Effects of Organic Soil Amendments on Soil Physiochemical and Crop Physiological Properties of Field Grown Corn (*Zea mays*) and Soybean (*Glycine Max*)

Abstract

Short-term water stress during the reproductive period of summer grown crops is a common occurrence in the U.S. southeastern Piedmont region. Plants have evolved an antioxidative mechanism to ameliorate this oxidative stress. The application of humic substances has been shown to increase antioxidant activity of water stressed crops; thus, it is proposed that humic substances in land-applied organic amendments may improve the health and yield of summer grown crops compared to inorganically fertilized crops. Research was conducted to assess the effects of organic and inorganic soil amendments on soil physicochemical properties and plant physiological responses. Corn and soybean were cultivated at the Northern Piedmont Agriculture Research and Experiment Station in Orange, Virginia in 2004 and 2005, respectively. Neither crop experienced water stress during the sampling period (July 14-August 27, 2004; August 12-September 16, 2005). Treatment differences in leaf antioxidant activity were only observed in the corn. All corn plants that were fertilized with amendments supplying the crop's nitrogen needs, regardless of the source, had greater leaf nitrogen (+29%), chlorophyll (+33%), and protein contents (+37%), lower superoxide dismutase (-29%) and ascorbate peroxidase (-17%) activities, and lower malondialdehyde (-33%) contents relative to the control and low nitrogen treatments. There were no observed differences in catalase activity, which was likely due to the evolutionary advantage of C_4 metabolism. Yield was strongly related to midseason leaf nitrogen contents (R^2=0.87, $p<0.0001$) and not soil humified carbon (R^2=0.02, p=0.0543). There were no observed treatment differences in soybean leaf physiology and metabolism. Differences, however, were observed over time. As the leaves senesced, leaf chlorophyll, protein, superoxide dismutase and catalase activities decreased, and the malondialdehyde content increased. Ascorbate peroxidase activity slightly increased with time. Catalase activity in soybean was primarily linked to the oxidation of glycolate, a product of photorespiration, and not the formation of reactive oxygen species in the chloroplasts. The organically amended treatments had higher yields (9-21% increase), greater protein contents (4-9% increase), and seed weights (5-14% increase) relative to the fertilizer and control treatments. I conclude that differences in

soybean yield and seed quality were due to non-nutritive benefits of the organic amendments and not differences in available water or plant nutrition.

Introduction

Water stress is the most critical environmental factor limiting crop production in the Piedmont soil physiographic province, which extends from Maryland to Alabama (Southeast Regional Climate Center, 2003a). Short-term crop water stress is common during summer months due to higher evapotranspiration rates and lower precipitation. Although often temporary, these stresses can significantly reduce yields since adequate moisture is essential for successful growth and development during the sensitive reproductive stage of summer crops.

Periodically, summer crops in the region sustain prolonged water deficits. The National Drought Mitigation Center issued 'severe' and 'extreme' drought indices for the Virginia Piedmont during the summers of 1999 and 2002 (National Drought Mitigation Center, 2003). Precipitation was 14% and 24% less in 1999 and 2002, respectively, than precipitation occurring in a normal year (Southeast Regional Climate Center, 2003b). Corn and soybean yields in 1999 and 2002 were 35% to 57% and 11% to 43% lower, respectively, than average yields produced in the region (National Agricultural Statistics Service, 2003).

During water stress, overall photosynthetic efficiency is compromised and excessive concentrations of reactive oxygen species are generated within the chloroplast. Reactive oxygen species are partially reduced forms of O_2 that are capable of unrestricted oxidation of cellular components including the thiol and iron-sulfur clusters of peptides in the DNA bases (Mano, 2002) and the lipid peroxidation of the chloroplast membrane (as measured by malondialdehyde (MDA) content). Reactive oxygen species also cause (Yan et al., 1996; Hung and Kao, 1997) and eventually cause cell death. Reactive oxygen species are naturally generated due to the intrinsic inefficiencies of photosynthesis. Plants have evolved an antioxidant scavenging system to effectively remove excessive reactive oxygen species from the chloroplast and maintain their concentrations at steady-state levels (Asada, 1994). It has been well documented that an up-regulation of antioxidant activity during stress increases the stress tolerance of plants (Longo et al., 1993; Li et al., 1994; Jiang and Zhang, 2001; Du et al., 2005; Ge at al., 2005). Pastori and Trippi (1993) observed greater antioxidant activity in more drought resistant plants than in less

resistant ones. Indeed, Stepien and Klobus (2005) observed greater antioxidant efficiencies and a lower MDA content in water stressed corn than in wheat.

Increased antioxidant activity has also been documented to retard the natural process of leaf senescence (Lin et al., 1988; Pastori and Trippi, 1993). Prochazkova et al. (2001) observed greater antioxidant activity over a longer period in a later maturing corn cultivar than in a relatively early maturing one. The authors concluded that the earlier decrease in antioxidant activity in the faster maturing cultivar contributed to an earlier senescence.

There are three major antioxidants that quench free radicals. Superoxide dismutase (SOD) reduces superoxide to peroxide (Asada, 1994) and is considered the first response and most important antioxidant within the chloroplast (Perl-Treves and Perl, 2002). Ascorbate peroxidase (APX), also located in the chloroplast, reduces peroxide to water as does catalase (CAT), which is located in the peroxisome. Peroxide can be generated *via* SOD activity or within the peroxisome during the oxidation of glycolate, a product of photorespiration. C_4 plant species have evolved an alternative photosynthetic pathway to prevent glycolate production. Researchers have observed that CAT activity in C_4 species is predominately driven by the formation of reactive oxygen species in the chloroplast (Tolbert et al., 1969), though corn CAT activity has been documented to be unresponsive to changes in the intercellular redox status during stress (Alber and Scandalios, 1993). Catalase activity in C_3 plant species appears to be driven by the oxidation of glycolate (Lyu-bimov and Zastrizhnaya, 1992).

The soil-based application of organic amendments to field grown crops may have an ameliorating effect on drought stressed crops. Sahs and Lesoing (1985) observed higher sweet corn yields in plots amended with beef feedlot manure than those that were inorganically fertilized during drought years. Heckman et al. (1987) found that field grown soybeans fertilized with sewage sludge had increased drought resistance and nitrogen fixation than the control treatment.

Improved drought tolerance of crops grown in organically amended soils has been linked to the maintenance of optimum leaf health. In five-week old water stressed maize seedlings, Xu (2000) measured higher photosynthetic rates when the soils were organically amended. HuiLan et al. (1998) noted that the application of organic amendments increased water stress resistance of sweet corn leaves. In particular, stomatal and curticular conductances of the leaves were lower in these plants than in inorganically-fertilized plants. Researchers speculate that the hormone-like

properties of humic substances may play a causal role in drought stress amelioration (Serdyuk et al., 1999; Kulikova et al., 2003; Chen et al., 2004; Quaggiotti et al., 2004; Zhang and Ervin, 2004).

Humic substances are the major constituents of stable organic matter. These materials are naturally occurring, ubiquitous organic compounds that contain relatively high molecular weights, are yellow-black in color, and are formed by secondary synthesis reactions between plant and animal remains and microbial metabolites (Stevenson, 1994b). Humic substances are operationally defined, based on solubility. Fulvic acids represent about 20% of humic substances (Epstein, 1997), are relatively low in molecular weight (1000-4000 g/mol), and soluble in both alkali and acidic solutions (Stevenson, 1994b). Humic acids represent roughly 80% of humic substances (Epstein, 1997), have relatively large molecular weights (12,000-300,000 g/mol), and are insoluble in acidic solutions (Stevenson, 1994b).

Most experiments designed to elucidate potential ameliorative effects of humic substances on drought stressed crops is limited to their foliar application in pot studies. Xudan (1986) foliarly applied fulvic acid to pot grown wheat plants prior to imposing a nine-day dry down period. These plants maintained greater stomatal conductances, contained greater chlorophyll contents and increased ^{32}P uptake relative to the control. Yan and Schmidt (1993) applied a commercially available seaweed extract to pot grown drought stressed perennial ryegrass and observed increased cell membrane fluidity and permeability relative to the control treatment. Zhang and Schmidt (1999, 2000) foliarly applied a commercially available seaweed extract and humic acid solution to drought-stressed tall fescue, creeping bentgrass, and Kentucky bluegrass, and observed increases in leaf water status and antioxidant activities relative to the control. Research exploring possible ameliorative effects of land applied compost humic substances on drought stressed agronomic crops is lacking. Further investigation is required to discover whether organic matter fractions in compost may elicit plant physiological benefits under field conditions.

The objectives of this study are to compare the effects of repeated applications of inorganic fertilizer, poultry litter, and two composts on

1. Changes in soil physiochemical properties (i.e., nutrient concentrations, bulk density, water holding capacity, organic carbon, humic and fulvic acid carbon). I hypothesize that the organically amended soils will have greater soil fertility, increased organic and humic

carbon content, decreased bulk density, and greater water holding capacity than inorganically fertilized and control soils.

2. Differences in corn and soybean total leaf protein and chlorophyll contents; leaf water potential and photochemical efficiencies; leaf antioxidant activities (i.e., superoxide dismutase, ascorbate peroxidase, catalase); lipid peroxidation (i.e. malondiadehyde concentration), canopy-air temperature ((Delta T) soybean only); yield and seed quality (i.e., protein, oil, starch, density, and fiber (soybean only)) during the summer 2004 and 2005 field seasons. I hypothesize that crops grown in the organically amended soils will have equal or greater leaf protein and chlorophyll contents, greater antioxidant activity, lower malondiadehyde concentrations and Delta T values, and increased yields and seed quality than inorganically fertilized and control plants.

Materials and Methods

Experimental Design

Site Description

This research was conducted at the Northern Piedmont Agricultural Research and Extension Center in Orange, Virginia on a Fauquier silty clay loam (fine, mixed, mesic Ultic Hapludalf). Site elevation is approximately 180 m (590 ft) above sea level, 38° 2' N latitude and 78° 1' W longitude. Annual temperatures range from 0°C (32°F) to 24°C (76°F), and average annual precipitation is 109 cm (47 in).

Phase I of Study: 2000-2002

Seven treatments established in spring 2000 and implemented through 2002 were modified in spring 2003 and investigated through 2005. The original treatments were applied to 3.7 x 7.6m plots arranged in a completely randomized block design with four replications and included a control; annual yard waste compost at 20% agronomic N; annual yard waste compost at 20% agronomic N + supplemental NH_4NO_3 fertilizer; biannual yard waste compost at 100% agronomic N rate; biannual yard waste compost at 100% agronomic N rate + NH_4NO_3 fertilizer; annual poultry litter at agronomic nitrogen rate; and annual commercial fertilizer treatment. No amendments were ever applied to the control treatment (Table 3.1).

The first three years of this study examined changes in soil and water quality and yields of a vegetable production system (Evanylo et al., 2002; Sherony et al., 2002; Evanylo et al.,

2003a; Evanylo et al., 2003b). Crops grown included pumpkin (*Cucurbita pepo*; V. Magic Latern) in 2000, sweet corn (*Zea mays*; V. Silver Queen) in 2001, and bell pepper (*Capsicum annuum*; V. Aristotle) in 2002. Cereal rye (*Secale cereale*) was planted in all plots in the autumn of each year as a winter cover crop and incorporated by disking prior to applying amendments each spring.

The nitrogen requirements for pumpkins, sweet corn, and bell peppers were estimated as 84, 168, and 140 kg/ha, respectively, based on Virginia Cooperative extension (VCE) vegetable production recommendations (Alexander et al., 2000). Limestone, phosphorus, and potassium requirements were determined by Virginia Cooperative Extension (VCE) soil test recommendations (Donohue and Heckendorn, 1994). Ammonium nitrate (33-0-0), triple superphosphate (0-46-0), and muriate of potash (0-0-60) were used to apply nitrogen, phosphorus, and potassium, respectively.

The original treatments were applied annually in mid-April and incorporated with a rototiller to a depth of 15 cm on the day of application. Crops were planted within a week of the application of the amendments. Vegetables were mulched with barley (*Hordeum vulgare*) straw in all years to control weeds.

Phase II of Study: 2003-2005

The treatments implemented in 2003 and 2004 included the continuation of three of the original treatments from years 2000-2002: annual commercial inorganic fertilizer applied according to soil test laboratory recommendations, annual poultry litter applied at calculated agronomic nitrogen rates, and the unamended control. The original annual low compost rate and biannual agronomic N compost rate treatments, with and without supplemental nitrogen fertilizer, were modified as follows (also see Tables 3.1 and 3.2): Low rate yard waste-poultry litter compost treatments with and without supplemental nitrogen fertilizer selected randomly from two of the four replications remained at low yard waste-poultry litter compost application rates (30% agronomic N) in both 2003 and 2004. The remaining two replications from the original low yard waste-poultry litter compost application rate with and without supplemental nitrogen fertilizer were converted to low rate treatments of biosolids compost. Two of the four replications (randomly selected) of the biannual agronomic nitrogen rate of yard waste-poultry litter compost with and without supplemental nitrogen fertilizer were converted to annual agronomic N application rates of yard waste-poultry litter compost in 2003 and 2004. The

remaining replications of these treatments were converted to agronomic N rates of biosolids compost in 2003 and 2004. These modifications enabled the new treatments to remain at the same relative compost application rates as in 2000 to 2002.

The new treatments were:

1) Inorganic fertilizer (FERT): per Virginia Tech Soil Test Lab recommendations

2) Agronomic yard waste compost (AYWC): 100% agronomic N compost rate

3) Low yard waste compost (LYWC): 30% agronomic N compost rate

4) Agronomic biosolids compost (ABSC): 100% agronomic N compost rate

5) Low biosolids compost (LBSC): 30% agronomic N compost rate

6) Poultry litter (PL): 100% agronomic N rate

7) Control (CTRL): no amendments or fertilizer added

Panorama Pay Dirt Compost (PYWC; Earlysville, VA) comprised of 1 part poultry litter to 2 parts yard waste (leaves only) was composted for 120 days using windrow technology. A biosolids compost obtained from the Rivanna Water and Sewer Authority (RBSC; Charlottesville, VA) was comprised of an anaerobically-digested biosolids dewatered with $Ca(OH)_2$ and composted with wood chips (1:2 ratio of biosolids and woodchips) composted for five consecutive days at 66°C via static pile technology. The material was cured for an additional 10 days after screening the compost through a 0.95 cm sieve to remove woodchips. The poultry litter used in the study was a commercial non-composted litter (PL) from Valley Pride (Harrisonburg, Virginia). All five organic amendments were analyzed at A&L Eastern Agricultural Laboratories, Inc. (Richmond, Virginia) for routine organic amendment analyses (Table 3.3).

The crops included *Zea mays* (Pioneer 31G20) in 2003 and 2004 and *Glycine max* (Delta Pine 4933RR) in 2005. I conducted my study on the corn in 2004 and the soybean in 2005. Each winter, cereal rye (*Secale cereale* L.) was planted and incorporated by disking prior to applying amendments each spring. No organic amendments or inorganic fertilizer was applied in spring 2005 because the soybean crop required no nitrogen fertilizer.

Plant available N in the composts and poultry litter were estimated by adding 100% of the measured NO_3-N and NH_4-N and the fraction of organic N estimated to be mineralizable during the first season. The mineralization coefficients used were 0.1 for the composts and 0.6 for the poultry litter (Table 3.3) (Evanylo, 1994; DCR, 2002). The lime requirement was determined by the Adams-Evans single buffer method (Sims, 1996). Treatments were applied on June 11, 2004 and were immediately incorporated to a 15 cm depth with a rototiller. Total rates of organic by-products and accompanying carbon are listed in Table 3.4. Total macro- and micronutrients added are listed in Table 3.5. Corn (Pioneer 31G20) was planted June 11, 2004 and thinned to approximately 52,000 plants/ha three weeks after emergence. Lumax (2-chloro-4-ethylamni-6-isopropylamino-s-triazine) was applied at planting for weed control. Lorsban (O, O-diethyl-O-(3,5,6-trichloro-2-pyridinyl) phosphorothioate) was applied in the row. *Bradyrhizobium* inoculated soybean was planted May 31, 2005.

Soil Sampling and Monitoring

Ten soil samples were collected at a depth of 0-15 cm on June 4, 2004 and August 26, 2005 for fulvic and humic acid extractions. Three samples for bulk density determination were collected from the CTRL, LYWC, and AYWC treatment plots to a depth of 15 cm on June 30, 2004 (Grossman and Reinsch, 2002). Three soil cores were collected in 5-cm increments to a depth of 15cm on June 23, 2005 for bulk density (Grossman and Reinsch, 2002) and plant available water determination (Dane and Hopmans, 2002). In 2004, soil moisture readings were taken every 7 to 9 days using a hand-held TDR (Hydrosense; Campbell Scientific, Edmonton, Alberta) beginning July 14 (seven days after tasseling). In 2005, soil moisture readings were taken every 7 days using the Trace System I TDR (Soil Moisture Corporation, Santa Barbara, CA) beginning August 12 (early podfill). Ten soil samples collected on September 20, 2004 and August 26, 2005 were used to determine C and N content (VarioMax CNS macro-elemental analyzer; Nelson and Sommers, 1996; Bremmer, 1996) and for routine soil test analyses by the Virginia Tech Soil Testing Lab (pH, Mehlich 1-P, K, Ca, Mg, Cu, Fe, Zn; Donohue and Friedericks, 1984).

Humic Substances Extraction

Humic and fulvic acid contents of the organic amendments and the amended soils were determined using a modified International Humic Substances Society Method (Zhang, 2004).

One gram of organic amendment or 20 g of air dried soil passed through a 2 mm sieve was mixed with 200 ml of 0.1 N NaOH in a 250 ml centrifuge bottle, flushed with N_2 to prevent oxidation of organic matter, and shaken for 16 hours. The suspension was allowed to settle for 12 hours and then centrifuged at 6,000 g for 20 minutes. The supernatant was acidified to pH 1 with 6 ml of 6 N HCl, allowed to settle for 12 hours and then centrifuged at 6,000 g for 20 minutes. The supernatant, representative of the fulvic acid fraction, was decanted into a 50-ml disposable plastic vial and stored at 4°C. The organic carbon content was determined with a carbon auto analyzer by the analytical services laboratory of North Carolina State University (Nelson and Sommers, 1996). The humic acid was redissolved in 50 ml of 0.1 N KOH and then mixed with 0.745 g KCl to give a potassium concentration of 0.3 N. Oxygen was removed by flushing with N_2. The suspension was centrifuged at 6,000 g for 20 minutes. The supernatant was acidified to pH 1 with 2.01 ml of 6 N HCl and allowed to settle for 12 hours. After centrifugation at 6,000 g for 20 minutes, the supernatant was decanted and the precipitate was oven-dried in an aluminum tin at 55°C for 24 hours. Organic carbon analysis was determined using a CNS macro-elemental analyzer by the analytical services laboratory of North Carolina State University (Nelson and Sommers, 1996).

In field plant measurements

Five corn ear leaves were sampled at the silking stage on July 14, 2004, dried at 65°C, ground in a Wiley Mill to pass a 0.85 mm sieve for TKN (EPA 351.2) and TKP (EPA 365.4) analyses (USEPA, 1979). Ten soybean leaflets from the second oldest, fifth node leaflet were sampled August 18, 2005 for N (VarioMax CNS macro-elemental analyzer; Bremmer, 1996) and P (Inductively Coupled Plasma Spectroscopy; Soltanpour et al., 1996) contents.

Corn leaf sampling and measurements for physiological variables were performed every 7 to 9 days, beginning seven days after silking and culminating at the R5 stage (56 days after silking). Soybean leaf sampling was performed every 7 days, beginning at the podfill stage and culminating at R6 stage (35 days after podfill). Measurements were made on three plants in each treatment to form a composite sample. On the 2005 soybean crop, Delta T measurements were taken using an infrared thermometer with accuracy to 0.2˚C (Raynger ST, Raytek, Santa Cruz, CA). The infrared thermometer senses emitted, reflected and transmitted energy and converts the reading into temperature. As soil water potential decreases, evapotranspiration is limited, which causes canopy temperatures to rise. Chlorophyll content and PSII photochemical

efficiency measurements were determined from a corn ear leaf blade or soybean second oldest, fifth node leaflet using a chlorophyll meter (Minolta SPAD 502 Meter; Spectrum Technologies, Inc., Plainfield, Illinois) and a dual wavelength fluorometer (OS-50; Opti-Sciences, Inc., Tyngsboro, Massachusetts), respectively. The leaves were dark adapted for at least 15 minutes using an aluminum foil sleeve for the corn and the FL-DC dark adaption cuvette (OS-50; Opti-Sciences, Inc., Tyngsboro, Massachusetts) for the soybean. Midday leaf water potentials were measured from the same blade or leaflet using a pressure chamber (PMS-600; PMS Instruments Co., Corvallis, Oregon.). One half of the remaining corn blade and the two remaining soybean leaflets were freeze-dried and used for antioxidant and MDA analysis using standard procedures as described in Zhang et al., (2003).

Corn ears were hand harvested at black layer formation (R6) (September 14, 2004) from one 3m section of the center rows. Yields were adjusted to a 155 g/kg moisture content basis. Soybean was harvested from the two center rows at full maturity using a combine on October 20, 2005. Yield was adjusted to 130 g/kg moisture content basis. The remaining corn and soybean plants were removed from the plots both years.

Leaf laboratory analyses

Chlorophyll content: Quantification of chlorophyll content was determined using the dimethyl sulphoxide (DMSO) chlorophyll extraction method of Hiscox & Isrealstam (1979) with minor modifications. Glass centrifuge bottles containing 7 ml of DMSO were preheated to 65°C in a water bath. Five discs (total area, 1.41 cm^2) punched from the previously frozen (-80°C) composite sample were incubated in vials for 50 minutes and were subsequently topped to 10 ml with additional DMSO. Two milliliters of the extract were transferred to a disposable polyestrene cuvette having a transmittance of 340-800 nanometers (VWR, 5801 7-847; West Chester, Pennsylvania). A spectrophotometer (Biomate 3 series; Rochester, New York) calibrated at 645 and 663 nm using pure DMSO was used to determine total chlorophyll concentration using Arnon's (1949) equation: $0.0202A_{645} + 0.00802A_{663}$ = mg chlorophyll/ml solution. The chlorophyll concentration was then converted to leaf chlorophyll content by the equation: (mg chlorophyll/ml solution)*(10ml solution/1.41 cm^2 total leaf area) = mg chloropyll/cm^2, and a regression equation between SPAD readings and leaf chlorophyll content was established.

Crude protein extraction: Leaf tissue (0.25 g fresh weight) previously stored at -80°C was macerated with mortar and pestle in liquid nitrogen, and mixed with 3 ml of 0.05 M

sodium phosphate buffer, pH 7, containing 1% polyvinylpyrrolidone and 0.2 mM EDTA. Two milliliters of the homogenate were centrifuged at 4°C for 20 minutes at 15,000 g. The supernatant was stored at 4°C until further analysis.

Total leaf protein assay: Leaf protein analysis was conducted using the crude protein extract and the method of Bradford (1976) with bovine serum albumin as a standard.

Superoxide dismutase (SOD) activity: In 2004, 1.38 ml of 50 mM sodium phosphate buffer, pH 7.8, 15 µl of 10mM EDTA, 60 µl of 0.325 M methionine, 15 µl of 6.3 mM NBT, 5 µl of the crude protein extract, were mixed in a disposable polyestrene cuvette. Fifteen microliters of 130 µM riboflavin was added, and the cuvettes were secured on a rotating cutoff under one circular fluorescent bulb (irradiance = 60 $mol \cdot m^{-2} \cdot s^{-1}$) for 30 minutes at 25°C to initiate reaction. The absorbance was read 560 nm, with one non-irradiated mixture serving as a blank (Zhang, 2003).

One unit of activity =

{1000µl*leaf protein (mg)}/{amount of extract*[($Abs_{(sample)}$ -1)/ $Abs_{(light\ blank)}$]}

In 2005, SOD activity was determined using a microplate reader (Ospys MR; Thermo Labsystems, Chantilly, VA). The reaction solution included 50 mM Pipes buffer, pH 7.5, 0.4 mM o-dianisidine, 0.5 mM DTPA, and 26 µM riboflavin. In each well, 20 µl of enzyme extract was added to125 µl of reaction solution. The absorbance was read at 25°C after a 30 minute reaction period under one circular fluorescent bulb (irradiance = 60 $mol \cdot m^{-2} \cdot s^{-1}$). Superoxide dismutase activity was determined from a standard curve and expressed as unit of activity/mg protein (Zhang, 2005).

Ascorbate peroxidase (APX) activity: The reaction mixture contained 1.405 ml of 50 mM of phosphate buffer, pH 7, 15 µl of 10 mM EDTA, 15 µl of 50mM ascorbic acid, and 50 µl of enzyme extract in a polyestrene cuvette. Fifteen microliters of 10 mM H_2O_2 was added just prior to measuring the absorbance at 290 nm at 0 and 1 minute for corn and 0 and two minutes for soybean (Zhang, 2003).

One unit of activity = change in absorbance/(0.01)/minute/ mg total leaf protein

Catalase (CAT) activity: The reaction mixture contained 1.424 ml of 50 mM phosphate buffer, pH 7, and 26 µl of 3% H_2O_2 in a polyestrene cuvette. Fifty microliters of crude protein

extract was added just prior to measuring the absorbance at 240 nm at 0 and two minutes (Zhang, 2003).

1 unit activity = change in absorbance/(0.1)/minute/mg total leaf protein.

Malondialdehyde (MDA) concentration: Lipid peroxidation of chlorplasts was determined using the method of Jiang and Zhang (2001). The concentration of MDA, a product of lipid peroxidation, was determined using the molar extinction coefficient of 155 $mM^{-1}cm^{-1}$.

Seed biochemical measurements

Seed quality (i.e., protein, oil, starch, density, fiber (soybean only)), and soybean 100 g seed weight were determined by the Iowa State Grain Quality Laboratory using nuclear resonance spectroscopy techniques.

Data Analysis

Analysis of variance and mean separation data were performed using the randomized block design PROC GLM procedure for mid-season leaf N & P contents, yield, and seed quality parameters (SAS Institute, 2002). Analysis of variance and mean separation data were performed using the PROC MIXED repeated measures procedure for end of season soil parameters and leaf physiological measurements. The least significant difference procedure (LSD) with a probability level of 0.05 was used to determine significant differences between treatment means.

Results and Discussion

Climatological parameters at the Northern Piedmont Agriculture and Research Extension Center

In 2004, monthly and total precipitation was greater than the 30 year average (Table 3.6). Leaf sampling began July 14, 2004 and ended August 27, 2004. The corn did not exhibit signs of water stress during the sampling season. The exceptionally high precipitation in July 2004 was due to the regular occurrence of afternoon thundershowers and Hurricane Isabel.

In July 2005, monthly precipitation was much greater than the 30 year average (Table 3.6). Leaf sampling began August 12, 2005 and ended September 16, 2005. Despite the

relatively low precipitation values during these months, there were no biological indicators of water stress. It is possible the deep rooting system of the soybean provided sufficient water for the developing crop.

Monthly air temperatures in 2004 and 2005 were similar to the 30 year average (Table 3.6). Air temperatures on the 2004 and 2005 sampling dates were also near average values (Table 3.7). On August 26, 2005, the air temperature was relatively low at 20.51°C and the sky was overcast.

Soil Fertility

Nitrogen (N)

All treatments were applied on an N basis. End of season soil data indicate that the AYWC treatment had the greatest soil N content followed by the ABSC>LYWC>LBSC=PL= FERT=CTRL treatments (Table 3.8). Both Panorama yard waste compost treatments (i.e., AYWC and LYWC) had greater soil N values than the ABSC, PL, and LBSC treatments, respectively. The N fertilizer value of Rivanna biosolids compost (30%) and poultry litter (49%) were considerably higher than the N fertilizer value of Panorama yard waste compost (10%) as determined from the N mineralization greenhouse study (Table 2.7). The greater soil N contents in the soil of the two Panorama yard waste compost treatments were likely due to the somewhat slower N mineralization of the material. Increases in 2005 soil nitrogen contents were likely due to N fixation from soybeans (Table 3.9).

Phosphorus (P)

All organically amended treatments applied at the agronomic nitrogen rate (i.e. AYWC, ABSC, PL) contained greater soil P contents than the FERT treatment (Table 3.8). The 2005 soil P concentrations increased in all treatments following the soybean crop (Table 3.9). The ratio of calculated plant available N to total P of the organically amendments were between 0.38 and 2.10 (Table 3.3). Gilbertson et al. (1979) have calculated a mean N:P uptake ratio of 5.9 for corn. Thus, the N-based application rates of the organic amendments resulted in P applications that exceeded crop needs.

Several researchers have observed elevated soil P concentrations when organic amendments were applied on an N basis (Eghball and Gilley, 1999; Sharply and Moyer, 2000;

Eghball, 2002). The Virginia Tech Soil Testing Lab reported that soil P concentrations for the organically amended treatments were sufficient for plant growth and that applications of additional P fertilizer would not improve future crop yields. High soil P concentrations are not detrimental to plant growth, but may cause water impairment if transported from the field site *via* erosion and/or runoff. An extensive study on the potential movement of P at this site was conducted by Spargo (2004).

Potassium (K)

Soil K concentrations were greatest in the AYWC treatment (Table 3.8). The PL and LYWC treatments had greater soil K concentrations than the ABSC and LBSC treatments. The relatively large soil K content of the PL treatment despite its low application rate (Table 3.4) was due to the exceptionally high K levels of the poultry litter amendment (Table 3.3). It is common practice to add mineral supplements to animal feed in confined animal farming operations (Blezinger, 2001; Kegley, 2001). The amount of nutrient supplied often exceeds the assimilatory capacity of the animal, and excess minerals are excreted in the waste. The low soil K contents of the ABSC and LBSC treatments were due to the relatively low K concentration of the amendment (Table 3.3). The LBSC, CTRL, and FERT treatments had the lowest soil K contents. The lower K concentration in the FERT compared to the CTRL treatment may be due to increased root exploration and nutrient uptake in the adequately fertilized soil. Soil K increased in 2005 (Table 3.9).

Calcium (Ca) and magnesium (Mg)

Lime was added differentially to treatment plots in spring 2004 to limit the confounding effect of soil pH on P availability (Spargo, 2004). The ABSC treatment, nevertheless, had the highest pH and Ca contents in (Table 3.8). The biosolids were dewatered using $Ca(OH)_2$, which increased CCE (Table 3.3). All other treatments had similar pH values. The Ca contents of the organically amended treatments were greater than the FERT and CTRL treatments likely due to its addition in the composts and poultry litter.

All organically amended treatments had greater soil Mg contents than the FERT treatment in 2004 (Table 3.8). The AYWC treatment had the greatest soil Mg concentrations. The poultry litter amendment contained the highest Mg concentration (5.80 mg/kg, Table 3.3), which resulted in greater soil Mg contents than the ABSC treatment despite the relatively low application rate (Table 3.4). The FERT treatment had a slightly lower Mg concentration than the

CTRL. This may be due to increased root growth and nutrient uptake of crops planted in the adequately fertilized soil.

There were no changes in soil magnesium contents from 2004 to 2005 (Table 3.9).

Micronutrients (Cu, Fe, Mn, Zn)

End of season soil Cu contents were greatest in the PL treatment followed by the CTRL and FERT treatments (Table 3.8). The relatively high Cu content of the poultry litter amendment (Table 3.3) is due to its use as a supplement in animal feed (Blezinger, 2001; Kegley, 2001). The LYWC and LBSC treatments added more Cu to soils than the PL treatment (Table 3.5); however, extractable Cu was lower in the compost amended soils. The AYWC and ABSC contributed the greatest amount of Cu to the soil (Table 3.5), but extractable concentrations were the lowest among all treatments (Table 3.8). A similar phenomenon occurred with soil Fe content where increases in organic carbon decreased the amount of extractable Fe (Tables 3.4, 3.5, 3.8).

This inverse relationship between the total amount of nutrient applied and the quantity of the nutrient extracted is the opposite of what was observed with Zn and Mn concentrations where extractability increased with increasing application rates (Tables 3.5, 3.8). Copper and Fe form relatively stronger complexes with organic ligands (Havlin et al., 1999), and are tightly bound to the organic material due to the humification process of composting (Epstein, 1997). This greatly decreases the extractability of these elements. The uncomposted PL amendment appears to not provide the same binding of Cu as do the composts; thus, the Cu added with the PL is more readily extractable.

Soil Organic Carbon (C)

Soil organic C contents were similar in spring 2000 prior to the implementation of this study (Table 3.10). The application rates of all organic amendments were made on an N basis, and there were large differences in the total amount of carbon applied in each treatment (Table 3.4). The AYWC treatment contained the greatest organic carbon content among the organically amended treatments, while PL had the lowest and was similar to the CTRL and FERT treatments (Table 3.10). Entry et al. (1997) also observed that a poultry litter amended Typic Hapludult in Alabama contained a soil carbon content significantly lower than compost amended soils and was similar to the fertilized control. Paul and Beauchamp (1989) observed that CO_2 evolution in a poultry litter amended silt loam was over 10 times greater than in the same soil amended with several different composts during a seven-day incubation period. In addition to supplying low

rates of C, the poultry litter had not gone through as extensive a humification process as had the composted residuals; thus, the poultry litter C was readily available for microbial use and did not improve soil organic matter content. The organic carbon contents of the ABSC, LYWC, and LBSC were greater than the FERT and CTRL treatments.

Fulvic and Humic Acid

Organic Amendments

The Poultry Litter had the greatest fulvic acid-carbon content followed by the Panorama yard waste compost and Rivanna biosolids compost (Table 3.11). According to the tenants of the polyphenol theory, fulvic acid is relatively less humified than humic acid (Stevenson, 1994). The poultry litter was the only non-composted amendment. The greater quantity of extractable fulvic acid-carbon from this residual may indicate that much of the carbon was weakly humified.

The relative rankings of extractable humic acid-carbon from the amendments are PYWC>>PL>RBSC (Table 3.11). The lignin theory asserts that humic acid is comprised of humified lignin molecules. Sodium hydroxide is often used to extract lignin from wood fibers in paper processing plants. The greater quantity of humic acid-carbon in the Panorama yard waste compost and poultry litter is likely not due to the sole extraction of humified carbon, but the extraction of lignified materials from the woody debris of the compost and poultry bedding as well. Although the composting process of Rivanana biosolids uses wood chips as a bulking agent, these materials are sieved from the organic fraction after five days of composting. The result is a lower content of a humified materials in the compost.

Total NaOH extractable carbon was greatest in the poultry litter, due to the very high extractable fulvic acid-carbon content. Panorama yard waste compost had a greater total NaOH extractable carbon content than the Rivanna biosolids compost.

Amended soil

The AYWC treatment contained the greatest fulvic acid-content (Table 3.12). The ABSC and LYWC treatments had moderately lower fulvic acid-carbon contents. The PL and LBSC treatments had the lowest fulvic-acid content among the organically amended treatments. These rankings are likely due to the total amount of amendment applied in 2004 (Table 3.4).

The humic acid-carbon content of the AYWC treatment was greatest among all treatments followed by the LBSC treatment (Tables 3.12). All other treatments had similar humic acid-carbon contents. The extraction efficiency of humic acid-carbon from soil can vary

from 30 to 50% (Chao Shang, personal communication) as humic acid is often covalently bound with cations, especially iron and aluminum (Donisa et al., 2003). The relative ranking of humic acid-carbon was as follows: AYWC>>ABSC>LYWC=LBSC=FERT=PL=CTRL. It appears that the humic acid-carbon content follows the ranking of the amendment application rates. The non-composted PL treatment has the lowest humic acid-carbon content among all treatments. The carbon applied *via* poultry litter is easily mineralized by microbes. Paul and Beauchamp (1989) observed that increases in microbial activity decreases soil organic matter content. The relatively lower humic acid-carbon content in this treatment indicates that pelletized poultry litter does not contribute to the humified carbon content.

The fulvic acid-carbon content is considerably larger than the humic acid-carbon content in nearly all of the treatments (Table 3.12). This was rather surprising as the addition of organic amendments to soils has been documented to increase humic acid-carbon more than of fulvic acid-carbon (Nardi et al., 2004; Zinati et al., 2001; Schnitzer and Kodama, 1992). An increase in humic acid-carbon content has been considered an indicator of soil organic matter humification and stability (Ji-ping et al., 2002). Wei and Xiao (1996) observed greater fulvic acid-carbon contents in soils when the predominant clay mineral was kaolinite, while higher humic acid-carbon contents were observed in soils where montmorillonite was the predominant clay. The large presence of 1:1 clays at this study site may favor the formation of fulvic acid-carbon.

Soil Bulk Density, Soil Water Holding Capacity, and Moisture Potential

In 2004, AYWC had a lower bulk density (0.97 g/cm^3) from 0 to 15 cm than the LWYC (1.27 g/cm^3) and CTRL (1.36 g/cm^3) treatments (Table 3.13). No differences in soil water holding capacity occurred at the 0 to 15 cm depth in the disturbed (ground, sieved, and repacked) soil samples. Soil moisture potential was not determined on Day 7.There were no differences in Ψ_{soil} throughout the sampling season likely due to the use of disturbed soil (15 cm depth) in the generation of the soil moisture release curves (Table 3.13).

In 2005, AYWC had the lowest bulk density (Table 3.14). The differences in bulk density decreased with depth among the treatments. Soils were sampled at 0-5 cm increments to a depth of 15 cm to preserve soil structure. The AYWC treatment had a greater soil water holding capacity than the CTRL at the 0-5 cm depth (Table 3.14). No differences in soil water holding capacity occurred at the 5-10 cm depth, but the LYWC treatment retained the most soil water

holding capacity at the 10 to 15 cm depth. Cumulative soil water holding capacity in the top 15 cm was greater in the LYWC but was similar to the AYWC treatment. The CTRL treatment had the lowest soil water holding capacity. The Ψ_{soil} was lowest on Day 7 and increased through Day 28. Soil moisture potential was not determined on Day 35. The decreased bulk densities and increased soil water holding capacities of the organically amended treatments relative to the CTRL is likely due to increased aggregation of soil particles by the addition of organic matter (Khaleel et al., 1981; Grandy et al., 2002; Elsharawy et al., 2003).

Statistical Interactions

There were no observed interactions between treatment and day for the either crop on any sampling date.

Corn (2004)

Midseason leaf nutrient content

Leaf N and P concentrations in ear leaves sampled at silking (July 14, 2004) were greatest in the agronomic N treatments (i.e., FERT, AYWC, ABSC, PL) (Table 3.15). The low nitrogen treatments (i.e. LYWC, LBSC) had N and P concentrations lower than the agronomic N treatments but higher than the CTRL.

Leaf Water Potential (Ψ_{leaf})

The Ψ_{leaf} is a measure of the tension difference between the roots and leaf that is required to extract water from the roots. Leaf water potential measurements were not taken Day 7, 42, 51 due to instrument unavailability. Differences in Ψ_{leaf} were not biologically meaningful (Table 3.16). The Ψ_{leaf} decreased with time throughout the sampling season possibly due to the senescence process of the leaves (Table 3.17).

Total leaf protein

The agronomic N treatments had the greatest total leaf protein contents (Table 3.16). The low N treatments had relatively lower values but were greater than the CTRL. Total protein contents remained relatively constant the first 29 days of sampling (Table 3.17). There was an increase in leaf protein on Day 35; after which, leaf protein contents began to decline as the leaves senesced.

Leaf chlorophyll

Chlorophyll contents were greatest in the agronomic N treatments (Table 3.16). The low nitrogen treatments had greater chlorophyll values than the CTRL treatment. Chlorophyll contents increased on Day 22 and remained stable through Day 35 (Table 3.17). There was a decrease in leaf chlorophyll contents on Days 42 and 51, likely due to the senescence of the leaves. Prochackova et al. (2004) also observed an increase in maize leaf chlorophyll content during early reproductive growth followed by a decline in chlorophyll contents.

Photochemical Efficiency (Fv/Fm)

No Fv/Fm measurements were taken on Day 7 due to fluorometer malfunction. Most agronomic N treatments had greater Fv/Fm values than the low N treatments (Table 3.16). The PL treatment had a similar Fv/Fm value to the low N treatments. The low N treatments had greater Fv/Fm values than the CTRL treatment (Table 3.16). Khamis et al. (1990) observed greater Fv/Fm values in N replete than N deficient corn seedlings. Fv/Fm readings increased with time and were highest at Day 29 (Table 3.17). Treatment differences in Fv/Fm, although significant, are less than expected, given the relatively large variation of leaf chlorophyll contents (Table 3.16). Fv/Fm readings were taken after the ear leaves were covered with an aluminum foil sleeve for at least 15 minutes. The sleeves had to be partially lifted during measurement. It is likely that the differences in Fv/Fm are less definitive due to stray light that reached the fluorometer sensor.

Superoxide Dismutase (SOD)

Superoxide dismutase activity was lowest in the agronomic nitrogen treatments (Table 3.16). The low nitrogen and CTRL treatments had higher SOD activities. Tewari et al. (2004) observed greater SOD activity in nitrogen starved maize. The lower leaf nitrogen and chlorophyll contents of the low nitrogen and CTRL treatments likely created an environment that generated more reactive oxygen species. At Day 22 (R3-milk stage), there was an increase in SOD activity (Table 3.17). Kernels at this stage of development are undergoing rapid cellular expansion due to the accumulation of starch. The increase in SOD activity was simultaneous to an increase in chlorophyll content (Table 3.16). Perhaps on Day 22 there was an increase in photosynthetic activity due to the very strong demand of kernel sink. The increased activity may increase the formation of superoxide due to the intrinsic inefficiencies of Photosystem I. Prochazkova et al. (2001) also observed increased SOD activity in maize leaves up to 25 days after tasseling.

Superoxide dismutase activity decreased from Day 29 through 51. A decrease in SOD activity is known as a contributing factor to leaf senescence (Lin et al., 1988; Pastori and Trippi, 1993).

Ascorbate Peroxidase (APX)

The CTRL, LYWC, and LBSC treatments had the greatest APX activities (Table 3.16). All agronomic N treatments had lower APX activities. Ascorbate peroxidase activity is regulated by the formation of peroxide from SOD activity. The N replete treatments had greater photosynthetic efficiencies and generated less ROS than the low N and CTRL treatments. Ascorbate peroxidase activity increased from Day 7 to Day 29 (Table 3.17). Prochazkova et al. (2001) also observed an increase in maize leaf APX activity during early reproductive growth. Increased APX activity during this time is likely due to the increased formation of peroxide from elevated SOD activity. APX activity decreased on Day 35, even after a decrease in SOD activity, but values remained higher than at the beginning of the sampling season (Table 3.17). It appears the down regulation of APX activity is related to intercellular peroxide concentrations and not absolute SOD activity. Increased APX activity during the latter part of the season contrasts with the results of Prochazkova et al. (2001) who observed decreased APX activity with age. Pastori and Trippi (1993) observed no change in maize leaf APX activity during senescence. Leaf APX activity varies among cultivars and is related to general stress tolerance. The greater activity observed in the cultivar used in this study may indicate that it is relatively more resistant to oxidative stress than the cultivars used in the other studies. The increased APX activity could not delay oxidation indefinitely as lipid peroxidation increased over time (Table 3.17).

Catalase (CAT)

There were no biologically significant differences in CAT activity (Table 3.16). Catalase is located in large quantities in the peroxisome and its activity is stimulated only by millimolar concentrations of peroxide (Asada, 1994). It does not require reducing equivalents like APX to reduce peroxide. Subsequently, it may be less sensitive to the redox status of the cell and its activity may not be affected by stress (Arora et al., 2002; Mittler, 2002). Alber and Scandalios (1993) observed that a maize mutant deficient in two CAT isozymes had adequate growth under atmospheric conditions and resembled the wild type in phenotype. Catalase activity decreased with time.

Malondialdehyde (MDA)

Malondialdehyde concentration quantifies the lipid peroxidation of chloroplast membranes (Heath and Packer, 1967). The CTRL treatment had the greatest MDA content (Table 3.16). The two low N treatments had greater MDA content than the agronomic N treatments. The relative rankings of MDA content were consistent with the other parameters observed to this study. The chlorophyll and Fv/Fm measurements were lowest in the CTRL and low nitrogen treatments, and the antioxidant activities of these treatments were greater than in the agronomic N treatments.

At Day 7, MDA contents were relatively high compared to later sampling dates (Table 3.17). Dhindsa et al. (1981) observed that younger tobacco leaves had greater MDA contents than fully expanded leaves. They concluded that increased lipid peroxidation of younger leaves may have a role in the mechanism involving premature leaf abscission. Malondialdehyde was not determined on leaves collected on Day 22 as these were destroyed. Malondialdehyde contents increased in all treatments at Day 42. Leaf senescence is associated with increased lipid peroxidation, and decreased antioxidant activities, total leaf protein, and chlorophyll contents (Table 3.17) as the plant comes closer to maturity (Dhindsa et al., 1981; Pastori and Trippi, 1993 Hung and Kao, 1996; Yan et al., 1996; Jiang and Huang, 2001; Prochazkova et al., 2001). The greater MDA contents of the CTRL and low nitrogen treatments are likely due to the cumulative effects of elevated reactive oxygen species throughout the sampling and not simply general senescence.

Yield and seed composition

The corn was harvested September 14, 2004, 126 days after planting. Yields closely followed the midseason leaf nitrogen contents with the agronomic nitrogen treatments having yields at 10.70 Mg/ha or greater (Table 3.18). The low nitrogen treatments had yields between 7.90-8.95 Mg/ha. The CTRL treatment had the lowest yield at 5.40 Mg/ha. The existence of favorable weather conditions during the 2004 growing season was demonstrated by the attainment of long term mean corn yields (8.13 Mg/ha for Fauquier; Simpson et al., 1993) in every treatment, except the CTRL.

The ABSC treatment had the greatest kernel protein content followed by the FERT and AYWC treatments (Table 3.18). These treatments had greater protein contents than the PL treatment. The LYWC and LBSC treatments had greater protein contents than the CTRL. Kernel

oil contents were greatest in the ABSC, LYWC, FERT, and AYWC treatments (Table 3.18). The author has no explanation why the LYWC had such an high oil content. The PL, CTRL, and LBSC treatments had relatively lower oil contents, and the LBSC, CTRL, and LYWC treatments had the greatest kernel starch components (Table 3.18). The AYWC, ABSC, FERT, LYWC and PL treatments had the greatest kernel densities, and the CTRL treatment had the lowest kernel density (Table 3.18).

Differences in leaf health, corn yields, and seed composition were strongly associated with midseason leaf nitrogen contents and not humified carbon content (Table 3.19). The agronomic nitrogen treatments had greater chlorophyll, total leaf protein contents, Fv/Fm values, lower SOD activities and MDA contents, and outperformed the low nitrogen and CTRL treatments in yield, seed protein and oil contents, and density.

Soybean (2005)

Midseason leaf nutrient content

There were no differences in midseason (August 18, 2005) leaf N and P concentrations among the treatments (Table 3.20). Soil amendment N availability is not a critical factor for supplying plant N to legumes.

Leaf Water Potential (Ψ_{leaf})

There were significant differences in Ψ_{leaf} among treatments (Table 3.21), but there were not biologically significant. The relatively low Ψ_{leaf} measurements at Day 7 were due to overcast skies during sampling (August 19, 2005) (Table 3.22).

Total leaf protein

There were no differences in total leaf protein contents among treatments (Table 3.21). There was an increase in leaf protein content at Day 7. Total leaf protein declined from Day 14 to Day 35 (Table 3.22).

Leaf chlorophyll

There were no differences in leaf chlorophyll contents among the treatments (Table 3.21). Chlorophyll contents increased in all treatments on Day 7 to Day 15 and remained constant until Day 28 (Table 3.22). Chlorophyll contents decreased on Day 35.

Photochemical Efficiency (Fv/Fm)

Photochemical efficiency measurements were only taken twice due to instrument repair. Treatment differences in Fv/Fm were not biologically meaningful (Table 3.21), and Fv/Fm did not change between the two days (Table 3.22).

Delta T

Delta T measures the difference between canopy and air temperatures and is a non-destructive indicator of leaf stress. The CTRL treatment had the lowest Delta T values and was similar to most other treatments except the ABSC, AYWC, and LYWC treatments which had higher Delta T values. The relatively cooler canopies of these treatments indicate increased transpiration rates. Delta T values were positive at all sampling dates except Day 21 when the air temperature was relatively warm (27.47°C) (Tables 3.7, 3.22). The same air temperature occurred at Day 0 as at Day 21. It appears that the metabolic efficiencies of the relatively younger leaves at Day 0 were less able to efficiently transpire and increased canopy temperatures. Malondiadehyde concentrations were also higher on this date (Table 3.22). The low Delta T values at Day 7 were due to overcast skies at the time of sampling (August 26, 2005). The relatively higher Delta T values at Days 28 and 35 are due to decreased air temperature.

Superoxide Dismutase (SOD)

There were no treatment differences in SOD activity (Table 3.21). The lowest SOD activities occurred at Day 7 when the skies were overcast during sampling (August 26, 2005). The low SOD activities indicate that relatively few reactive oxygen species were generated on this date. Superoxide dismutase activity increased from Day 14 to Day 28 indicating an increase in the formation of active oxygen species (Table 3.22). Superoxide dismutase activity declined in all treatments on Day 35. A process that likely causes leaf senescence.

Ascorbate Peroxidase (APX)

There were no treatment differences in APX activity (Table 3.21). Ascorbate peroxidase activity increased on Day 7 (Table 3.22) perhaps indicating that the down regulation of APX activity may not be directly coupled with SOD activity, but the residual intercellular concentration of peroxide. Ascorbate peroxidase activity also increased on Day 35. It is likely

that the down regulation of APX activity is not directly related to SOD activity, but intercellular peroxide concentrations.

Catalase (CAT)

There were no treatment differences in CAT activity (Table 3.21). Tolbert et al. (1969) observed that the oxidation of glycolate, a product of photorespiration, accounts for most of the peroxide scavenged by CAT in C_3 species. Catalase does not require reducing substrates for its activity, but is directly consumed during radical quenching (Mittler, 2002). The greater CAT activity on Day 7 (Table 3.22) was likely due to the diffuse light conditions that decreased the photorespiration potential of the crop. Thus, catalase was not actively consumed on this date. The rate of photosynthesis decreases during rapid seed fill (Day 14 to Day 28) as photosynthate is primarily used for seed development and not root or nodule growth (Burton, 1997). This may explain the lower CAT activity observed during these sampling dates. Catalase activity was lowest at Day 35 and likely contributed to leaf senescence (Table 3.22).

Malondialdehyde (MDA)

There were no treatment differences in MDA content (Table 3.21). At Day 0, MDA contents were relatively high compared to later sampling dates. Dhindsa et al. (1981) observed that younger tobacco leaves had greater MDA contents than fully expanded leaves. They concluded that increased lipid peroxidation in younger leaves may have a role in the mechanism involving premature leaf abscission. Malondialdehyde content decreased at Day 7 and 14 and then increased on Days 21 through 35 (Table 3.22). Increased MDA contents at Day 35 contrast with decreasing SOD and CAT activities on that date (Table 3.22). Superoxide dismutase and CAT are suspected to control the oxidative process of lipid peroxidation (Pastori and Trippi, 1993; Prochazkova, 2001; Mittler, 2002). Several researchers have observed the inverse relationship between antioxidant activities and lipid peroxidation as leaves undergo senescence (Dhindsa et al., 1981; Xu and Zou, 1993; Jiang and Huang, 2001).

Yield and seed composition

Yields in ABSC and AYWC were 20% greater than in the CTRL and FERT treatments (Table 3.23). The PL, LYWC, and LBSC yields were on average 10% greater than the CTRL and FERT treatments (Table 3.23). Seed protein contents and 100 seed weight followed a similar pattern where the organically amended treatments were 4-9% and 5-14% greater, respectively than the CRTL and FERT treatments (Table 3.23). The rankings of seed oil, fiber,

and carbohydrate contents occurred in reverse order where the FERT and CTRL treatments had the greatest non-protein contents followed by the PL, LBSC, LYWC treatments (Table 3.23). The ABSC and AYWC treatments had the lowest non-protein contents (Table 3.23).

Several researchers have observed increased yield and improved seed quality in inoculated soybean receiving organic amendments or influenced by the residual effects of the amendments (Appavu and Saranan, 2000; Moharram et al., 1999; Sato et al., 2001; Duraisamy and Mani, 2002; Patil et al., 2003; Vyas et al., 2003). A few researchers observed that soybean planted in organically amended soils had greater nodule numbers (Selvam et al., 2000; Gamba et al., 2003, nitrogen fixation (Prabakaran and Ravi, 1996; Moharram et al., 1999; Vieira, 2001), and leaf chlorophyll contents (Ghosh et al., 2004) relative to non-amended soybeans, though these differences diminished with time (Selvam et al., 2000; Vieira, 2001; Gayen et al., 2004; Ghosh et al., 2004). In this study, there were no observed differences in leaf nitrogen, protein and chlorophyll contents, antioxidant activities, and chlorophyll lipid peroxidation throughout the sampling period. The large differences in yield and seed quality may be attributed to non-nutritive constituents within the organic amendments that beneficially improved crop development.

Comparison of Corn and Soybean Antioxidant Activities

Corn had relatively higher antioxidant activities than soybean (Tables 3.16, 3.21). Stepien and Klobus (2005) also observed greater antioxidant activities in corn as compared against wheat. The function of CAT was very different between the two crops. In corn, CAT appears insensitive to the intercellular redox concentration. This may be due to the evolutionary characteristics of C_4 metabolism that reduces glycolate production and peroxide generation within the peoxisome. In soybean, CAT activity appears to be linked to the oxidation of glycolate and not the formation of reactive oxygen species within the chloroplasts. The greater MDA contents of soybean indicate that the corn antioxidant scavenging mechanism was more efficient at quenching free radicals. A similar result was obtained by Stepien and Klobus (2005) in comparing corn MDA contents against wheat.

Conclusion

The application of organic amendments improved soil fertility and increased total organic and humified carbon contents relative to the inorganically fertilized and control treatments. Bulk density was lower in the treatments that received composts, although the differences declined

with depth in 2005. Differences in soil moisture holding capacity were observed in 2005 only. The slight improvements in moisture holding capacity were likely due to the relatively high inherent water-holding capacity of the clayey soil prior to the addition of the amendments. Improvements in soil fertility, total carbon, and humified carbon persisted into the following year when no amendments were applied. Overall, amending this clay loam soil with compost was most valuable in improving soil chemical properties that affect fertility and bulk density, but little benefit on soil moisture holding capacity occurred.

I was unable to test my hypothesis whether humic substances within organic amendments may ameliorate crop water stress, as neither the corn nor soybean experienced water stress (as measured by Ψ_{leaf}) during sampling season. Treatment differences in corn leaf chlorophyll and protein contents, antioxidant activities, and chlorophyll lipid peroxidation were based on plant available nitrogen. Midseason leaf N concentrations and not soil humified carbon was highly correlated with improvements in corn yield, from which I infer that the chief benefits of the organic amendments on corn growth were in their N-supplying capabilities. There were no treatment differences in the soybean leaf parameters measured, but changes were observed over time. The significant differences in soybean yield and seed composition could not be justified by differences in nutrition. The presence of non-nutritive constituents may better explicate the observed phenomena.

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Table 3.1 Treatment descriptions during Phase I of the study, 2000-2002. FERT= Inorganic Fertilizer; BCF=100% N Biennial Compost with Fertilizer; BC=100% N Biennial Compost without Fertilizer; PL=Poultry Litter; LCF=20% N Low Compost with Fertilizer; LC=20% N Low Compost without Fertilizer; CTRL= No amendments Applied

	2000	2001	2002
		Crop†	
Treatment	Pumpkins	Sweet Corn	Peppers
FERT	Commercial Fert‡	Commercial Fert	Commercial Fert
BCF	100% N rate compost§	Commercial Fert	100% N rate compost
BC	100% N rate compost	---------	100% N rate compost
PL	100% N rate poultry litter	100% N rate poultry litter	100% N rate poultry litter
LCF	20% N rate compost + fertilizer	20% N rate compost + fertilizer	20% N rate compost + fertilizer
LC	20% N rate compost	20% N rate compost	20% N rate compost
CTRL	---------	---------	---------

† Crop rotation included a winder cover crop of cereal rye
‡Fertilizer applied as NH_4NO_3 and Triple Super Phosphate
§ All compost treatments used Panorama Paydirt yard waste compost

Table 3.2 Treatment descriptions during Phase II of the study, 2003-2005. FERT=Inorganic Fertilizer; ABSC=100% N Biosolids Compost; AYWC=100% N Yard Waste Compost; PL=Poultry Litter; LBSC=30% N Biosolids Compost; LYWC= 30% N Yard Waste Compost; CTRL=No Amendments Applied

	2003	2004	2005
		Crop†	
Treatment	Corn	Corn	Soybean
FERT	Commercial Fert‡	Commercial Fert	---------
ABSC	100% N rate compost§	100% N rate compost	---------
AYWC	100% N rate compost¶	100% N rate compost	---------
PL	100% N rate poultry litter	100% N rate poultry litter	---------
LBSC	30% N rate compost§	30% N rate compost	---------
LYWC	30% N rate compost¶	30% N rate compost	---------
CTRL	---------	---------	---------

† Crop rotation included a winter cover crop of cereal rye
‡ Fertilizer applied as NH_4NO_3 and triple super phosphate
§ Compost prepared from Rivana Biosolids
¶ Compost prepared from Panorama Yard Waste

Table 3.3 Select chemical properties of the organic residuals applied in 2004. PYWC=Panorama Yard Waste Compost; RBSC= Rivanna Biosolids Compost; PL= Poultry Litter

	TKN†	NH4-N	NO3-N	PAN‡	C§	TP¶	K	Ca
Residual				g/kg				
PYWC	20.2	0.2	0.89	3.1	377.0	4.0	6.8	21.1
RBSC	26.0	3.9	0.10	6.2	257.0	16.5	1.1	129.0
PL	56.5	7.7	0.04	37.0	476.0	18.0	26.3	29.9

	Mg	Mn	Zn	Cu	Fe	PAN:TP	C:N	CCE#
Residual	----------g/kg----------							%
PYWC	3.0	1.0	0.2	0.2	10.0	0.8	19.0	7.9
RBSC	3.1	0.7	0.7	0.4	38.7	0.4	10.0	34.3
PL	5.8	0.6	0.5	0.5	0.8	2.1	8.0	6.2

† Total Kjeldahl Nitrogen, EPA 351.3 (USEPA, 1979)
‡ Plant available nitrogen. Estimated by adding 100% of the measured (NO_3+NH_4)-N and the fraction of organic N estimated to be mineralizable during the first season. Mineralization coefficients used were 0.1for composted materials and 0.6 for poultry litter.
§ Organic carbon, EPA 415.1 (USEPA, 1999)
¶ Total phosphorus, EPA 3052 microwave assisted digestion (USEPA, 1999)
# Calcium carbonate equivalence, AOAC 955.01 (AOAC, 1975)

Table 3.4 Cumulative application rates and total carbon added of organically amended treatments from 2000 to 2004. FERT=Inorganic Fertilizer; ABSC=100% Biosolids Compost; AYWC=100% N Yard Waste Compost; PL=100% Poultry

Litter; LBSC=30% N Biosolids Compost; LYWC= 30% N Yard Waste Compost; CTRL=No Amendments Applied.

	Application Rate						Carbon Added					
Treatment	2000	2001	2002	2003†	2004	Sum	2000	2001	2002	2003‡	2004	Sum
	Mg/ha (dw)											
FERT	-	-	-	-	-	-	-	-	-	-	-	-
ABSC	43.7	-	40.8	20.9	20.6	126	12.9	-	18.5	4.63	5.28	41.3
AYWC	43.7	-	40.8	69.7	47.6	201.8	12.9	-	18.5	26.6	18.0	76.0
PL	2.15	4.76	5.78	5.05	4.15	21.89	1.04	2.31	2.75	2.38	1.98	10.5
LBSC	8.72	6.35	6.15	6.28	6.18	33.68	2.58	2.58	3.7	1.39	1.58	11.8
LYWC§	8.72	6.35	6.15	20.9	14.3	56.42	2.58	2.58	3.7	7.98	5.4	22.2
CTRL	-	-	-	-	-	-	-	-	-	-	-	-

† Prior to 2003, compost treatments received yard waste composts. In 2003, the treatments were modified to include biosolids compost.

‡ Total organic carbon reported as determined by EPA 415.1 (USEPA, 1999)

§2000-2002, all compost treatments received yard waste composts. In 2003, the treatments were modified to include biosolids compost.

Table 3.5 Total macro- and micronutrients added in all treatments in 2004. FERT=Inorganic Fertilizer; ABSC=100% N Biosolids Compost; AYWC=100% N Yard Waste Compost; PL=100% Poultry Litter; LBSC=30% N Biosolids Compost; LYWC= 30% N Yard Waste Compost; CTRL=No Amendments Applied

	N†	PAN‡	P§	K	Ca	Mg	Mn	Zn	Cu	Fe	C
Treatment	----------kg/ha----------										Mg/ha
FERT	146	146	24	-	-	-	-	-	-	-	-
ABSC	536	146	340	23	2657	64	14.	15.	8	79	5
AYWC	17745	146	190	323	1004	143	50	10	7	476	18
PL	234	146	75	109	128	24	2	2	2	3	2
LBSC	161	146	102	6	797	19	4	5	2	239	2
LYWC	5331	146	57	97	304	43	15	3	2	143	5
CTRL	-	-	-	-	-	-	-	-	-	-	-

† Total Kjeldahl Nitrogen, EPA 351.3 (USEPA, 1979)

‡ Plant available nitrogen. Estimated by adding 100% of the measured (NO_3+NH_4)-N and the fraction of organic N estimated to be mineralizable during the first season. Mineralization coefficients used were 0.1 for composted materials and 0.6 for poultry litter.

§ Total Phosphorus applied by Triple Super Phosphate or organic residual treatment reported as determined by EPA 3052 (USEPA, 1999)

Table 3.6 Climatological parameters at Northern Piedmont Agriculture and Research Station.

	Precipitation			Temperature		
	30 yr mean	2004	2005	30 yr mean	2004	2005
Month	cm			°C		
May	11.25	12.1	7.88	17.5	20.62	15.87
June	8.69	13.1	1.77	22.11	17.05	23.01
July	11.35	23	22.55	24.28	23.61	25.44
August	10.87	4.52	2.18	23.56	22.56	24.77
September	8.99	17.6	5.74	19.89	19.47	21.68
Total	51.15	70.32	40.12			

Table 3.7 Air temperatures at Northern Piedmont Agriculture and Research Station on sampling dates in 2004 and 2005, respectively.

Sampling Date 2004	Temperature (°C)	Sampling Date 2005	Temperature (°C)
7/14	26.76	8/12	27.47
7/22	26.41	8/19	21.43
7/29	23.51	8/26	20.51
8/4	28.52	9/2	27.47
8/11	24.12	9/9	23.37
8/18	24.43	9/16	25.19
8/27	24.07		

Table 3.8 Summer 2004 and 2005 end of season soil data†. FERT=Inorganic Fertilizer; ABSC=100% N Biosolids Compost; AYWC=100% N Yard Waste Compost; PL=100% Poultry Litter; LBSC=30% N Biosolids Compost; LYWC= 30% N Yard Waste Compost; CTRL=No Amendments Applied. Treatment means (four replications) followed by the same letter are not significantly different within the column at 0.05 level of significance.

Treatment	pH	TN‡	P§	K	Ca
		g/kg	----------mg/kg----------		
FERT	6.58 d	0.82 d	24.5 de	158.3 e	1307 d
ABSC	7.33 a	1.59 b	80.1 b	184.8 d	3378 a
AYWC	6.72 cd	2.31 a	110.5 a	304.3 a	2620 b
PL	6.90 b	0.95 d	36.8 c	246.6 b	1488 d
LBSC	6.94 b	0.97 d	34.9 cd	154.5 e	1793 c
LYWC	6.85 bc	1.21 c	30.6 cd	202.3 c	1698 cd
CTRL	6.75 c	0.76 e	14.8 e	168.4 de	1234 d

Treatment	Mg	Zn	Mn	Cu	Fe
	----------mg/kg----------				
FERT	101.4 e	2.2 d	40.9 c	1.2 bc	9.1 a
ABSC	153.1 bc	9.4 b	47.0 ab	0.4 d	6.7 bc
AYWC	301.0 a	11.3 a	52.7 a	0.4 d	5.1 c
PL	148.9 c	4.6 c	42.7 bc	2.3 a	7.0 b
LBSC	131.5 d	4.8 c	40.0 bc	0.9 c	9.3 a
LYWC	168.8 b	4.3 c	42.7 b	0.8 c	7.4 b
CTRL	123.6 d	2.0 d	38.0 c	1.3 b	7.9 ab

† As reported by the Virginia Tech Soil Testing Lab

‡ Total N as determined by CNS

§ P, K, Ca, Mg, Zn, Cu, and Fe are Mehlich I extractable concentrations

Table 3.9 Differences in end of season data†. FERT=Inorganic Fertilizer; ABSC=100% N Biosolids Compost; AYWC=100% N Yard Waste Compost; PL=100% Poultry Litter; LBSC=30% N Biosolids Compost; LYWC= 30% N Yard Waste Compost; CTRL=No Amendments Applied. Treatment means (four replications) followed by the same letter are not significantly different within the column at 0.05 level of significance.

Year	pH	TN‡	P§	K	Ca
		g/kg	----------mg/kg----------		
2004	6.89 a	1.42 b	36.3 b	193.4 b	1690 b
2005	6.85 a	2.31 a	58.61a	212.1 a	2174 a

Year	Mg	Zn	Mn	Cu	Fe
		----------mg/kg----------			
2004	159.3 a	4.7 b	36.6 b	1.3 a	6.8 b
2005	163.1 a	6.3 a	54.3 a	0.8 b	8.2 a

† As reported by the Virginia Tech Soil Testing Lab

‡ Total N as determined by CNS

§ P, K, Ca, Mg, Zn, Cu, and Fe are Mehlich I extractable concentrations

Table 3.10 Soil total organic carbon contents in long-term organically amended soil. FERT=Inorganic Fertilizer; ABSC=100% Biosolids Compost; AYWC=100% N Yard Waste Compost; PL=Poultry Litter; LBSC=30% N Biosolids Compost; LYWC= 30% N Yard Waste Compost; CTRL=No Amendments Applied. Treatment means (four replications) followed by the same letter are not significantly different within the column at 0.05 level of significance.

Treatment	Total Organic Carbon†
	g/kg
FERT	17.3 e
ABSC	29.5 b
AYWC	48.8 a
PL	18.7 de
LBSC	20.5 d
LYWC	25.1 c
CTRL	16.7 e

Year	Total Organic Carbon†
	g/kg
2000	15.3 c
2004	21.7 b
2005	28.8 a

† Total C as determined by CNS

Table 3.11 NaOH extractable carbon from organic amendments. PYWC=Panorama Yard Waste Compost; RBSC= Rivanna Biosolids Compost; PL= Poultry Litter. Treatment means (four replications) followed by the same letter are not significantly different within the column at 0.05 level of significance.

	Amendment FA-C†	Amendment HA-C ‡	Total NaOH Ext. Hum-C §
Amendment		mg/g	
PYWC	62.4 b	110 a	172 b
RBSC	39.5 c	26.0 c	65.5 c
Poultry litter	312 a	65.0 b	377 a

†Fulvic acid carbon extracted using 0.1N NaOH
‡Humic acid carbon extracted using 0.1N NaOH
§Total NaOH extractable humified carbon

Table 3.12 NaOH extractable carbon in long-term amended soil. FERT=Inorganic Fertilizer; ABSC=100% N Biosolids Compost; AYWC=100% N Yard Waste Compost; PL=Poultry Litter; LBSC=30% N Biosolids Compost; LYWC= 30% N Yard Waste Compost; CTRL=No Amendments Applied. Treatment means (four replications) followed by the same letter are not significantly different within the column at 0.05 level of significance.

Treatment	FA-C†	HA-C ‡	Hum-C §
		g/kg	
FERT	2.95 f	1.49 de	4.44 c
ABSC	3.51 bc	2.60 bc	6.12 b
AYWC	4.85 a	5.66 a	10.5 a
PL	3.29 cd	1.41 e	4.70 c
LBSC	3.17 de	1.70 de	4.87 c
LYWC	3.60 b	2.33 cd	5.94 b
CTRL§	3.02 ef	1.22 e	4.24 c

Year	FA-C†	HA-C ‡	Hum-C §
		g/kg	
2004	3.47 a	1.90 b	5.36 b
2005	3.51 a	2.79 a	6.30 a

†Fulvic acid carbon extracted using 0.1N NaOH
‡Humic acid carbon extracted using 0.1N NaOH
§Total NaOH extractable humified carbon

Table 3.13 2004 Soil bulk density, soil water holding capacity (SWHC), and soil water potential of selected treatments. CTRL=No Amendments Applied; LYWC= 30% N Yard Waste Compost; AYWC=100% N Yard Waste Compost. Treatment means (three replications) followed by the same letter are not significantly different within the column at 0.05 level of significance.

	Bulk Density	Total SWHC	Ψ_{soil}					
			Day 15†	Day 22	Day 29	Day 35	Day 42	Day 51
Treatment	g/cm^3	cm/15cm	----------MPa----------					
CTRL	1.36 a	3.67 a	0.72 a	0.03 a	0.08 a	0.12 a	0.08 a	0.13 a
LYWC	1.27 a	3.84 a						
AYWC	0.97 b	3.88 a						

† Days after silking: July 14, 2004. Ψ_{soil} was not determined on Day 7.

Table 3.14 2005 Soil bulk density, soil water holding capacity (SWHC), and water potential of selected treatments. CTRL=No Amendments Applied; LYWC= 30% N Yard Waste Compost; AYWC=100% N Yard Waste Compost. Treatment means (three replications) followed by the same letter are not significantly different within the column at 0.05 level of significance.

Treatment	Bulk Density			Total SWHC				Ψ_{soil}				
	----------g/cm^3----------			----------%----------			Total	Day 0†	Day 7	Day 14	Day 21	Day 28
	0-5cm	5-10cm	10-15 cm	0-5cm	5-10cm	10-15 cm	cm/15cm	----------MPa----------				
CTRL	1.53 a	1.73 a	1.76 a	15.12 b	18.98 a	21.76 b	8.38 b	1.15 b	0.24 c	1.24 b	1.08 b	1.86 a
LYWC	1.48 a	1.71 a	1.67 a	18.67 ab	25.75 a	24.67 a	10.36 a					
AYWC	1.26 b	1.58 b	1.62 a	23.60 a	20.73 a	20.03 b	9.65 ab					

†Days after beginning podfill: August 12, 2005.

Table 3.15 2004 Corn midseason leaf N and P contents (July 14, 2004). FERT=Inorganic Fertilizer; ABSC=100% N Biosolids Compost; AYWC=100% N Yard Waste Compost; PL=Poultry Litter; LBSC=30% N Biosolids Compost; LYWC= 30% N Yard Waste Compost; CTRL=No Amendments Applied. Treatment means (four replications) followed by the same letter are not significantly different within the column at 0.05 level of significance.

	N†	P‡
Treatment	**g/kg**	
FERT	26.6 a	3.83 ab
ABSC	25.8 a	3.73 b
AYWC	25.5 a	4.03 a
PL	25.4 a	3.68 b
LBSC	19.4 b	2.65 d
LYWC	20.5 b	3.20 c
CTRL	15.0 c	2.15 e

†As determined by CNS
‡As determined by ICP-OES

Table 3.16 2004 Corn physiological parameters averaged across all sampling dates. There was no day*treatment interaction on any sampling date. Ψ_{leaf} = Leaf Water Potential; Pro=Total Leaf Protein; Chyl= Leaf Chlorophyll; Fv/Fm= Photochemical Efficiency of PSII; SOD=Superoxide Dismutase; APX=Ascorbate Peroxidase; CAT=Catalase; MDA= Malondialdehyde Concentration. FERT=Inorganic Fertilizer; ABSC=100% N Biosolids Compost; AYWC=100% N Yard Waste Compost; PL=Poultry Litter; LBSC=30% N Biosolids Compost; LYWC= 30% N Yard Waste Compost; CTRL=No Amendments Applied. Treatment means (four replications) followed by the same letter are not significantly different within the column at 0.05 level of significance.

Treatment	Ψ_{leaf}	Pro	Chyl	Fv/Fm	SOD	APX	CAT	MDA
	MPa	mg/g	mg/cm^2		-----Unit activity/ mg protein-----	-----Unit activity/ µg protein-----		mol MDA/g chyl
FERT	-1.44 ab	14.34 a	0.059 a	0.784 a	49.7 b	37.1 b	339 a	0.21 c
ABSC	-1.48 a	13.26 a	0.059 a	0.787 a	53.1 b	39.9 b	355 a	0.21 c
AYWC	-1.41 ab	13.35 a	0.060 a	0.787 a	54.4 b	38.3 b	342 a	0.22 c
PL	-1.46 a	13.67 a	0.056 a	0.778 ab	53.7 b	39.6 b	302 a	0.22 c
LBSC	-1.35 b	8.97 a	0.042 b	0.770 b	72.4 a	47.6 a	360 a	0.31 b
LYWC	-1.38 ab	10.37 a	0.046 b	0.771 b	69.0 a	44.2 a	312 a	0.27 b
CTRL	-1.45 ab	6.51 c	0.029 c	0.759 c	81.9 a	48.0 a	378 a	0.38 a

Table 3.17 2004 Changes in corn physiological parameters over time averaged across all treatments. There was no day*treatment interaction on any sampling date. Ψ_{leaf} = Leaf Water Potential; Pro=Total Leaf Protein; Chyl= Leaf Chlorophyll; Fv/Fm= Photochemical Efficiency of PSII; SOD=Superoxide Dismutase; APX=Ascorbate Peroxidase; CAT=Catalase; MDA= Malondialdehyde Concentration. Treatment means (four replications) followed by the same letter are not significantly different within the column at 0.05 level of significance.

Day†	Ψ_{leaf}	Pro	Chyl	Fv/Fm	SOD	APX	CAT	MDA
	MPa	mg/g	mg/cm^2		-----Unit activity/ mg protein-----	-----Unit activity/ µg protein-----		mol MDA/g chyl
7	----------‡	12.69 b	0.052 ab	----------	76.6 b	23.2 e	545 a	0.26 bc
15	-1.53 a	12.52 b	0.051 b	0.774 b	72.2 b	35.7 d	317 c	0.12 c
22	-1.47 ab	12.71 b	0.053 a	0.778 ab	102.2 a	40.4 cd	273 c	----------
29	-1.40 bc	11.61 b	0.054 a	0.789 a	41.3 c	53.6 a	325 c	0.23 c
35	-1.29 d	14.78 a	0.051 ab	0.781 ab	40.7 c	43.3 bc	305 c	0.22 c
42	----------	9.41 c	0.048 c	0.777 b	39.1 d	49.4 ab	405 b	0.29 b
51	----------	6.74 d	0.042 d	0.760 c	31.0 e	49.0 b	219 d	0.36 a

† Days after silking: July 14, 2004

‡ Measurements were not taken on this day

Table 3.18 2004 Corn yield and seed composition. FERT=Inorganic Fertilizer; ABSC=100% N Biosolids Compost; AYWC=100% N Yard Waste Compost; PL=Poultry Litter; LBSC=30% N Biosolids Compost; LYWC= 30% N Yard Waste Compost; CTRL=No Amendments Applied. Treatment means (four replications) followed by the same letter are not significantly different within the column at 0.05 level of significance.

	Yield	Protein	Oil	Starch	Density
Treatment	Mg/ha	----------%----------			g/cm^3
FERT	11.47 a	7.43 b	3.60 a	61.15 cd	1.28 ab
ABSC	11.13 a	7.91 a	3.68 a	60.71 d	1.28 ab
AYWC	11.77 a	7.38 b	3.60 a	61.15 cd	1.29 a
PL	10.70 a	6.98 c	3.53 b	61.40 bc	1.28 ab
LBSC	7.90 b	6.21 d	3.49 b	61.92 a	1.27 b
LYWC	8.95 b	6.50 d	3.65 a	61.80 ab	1.28 ab
CTRL	5.47 c	5.25 e	3.53 b	61.81 ab	1.23 c

Table 3.19 Stepwise multiple linear regression of corn yield against four variables of soil nitrogen and humified carbon contents.

Variable	In	Out	Partial R^2	Model R^2	p>F
Percent N tissue	X		0.8720	0.8720	<0.0001
Fulvic acid-carbon	X		0.0254	0.0974	0.0199
Total humified carbon	X		0.0150	0.9120	0.0543
Humic acid-carbon		X			

All variables in the model are significant at the 0.100 level.

Table 3.20 2005 Midseason Soybean leaf N and P contents (August 19, 2005). FERT=Inorganic Fertilizer; ABSC=100% N Biosolids Compost; AYWC=100% N Yard Waste Compost; PL=Poultry Litter; LBSC=30% N Biosolids Compost; LYWC= 30% N Yard Waste Compost; CTRL=No Amendments Applied. Treatment means (four replications) followed by the same letter are not significantly different within the column at 0.05 level of significance.

Treatment	N†	P‡
	g/kg	
FERT	63.5 b	10.5 a
ABSC	66.2 a	10.5 a
AYWC	64.0 ab	10.6 a
PL	66.8 a	10.8 a
LBSC	65.5 ab	10.7 a
LYWC	65.2 ab	10.9 a
CTRL	64.6 ab	10.6 a

†As determined by CNS
‡As determined by ICP-OES

Table 3.21 2005 Soybean physiological parameters averaged across all sampling dates. There was no day*treatment interaction on any sampling date. Ψ_{leaf} = Leaf Water Potential; Pro=Total Leaf Protein; Chyl= Leaf Chlorophyll; Fv/Fm= Photochemical Efficiency of PSII; Delta T= Difference between Canopy and Air Temperature; SOD=Superoxide Dismutase; APX=Ascorbate Peroxidase; CAT=Catalase; MDA= Malondialdehyde Concentration. FERT=Inorganic Fertilizer; ABSC=100% N Biosolids Compost; AYWC=100% N Yard Waste Compost; PL=Poultry Litter; LBSC=30% N Biosolids Compost; LYWC= 30% N Yard Waste Compost; CTRL=No Amendments Applied. Treatment means (four replications) followed by the same letter are not significantly different within the column at 0.05 level of significance.

Treatment	Ψ_{leaf}	Pro	Chyl	Fv/Fm	Delta T	SOD	APX	CAT	MDA
	MPa	mg/g	mg/cm^2		° C	-----Unit activity/ mg protein-----	-----Unit activity/ µg protein-----		mol MDA/g chyl
FERT	-1.65 a	18.39 a	0.058 a	0.763 ab	1.60 ab	30.5 a	23.7 a	119 a	5.41 a
ABSC	-1.49 ab	18.08 a	0.059 a	0.748 ab	2.01 a	30.7 a	22.7 a	126 a	4.91 a
AYWC	-1.49 ab	18.40 a	0.060 a	0.774 a	2.06 a	25.9 a	24.9 a	115 a	4.77 a
PL	-1.42 b	18.72 a	0.061 a	0.725 b	1.67 ab	24.8 a	22.1 a	108 a	5.11 a
LBSC	-1.37 b	18.79 a	0.063 a	0.764 ab	1.87 a	26.5 a	26.4 a	135 a	4.80 a
LYWC	-1.34 b	18.46 a	0.063 a	0.736 ab	1.59 ab	28.2 a	23.7 a	108 a	4.80 a
CTRL	-1.41 b	18.59 a	0.061 a	0.743 ab	1.28 b	26.0 a	23.9 a	106 a	5.23 a

Table 3.22 2005 Changes in soybean physiological parameters over time averaged across all treatments. There was no day*treatment interaction on any sampling date. Ψ_{leaf} = Leaf Water Potential; Pro=Total Leaf Protein; Chyl= Leaf Chlorophyll; Fv/Fm= Photochemical Efficiency of PSII; Delta T= Difference between Canopy and Air Temperature; SOD=Superoxide Dismutase; APX=Ascorbate Peroxidase; CAT=Catalase; MDA= Malondialdehyde Concentration. Treatment means (four replications) followed by the same letter are not significantly different within the column at 0.05 level of significance.

Day†	Ψ_{leaf}	Pro	Chyl	Fv/Fm	Delta T	SOD	APX	CAT	MDA
	MPa	mg/g	mg/cm^2		° C	-----Unit activity/ mg protein----	-----Unit activity/ µg protein-----		mol MDA/g chyl
0	-1.38 c	19.14 c	0.036 d	0.757 a	2.17 c	18.5 bc	23.7 c	177 b	6.45 a
7	-0.78 d	22.03 a	0.067 b	----------‡	0.59 d	15.7 c	28.1 b	254 a	3.87 c
14	-1.52 b	20.49 b	0.072 a	----------	2.47 bc	33.3 a	20.3 c	68.8 d	3.78 c
21	-1.73 a	18.91 c	0.073 a	----------	-1.31 e	38.1 a	19.9 c	92.3 c	5.11 b
28	-1.66 ab	17.62 d	0.070 ab	----------	2.98 ab	37.1 a	20.9 c	71.7 cd	4.91 b
35	-1.64 ab	12.74 e	0.045 c	0.744 a	3.43 a	22.3 b	30.9 a	36.6 e	5.91 a

† Days after podfill: August 12, 2005

‡ Measurements were not taken on this day

Table 3.23 2005 Soybean yield and seed composition. FERT=Inorganic Fertilizer; ABSC=100% N Biosolids Compost; AYWC=100% N Yard Waste Compost; PL=Poultry Litter; LBSC=30% N Biosolids Compost; LYWC= 30% N Yard Waste Compost; CTRL=No Amendments Applied. Treatment means (four replications) followed by the same letter are not significantly different within the column at 0.05 level of significance.

	Yield	Protein	Oil	Fiber	Carbs	100 seed weight
Treatment	(Mg/ha)	----------%----------				g
FERT	1.17 d	32.38 d	20.16 ab	4.95 a	24.51 a	12.0 c
ABSC	1.49 a	35.64 a	18.94 d	4.70 c	22.73 d	13.5 a
AYWC	1.43 ab	35.16 ab	19.23 cd	4.73 bc	22.89 cd	13.8 a
PL	1.35 bc	34.20 bc	19.53 c	4.80 b	23.48 bc	12.3 bc
LBSC	1.29 c	34.25 bc	19.68 bc	4.80 b	23.28 bcd	12.5 bc
LYWC	1.29 c	33.85 c	19.70 bc	4.80 b	23.65 b	13.0 ab
CTRL	1.18 d	32.33 d	20.28 a	4.95 a	24.45 a	11.8 c