	247	17.8	18.8
Cottonseed meal, topdressed	1479	1249	267	259	18.6	20.8
Cottonseed meal with soapstock, incorporated	1217	1189	256	257	17.8	19.5
Cottonseed meal with soapstock, topdressed	1080	1148	229	236	17.9	18.3
Canola meal, incorporated	1064	1105	234	235	20.0	19.5
Canola meal, topdressed	1103	1201	256	260	19.3	21.3
Urea, incorporated	1129	1129	245	240	19.4	19.2
Urea, topdressed	1131	1154	227	234	17.8	17.5
Control, no treatment	1148	1181	250	248	18.8	18.6

Table 2.3. Soil Fe, Zn, B, and Cu for marigold plots fertilized with cottonseed meal with or without soapstock, canola meal, or urea applied as a topdress or incorporated and control (no treatment). n=4.

	Fe (mg kg^{-1})		Zn (mg kg^{-1})		B (mg kg^{-1})		Cu (mg kg^{-1})	
Treatment	2008	2009	2008	2009	2008	2009	2008	2009
Cottonseed meal, incorporated	38.2	52.8*[(1)]	1.08	1.08	0.29	0.42*	1.30	1.20
Cottonseed meal, topdressed	39.1	49.0	0.95	0.95	0.30	0.42*	1.07	1.23
Cottonseed meal with soapstock, incorporated	40.2	52.9	1.05	1.15	0.30	0.44*	1.24	1.20
Cottonseed meal with soapstock, topdressed	39.2	52.4	1.04	1.00	0.29	0.41*	1.28	1.20
Canola meal, incorporated	50.5	61.0	1.15	1.13	0.30	0.42*	1.33	1.23
Canola meal, topdressed	45.1	60.5*	1.26	1.18	0.32	0.44*	1.24	1.20
Urea, incorporated	38.8	51.3	1.13	1.15	0.29	0.41*	1.47	1.23*
Urea, topdressed	46.5	56.9	1.36	1.33	0.29	0.41*	1.42	1.28
Control, no treatment	48.6	61.0	1.14	1.25	0.32	0.47*	1.34	1.25

[(1)]*Denotes a significant difference between years at $P \leq 0.05$.

Table 2.4. Leaf total N, P, K, and total C concentration of marigolds fertilized with cottonseed meal with or without soapstock, canola meal, or urea applied as a topdress or incorporated and control (no treatment). n=4.

	Total N (%)		P (%)		K (%)		Total C (%)	
Treatment	2008	2009	2008	2009	2008	2009	2008	2009
Cottonseed meal, incorporated	2.97	3.16	0.27	0.21	1.84	1.41	39.9	40.9
Cottonseed meal, topdressed	2.97	3.64	0.28	0.19	1.85	1.25	39.7	46.9
Cottonseed meal with soapstock, incorporated	3.20	3.12	0.27	0.21	1.82	1.43	40.6	40.6
Cottonseed meal with soapstock, topdressed	2.97	3.43	0.27	0.21	1.70	1.35	40.1	41.1
Canola meal, incorporated	2.63	3.05	0.28	0.24	2.00	1.55	39.2	39.9
Canola meal, topdressed	2.87	3.34	0.27	0.21	1.85	1.31	39.7	40.8
Urea, incorporated	3.60	3.28	0.28	0.21	1.76	1.44	52.3	40.0
Urea, topdressed	2.97	3.34	0.31	0.22	1.89	1.48	40.6	40.7
Control, no treatment	3.10	4.01	0.31	0.21	1.98	1.51	39.9	50.5

Table 2.5. Leaf Ca, Mg, and S concentration of marigolds fertilized with cottonseed meal with or without soapstock, canola meal, or urea applied as a topdress or incorporated and control (no treatment). n=4.

	Ca (%)		Mg (%)		S (%)	
Treatment	2008	2009	2008	2009	2008	2009
Cottonseed meal, incorporated	2.53	2.45	0.31	0.25	0.43	0.32
Cottonseed meal, topdressed	2.53	2.29	0.31	0.26	0.46	0.31
Cottonseed meal with soapstock, incorporated	2.49	2.66	0.33	0.28	0.42	0.32
Cottonseed meal with soapstock, topdressed	2.24	2.23	0.30	0.27	0.38	0.31
Canola meal, incorporated	2.76	2.58	0.34	0.30	0.47	0.37
Canola meal, topdressed	2.50	2.18	0.31	0.26	0.42	0.32
Urea, incorporated	2.43	2.39	0.33	0.28	0.43	0.34
Urea, topdressed	2.26	2.49	0.33	0.26	0.37	0.37
Control, no treatment	2.65	2.36	0.33	0.26	0.46	0.39

Table 2.6. Leaf Na concentration and Zn and Mn content of marigolds fertilized with cottonseed meal with or without soapstock, canola meal, or urea applied as a topdress or incorporated and control (no treatment). n=4.

	Na (%)		Zn (mg kg^{-1})		Mn (mg kg^{-1})	
Treatment	2008	2009	2008	2009	2008	2009
Cottonseed meal, incorporated	0.0042	0.0155	63.4	50.3	192	184
Cottonseed meal, topdressed	0.0033	0.0150	63.4	49.5	175	187
Cottonseed meal with soapstock, incorporated	0.0042	0.0160	61.4	54.0	196	211
Cottonseed meal with soapstock, topdressed	0.0034	0.0153	59.7	51.5	161	163
Canola meal, incorporated	0.0045	0.0180	69.4	60.2	208	220
Canola meal, topdressed	0.0041	0.0155	64.6	52.7	198	162
Urea, incorporated	0.0037	0.0158	67.6	57.3	222	197
Urea, topdressed	0.0036	0.0173	65.1	58.8	171	177
Control, no treatment	0.0039	0.0165	65.8	54.4	193	159

(1) In columns, means followed by the same letter are not significantly different at $P \leq 0.05$.

Table 2.7. Growth in height and width, top dry weight at harvest in 2009, and visual quality in July and August 2009 of marigolds fertilized with cottonseed meal with or without soapstock, canola meal, or urea applied as a topdress or incorporated and control (no treatment). Data for 2008 and 2009 were pooled for growth in height and width. Visual quality was based on a scale of 1-5 (1= dead, no green or new growth, 2= >50% of plant was chlorotic or necrotic, small size, very little new growth, and little flowering, 3= 25% to 50% of plant exhibiting chlorosis or necrosis, new green growth, medium size, and moderate flowering, 4= 15% to 25% of plant chlorotic or necrotic, mostly green, vigorous new growth and flowering, large round shape, 5= plant exhibiting <15% chlorosis or necrosis, generally green color throughout, large round shape, and vigorous flowering). n=10.

Treatment	Height difference (cm)		Width difference (cm)	Shoot dry weight (g)		July 2009 rating		August 2009 rating	
Cottonseed meal, incorporated	12.0	a[(1)]	14.0	108.2	a	4.33	a	4.51	ab
Cottonseed meal, topdressed	9.9	c	11.8	79.9	c	4.00	b	4.00	def
Cottonseed meal with soapstock, incorporated	8.9	c	11.8	94.4	b	4.25	ab	4.32	abc
Cottonseed meal with soapstock, topdressed	10.1	bc	13.4	83.7	c	4.15	ab	4.26	bcd
Canola meal, incorporated	10.2	bc	13.3	91.8	b	4.15	ab	4.33	abc
Canola meal, topdressed	10.5	bc	14.4	103.2	a	4.35	a	4.58	a
Urea, incorporated	10.3	bc	14.3	94.6	b	4.13	ab	4.26	cde
Urea, topdressed	9.5	c	13.2	80.3	c	3.68	c	3.97	f
Control, no treatment	11.4	ab	13.2	81.0	c	3.65	c	3.84	f

[(1)]In columns, means followed by the same letter are not significantly different at $P \leq 0.05$.

Table 2.8. Soil pH, NO_3-N, P, and K for redbud plots fertilized with cottonseed meal with or without soapstock, canola meal, or urea applied as a topdress or incorporated and control (no treatment). n=4.

	pH		NO_3-N (mg kg^{-1})		P (mg kg^{-1})		K (mg kg^{-1})	
Treatment	2008	2009	2008	2009	2008	2009	2008	2009
Cottonseed meal, incorporated	7.3	7.2	24.0	13.9	24.6	23.4	127.5	121.8
Cottonseed meal, topdressed	7.3	7.3	22.6	13.8	25.0	21.5	122.0	118.5
Cottonseed meal with soapstock, incorporated	7.5	7.4	17.2	10.9	25.9	24.1	121.5	115.1
Cottonseed meal with soapstock, topdressed	7.4	7.3	23.1	19.5	40.6	36.1	142.3	131.5
Canola meal, incorporated	7.5	7.4	24.6	11.1*[(1)]	25.8	28.1	121.8	120.6
Canola meal, topdressed	7.3	7.2	21.1	13.3	29.9	33.6	113.1	117.3
Urea, incorporated	7.6	7.5	21.1	11.6	24.6	19.8	122.4	115.4
Urea, topdressed	7.5	7.3	19.2	16.2	25.8	22.5	119.8	114.6
Control, no treatment	7.5	7.4	18.3	9.5	21.1	19.8	112.9	109.6

[(1)]*Denotes a significant difference between years at $P \leq 0.05$.

Table 2.9. Soil Ca, Mg, and SO_4-S for redbud plots fertilized with cottonseed meal with or without soapstock, canola meal, or urea applied as a topdress or incorporated and control (no treatment). n=4.

	Ca (mg kg^{-1})		Mg (mg kg^{-1})		SO_4 -S (mg kg^{-1})	
Treatment	2008	2009	2008	2009	2008	2009
Cottonseed meal, incorporated	1679	1615	368	335*[(1)]	10.9	7.8*
Cottonseed meal, topdressed	1702	1615	367	349	10.9	8.3*
Cottonseed meal with soapstock, incorporated	1802	1673	365	337*	10.4	7.6*
Cottonseed meal with soapstock, topdressed	1735	1617	368	335*	9.0	8.1
Canola meal, incorporated	1819	1778	357	334	10.8	10.5
Canola meal, topdressed	1571	1574	350	340	9.3	9.0
Urea, incorporated	1822	1752	373	345*	9.5	7.6
Urea, topdressed	1609	1615	338	327	10.0	8.1
Control, no treatment	1831	1555*	360	327*	10.0	6.6*

[(1)]*Denotes a significant difference between years at $P \leq 0.05$.

Table 2.10. Soil Fe, Zn, B, and Cu for redbud plots fertilized with cottonseed meal with or without soapstock, canola meal, or urea applied as a topdress or incorporated and control (no treatment). n=4.

	Fe (mg kg^{-1})		Zn (mg kg^{-1})		B (mg kg^{-1})		Cu (mg kg^{-1})	
Treatment	2008	2009	2008	2009	2008	2009	2008	2009
Cottonseed meal, incorporated	13.8	18.9*[(1)]	1.72	1.63	0.29	0.34*	1.50	1.23*
Cottonseed meal, topdressed	13.4	18.4	1.33	1.38	0.27	0.34*	1.41	1.13*
Cottonseed meal with soapstock, incorporated	11.3	17.5*	1.32	1.50	0.28	0.35*	1.46	1.20
Cottonseed meal with soapstock, topdressed	12.4	16.1	1.62	1.63	0.29	0.35*	1.51	1.05*
Canola meal, incorporated	11.1	15.8	1.65	1.68	0.31	0.36*	1.61	1.23*
Canola meal, topdressed	12.7	18.8*	1.42	1.58	0.27	0.32*	1.49	1.13*
Urea, incorporated	12.2	18.3*	1.28	1.53	0.30	0.38*	1.60	1.28*
Urea, topdressed	10.2	13.8	1.74	1.45	0.28	0.31	1.55	1.13*
Control, no treatment	10.7	16.7*	1.11	1.20	0.28	0.34*	1.48	1.25

[(1)]*Denotes a significant difference between years at $P \leq 0.05$.

Table 2.11. Leaf total N, P, K, and total C concentration of redbuds fertilized with cottonseed meal with or without soapstock, canola meal, or urea applied as a topdress or incorporated and control (no treatment). n=4.

	Total N (%)		P (%)			K (%)		Total C (%)	
Treatment	2008	2009	2008	2009		2008	2009	2008	2009
Cottonseed meal, incorporated	2.34	2.40	0.18	0.18	b[(1)]	0.80	0.68	46.6	50.1
Cottonseed meal, topdressed	2.31	2.43	0.21	0.30	a	0.75	0.81	46.9	50.2
Cottonseed meal with soapstock, incorporated	2.38	2.43	0.22	0.17	b	0.68	0.67	46.5	50.8
Cottonseed meal with soapstock, topdressed	2.31	2.34	0.25	0.24	ab	0.73	0.68	46.8	50.1
Canola meal, incorporated	2.27	2.38	0.25	0.21	b	0.89	0.76	46.6	50.2
Canola meal, topdressed	2.29	2.32	0.25	0.21	b	0.73	0.72	46.4	49.4
Urea, incorporated	2.34	2.37	0.21	0.17	b	0.82	0.73	46.2	49.8
Urea, topdressed	2.21	2.39	0.19	0.22	b	0.74	0.74	46.6	50.0
Control, no treatment	2.18	2.39	0.25	0.17	b	0.73	0.77	46.6	50.2

[(1)]In columns, means followed by the same letter are not significantly different at $P \leq 0.05$.

Table 2.12. Leaf Ca, Mg, and S concentration of redbuds fertilized with cottonseed meal with or without soapstock, canola meal, or urea applied as a topdress or incorporated and control (no treatment). n=4.

	Ca (%)		Mg (%)		S (%)	
Treatment	2008	2009	2008	2009	2008	2009
Cottonseed meal, incorporated	0.98	1.87	0.20	0.33	0.13	0.15
Cottonseed meal, topdressed	1.15	1.79	0.23	0.34	0.13	0.15
Cottonseed meal with soapstock, incorporated	1.17	1.59	0.24	0.28	0.12	0.14
Cottonseed meal with soapstock, topdressed	1.28	1.94	0.27	0.35	0.13	0.16
Canola meal, incorporated	1.11	1.96	0.24	0.35	0.13	0.16
Canola meal, topdressed	1.11	2.01	0.22	0.35	0.12	0.15
Urea, incorporated	1.08	1.74	0.22	0.34	0.13	0.15
Urea, topdressed	1.16	1.96	0.23	0.33	0.13	0.16
Control, no treatment	1.24	1.63	0.27	0.29	0.13	0.15

Table 2.13. Leaf Na concentration and Fe and Zn content of redbuds fertilized with cottonseed meal with or without soapstock, canola meal, or urea applied as a topdress or incorporated and control (no treatment). n=4.

	Na (%)		Fe (mg kg^{-1})		Zn (mg kg^{-1})	
Treatment	2008	2009	2008	2009	2008	2009
Cottonseed meal, incorporated	0.0032	0.0063	40.0	32.4	14.1	13.6
Cottonseed meal, topdressed	0.0032	0.0065	46.2	36.1	13.5	14.2
Cottonseed meal with soapstock, incorporated	0.0028	0.0055	47.9	25.9	12.3	12.7
Cottonseed meal with soapstock, topdressed	0.0029	0.0073	47.6	32.8	14.4	15.2
Canola meal, incorporated	0.0031	0.0058	41.7	32.0	13.7	13.7
Canola meal, topdressed	0.0034	0.0058	56.0	32.3	12.5	13.9
Urea, incorporated	0.0031	0.0060	41.9	42.8	13.8	13.9
Urea, topdressed	0.0025	0.0063	47.1	37.4	12.4	15.9
Control, no treatment	0.0024	0.0058	52.9	28.9	13.0	12.8

Table 2.14. Leaf Cu and Mn content of redbuds fertilized with cottonseed meal with or without soapstock, canola meal, or urea applied as a topdress or incorporated and control (no treatment). n=4.

	Cu ($mg \cdot kg^{-1}$)		Mn ($mg\ kg^{-1}$)	
Treatment	2008	2009	2008	2009
Cottonseed meal, incorporated	9.11	4.89	31.4	48.6
Cottonseed meal, topdressed	8.31	6.88	30.6	43.8
Cottonseed meal with soapstock, incorporated	6.36	3.85	33.2	46.7
Cottonseed meal with soapstock, topdressed	7.34	4.66	34.4	54.3
Canola meal, incorporated	5.95	4.22	34.7	51.3
Canola meal, topdressed	7.23	4.25	27.5	50.1
Urea, incorporated	7.07	4.58	32.9	43.5
Urea, topdressed	6.84	4.67	32.4	48.9
Control, no treatment	7.87	4.01	37.3	41.3

(1)In columns, means followed by the same letter are not significantly different at $P \leq 0.05$.

Table 2.15. Growth in height and width and dry weight at harvest of redbuds fertilized with cottonseed meal with or without soapstock, canola meal, or urea applied as a topdress or incorporated and control (no treatment). Data for 2008 and 2009 were pooled for growth in height and width. n=8. Above ground shoots, leaves, and roots of redbuds were harvested in 2009. n=4.

Treatment	Height Difference (cm)	Width Difference (cm)	Leaves (g)	Shoots (g)	Roots (g)	Tree Total (g)
Cottonseed meal, incorporated	34.6	6.64	449cd[(1)]	1021bc	809d	2279bc
Cottonseed meal, topdressed	41.5	5.83	566b	1222ab	984ab	2426bc
Cottonseed meal with soapstock, incorporated	42.0	7.12	445cd	1005bc	978abc	2428bc
Cottonseed meal with soapstock, topdressed	36.9	5.61	433bcd	922 bc	838bcd	1880c
Canola meal, incorporated	40.5	6.70	535bcd	1168bc	809d	2512b
Canola meal, topdressed	38.9	6.25	488bcd	1116bc	825cd	2429bc
Urea, incorporated	45.4	7.55	686a	1427ab	1079 a	3192a
Urea, topdressed	26.9	5.26	381d	838 c	763d	1981c
Control, no treatment	27.4	5.39	562b	1179bc	781d	2521b

[(1)]In columns, means followed by the same letter are not significantly different at $P \leq 0.05$.

Table 2.16. Average monthly high and low temperatures with standard deviations, highest and lowest temperatures, and rainfall at the Oklahoma State University Botanical Garden (Stillwater, OK) for May 2008 through August 2009. Temperature and rainfall provided by Oklahoma Mesonet retrieved on 15 March 2010.

		Average High (°C)	Average Low (°C)	Highest Temperature (°C)	Lowest Temperature (°C)	Rainfall (cm)
2008	May	27.2 ± 4.1	13.9 ± 5.4	33.89	2.22	16.18
	June	31.1 ± 2.7	20.0 ± 3.0	34.44	13.89	12.50
	July	33.8 ± 2.6	21.7 ± 2.0	38.89	12.78	12.70
	August	32.8 ± 4.4	21.7 ± 2.4	40.00	14.44	3.35
	September	28.3 ± 3.3	14.4 ± 4.4	33.89	6.67	4.19
	October	23.3 ± 5.4	7.8 ± 5.5	30.00	-3.89	5.26
	November	17.2 ± 5.9	2.8 ± 4.9	27.22	-5.00	6.73
	December	10.5 ± 8.7	-3.3 ± 6.1	25.00	-12.78	1.98
2009	January	9.5 ± 8.4	-5.6 ± 3.4	25.56	-13.89	0.43
	February	15.5 ± 6.4	1.1 ± 6.9	25.00	-10.00	7.11
	March	18.3 ± 7.7	5.0 ± 6.5	30.00	-7.78	9.22
	April	23.3 ± 6.9	7.8 ± 6.8	33.89	-4.44	12.88
	May	25.0 ± 5.4	12.8 ± 3.2	33.33	6.67	8.28
	June	33.3 ± 4.1	20.6 ± 3.6	40.00	11.11	4.39
	July	33.9 ± 4.5	20.6 ± 3.5	42.78	15.56	12.60
	August	31.1 ± 3.3	20.0 ± 3.4	37.22	11.11	19.05

Chapter III

MINERALIZATION OF NITROGEN FROM COTTONSEED MEAL WITH OR WITHOUT SOAPSTOCK OR CANOLA MEAL WITHOUT SOAPSTOCK

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ABSTRACT

Nitrogen (N) is released from organic materials by the process of mineralization. Mineralization rates can be difficult to determine and vary by organic material and environmental conditions. Determining the rate of mineralization for cottonseed meal with or without soapstock or canola meal will help to establish application rates for consumers. To determine mineralization rates, treatments of cottonseed meal, cottonseed meal with soapstock, canola meal, or no treatment (control) were incubated under controlled conditions. Treatments were incorporated using three different loam soils commonly found in ornamental situations at a rate of 4.9 g m^{-2} *N. Experimental units were incubated for 0, 3, 7, 14, 30, and 60 days and kept at a moisture content of 60% field capacity and then analyzed for total C, total N,* NO_3*-N, and* NH_4*-N. Few differences in total N or total C content occurred.* NH_4*-N rapidly increased with all seed meal amendments during the first 7 to 14 days of incubation then decreased. Nitrate increased in the seed meal treatments between 7 to 14 days of incubation as* NH_4*-N ions*

declined. Cottonseed meal with or without soapstock and canola meal can increase plant available N in soils.

Keywords: organic fertilizer, nitrogen release

INTRODUCTION

Soil is a medium for plant growth, houses and filters our water supply, modifies the atmosphere, serves as a habitat for microbes, and recycles organic materials (Brady and Weil, 2008). Soil supplies plants with essential elements, stores water and air, provides structural support, and moderates temperature around plant roots (Brady and Weil, 2008). Soil capacity for recycling waste is high. Microbes live in the soil and feed on organic residues releasing inorganic compounds that are absorbed by plant roots (Sylvia et al., 2005).

Addition of organic matter benefits the soil system. Adding organic residue increases microbial populations and resulting activity, mineralization, metal ion chelation, aggregation, water availability, availability of macro- and micronutrients, and leads to less water runoff and water pollution (Brady and Weil, 2008). Mineralization is the release of inorganic compounds from organic material. Decomposition of organic material involves the breakdown of proteins, sugars, starches, hemicelluloses, cellulose, fats, waxes, lignin, and phenolic compounds (Brady and Weil, 2008). Mineralization is often the last step of the decomposition process, after microbes feed on the organic material releasing plant available nitrogen (N), phosphorus (P), and other essential elements (Brady and Weil, 2008). Rate of decomposition of organic material varies depending on environmental conditions and the quality of organic residue. Environmental factors that favor decomposition and mineralization include a neutral pH, moist aerated

soil (about 60% pore space filled with water), and warm temperature (25 to 45°C) (Brady and Weil, 2008). Physical characteristics of an easily decomposable organic residue include small particle size, high N content, low carbon to nitrogen ratio (C/N), and low concentrations of lignin and polyphenols (Brady and Weil, 2008). Organic residues with high lignin and polyphenol content do not decompose readily due to limited microbe activity, but those with high amounts of protein and carbohydrates decompose readily in the presence of microorganisms and more rapidly release plant available nutrients (Sylvia et al., 2005). The mineralization rate of organic material and resulting release of plant available nutrients is difficult to determine because of unpredictable environmental factors like temperature, water, and the soil microbial population (Bacon, 1995)

Nitrogen is an essential plant macronutrient, and plant growth and quality can decrease when N is deficient. Nitrogen is a component of proteins and enzymes that are important to metabolic processes involved in synthesis and transfer of energy (Brady and Weil, 2008). Adequate N is important for plant growth, seed and fruit production, and quality of leaf and forage crops. Plants take up N as NH_4 and NO_3. Microorganisms decompose organic matter and release NH_4 and NO_3 (Bacon, 1995). Inorganic N is not immediately available for plant uptake in the first stages of organic decay. Microbes consume N until more inorganic N is available than can be consumed by microbes, creating N for plant uptake (Sylvia et al., 2005).

Organic and synthetic fertilizers are used to increase the nutrient content of the soils. Examples of plant byproducts used as organic fertilizers include: seed meals, leaf and wood compost, and wood ash (Hall, 1998). Animal by-products used as organic fertilizers include bone meal, blood meal, feather meal, manure, and sewage sludge (Hall,

1998). Plant and animal byproducts can differ greatly in nutrient content. Animal manure, for example can be a good fertilizer source but nutrient content differs widely among operations and animal species. Plant and animal byproducts can release nutrients slowly for crops, providing a way to dispose of waste and return nutrients to the soil.

Seed meals are the byproducts of oilseed processing. Oil is extracted from cotton (*Gossypium hirsutum* L.) seed and canola (*Brassica rapa* L.) seed for cooking purposes though recent interest in using these oils for production of bio-fuels has increased. A hexane extraction method (Zeigler et al., 1982) is used to remove oil from the seeds leaving meal and soapstock as byproducts. Soapstock is an undesirable chemical compound removed by a chemical reaction during caustic refining (Kuk et al., 2005). Soapstock consists of low quality fatty acids (Davis et al., 2002). Processors add it to meal because it increases nutritional value for animal feed and provides a means of disposal (Kuk et al., 2005). Other alternative uses for cottonseed and canola meal include using it as a source of protein in feed rations for livestock. Cottonseed and canola meal contain about 41 and 36 percent protein, respectively, and add nutritional value for consumption of various livestock (Conkling, 2008).

Seed meals have the potential to be good organic fertilizers. They are high in nutrients and easily soluble compounds that make them ideal for microbial breakdown and release of macro- and micronutrients. Cottonseed meals generally contain 6 to 7% N, 1.3% P, and 1.6% K; have a pH of 6.5, total carbon content of 35% to 45%, and 41% protein. Canola seed meal contains about 5 to 6% N, 0.8% P, and 0.8% K, has a pH of 6.0, total carbon content of 35% to 45%, and 37% protein.

RELATED LITERATURE

Research about mineralization rates of cottonseed meal and canola meal is limited. Snyder et al. (2009) tested the effect of brassicaceae seed meals (canola and mustard) on growth of carrots, microbial biomass nitrogen, and nitrogen mineralization and found that the seasonal percent mineralization of brassicaceae seed meals ranged from 30% to 81% in a 96 day period. The study also showed greater N mineralization in meal-amended plots than control plots and determined that the meals mineralize at rates adequate for plant N needs (Snyder et al., 2009). Various research studies have been performed to determine the mineralization rates of other organic materials such as animal manure. Gale et al. (2006) examined the decomposition and availability of N released from manure, compost, and specialty products (pelleted organic fertilizer, feather meal, and canola meal) under field and laboratory conditions to determine accuracy of mineralization prediction models based on C/N ratios. Specialty products with C/N ratios of 4 to 8 decomposed 76% and released an average of 78% plant available N in 70 days and broiler litter with C/N ratios of 8 to 10 averaged 40% plant available N release (Gale et al., 2006). Kelderer et al. (2008) sought to improve efficiency of commonly used organic fertilizers by determining N mineralization rates. They tested the mineralization rates for castor seed meal and three seed cakes. After 14 days, of incubation 16% of N mineralized from castor seed meal while 2%, 13%, and 21% mineralized from the seed cakes, and after 60 days of incubation 27% of N mineralized from castor seed meal and 20%, 21%, 30% mineralized from the seed cakes. The seed meal mineralization rates were well behind ammonium nitrate synthetic fertilizer N mineralization percent which was 75% after14 days and 71% after 60 days (Kelderer et al., 2008).

More knowledge and testing are needed to determine the rate of decomposition for cottonseed meal and canola meal and establish application rates. The objective of this study is to determine mineralization of NH_4-N and NO_3-N from three mineral soils amended with cottonseed and canola meal.

MATERIALS AND METHODS

Soil was collected from three sites: *a*) agricultural production site (Norge loam, fine-silty, mixed, thermic Udic Paleustolls, 35% sand, 45% silt, and 20% clay, Oklahoma State University Botanical Garden Stillwater, OK), *b*) recently disturbed construction soil, (clay loam, 35% sand, 37.5% silt and 27.5% clay, Oklahoma State University, Stillwater, OK), and *c*) previously disturbed soil collected from a residential site that was built in the late 1950's, (loam, 50% sand, 30% silt, and 20% clay, corner of Hester Street and Tyler Avenue, Stillwater, OK). The pH of the soils was 5.8, 8.0, and 7.5, respectively. Soils were sieved through a 12 mm mesh screen and air dried. Cottonseed meal with or without soapstock or canola meal without soapstock was thoroughly mixed into each soil type at the recommended fertilizer rate for turf and landscape plants of 4.9 g m^{-2} N. Soil with each amendment or non amended soil (control) was placed in separate 473 ml plastic cups (Solo Cup Company, Lake Forest, IL) at 300 g (58.8 cm^3) per cup. Each soil type contained three replications of the following treatments:

1) cottonseed meal,
2) cottonseed meal with soapstock,
3) canola meal, and
4) control, no treatment.

Treatments were randomized and maintained in darkness at 22° C. Incubation was initiated by adding moisture (tap water) to soil in each cup to achieve 60% field capacity. This moisture content was maintained throughout the study by monitoring total mass of the soil + amendment + cup adjusted to the proper weight. Tap water was added to each treatment every 72 hr to maintain 60% field capacity until sampling. Soil was sampled 0, 3, 7, 14, 30, and 60 days after incubation began. At sampling, soil was placed in a soil bag and dried in an oven at 30° C to prevent N volatilization. Soil was then analyzed for total N and carbon (carbon and nitrogen analyzer, Leco TruSpec, St. Joseph, MI) and inorganic N (1M KC1 extraction followed by colorimetric flow-injection analysis, Lachat QuickChem 8000, Loveland, CO) (Soil, Water, and Forage Analytical Laboratory, Oklahoma State University, Stillwater, OK).

Statistics. A randomized complete block design with four treatments (described above) and three replications was used. Data were analyzed using PROC MIXED in PC SAS Version 9.1 (SAS Institute, Cary, NC). A two way factorial was used with treatment and days incubated as the factors of interest. For significant interactions, data were analyzed using GLM and trend procedures for treatments using 40 degree of freedom F-tests. Differences were assessed with a significance level of 0.05.

The total amount of N mineralized was determined by adding NH_4-N and NO_3-N to get total inorganic N. Total inorganic N for each treatment was subtracted from the control and divided by the amount of organic N added.

RESULTS

Total N. No differences occurred in Total N content for any treatment or soil type during the incubation period, except in soil *c* where cottonseed meal with soapstock was greater than cottonseed meal without soapstock and canola at day 60 (Figure 3.1).

NH_4-N. Differences in NH_4-N occurred among cottonseed meal, cottonseed meal with soapstock, and canola meal treatments during incubation intervals, between treatments, and between soil types.

Soil *a*. Amount of NH_4-N in soil incorporated with cottonseed meal, cottonseed meal with soapstock, and canola meal treatments increased curvilinearly to 42%, 31%, and 30%, respectively, during the first 14 days of incubation then decreased (Figure 3.2). Ammonium content in the control treatment decreased linearly during the days of incubation. Compared to the other seed meals, NH_4-N content increased more in cottonseed meal treatments and was greatest at incubation day 14. Canola meal NH_4-N content was greatest at incubation day 7 and increased more than cotton seed meal without soapstock which was greatest at incubation day 14.

Soil *b*. Content of NH_4-N increased curvilinearly during the first 14 days of incubation to 27% in cottonseed meal, 26% in cottonseed meal with soapstock, and 25% in canola treatments. Cottonseed meal with soapstock treatments had a greater increase in NH_4-N content than canola meal followed by cottonseed meal and all seed meal treatments released the highest content at incubation day 7.

Soil *c*. Cottonseed meal, cottonseed meal with soapstock, and canola meal increased curvilinearly in NH_4-N content to 27%, 34%, and 31% during the first 14 days of incubation then decreased (Figure 3.2). Amount of NH_4-N in the control decreased linearly during incubation. Cottonseed meal with soapstock treatments had the greatest

increase in NH_4 content occurring at incubation day 14. Ammonium content in treatments amended with canola meal was greater than cottonseed meal amendments and both were highest at incubation day 7.

NO_3-N. Differences in NO_3-N occurred among cottonseed meal, cottonseed meal with soapstock, and canola meal treatments during incubation intervals, between treatments, and between soil types.

Soil *a*. Nitrate content in soil incorporated with cottonseed meal, cottonseed meal with soapstock, canola meal without soapstock, or no treatment increased curvilinearly during the 60 days of incubation to 62, 60, 63, and 21 mg kg^{-1}, respectively (Figure 3.3).

Soil b. Amount of NO_3-N increased curvilinearly to 66 mg kg^{-1} in cottonseed meal, 53 mg kg^{-1} with cottonseed meal with soapstock treatments, and 61 mg kg^{-1} with canola meal during incubation (Figure 3.3).

Soil *c*. Nitrate amount increased curvilinearly in treatments of cottonseed meal, cottonseed meal with soapstock, and canola meal to 52, 60, and 50 mg kg^{-1}, respectively, during the 60 days of incubation (Figure 3.3). Nitrate amount in the control linearly increased to 20 mg kg^{-1} during incubation (Figure 3.3).

Total C. Few differences occurred in total C percent. Control was less than the seed meal treatments at incubation day 60 in soil *a* (Figure 3.4). No differences occurred in soil b (Figure 3.4). In soil *c*, total C decreased in cottonseed meal during days 0 to 3 (Figure 3.4). Cottonseed meal with soapstock at day 60 was greater than cottonseed meal without soapstock, canola meal, and control treatments (Figure 3.4).

Inorganic N Mineralized. Total inorganic N mineralized increased in cottonseed meal, cottonseed meal with soapstock, and canola meal without soapstock treatments in all soils tested.

Soil *a*. Total inorganic N mineralized in soil incorporated with cottonseed meal, cottonseed meal with soapstock, and canola meal to 84%, 87%, and 60%, respectively, by day 60 (Figure 3.5). Cottonseed meal mineralized the greatest amount of N followed by cottonseed meal with soapstock and then canola meal.

Soil *b*. Amount of total inorganic N mineralized in cottonseed meal and cottonseed meal with soapstock increased curvilinearly to 86% and 83%, respectively, during the first 30 days of incubation then decreased (Figure 3.5). Canola meal treatments increased in mineralized total N to 57% during the 60 day incubation period (Figure 3.5). The greatest amount of N mineralized occurred in the cottonseed meal treatment followed by cottonseed meal with soapstock and then canola meal.

Soil *c*. Total mineralized inorganic N increased curvilinearly in cottonseed meal, cottonseed meal with soapstock, and canola meal increased curvilinearly to 70%, 55%, and 45%, respectively, during the first 30 days of incubation then decreased (Figure 3.5). Cottonseed meal with soapstock mineralized the greatest amount followed by cottonseed meal and then canola meal.

DISCUSSION

Mineralization rates are difficult to predict and were not well determined in past studies for cottonseed or canola meal. The time required to decompose organic material depends on the nature of the residue and soil. Cottonseed meal and canola meal exhibit characteristics favorable for release of inorganic N. Cottonseed meal has 6 to 7% N, a pH

of 6.5, and total carbon content of 35% to 45% and canola seed meal contains about 5 to 6% N, a pH of 6.0, and total carbon content of 35% to 45%. An environment conducive for organic decomposition was created to examine the release of inorganic forms of N from cottonseed meal and canola meal. The environment had adequate soil moisture (60% field capacity) and air temperature (22° C) to promote microbial breakdown of organic residues.

Total N content was generally constant for each treatment and soil type. Total N was not expected to change because it is a measure of both organic and inorganic forms of N. As organic forms of N mineralize and transform to inorganic forms the total amount of N should not change unless N was lost by NH_3 volatilization or denitrification. Since there was no change in Total N, no NH_3 volatilization or denitrification occurred.

Increases in NH_4-N occurred as a result of ammonification of the seed meals. Ammonification occurs when organic N is converted to NH_4-N mediated by soil microbes (Sylvia et al., 2005). Materials that are high in nitrogen and contain C/N ratios below 20 such as cottonseed or canola meals contain enough N to meet the needs of decomposing organisms. After the application of organic residues to soil there is an initial increase in soil microbes that feed on the new supply of organic material, after microbial populations level they decline back to a steady-state condition (Sylvia et al., 2005). The mineralization of organic N follows the same pattern where the NH_4-N amounts initially increase then steadily decrease because the microbes decompose the organic N. Ammonium was highest in all soils at 7 to 14 days of incubation and then decreased.

Nitrate is produced by nitrification when NH_4-N ions are oxidized by soil bacteria to yield NO_3-N which is quickly transformed by bacteria into NO_3-N (Brady and Weil,

2008). Nitrate content did not immediately increase when the seed meals were added to the soil. The release of NO_3-N followed trends in which the decomposition of organic N released NH_4-N that was then available for soil bacteria to transform into NO_3-N. As NH_4-N content peaked and began to fall, NO_3-N content increased in the soils. Oxidation of NH_4-N ions by soil bacteria most likely yielded increases in NO_3-N. Increases in NO_3-N occurred for all of the seed meal treatments.

Mineralization of organic N into inorganic forms occurred in seed meal treatments in each soil type. Nutrients are most available in soils with a near neutral pH of 6.0 to 7.0 and that contain the most diverse communities of soil microbes and bacteria (Sylvia et al., 2005). Mineralization rates steadily increased in soil *a*, which had a pH of 5.8. Organic nitrogen was slower to mineralize in soils *b* and *c* which had a higher soil pH of 8.0 and 7.5, respectively. Loam soil with neutral pH (soil *a*) mineralized 60% to 87% of the organic nitrogen from seed meals during 60 days of incubation (Figure 3.5). Loam soil with high pH (soil *b*) mineralized 83% and 86% organic N from cottonseed meal without soapstock and cottonseed meal with soapstock, respectively, during the first 30 days of incubation while canola meal without soapstock mineralized 56% during 60 days of incubation (Figure 3.5). Clay loam with high pH (soil *c*) mineralized 44% to 70% of the organic nitrogen from seed meals during the first 30 days of incubation (Figure 3.5). Inorganic N in canola meal treatments at day 14 for soil *a*, *b*, and *c* were 52, 36, and 38%, respectively which were similar to that of Gale et al. (2006) who found that plant available N released from canola meal was 39% on day 14 and 41% on 70. Seed meals mineralized at higher rates than broiler litter with C/N ratios of 8 to 10 which averaged 40% plant available N release in 70 days (Gale et al., 2006).

Rate of nitrogen mineralization from cottonseed meal with or without soapstock or canola meal without soapstock is dependent on environmental conditions and the nature of the soil. Cottonseed meal with and without soapstock and canola meal can increase plant available N in soils.

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Figure 3.1. Amount of total N (%) in soil *a* (agricultural production site), soil *b* (recently disturbed construction site soil), and soil *c* (previously disturbed soil collected from a residential site that was built in the late 1950's) incorporated with cottonseed meal without or without soapstock or canola meal or no treatment at 0, 3, 7, 14, 30, and 60 days of incubation. There were no significant difference among treatments or incubation times, except on day 60 in soil *c*. Vertical bar represents protected LSD at $P \leq 0.05$ % for incubation day 60.

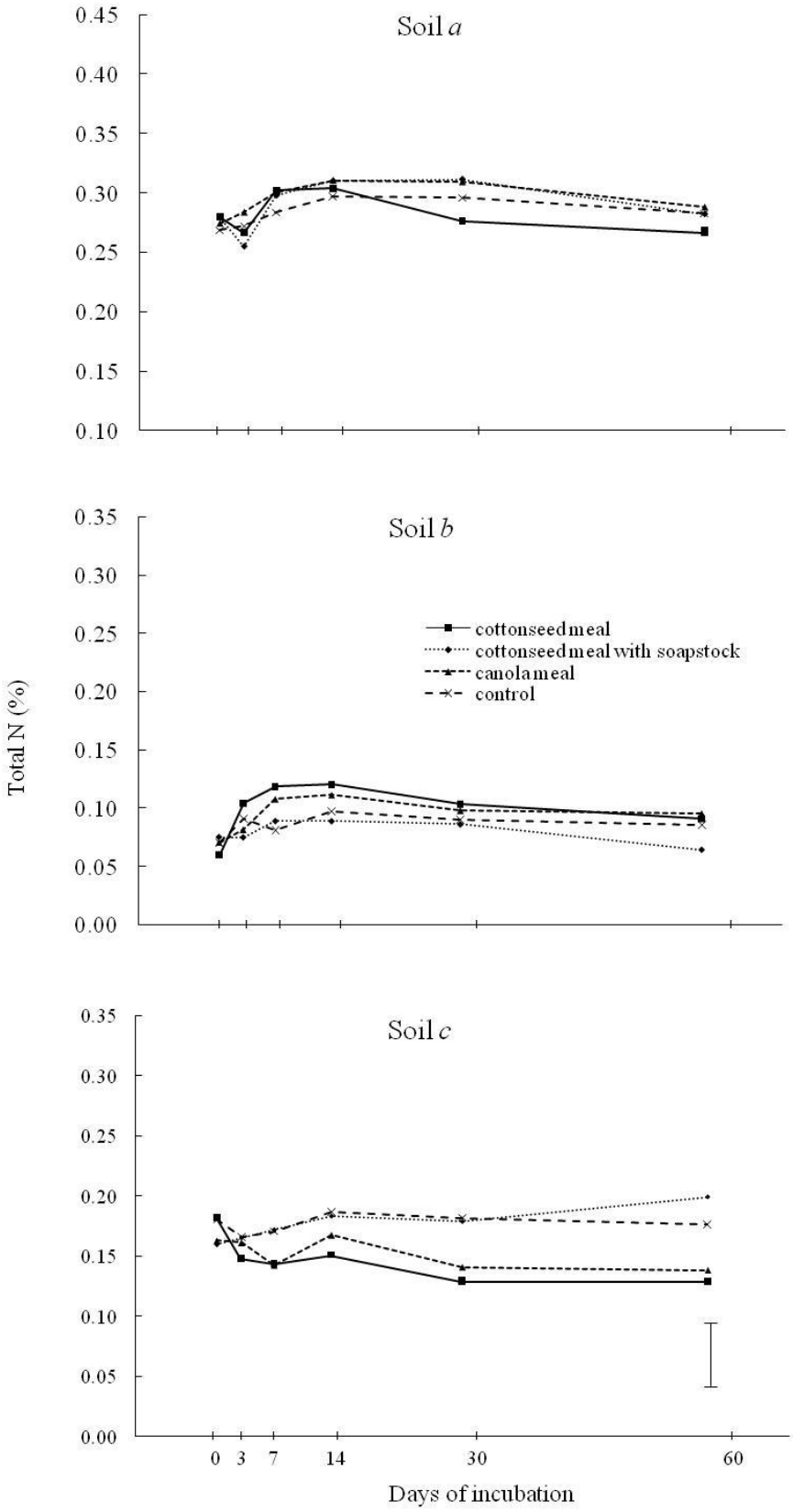

Soil a
Soil b
Soil c
Total N (%)
cottonseed meal
cottonseed meal with soapstock
canola meal
control
0.45
0.40
0.35
0.30
0.25
0.20
0.15
0.10
0.05
0.00
0 3 7 14 30 60
Days of incubation

Figure 3.2. Amount of NH_4-N (mg kg^{-1}) in soil *a* (agricultural production site), soil *b* (recently disturbed construction site soil), and soil *c* (previously disturbed soil collected from a residential site that was built in the late 1950's) incorporated with cottonseed meal without or without soapstock or canola meal or no treatment at 0, 3, 7, 14, 30, and 60 days of incubation. Predicted regression equations for NH_4-N: soil *a*) cottonseed meal $y=8.45 + 4.22x - 0.157x^2 + 0.00152x^3$, $r^2=0.909$, cottonseed meal with soapstock $y=10.31 + 2.77x - 0.101x^2 + 0.00097x^3$, $r^2=0.809$, canola meal $\hat{y}=11.44 + 3.60x - 0.161x^2 + 0.00172x^3$, $r^2=0.861$, control $y=7.43 - 0.08x$, $r^2=0.529$; soil *b*) cottonseed meal $y=3.62 + 4.05x - 0.177x^2 + 0.00183x^3$, $r^2=0.789$, cottonseed meal with soapstock $y=1.05 + 4.35x - 0.179x^2 + 0.00179x^3$, $r^2=0.824$, canola meal $y=5.81 + 4.51x - 0.214x^2 + 0.00230x^3$, $r^2=0.910$, control was not significant; and soil *c*) cottonseed meal $y=12.94x - 0.157x^2 + 0.00152x^3$, $r^2=0.909$, cottonseed meal with soapstock $y=9.08 + 2.92x - 0.123x^2 + 0.00123x^3$, $r^2=0.891$, canola meal $y=14.25 + 2.56x - 0.121x^2 + 0.00130x^3$, $r^2=0.680$, control $y=9.60 - 0.09x$, $r^2=0.680$. Significance was determined at $P \leq 0.05$.

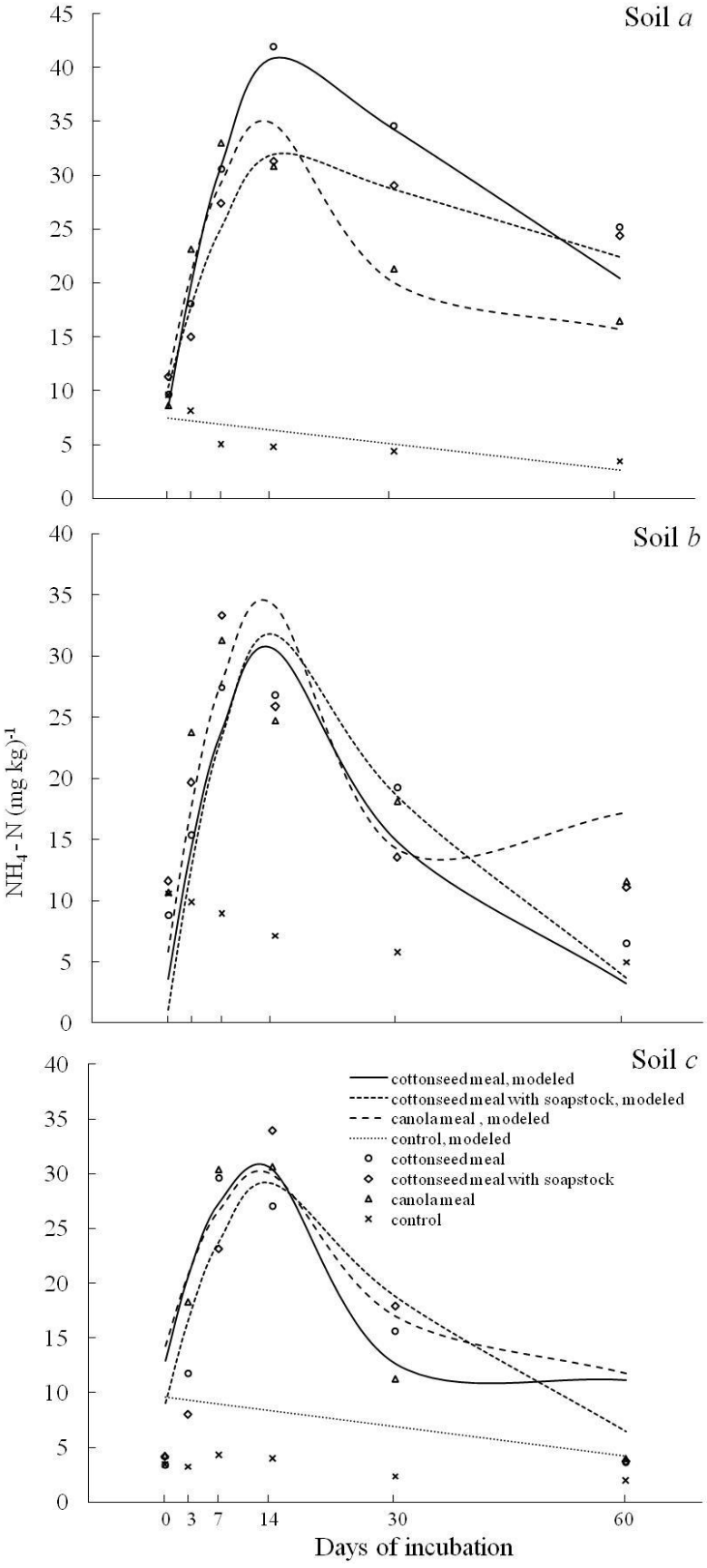

Soil a
Soil b
Soil c
NH4-N (mg kg)-1
Days of incubation
0 3 7 14 30 60
cottonseed meal, modeled
cottonseed meal with soapstock, modeled
canola meal , modeled
control, modeled
cottonseed meal
cottonseed meal with soapstock
canola meal
control

Figure 3.3. Amount of NO_3-N (mg kg^{-1}) in soil *a* (agricultural production site), soil *b* (recently disturbed construction site soil), and soil *c* (previously disturbed soil collected from a residential site that was built in the late 1950's) incorporated with cottonseed meal without or without soapstock or canola meal or no treatment at 0, 3, 7, 14, 30, and 60 days of incubation. Predicted regression equations for NO_3-N: soil *a*) cottonseed meal $y=5.69 + 2.07x - 0.037x^2 + 0.00031x^3$, $r^2=0.984$, cottonseed meal with soapstock $y=7.88 + 2.19x - 0.034x^2 + 0.00019x^3$, $r^2=0.991$, canola meal $y=5.54 + 2.65x - 0.046x^2 + 0.00030x^3$, $r^2=0.991$, control $y=7.86 + 0.60x - 0.063x^2$, $r^2=0.782$; soil *b*) cottonseed meal $y= 2.85 - 1.31x + 0.155x^2 - 0.00199x^3$, $r^2=0.973$, cottonseed meal with soapstock $y=1.05 + 4.35x - 0.179x^2 + 0.00179x^3$, $r^2=0.824$, canola meal $y=0.39 + 0.27x + 0.053x^2 - 0.00069x^3$, $r^2=0.890$, control was not significant; and soil *c*) cottonseed meal $y=0.36 + 2.01x - 0.018x^2$, $r^2=0.987$, cottonseed meal with soapstock $y=1.61 + 2.88x - 0.032x^2$, $r^2=0.696$, canola meal $y=0.87 + 2.25x - 0.0235x^2$, $r^2=0.968$, control $y=1.17 + 0.04x$, $r^2=0.734$. Significance was determined at $P \leq 0.05$.

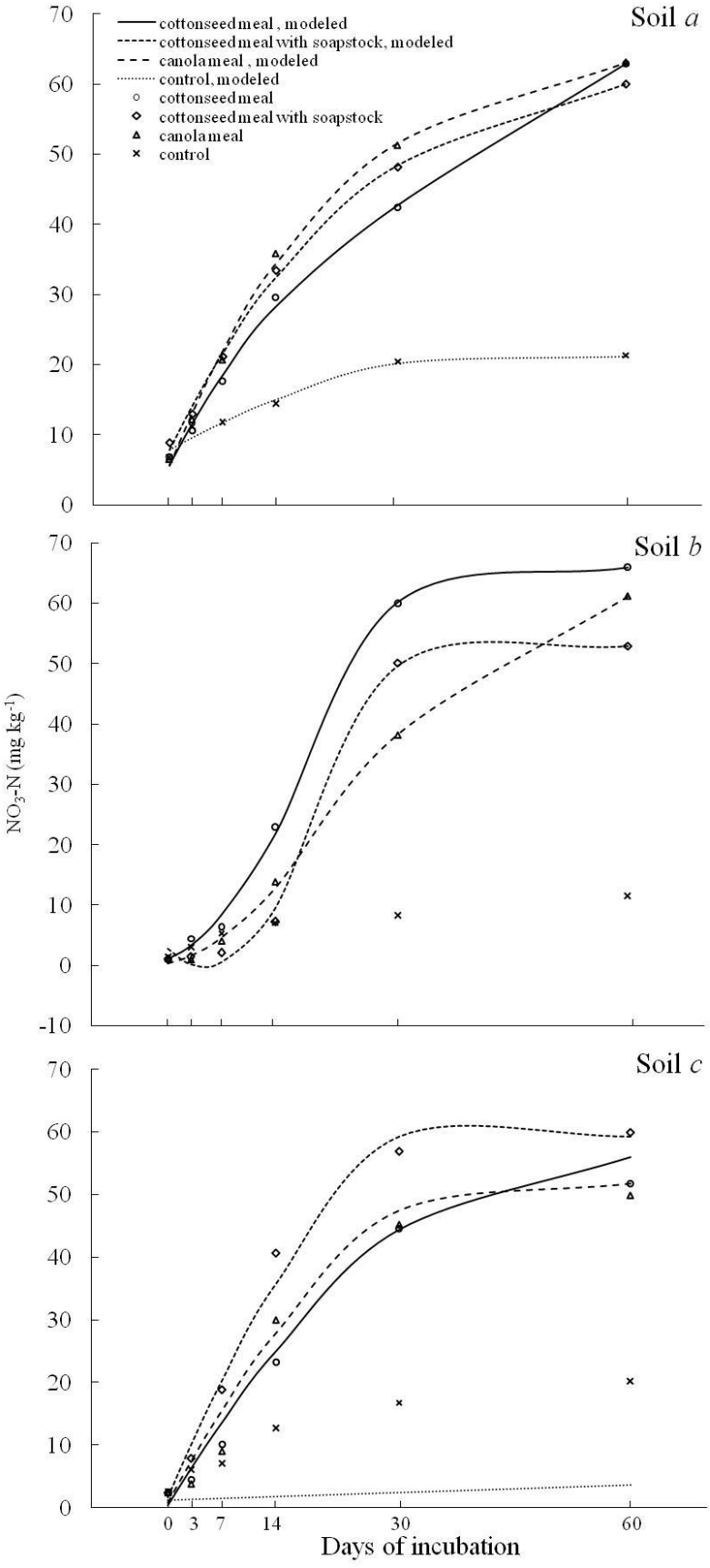

Soil a
Soil b
Soil c
cottonseed meal , modeled
cottonseed meal with soapstock, modeled
canola meal , modeled
control, modeled
cottonseed meal
cottonseed meal with soapstock
canola meal
control
NO3-N (mg kg-1)
Days of incubation
0 3 7 14 30 60
70 60 50 40 30 20 10 0
70 60 50 40 30 20 10 0 -10
70 60 50 40 30 20 10 0

Figure 3.4. Amount of total C (%) in soil *a* (agricultural production site), soil *b* (recently disturbed construction site soil), and soil *c* (previously disturbed soil collected from a residential site that was built in the late 1950's) incorporated with cottonseed meal without or without soapstock or canola meal or no treatment at 0, 3, 7, 14, 30, and 60 days of incubation. There were no significant difference among treatments or incubation times, except on day 60 in soil *a* and *c*. Vertical bar represents protected LSD at $P \leq 0.05$ % for incubation day 60.

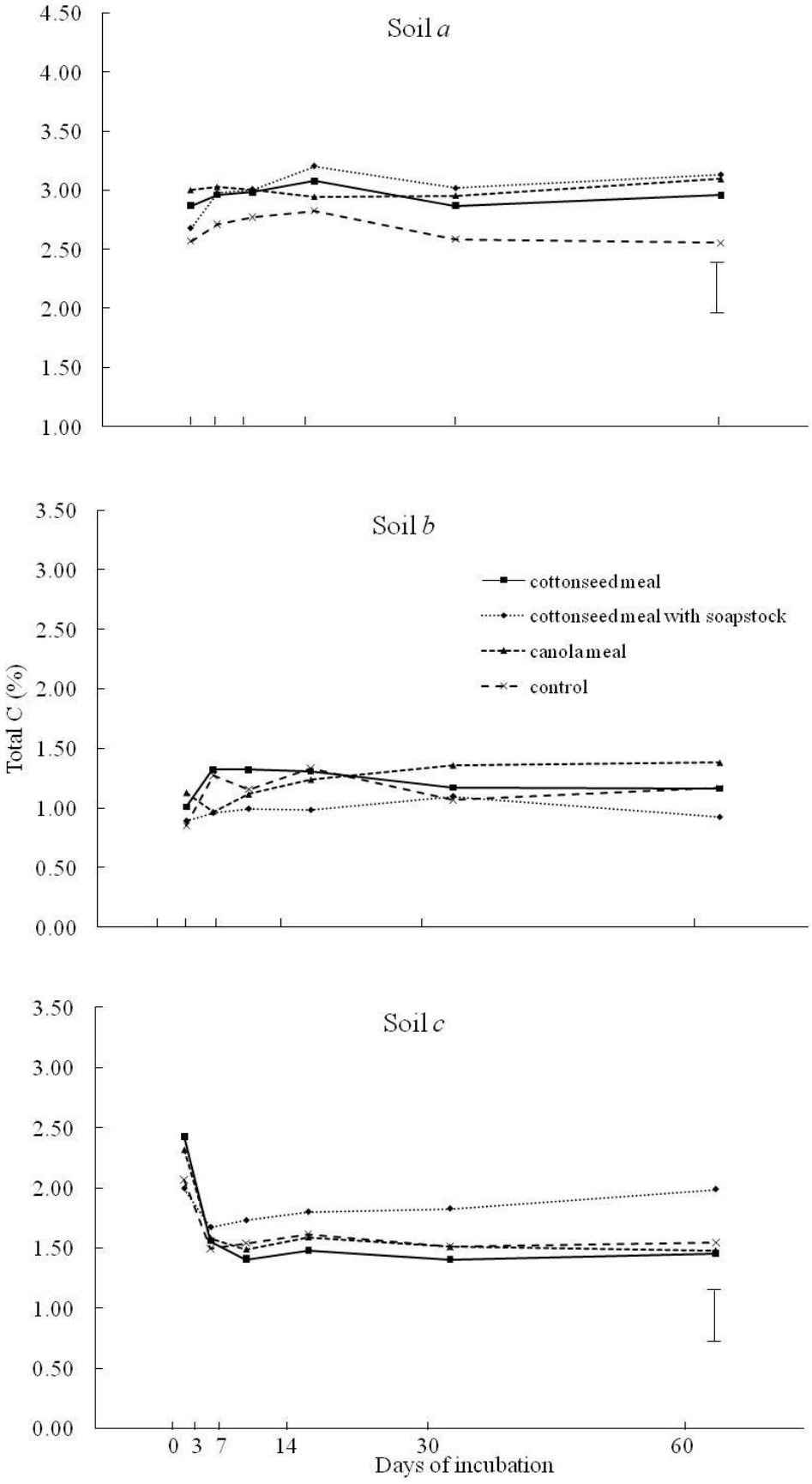
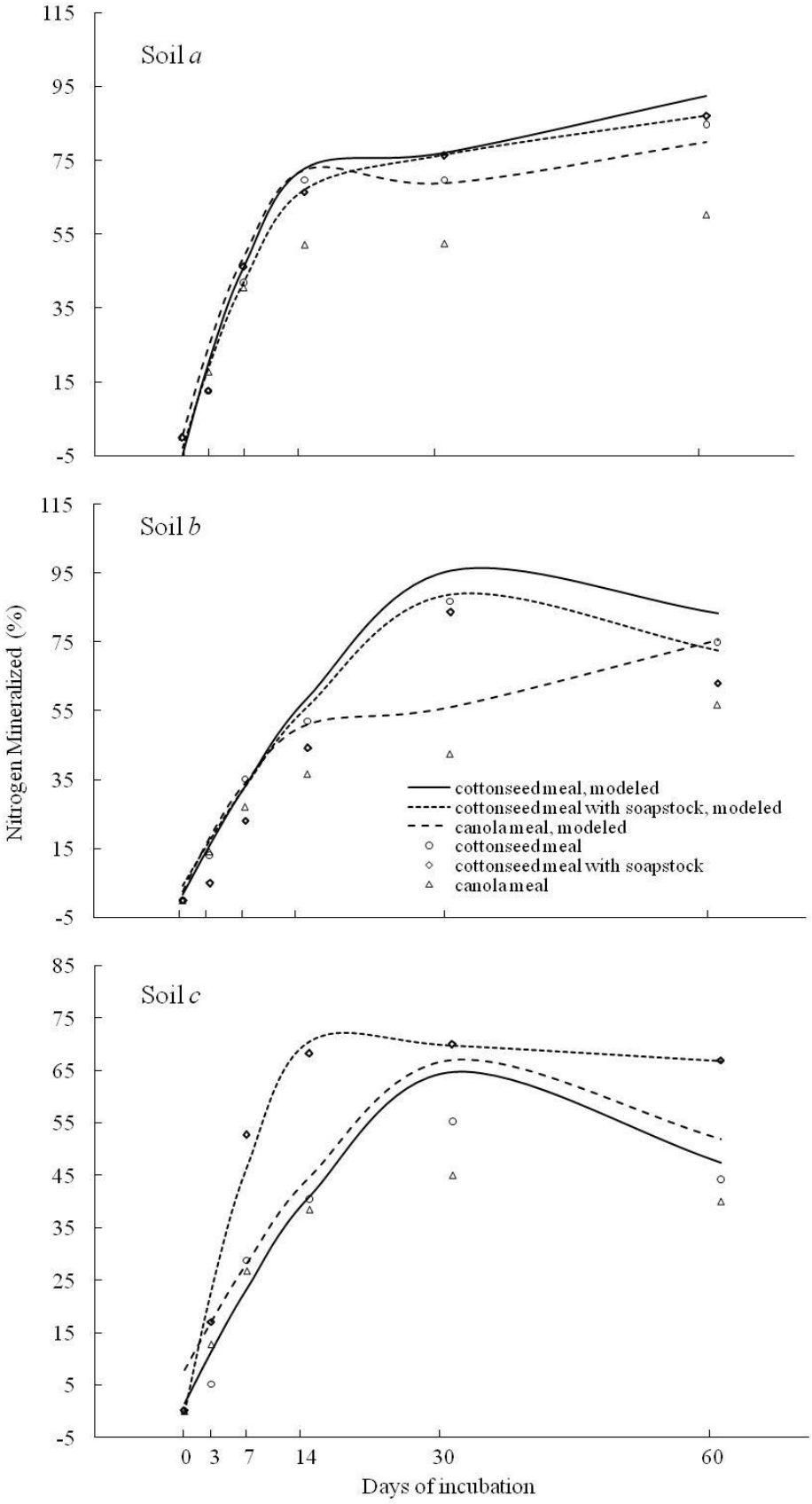

Soil a
Soil b
Soil c
cottonseed meal
cottonseed meal with soapstock
canola meal
control
Total C (%)
Days of incubation
4.50
4.00
3.50
3.00
2.50
2.00
1.50
1.00
0.50
0.00
0
3
7
14
30
60

Figure 3.5. Amount of N (%) mineralized in soil *a* (agricultural production site), soil *b* (recently disturbed construction site soil), and soil *c* (previously disturbed soil collected from a residential site that was built in the late 1950's) incorporated with cottonseed meal without or without soapstock or canola meal or no treatment at 0, 3, 7, 14, 30, and 60 days of incubation. Predicted regression equations for mineralized N: soil *a*) cottonseed meal $y=-4.69 + 9.26x - 0.309x^2 + 0.00302x^3$ $r^2=0.969$, cottonseed meal with soapstock $y=-2.85 + 8.05x - 0.251x^2 + 0.00236x^3$ $r^2=0.972$, canola meal $y=0.69 + 8.97x - 0.319x^2 + 0.00319x^3$, $r^2=0.983$; soil *b*) cottonseed meal $y= 4.29 + 4.49x - 0.0559x^2$, $r^2=0.932$, cottonseed meal with soapstock $y=1.05 + 4.35x - 0.179x^2 + 0.00179x^3$, $r^2=0.824$, canola meal $y=2.39 + 5.73x + 0.187x^2 - 0.00187x^3$, $r^2=0.729$; soil *c*) cottonseed meal $y=1.58 + 3.45x - 0.0447x^2$, $r^2=0.937$, cottonseed meal with soapstock $y=-0.16 + 8.61x - 0.293x^2 +.00282x^3$, $r^2=0.575$, canola meal $y=7.98 + 3.21x - 0.0412x^2$, $r^2=0.975$. Significance was determined at $P \leq 0.05$. Lines represent predicted regression equations.


Soil a
Soil b
Soil c
Nitrogen Mineralized (%)
Days of incubation
cottonseed meal, modeled
cottonseed meal with soapstock, modeled
canola meal, modeled
cottonseed meal
cottonseed meal with soapstock
canola meal

Chapter IV

PARTITIONING OF NITROGEN, PHOSPHORUS, AND POTASSIUM IN REDBUD TREES

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ABSTRACT

*The partitioning of nitrogen (N), phosphorus (P), and potassium (K) in redbud (*Cercis canadensis *L.) was examined at four physiological stages to determine when and where the nutrients were present. Above ground perennial shoots, leaves, and roots were analyzed for N, P, and K at dormancy, budbreak, leaf maturation, and leaf drop. No difference occurred between plants fertilized with urea and untreated control plants except the concentration of N in the leaves was greater in plants fertilized with urea at budbreak than in leaves of untreated control plants. Differences in N, P, and K concentration and content of N, P, and K in redbud leaves, shoots, and roots occurred among physiological stages except concentration of N and P in the roots did not differ among physiological stages. Concentration of N, P, and K was greatest at budbreak. Nitrogen and P content of leaves and shoots were transported to the roots after leaf maturation. Redbud nutrient demand is greatest during the spring when trees are rapidly growing and absorbing N, P, and K.*

Keywords: *Cercis canadensis*, nutrient allocation, biomass estimation

INTRODUCTION

Plant nutrients are chemical elements essential for plant growth and reproduction. For an element to be a nutrient it must be vital for the plant to complete its life cycle, no other element can substitute, and it must be required by all plants (Barker and Pilbeam, 2007). Plants absorb nutrients from the soil or nutrient solutions. Macronutrients are elements required in large amounts (0.01% and greater in plant tissue dry mass of most plants) and micronutrients are required only in small amounts (less than 0.01% of the dry mass of most plant tissues) (Barker and Pilbeam, 2007). Nitrogen, P, and K are macronutrients that are frequently deficient in plants.

Nitrogen is a necessary component of many plant compounds. Nitrogen is an essential element in amino acids, nucleic acids, and chlorophyll and is important for carbohydrate use, photosynthesis, and transfer of energy (Brady and Weil, 2008). Adequate N (2.5% to 4% in dry tissue matter) helps with plant growth, increases seed and fruit production, and improves the quality of leaf and forage crops while a shortage of N can reduce plant growth (Barker and Pilbeam, 2007).

Phosphorus is important for processes such as energy transfer and protein synthesis and is an essential component of adenosine triphosphate (ATP), deoxyribonucleic acid (DNA) and ribonucleic acid (RNA) (Brady and Weil, 2008). Sufficient P aids plants with photosynthesis, nitrogen fixation, flowering, fruit production and can enhance crop quality (Brady and Weil, 2008). Healthy plant tissue content of P ranges from 0.2% to 0.4% in dry matter (Barker and Pilbeam, 2007). Plants deficient in P

can exhibit reduced growth, less flowering, smaller fruit, and poor seed quality (Barker and Pilbeam, 2007).

Potassium is important for enzyme activation, protein synthesis, photosynthesis, and ion absorption and transport (Barker and Pilbeam, 2007). Adequate K (1% to 4% dry leaf tissue matter) assists plants with drought tolerance, winter hardiness, pest resistance, and crop quality (Brady and Weil, 2008). Plants take up N and P in both organic and inorganic forms while K is only taken up in ionic form (Brady and Weil, 2008). Nitrogen, P, and K are very mobile within plants and concentrations increase or decrease due to physiological demand. Nutrient concentration in plant parts such as leaves are high at early stages of growth and as the leaves mature nutrients are transported to other plant parts (Barker and Pilbeam, 2007).

Soil quality and nutrient availability are important for plant growth. Soils that lack sufficient nutrients are often amended with fertilizer to replenish those nutrients. Fertilizing can increase soil fertility and improve the health of plants (Brady and Weil, 2008). Timing should be carefully considered when applying fertilizer. To improve plant health and quality, nutrients should be available during periods when plants require them. Avoiding excess fertilization when plant utilization and uptake is low can reduce loss of fertilizer by volatilization, runoff, and leaching (Brady and Weil, 2008).

Tree biomass estimations determine amounts of individual or populations of plant biomass. Biomass estimates are useful to study tree carbon stocks, characterize ecosystems, and examine plant nutrition. Biomass is often used in nutrient allocation studies because it is closely related to energy content (Hickman and Pitelka, 1975).

Understanding nutrient partitioning in plants can help determine the critical periods of nutrient uptake during physiological changes in growth. Knowing when plants are utilizing nutrients can improve the efficiency of fertilizer application and establish the best time to fertilize.

RELATED LITERATURE

Limited literature exists on biomass estimates and nutrient partitioning in the concentration of macronutrients for ornamental trees such as redbud. A study by Acuña-Maldonado et al. (2003) determined that pecan (*Carya illinoinensis* Wangenh. C. Koch.) trees absorbed the largest annual amount of N during development of new shoots, leaves, and flowers. Another study showed that P and K concentrations increased in pecan trees during rapid new growth from budbreak until July and then decreased from July until the next budbreak (Smith, 2009). A study on the seasonal changes of nutrient content on aspen (*Populus tremuloides* Michx.) suckers showed large variations of N, P, and K occurred throughout the growing season (Alban, 1985). Alban (1985) determined that some perennial tissue nutrient concentration changes are directly related to re-translocation of nutrients from the foliage in the spring, midsummer, and fall. Tree biomass estimates are determined using equations. Jenkins et al. (2003) studied the efficiency of different allometric regression equations for estimating total above ground and component biomass for trees in the United States and determined that allometric regression equations are better suited for individual trees and small populations than for large scale forests of mixed species. Smith and Wood (2006) determined allometric pecan tree biomass estimates by using estimating equations from King and Schnell (1972). Smith and Wood (2006) used $Y = e^{a}X^{b}$ to effectively determine pecan biomass where Y

was the dry weight, e was the natural logarithm base, *a* and *b* were coefficients, and X was the trunk diameter measured at 1.4 m above the soil line.

The objective of this research is to determine the period(s) of nutrient demand in redbud trees to improve timing of fertilization, and reduce loss of nutrients by leaching and runoff.

MATERIALS AND METHODS

The study was conducted in a Norge loam (fine-silty, mixed, thermic Udic Paleustolls) at the Oklahoma State University Botanical Garden (Stillwater, OK). Bareroot redbud seedlings, averaging 94 cm tall, were planted 1.52 m apart into holes drilled with a 30.5 cm diameter augur on 5 May 2008. The two treatments used in this experiment were: trees fertilized with urea (46N-0P-0K, Agri-Nutrient, Port of Catoosa, OK) at a landscape recommended rate of 4.9 g m^{-2} N and untreated control. Urea was applied on 5 May 2008 and 20 May 2009. Three replications of trees from each treatment were harvested at four phenological stages: 1) dormancy (2 April 2009), 2) after budbreak (23 April 2009), 3) leaf maturation (11 August 2009), and 4) at leaf drop (21 October 2009). Prior to harvest, trunk diameter was measured at 6 cm above the soil line to estimate tree biomass. Trees were severed at the ground and divided into above ground perennial shoots, leaves, and roots. Roots of each tree were collected by digging an area around the trunk 1 m wide by 1 m long by 1 m deep and hand sieving the entire volume. Six 10-cm pieces were collected from the above ground perennial shoots of each tree and dried and weighed for analysis. All tree parts were dried in an oven at 55º C to a constant weight and then weighed. About 5 g each of dried leaves, shoots, and roots of each tree were ground with a Wiley mill to pass through an 0.84 mm mesh screen and placed in

separate aliquots until analysis. Samples were analyzed for total percent N (combustion method, Leco TrueSpec, St. Joseph, MI), P (colormetric analysis, Genesys 10 Spectrophotometer, ThermoSpectronic, Rochester, NY), and K (atomic absorption spectroscopy, 2380 Atomic Absorption Spectrophotometer, Perkin Elmer, Norwalk, CT).

Weight (mg) of N, P, and K for each plant component was determined by multiplying the tree weight by the N, P, or K concentration. Gain or loss of nutrient content was calculated from one sample time to the next using % change = $(y_2 - y_1)/y_1 * 100$, where y_1 is elemental concentration at the earlier sample time and y_2 is the elemental concentration at the subsequent sample time. Content or concentration of nutrients for each plant component were added to get total tree N, P, and K.

Biomass equations were fitted by least squares techniques using $Y = e^a X^b$ (King and Schnell, 1972). Where Y is the dry weight, e is the natural logarithm base, *a* and *b* are coefficients, and X is the trunk diameter measured 6 cm above the soil line.

Statistics. Data were analyzed using PROC MIXED in SAS Version 9.1 (SAS Institute, Cary, NC). Means were compared using the protected least significant difference at a level of 0.05.

RESULTS

Concentration of N in the leaves was greater in plants fertilized with urea than in unfertilized plants at budbreak (Figure 4.1). No differences in N concentration in shoots or roots occurred between plants receiving urea and no treatment (data not presented). Likewise, no difference in P or K concentration in leaves, stems, or roots existed between fertilizer treatments (data not presented).

Nitrogen, P, and K concentrations in leaves were greatest at budbreak (Figure 4.2). Leaf N, P, and K concentration did not differ between leaf maturation and leaf drop. Shoot percent N and P did not differ at dormancy, budbreak, or leaf drop, but shoot N and P were lower at leaf maturation. Potassium concentration in the shoots was greatest at budbreak and was lower but did not differ among dormancy, leaf maturation, and leaf drop. Potassium concentration in roots was greatest at leaf maturation and did not differ among dormancy, budbreak, and leaf drop. Trees accumulated 5.6% N during dormancy to budbreak, lost 3.8% N during budbreak to leaf maturation and 0.5 % N during leaf maturation to leaf drop. Phosphorus concentrations in the trees gained 0.5% during dormancy to budbreak and lost 0.3% during budbreak to leaf maturation and 0.02% during leaf maturation to leaf drop. Total tree K concentration gained 1.7% during dormancy to budbreak and lost 0.8% during budbreak to leaf maturation and 0.08 % during leaf maturation to leaf drop.

Leaf weight of N, P, and K increased between budbreak and leaf maturation and decreased from leaf maturation to leaf drop (Figure 4.3). Weight of N, P, and K in the shoots did not differ and was lowest between dormancy and budbreak, increased between budbreak and leaf maturation, and decreased from leaf maturation to leaf drop. Weight of N, P, and K in the roots did not differ between dormancy and budbreak, increased between budbreak and leaf maturation, and did not differ from leaf maturation to leaf drop. Redbud trees lost 0.1 g/tree N during dormancy to budbreak, accumulated 36.4 g/tree N during budbreak to leaf maturation, and lost 8.4 g/tree N during leaf maturation to leaf drop. Trees accumulated 3.3 g/tree P during budbreak to leaf maturation and lost 0.6 g/tree P during leaf maturation to leaf drop. Redbuds gained 0.06 g/tree K during

dormancy to budbreak, gained 10.0 g/tree K during budbreak to leaf maturation and lost 3.9 g/tree K during leaf maturation to leaf drop.

Biomass estimates of redbud trees were within predicted ranges based on allometric equations. Leaf, shoot, and root weight of redbuds ranging in caliper from 11.6 to 47.9 mm measured at 6 cm from the soil line were inside predicted estimation ranges.

DISCUSSION

Nutrients move among roots, stems and leaves of redbud trees throughout the growing season. Plant nutrient concentration adjusts depending on physiological changes. As leaves mature and begin to drop, nutrients are allocated to shoots and roots.

Treatment had little effect on N, P, or K concentration in the trees. Trees fertilized with urea had a greater concentration of N in the leaves at budbreak suggesting that fertilized plants absorbed more N than unfertilized plants, and applications of fertilizer during spring growth could increase N in the leaves (Figure 4.1).

Patterns of change in concentration of N, P, and K were similar among the tree parts. The greatest accumulation of nutrients was in leaves at budbreak during rapid growth (Figure 4.2). As the leaves began to mature, nutrient concentration of N, P, and K decreased in the leaves from budbreak to leaf drop (Figure 4.2). Shoots and roots were consistently opposite each other in concentration of N, P, and K. For example from budbreak to leaf maturation P concentration decreased in the shoots as it increased in the roots (Figure 4.2). The distribution of nutrients among tree parts suggests that nutrients shift between leaves, shoots, and roots throughout the season as determined in other studies (Acuña-Maldonado et al., 2003; Alban, 1985; and Smith, 2009).

Patterns of change in weight of N, P, and K in the trees were similar during the growing season. Nitrogen, P, and K increased in leaves, shoots, and roots from budbreak to leaf maturation when the trees were actively growing (Figure 4.3). After leaf maturation N and P in shoots and leaves declined as the content in the roots increased (Figure 4.3). Potassium content in roots followed a similar trend to that of N and P except content of K decreased by 6% between leaf maturation and leaf drop (Figure 4.3). Data suggest some of the nutrients were allocated to the roots after leaf maturation, though some nutrients were lost since total tree nutrient content decreased from leaf maturation to leaf drop.

Biomass estimates were within predicted estimates using allometric equations and reflected suggestions by Smith and Wood (2006) and Jenkins et al. (2003) (Figure 4.4). Smith and Wood (2006) suggested that tree biomass predictions were very accurate for trees of small diameter. Jenkins et al. (2003) concluded that estimates on individual trees were more precise than estimates on groups of trees. The caliper of the trees in this study were small, ranging from 11.6 to 47.9 mm measured at 6 cm above the soil line, and were individually sampled.

More research is proposed to determine the allocation of nutrients when redbuds flower since the trees in this study were immature and did not produce flowers. Data in this study and other studies (Acuña-Maldonado et al., 2003; Alban, 1985; and Smith, 2009) suggest that nutrient demand and absorption were greatest in the spring during rapid growth. The best time to apply fertilizer for redbud trees is before budbreak, to make nutrients available when plants are absorbing them in the greatest amount.

Applying fertilizer when plants are rapidly absorbing nutrients could reduce fertilizer loss and effectively decrease runoff, leaching, and volatilization of nutrients.

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Figure 4.1. Nitrogen concentration in redbud leaves at budbreak (23 April 2009), leaf maturation (11 August 2009), and leaf drop (21 October 2009) in trees fertilized with urea or not fertilized. Bar represents protected LSD at $P \leq 0.05$ %, n=3.

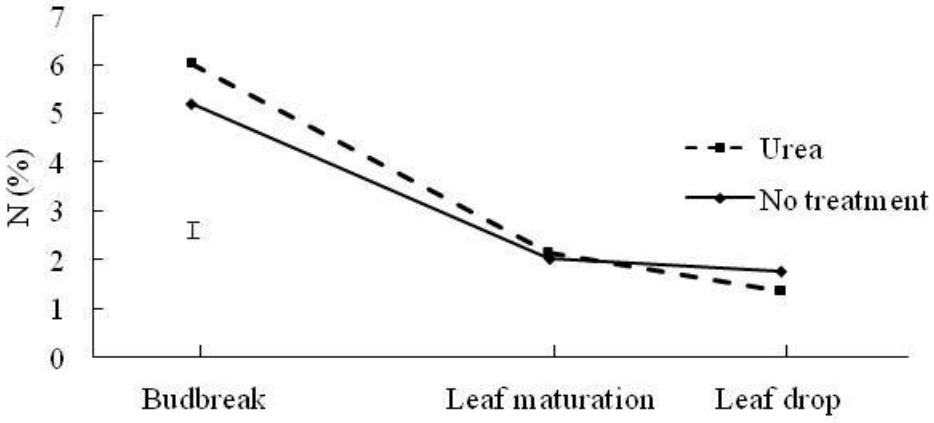

7
6
5
4
3
2
1
0
N (%)
Urea
No treatment
Budbreak
Leaf maturation
Leaf drop

Figure 4.2. Concentration of N, P, and K in redbud leaves, above ground perennial shoots, roots, and total tree at dormancy (2 April 2009), budbreak (23 April 2009), leaf maturation (11 August 2009), and leaf drop (21 October 2009). Bars represent protected LSD at $P \leq 0.05$ %. Percent N and P concentration in roots did not significantly differ among phonological growth stages, n=3.

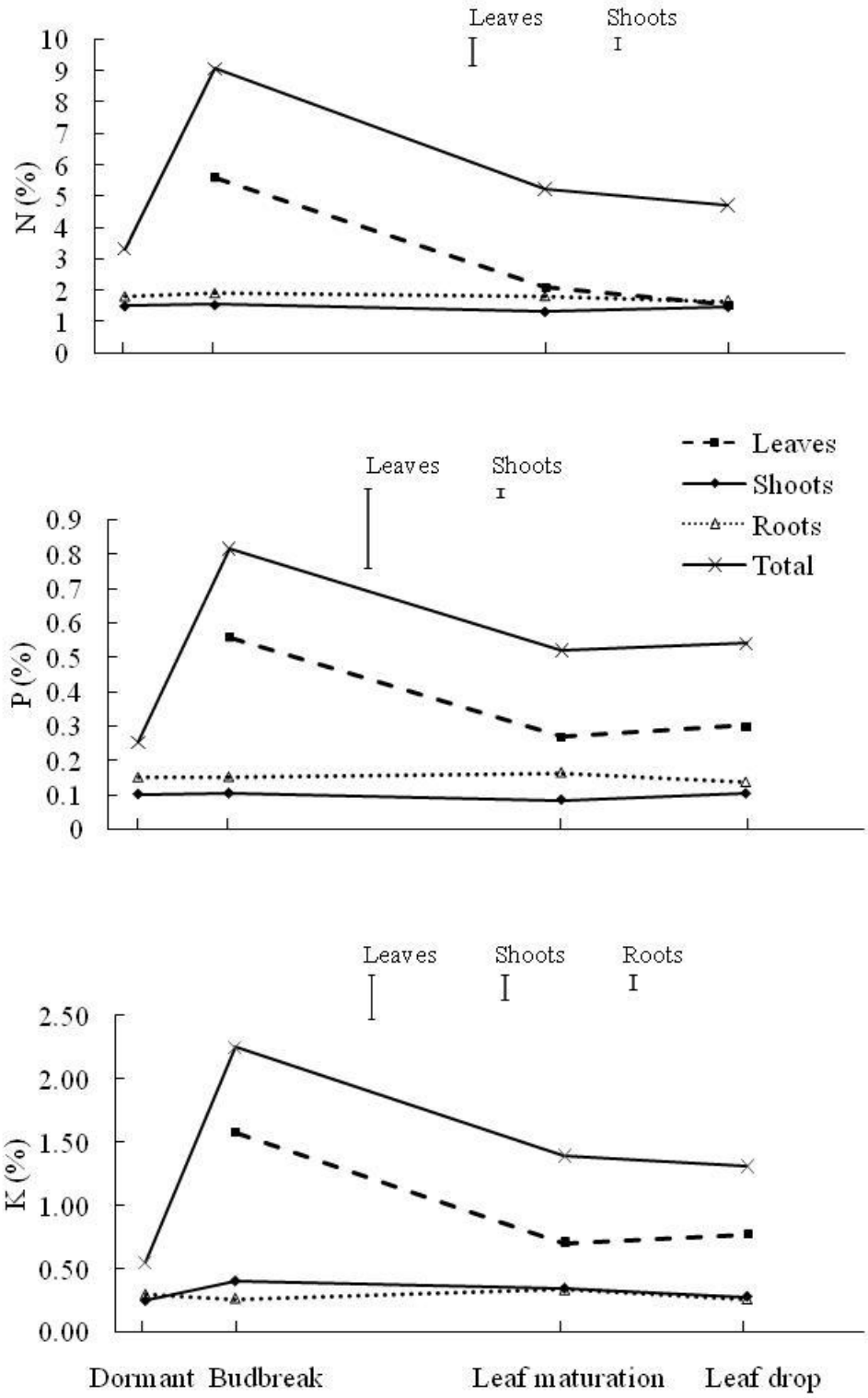

Leaves
Shoots
N (%)
10
9
8
7
6
5
4
3
2
1
0
Leaves
Shoots
Roots
Total
P (%)
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
Leaves
Shoots
Roots
K (%)
2.50
2.00
1.50
1.00
0.50
0.00
Dormant
Budbreak
Leaf maturation
Leaf drop

Figure 4.3. Weight of N, P, and K in redbud leaves, above ground perennial shoots, roots, and total tree at dormancy (2 April 2009), budbreak (23 April 2009), leaf maturation (11 August 2009), and leaf drop (21 October 2009). Bars represent protected LSD at $P \leq 0.05$ %. n=3.

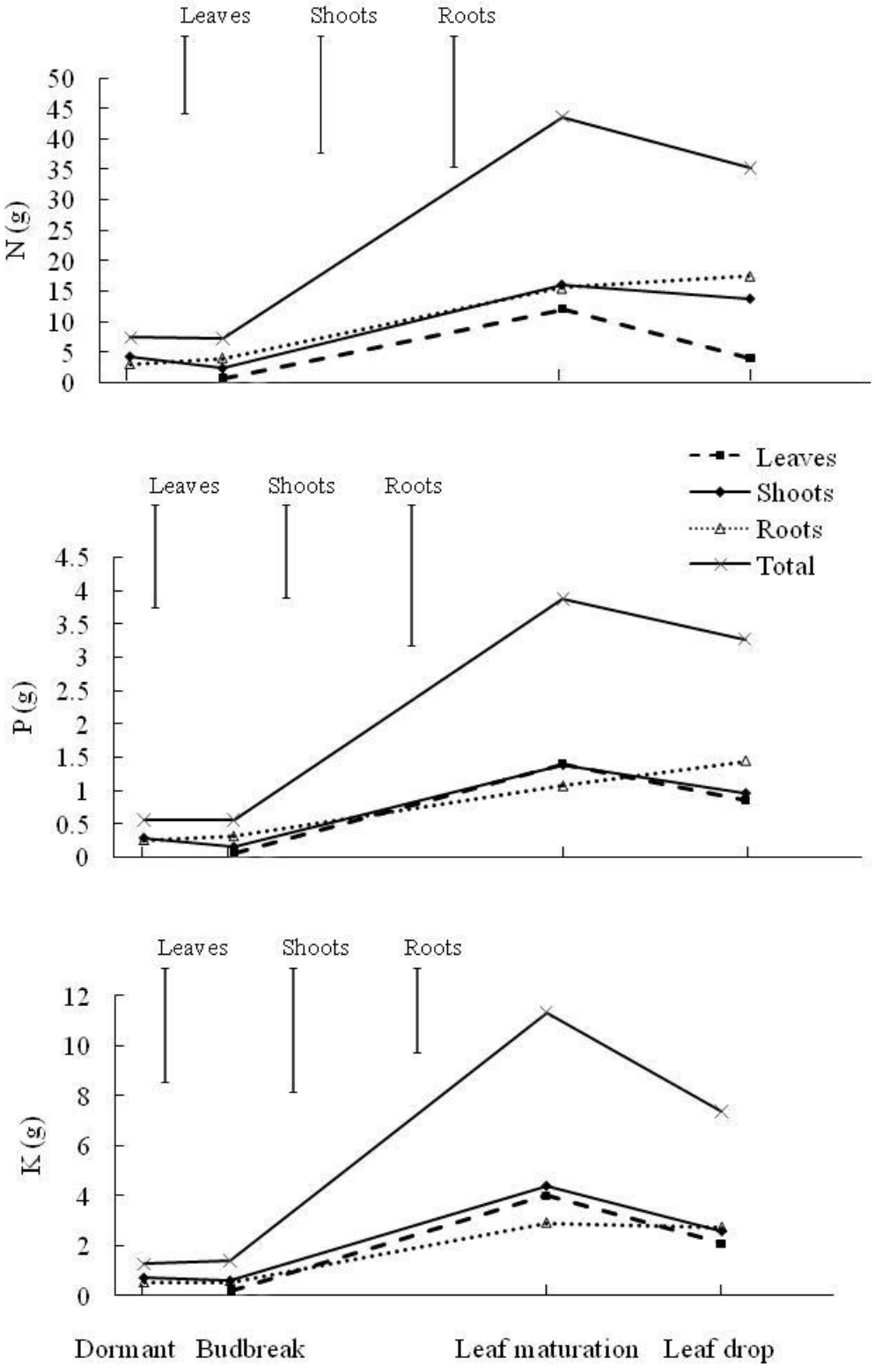
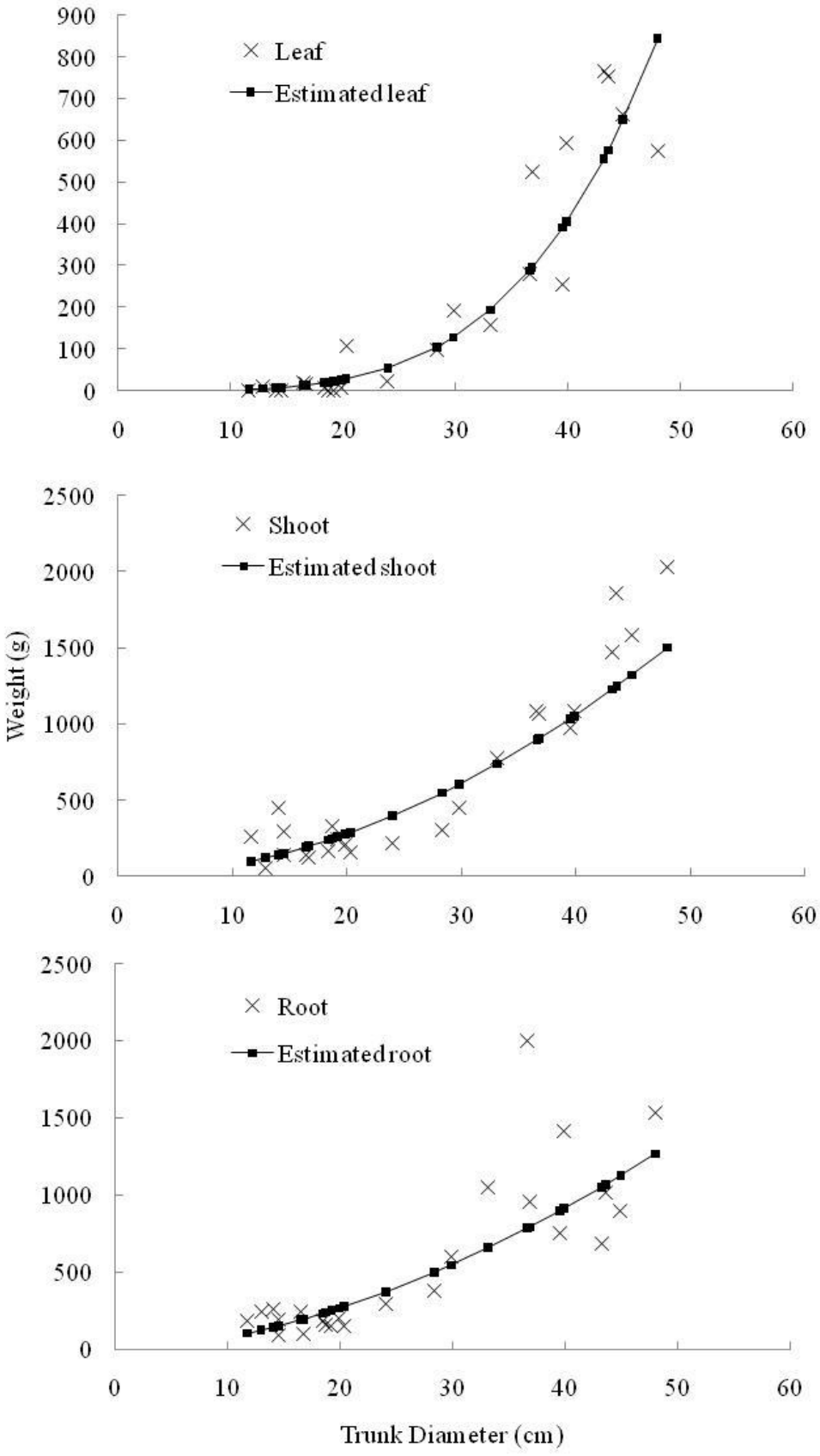

Leaves
Shoots
Roots
N (g)
50
45
40
35
30
25
20
15
10
5
0
Leaves
Shoots
Roots
Total
P (g)
4.5
4
3.5
3
2.5
2
1.5
1
0.5
0
K (g)
12
10
8
6
4
2
0
Dormant
Budbreak
Leaf maturation
Leaf drop

Figure 4.4. Biomass estimate of leaves, above ground perennial shoots, and roots for redbud trees with calipers ranging from 11.6 to 47.9 cm measured at 6 cm above the soil. The relationship between tree component and weight was determined using $Y = e^{a}X^{b}$, (King and Schnell, 1972). Where Y is the dry weight, e is the natural logarithm base, *a* and *b* are coefficients, and X is the trunk diameter measured at 6 cm above the soil line. n=6. Equations and r^2 for redbud leaf, shoot, and root components are $Y = e^{-0.8664}X^{3.9796}$, r^2=.840; $Y = e^{-0.1068}X^{1.9171}$, r^2=.760; and $Y = e^{0.2784}X^{1.7740}$, r^2=.760, respectively. F-test <.0001.


Leaf
Estimated leaf
Shoot
Estimated shoot
Root
Estimated root
Weight (g)
Trunk Diameter (cm)

Chapter V

SUMMARY

Organic materials are important sources of nutrients for many crops and can improve the health of soil and plants. Increasing bio-fuel production has stemmed production of oilseed crops such as canola and cottonseed. After oil is extracted, meal and other byproducts remain and must be disposed in some way. Using seed meals as an organic source of fertilizer provides a means of disposal, benefiting both fertilizer customers and oilseed producers.

The objectives of this study were to determine whether cottonseed meal or canola meal can be used as organic fertilizers that add N and other nutrients to the soil for plant use. Field and laboratory experiments examined the effect of cottonseed meal with or without soapstock or canola meal on the growth and visual quality of landscape plants, rate of seed meal N mineralization, and nutrient partitioning in redbud trees at different seasonal stages. Cottonseed meal and canola meal did not affect the growth of marigolds or redbuds growing outdoors in native soil and can provide adequate amounts of N and other nutrients for healthy plant growth. Cottonseed and canola meal both mineralized at rates sufficient for plant growth during the incubated laboratory experiment, and inorganic N increased as quickly as 3 days after incubation began. Results suggested that the best time to fertilize is during rapid plant growth and this occurred for redbud trees in spring during budbreak as new leaves were formed. Cottonseed meal with and without soapstock and canola meal can be used as organic fertilizers that provide plants with N and other nutrients.

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APPENDIX A

Nutrient analysis for cottonseed meal, cottonseed meal with soapstock, and canola meal analyzed by the Soil, Water, and Forage Analytical Laboratory, Oklahoma State University, Stillwater, OK on 21 January 2010.

Table A.1. Test results for cottonseed meal.

TEST	AS RECEIVED	AS RECEIVED (lbs/ton)	DRY BASIS (lbs/ton)
Moisture	7.40%		
Dry Matter	92.60%		
pH	6.5		
EC	3770µS/cm		
Soluble Salts	2525.9ppm	5.1	5.5
Phosphorus (P_2O_5)	2.80%	56.7	61.3
Calcium (Ca)	0.20%	4.6	4.9
Potassium (K_2O)	1.80%	35	37.8
Magnesium (Mg)	0.70%	13.4	14.5
Sodium (Na)	0.30%	5.4	5.9
Sulfur (S)	0.50%	10	10
Iron (Fe)	90.1ppm	0.2	0.2
Zinc (Zn)	65.7ppm	0.1	0.1
Copper (Cu)	14.7ppm	0	0
Manganese (Mn)	19.7ppm	0	0
Total C	45.50%	910	983.1
Total N	6.90%	137.4	148.5
Ammonium N	185.4ppm	0.4	0.4
Nitrate N	46.5ppm	0.1	0.1
Organic N	6.80%	137	148

Table A.2. Test results for cottonseed meal with soapstock.

TEST	AS RECEIVED	AS RECEIVED (lbs/ton)	DRY BASIS (lbs/ton)
Moisture	9.90%		
Dry Matter	90.10%		
pH	6.5		
EC	4340µS/cm		
Soluble Salts	2907.8ppm	5.8	6.5
Phosphorus (P_2O_5)	2.70%	54.7	60.7
Calcium (Ca)	0.20%	4.3	4.8
Potassium (K_2O)	1.70%	33.1	36.8
Magnesium (Mg)	0.60%	12.9	14.3
Sodium (Na)	0.20%	4.9	5.4
Sulfur (S)	0.50%	9	10
Iron (Fe)	78.3ppm	0.2	0.2
Zinc (Zn)	62.9ppm	0.1	0.1
Copper (Cu)	13.3ppm	0	0
Manganese (Mn)	17.5ppm	0	0
Total C	44.90%	898	996.3
Total N	7.50%	150	166.4
Ammonium N	213ppm	0.4	0.5
Nitrate N	1.7ppm	0	0
Organic N	7.50%	149.6	166

Table A.3. Test results for canola meal.

TEST	AS RECEIVED	AS RECEIVED (lbs/ton)	DRY BASIS (lbs/ton)
Moisture	8.20%		
Dry Matter	91.80%		
pH	5.7		
EC	3380µS/cm		
Soluble Salts	2264.6ppm	4.5	4.9
Phosphorus (P_2O_5)	2.80%	56.1	61.1
Calcium (Ca)	0.70%	13.5	14.7
Potassium (K_2O)	1.20%	24.9	27.1
Magnesium (Mg)	0.60%	12.4	13.5
Sodium (Na)	0.10%	1.7	1.8
Sulfur (S)	0.80%	16	17
Iron (Fe)	242.4ppm	0.5	0.5
Zinc (Zn)	68.0ppm	0.1	0.1
Copper (Cu)	5.6ppm	0	0
Manganese (Mn)	73.4ppm	0.1	0.2
Total C	45%	900	980.3
Total N	6.60%	131.2	142.9
Ammonium N	332.4ppm	0.7	0.7
Nitrate N	24.9ppm	0	0.1
Organic N	6.50%	130.5	142.2

APPENDIX B

Analytical results for cottonseed meal, cottonseed meal with soapstock, and canola meal analyzed by Pace Analytical Services, Inc., Lenexa, KS on 10 October 2008.

Table B.1. Analytical results for cottonseed meal, cottonseed meal with soapstock, and canola meal.

Cottonseed meal

PARAMETERS	DRY WEIGHT BASIS
Arsenic	Not Detectable mg/kg
Barium	2.6 mg/kg
Cadmium	Not Detectable mg/kg
Chromium	Not Detectable mg/kg
Lead ND	Not Detectable mg/kg
Selenium	2.0 mg/kg
Silver	Not Detectable mg/kg
Mercury	Not Detectable mg/kg
Percent Moisture	9.3%

Cottonseed meal with soapstock

PARAMETERS	DRY WEIGHT BASIS
Arsenic	Not Detectable mg/kg
Barium	3.0 mg/kg
Cadmium	Not Detectable mg/kg
Chromium	0.42 mg/kg
Lead ND	Not Detectable mg/kg
Selenium	2.1 mg/kg
Silver	Not Detectable mg/kg
Mercury	Not Detectable mg/kg
Percent Moisture	9.0%

Canola meal

PARAMETERS	DRY WEIGHT BASIS
Arsenic	Not Detectable mg/kg
Barium	28.9 mg/kg
Cadmium	Not Detectable mg/kg
Chromium	0.56 mg/kg
Lead ND	Not Detectable mg/kg
Selenium	2.7 mg/kg
Silver	Not Detectable mg/kg
Mercury	Not Detectable mg/kg
Percent Moisture	8.2%

APPENDIX C

Soils were topdressed with seed meals to determine the rate of mineralization of N from topdressed fertilizer methods. Soil was collected from three sites: *a*) agricultural production site (norge loam, fine-silty, mixed, thermic Udic Paleustolls, 35% sand, 45% silt, and 20% clay, Oklahoma State University Botanical Garden Stillwater, OK), *b*) recently disturbed construction soil, (clay loam, 35% sand, 37.5% silt and 27.5% clay, Oklahoma State University, Stillwater, OK), and *c*) previously disturbed soil collected from a residential site that was built in the late 1950's, (loam, 50% sand, 30% silt, and 20% clay, corner of Hester Street and Tyler Avenue, Stillwater, OK). Soil was evenly spread in plastic flats that were 52.2 cm long by 25.9 cm wide by 6 cm deep with 1500 g of soil per flat. A plastic mesh screen with 0.707 mm openings was placed over the soil then evenly covered with 500 g of soil. The following treatments were evenly spread over each soil type at the recommended fertilizer rate for turf and landscape plants of 4.9 g m^{-2} N: 1) cottonseed without soapstock, 2) cottonseed with soapstock, 3) canola without soapstock and 4) control (no treatment). Each soil type and meal treatment was replicated three times. Treatments were randomized and maintained in darkness at 22° C. Incubation was initiated by adding moisture (tap water) to soil in each flat to achieve 60% field capacity. This moisture content was maintained throughout the study by monitoring total mass of the soil + amendment + flat adjusted to the proper weight.

Tap water was added to each treatment to 60% field capacity every 24 hr until sampling. Soil was sampled 0, 3, 7, 14, 30, and 60 days after start of incubation. At sampling, all soil and meal, if present, on top of the screen was collected, placed in a soil bag, and dried in an oven at 30° C. Soil was then analyzed for total N and carbon (combustion method, Leco TruSpec, St. Joseph, MI) and inorganic N (1M KC1 extraction followed by colorimetric flow-injection analysis, Lachat QuickChem 8000, Loveland, CO) (Soil, Water, and Forage Analytical Laboratory, Oklahoma State University, Stillwater, OK).

The following graphs represent analysis of NH_4-N, NO_3-N, total N, total C, and rate of N mineralization of cottonseed meal without soapstock, cottonseed meal with soapstock, canola meal without soapstock, and no treatment (control) topdressed on soil *a*, *b*, and *c* described above. Mineralization of N was determined by subtracting total N of each treatment from the respective treatment total N at incubation day zero, n=3.

Figure C.1. Amount of NH_4-N (mg kg^{-1}) in soil *a* (agricultural production site), soil *b* (recently disturbed construction site soil), and soil *c* (previously disturbed soil collected from a residential site that was built in the late 1950's) topdressed with cottonseed meal without or without soapstock or canola meal or no treatment at 0, 3, 7, 14, 30, and 60 days of incubation.

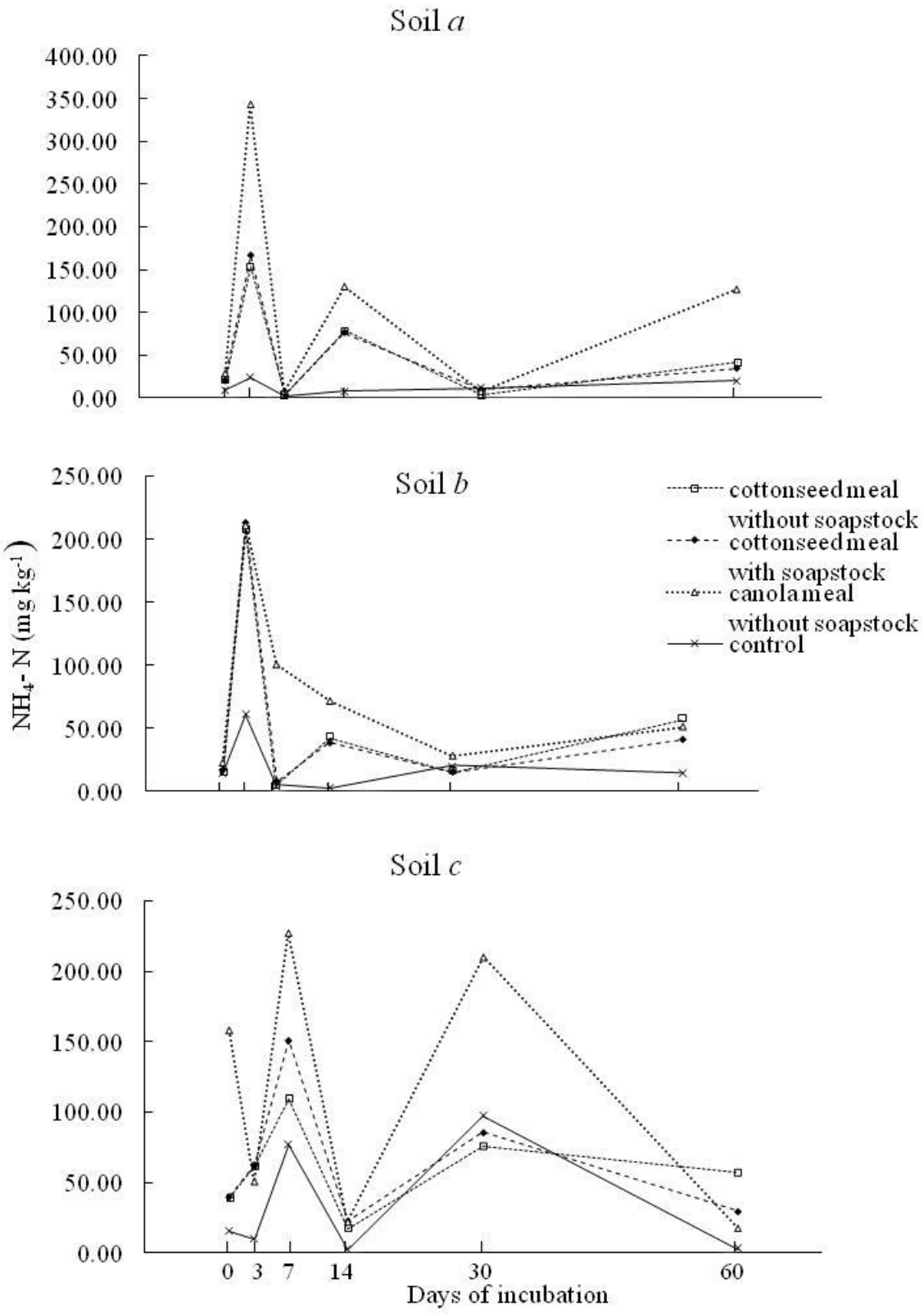

Soil a
400.00
350.00
300.00
250.00
200.00
150.00
100.00
50.00
0.00
Soil b
250.00
200.00
150.00
100.00
50.00
0.00
NH4- N (mg kg-1)
cottonseed meal
without soapstock cottonseed meal
with soapstock canola meal
without soapstock control
Soil c
250.00
200.00
150.00
100.00
50.00
0.00
0 3 7 14 30 60
Days of incubation

Figure C.2. Amount of NO_3-N (mg kg^{-1}) in soil *a* (agricultural production site), soil *b* (recently disturbed construction site soil), and soil *c* (previously disturbed soil collected from a residential site that was built in the late 1950's) topdressed with cottonseed meal without or without soapstock or canola meal or no treatment at 0, 3, 7, 14, 30, and 60 days of incubation.

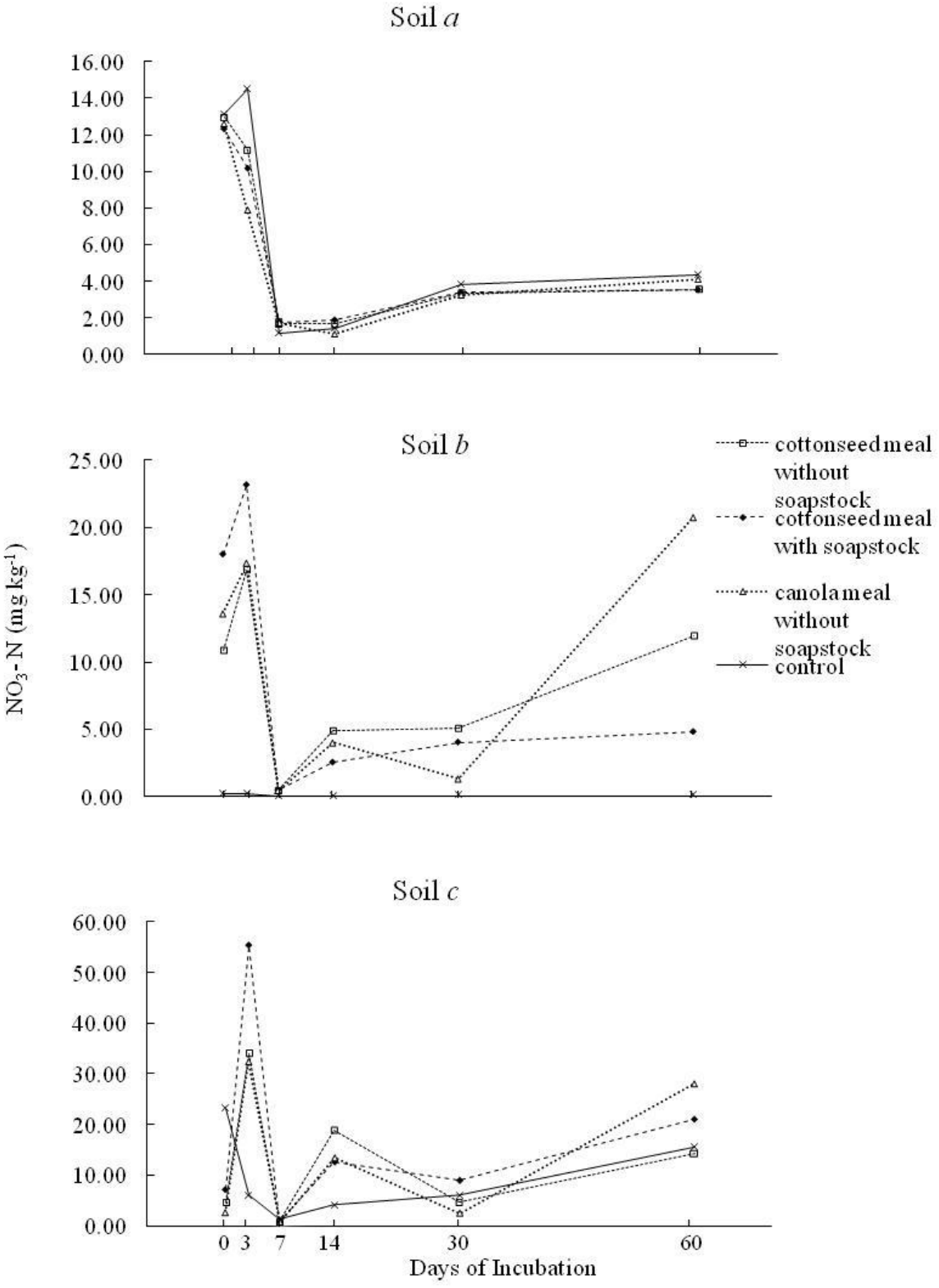

Soil a
16.00
14.00
12.00
10.00
8.00
6.00
4.00
2.00
0.00
Soil b
25.00
20.00
15.00
10.00
5.00
0.00
NO3- N (mg kg-1)
cottonseed meal without soapstock
cottonseed meal with soapstock
canola meal without soapstock
control
Soil c
60.00
50.00
40.00
30.00
20.00
10.00
0.00
0 3 7 14 30 60
Days of Incubation

Figure C.3. Amount of total N (%) in soil *a* (agricultural production site), soil *b* (recently disturbed construction site soil), and soil *c* (previously disturbed soil collected from a residential site that was built in the late 1950's) topdressed with cottonseed meal without or without soapstock or canola meal or no treatment at 0, 3, 7, 14, 30, and 60 days of incubation.

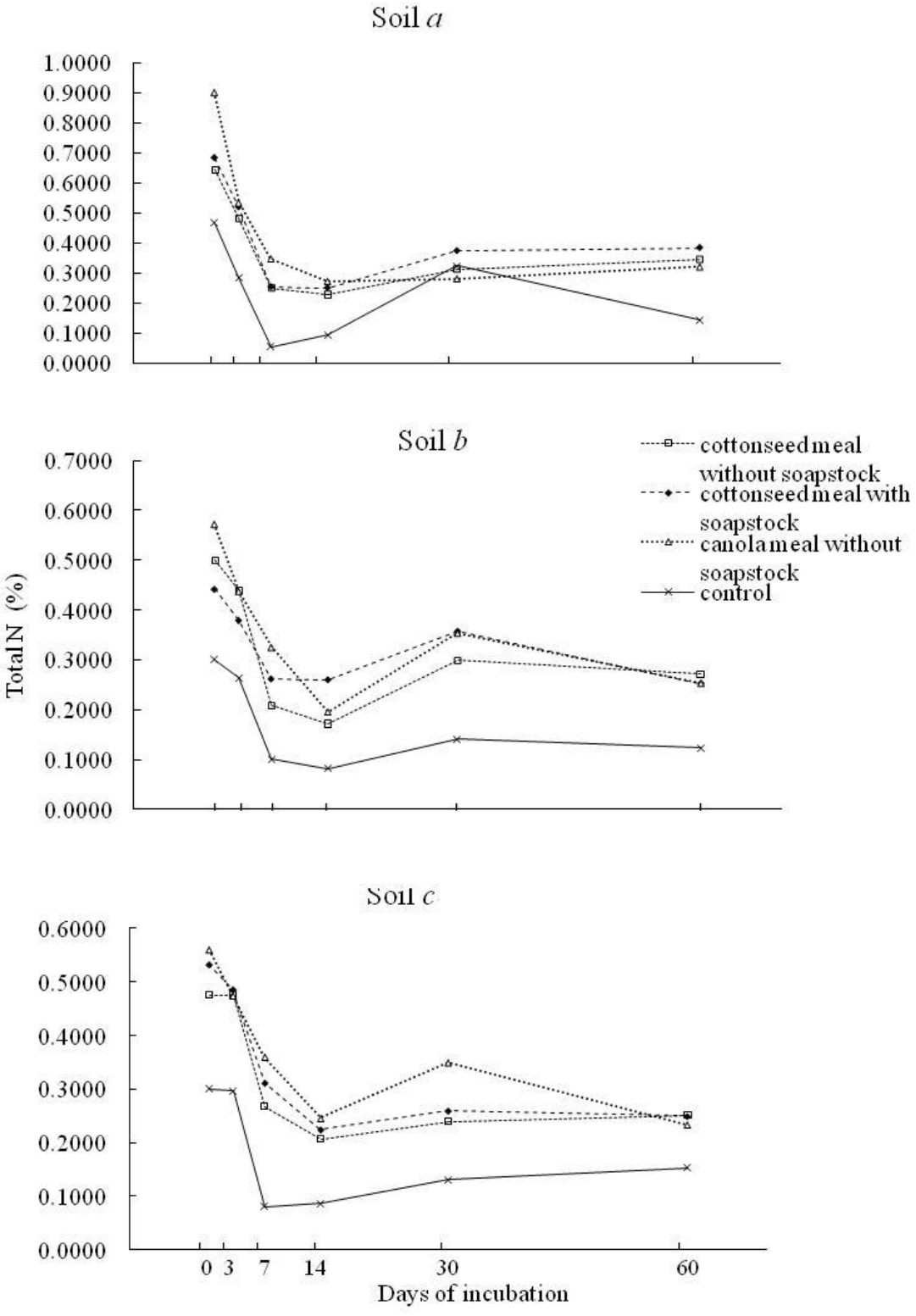

Soil a
1.0000
0.9000
0.8000
0.7000
0.6000
0.5000
0.4000
0.3000
0.2000
0.1000
0.0000
Soil b
Total N (%)
0.7000
0.6000
0.5000
0.4000
0.3000
0.2000
0.1000
0.0000
cottonseed meal without soapstock
cottonseed meal with soapstock
canola meal without soapstock
control
Soil c
0.6000
0.5000
0.4000
0.3000
0.2000
0.1000
0.0000
0 3 7 14 30 60
Days of incubation

Figure C.4. Amount of total C (%) in soil *a* (agricultural production site), soil *b* (recently disturbed construction site soil), and soil *c* (previously disturbed soil collected from a residential site that was built in the late 1950's) topdressed with cottonseed meal without or without soapstock or canola meal or no treatment at 0, 3, 7, 14, 30, and 60 days of incubation.

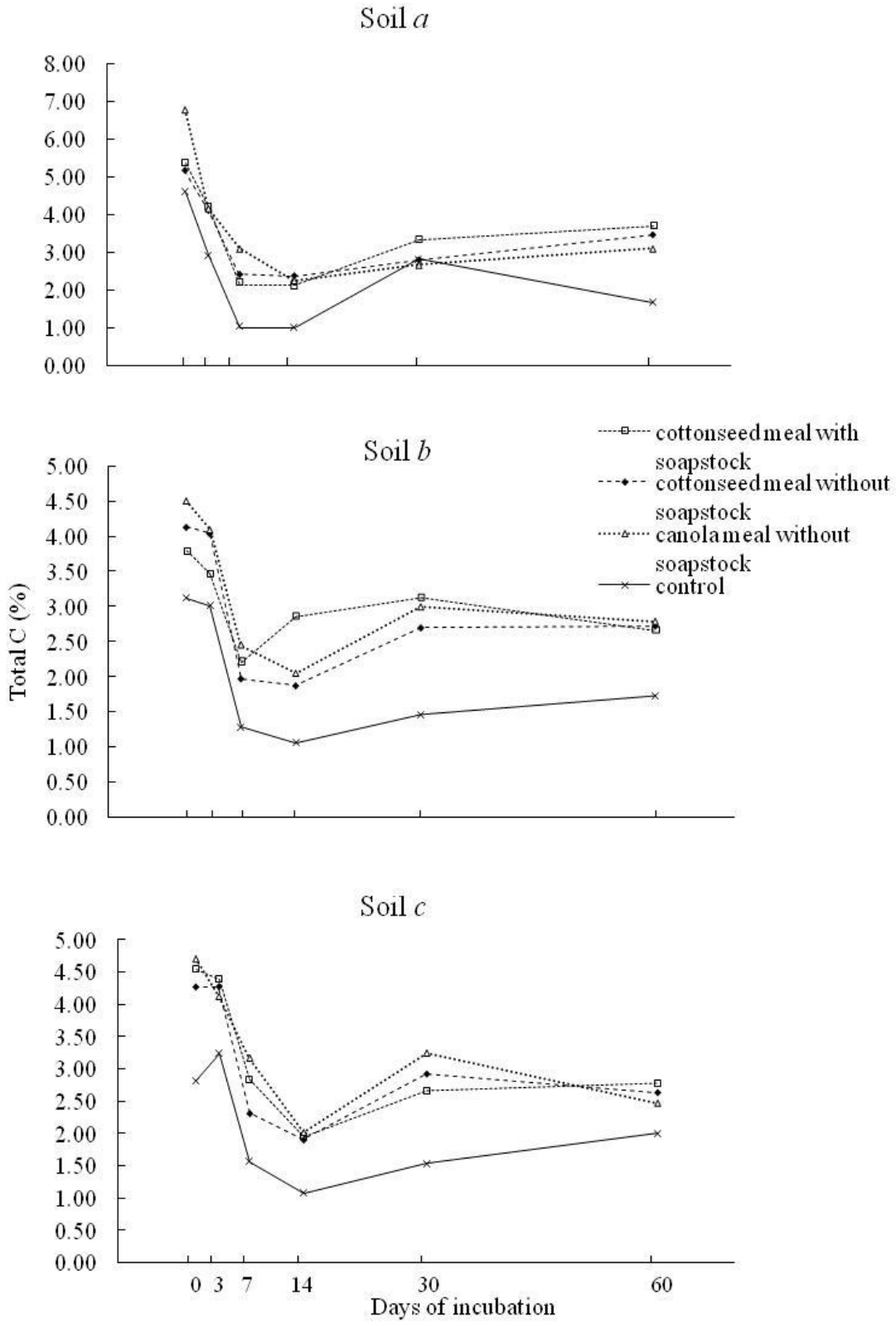
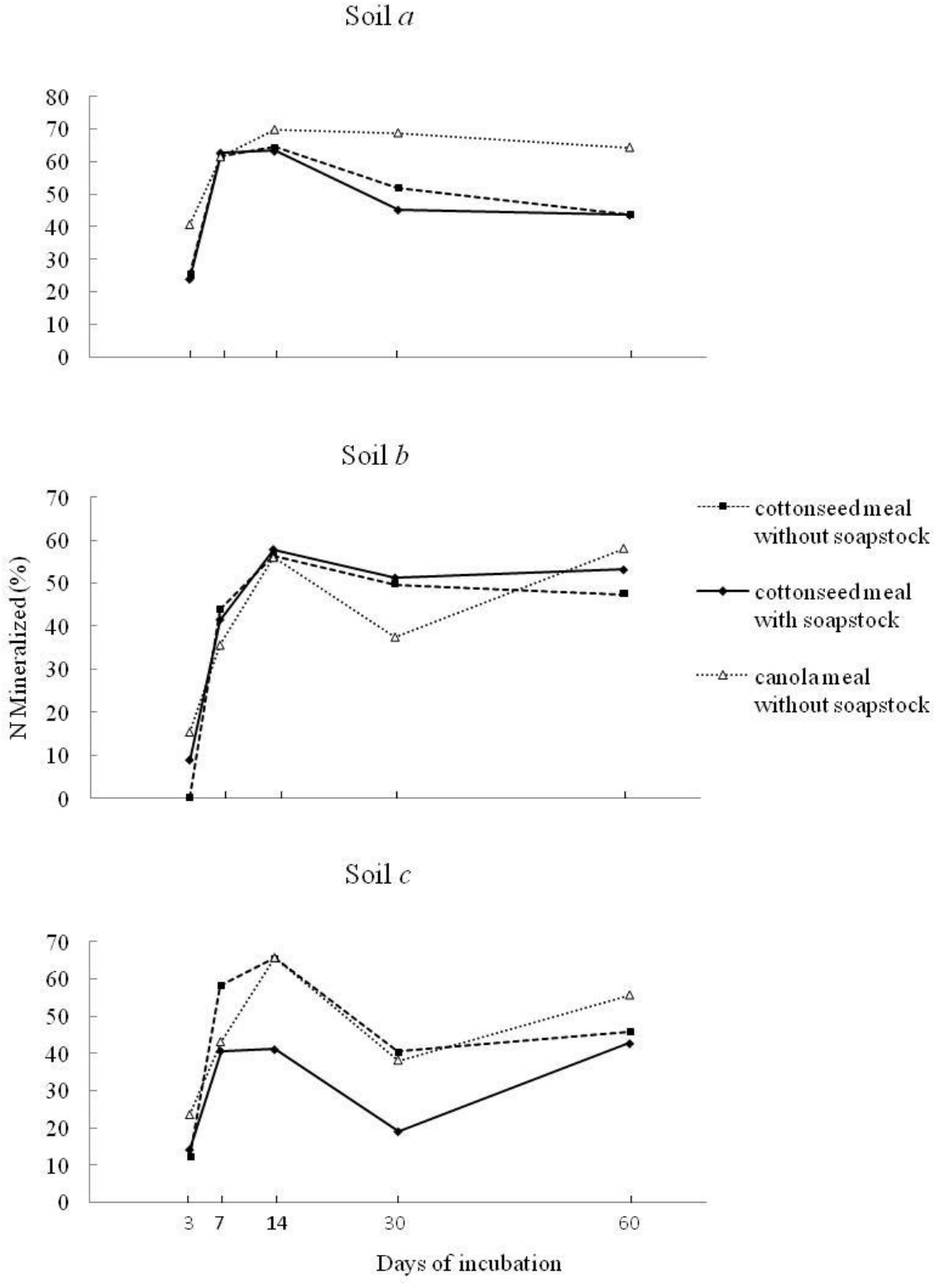

Soil a
8.00
7.00
6.00
5.00
4.00
3.00
2.00
1.00
0.00
Soil b
Total C (%)
5.00
4.50
4.00
3.50
3.00
2.50
2.00
1.50
1.00
0.50
0.00
cottonseed meal with soapstock
cottonseed meal without soapstock
canola meal without soapstock
control
Soil c
5.00
4.50
4.00
3.50
3.00
2.50
2.00
1.50
1.00
0.50
0.00
0 3 7 14 30 60
Days of incubation

Figure C.5. Amount of N (%) mineralized in soil *a* (agricultural production site), soil *b* (recently disturbed construction site soil), and soil *c* (previously disturbed soil collected from a residential site that was built in the late 1950's) topdressed with cottonseed meal without or without soapstock or canola meal or no treatment at 0, 3, 7, 14, 30, and 60 days of incubation.


Soil a
Soil b
Soil c
N Mineralized (%)
0
10
20
30
40
50
60
70
80
3
7
14
30
60
Days of incubation
cottonseed meal without soapstock
cottonseed meal with soapstock
canola meal without soapstock

VITA

Kathryn Elizabeth Fine

Candidate for the Degree of

Master of Science

Thesis: USE OF COTTONSEED MEAL WITH OR WITHOUT SOAPSTOCK OR CANOLA MEAL WITHOUT SOAPSTOCK AS AN ORGANIC FERTILIZER

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Name: Kathryn Elizabeth Fine Date of Degree: May, 2010

Institution: Oklahoma State University Location: Stillwater, Oklahoma

Title of Study: USE OF COTTONSEED MEAL WITH OR WITHOUT SOAPSTOCK OR CANOLA MEAL WITHOUT SOAPSTOCK AS AN ORGANIC FERTILIZER

Pages in Study: 108 Candidate for the Degree of Master of Science

Major Field: Horticulture

Scope and Method of Study: The objectives of this study were to determine whether cottonseed meal or canola meal could be used as organic fertilizers that add nitrogen (N) and other nutrients to the soil for plant use. Field experiments determined the affect of cottonseed meal with or without soapstock or canola meal on the growth and visual quality of marigold (*Tagetes erecta* L. 'Inca II Gold' or 'Inca II Yellow') and redbud (*Cercis Canadensis* L.) plants and nutrient partitioning in redbud trees at various seasonal stages. Rate of N mineralization from cottonseed meal with or without soapstock or canola meal was also determined.

Findings and Conclusions: Cottonseed meal and canola meal did not affect growth of marigolds or redbuds growing outdoors in native soil and can provide adequate nutrients for healthy plant growth. Nitrogen mineralized from cottonseed meal and canola meal at rates sufficient for plant growth. Under controlled conditions, increases in inorganic N occurred as quickly as 3 days. Results suggested that the best time to fertilize is during rapid plant growth and this occurred for redbud trees in spring during budbreak as new leaves were formed. Cottonseed meal with and without soapstock and canola meal are reasonable organic fertilizers that can provide N and other essential nutrients for plant uptake.

ADVISER'S APPROVAL: Dr. Janet C. Cole