

Introduction

Problem, Rationale, and Significance

In the United States, an average of 229.2 million metric tons of organic municipal solid waste (i.e. yard wastes, soiled paper and paper products, food and food processing wastes, organic industrial wastes, and woody waste) (USEPA, 2005), eight million dry metric tons of sewage sludge (USEPA, 1999), and six million dry metric tons of manure from confined animal farming operations (Economic Research Service, 2001) are generated each year. Safe handling, processing, and disposal of organic wastes involve the consideration of social, economic, and environmental costs. Applying these materials to land is a desirable means of disposal because it decreases total disposal costs, reduces the amount of material added to landfills, and recycles nutrients in soil systems (USEPA, 1999). Raw organic wastes are typically bulky and may have high pathogen levels and vector attraction. A process often employed to treat such wastes prior to land application is composting, which is the controlled, thermophillic, partial degradation of organic matter into a humus-like product (Adoni et al., 1999). Composted wastes have reduced volume, mass, vector attraction, pathogen content and weed seed viability than non-composted wastes. These benefits greatly increase the value of compost as a soil conditioner (Epstein, 1997).

The composting process significantly changes the physiochemical properties (e.g., bulk density, pH, nitrogen:phosphorus ratio, total carbon, carbon:nitrogen ratio, total nitrogen content, and plant available nitrogen) of organic wastes. Observed decreases in compost total nitrogen (Eneji et al., 2000; Nishio and Oka, 2003; Lin et al., 2003; Guster et al., 2005) are due to ammonia volatilization from microbial metabolic processes, the incorporation of nitrogen into the microbial biomass, and the fixation of nitrogen into humic substances, the major constituents of "stable" organic matter (Epstein, 1997).

Variability in starting materials and composting conditions influence the final composition and biological, physical, and chemical attributes of compost. Determining proper application rates that satisfy crop nutrient needs and minimize environmental degradation is essential to sound field management. Compost applications may be based on estimated plant available nitrogen contents; however, predicting compost nitrogen availability is difficult because nitrogen is slowly made available to plants via organic

matter mineralization (Glenn, 1992). Plant available nitrogen consists of the sum of inorganic N not lost via ammonia volatilization and the fraction of organic N that mineralizes to inorganic N during the season of application. A commonly employed method for estimating plant available nitrogen of various organic wastes is the use of greenhouse studies that compare plant N uptake from known rates of inorganic N to known rates of organic residuals containing known amounts of inorganic and organic N. In such studies, the relative nitrogen fertilizer equivalency of compost is compared to inorganic fertilizer (Muñoz et al., 2004).

Researchers have observed that the nitrogen content of organically amended soils is higher than soils receiving inorganic fertilization (Singh and Ghosh, 1999; Ceuvas et al., 2000; Chang and Cheng, 2000; Khatik and Dikshit, 2001; Sullivan et al., 2003; Rodriguez et al., 2005). This is likely due to higher rates of total nitrogen applied in organic wastes than in inorganic fertilizers in order to meet plant nutrient needs from the incompletely plant available nitrogen forms in such residuals.

Researchers have also observed that composted organic amendments can improve plant health beyond the nitrogen fertility value (Ayuso et al., 1996; Vadrighi et al., 1996; Buckerfield et al., 1999; Atiyeh et al., 2000a; Atiyeh et al., 2000b; Atiyeh et al., 2001; Atiyeh et al., 2002). Of particular interest is the apparent ameliorating effect of organic amendments 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. Hornick (1988) also observed increased sweet corn yields in organically amended sand and gravel spoils relative to plants that received inorganic fertilizer. HuiLan et al. (1998) noted that the application of organic amendments increased water stress resistance of sweet corn leaves. In particular, stomatal and cuticular conductances of the leaves were lower in these plants than in inorganically-fertilized plants. In five-week old water stressed maize seedlings, Xu (2000) recorded higher photosynthetic rates when the soils were organically amended. Heckman et al. (1987) found that field grown soybeans fertilized with sewage sludge had increased drought resistance and nitrogen fixation than the control treatment.

The phytohormonal activity of humic substances in composted organic amendments is thought to play a causal role in drought stress amelioration (Xu, 2000).

Subler et al. (1998) argue that the presence of humic substances may enhance crop production through directly providing plant growth regulators (phytohormones) or by stimulating microbial activity that supplies the substrates for hormone synthesis. Fossil-derived humic substances have been foliarly applied in most drought stress studies to investigate potential differences in plant physiology and metabolism (Xudan, 1986; Zhang and Schmidt, 1999; Zhang and Schmidt, 2000; Zhang and Ervin, 2004). There have been very few studies that investigated effects of land applied compost on leaf health, yield, and yield quality of drought stressed agronomic crops.

Thesis Objectives

1. Calculate nitrogen mineralization rates of composted and non-composted organic materials applied to a Fauquier silty clay loam in a greenhouse pot study in order to assess the nitrogen contributions to plant response in a corresponding field study. I hypothesize that organic amendments with a lower C:N ratio will mineralize more nitrogen than amendments with a greater C:N.
2. Determine the changes in soil physiochemical properties (e.g., nutrient concentrations, bulk density, water holding capacity, organic carbon, humic and fulvic acid-carbon) in a long term compost field study conducted on a Fauquier silty clay loam. I hypothesize that the Panorama yard waste compost, Rivanna biosolids compost, and poultry litter amendments applied at 100% agronomic N rates will increase soil fertility, organic and humic carbon content, decrease bulk density, and increase water holding capacity more than the same amendments applied at 30% agronomic N rates and the inorganically fertilized and control treatments.
3. Determine 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), air temperature-leaf temperature (ΔT) (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 treatments (see objective # 2) applied at 100% agronomic N rates will have equal or greater leaf protein and

chlorophyll contents, greater antioxidant activity, lower malondialdehyde concentrations and Delta T values, and increased yields and seed quality than the same amendments applied at 30% agronomic N and the inorganically fertilized and control treatments.

Previous Work

Compost May Increase Nutrient Availability

Nitrogen

Nitrogen mineralization is controlled by compost properties including organic carbon content, C:N, total nitrogen, and plant available nitrogen; soil moisture; microbial activity; and soil texture (Eghball et al., 2002; Agehara and Warnke, 2005; Cabrera et al., 2005). Compost C:N greater than 25:1 have been shown to immobilize nitrogen in soils (Tester et al., 1982; Chen et al., 1996; Douglas et al., 2003; Nishio and Oka, 2003; Gagon et al., 2004; Flavel et al., 2005). Although often used to estimate nitrogen mineralization (Sikora and Yakovchenko, 1996; Kumar and Goh, 2003; Khalil et al., 2005), some researchers concluded that C:N did not accurately estimate nitrogen mineralization and stated that total nitrogen was a better estimator of nitrogen mineralization (Kuo, 1995; Kessel and Reeves, 2003; Cabrera et al., 2005).

Low soil moisture conditions can decrease nitrogen mineralization. Eghball (2002) observed greater soil NO_3^- contents in inorganically fertilized soils than organically amended soils when precipitation was 56% and 80% below average. He concluded that this was due to decreased microbial activity in the amended soils. Many researchers have observed decreased nitrogen mineralization in fine- to medium- textured soils relative to course-textured soils (Veen et al., 1985; Sims, 1990; Benitez et al., 1997; Omay et al., 1997; Egelkraut et al., 2000; Griffin et al., 2002; Preusch et al., 2002), though a few have not (Ladd et al., 1977; Motavalli et al., 1989; Giardina et al., 2001). Thomsen and Olesen (2000) observed no differences in nitrogen mineralization based on soil type in a 266 day incubation study. Sørensen and Jensen (1995) observed that the protective capacity of finer soil particles (i.e. clay minerals) decreases over time. Finer textured soils may temporarily limit nitrogen mineralization due to physical protection of organic matter, the presence of anaerobic microsites within aggregates, and/or the greater

surface area that decreases the likelihood of microorganisms reaching the organic material (Paré and Gregorich, 1999; Thomsen and Olesen, 2000 Giardina et al., 2001). The larger pore sizes of coarse-textured soils renders recently mineralized nitrogen more susceptible to plant uptake or leaching (Nardi et al., 2004). Indeed, Davis et al. (1997) and Badran et al. (2000) observed less residual NO_3^- in sandy versus clayey soils.

Phosphorus

The application of organic amendments to soils has been shown to increase soil phosphorus content and plant available phosphorus (Mugwira, 1979; Lund and Doss, 1980; Reddy et al., 1980; Field et al., 1985; Schlegel, 1992; Kingery et al., 1994; Gao and Chang, 1996; Clark et al., 1998; Eghball et al., 2004). The N:P ratio of composted materials is relatively low due to nitrogen losses during composting (Eghball, 2002; Luo et al., 2005; Rodriguez et al., 2005). Compost applied on a nitrogen basis may significantly increase soil phosphorus levels as this ratio is usually significantly lower than crop N:P uptake (Kuo, 1995; Eghball et al., 2002; Park et al., 2004; Singer et al., 2004). Eghball et al. (2004) observed continued plant phosphorus uptake up to four years after nitrogen-based compost and manure applications ceased without the addition of phosphorus fertilizers. Excessive soil phosphorus levels are not detrimental to plant health, but can cause serious environmental degradation if the soil is subject to runoff and erosion.

Potassium, Secondary and Micronutrients

Compost may contain appreciable levels of potassium, calcium, magnesium, and micronutrients. The presence of these elements is usually due to feedstock composition and pre-composting processing. For example, biosolids are sometimes stabilized or dewatered with calcium hydroxide (Faulker, 2001), which can greatly increase the calcium content. Animal feed is often supplemented with minerals (e.g., copper, zinc, manganese) to maximize animal growth and development (Blezinger, 2001; Kegley, 2001). The ability of animals to utilize these minerals is generally less than the amount of mineral provided in the feed. It is consequently excreted as waste and incorporated into the organic amendment matrix (Kingery et al., 1994). Numerous researchers have documented increases in soil potassium (Kumar and Kumaraswary, 2000; Khatik and Dikshit, 2001; Chang and Cheng, 2000; Rodriguez et al., 2005) calcium and magnesium

(Abreu Junior et al., 2001; Eghball et al., 2002; Walker and Bernal, 2004), and micronutrients (Clark et al., 1998; Bulluck et al., 2002; Negm and Zaki, 2004; Yogananda et al., 2004) after the addition of composted materials.

The Humification of Compost

Nutrient mineralization in compost is attributed to the "active" carbon pool, where carbon is easily mineralized by microbes and serves as an available nutrient source to plants and microorganisms. The relative stability of compost (i.e. its resistance to rapid mineralization) is due to the presence of a "stable" carbon pool, where decomposed biomass is in a humified semi-final state. Humification occurs during composting and is the transformation of organic material into high molecular weight molecules termed humic substances (Adoni et al., 1999).

Humic Substances Defined

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, into three classes: fulvic acid, humic acid, and humin. 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). Humin is the non-extractable humic acid fraction. It is defined as very large humic acid molecules that are tightly bound to minerals and cannot be extracted (Stevenson, 1994a).

There are three major accepted theories of humic substances synthesis: the lignin theory, the polyphenol theory, and the sugar-amine theory. The lignin theory, popularized by Waksman (1932) is based on the assumption that humic substances represent modified lignins. Because lignins are resistant to microbial decay and are major plant polymers, they are often considered a major contributor to humic substances synthesis. Lignins oxidized by microbial degradation undergo condensation reactions with microbial amino

acids to yield the humic molecule. Waksman (1932) cites the following as evidence to support the lignin theory:

- i.) Both lignin and humic acid are decomposed with considerable difficulty by the great majority of fungi and bacteria.
- ii.) Both lignin and humic acid are soluble in alkali and precipitated by acids. Both are partly soluble in alcohol and pyridine and contain OCH_3 groups whose content diminishes during decomposition.
- iii.) Both lignin and humic acid are acidic in nature, both are able to combine with bases, and both are characterized by their capacity to undergo base exchange, although to a different quantitative extent.
- iv.) When lignins are warmed with aqueous alkali, they are transformed into methoxyl-containing oxidized humic acid. Humic acids have many properties in common with oxidized lignins.

The theory that degradation of complex polymers yields humic substances supports the assumption that larger humic molecules (i.e., humic acid) are synthesized first, and that their degradation yields smaller humic substances (i.e. fulvic acid).

The tenets of the polyphenol theory state that under aerobic conditions, lignin may be broken down into monomeric structural units such as polyphenols and quinones. These molecules react with microbially synthesized quinines and amino acids to form fulvic acid. Polymerization of several fulvic acids yield one humic acid molecule. Further polymerization of humic acid yields humin (Stevenson, 1994b).

The third theory of humic substances formation is the sugar-amino condensation theory (Stevenson, 1994b), also known as the melanoidin pathway and the Maillard reaction. Sugars and amines, which are relatively abundant in the soil environment, condense to form fulvic acid. Further polymerizations yields humic acid and finally humin.

Within the soil microenvironment, there is simultaneous microbial synthesis and degradation of newly formed humic substances. This likely prevents polymerization and the synthesis of larger humic acid molecules. Fulvic acid synthesis, therefore, is more likely explained by the latter two theories, and humic acid synthesis is more likely explained by the lignin theory.

Compost and Soil Humic Substances

The humification of composted organic wastes is much lower than that of native soil organic matter due to the relatively short composting period (Valasco et al., 2004). Researchers have observed the development of humic-like materials in composted materials over time. Tiquila (2003) observed an increase in fulvic and humic acid-like substances, and an increase in HA:FA of composted pig litter. Baddi et al. (2003) observed an increase in fulvic and humic acid-like substances, an increase in aromatic carbon, and a decrease in aliphatic carbon over time in composted olive mill waste over time. Chefetz et al. (1998) also observed an increase in aromatic carbon in composted municipal solid wastes over time, indicative of the increased stability of the final product. Numerous researchers have observed that humic-like substances extracted from composts are similar to, but poorly developed relative to soil organic matter. Fluorescence and electron spin spectroscopy reveal that these humic-like substances contain a greater nitrogen content (Boyd and Sommers, 1990; Ouatmane et al., 2002; García-Gil et al., 2004; Senesi, 2004), are more aliphatic (i.e. less aromatic) (Giusquiani et al., 1994; Yakimenko et al., 1995; Yona, 2003; Brunetti et al., 2005), and are more heterogenous in composition than native soil organic matter (Unsal and Ok, 2001; Senesi, 2004; Brunetti et al., 2005).

The humic-like substances of composts in amended soils have been documented to approach molecular properties typical of native humic substances (Senesi, 2004). There is a growing consensus that the humic-like structures of composts can be incorporated into native soil humic substances (Tomati et al., 2001; Gigliotti et al., 2003). Indeed, Leifeld et al. (2002) observed that the decomposition of sewage sludge compost in soil was the ongoing humification process of the compost itself.

The accumulation of humic substances ensures long-term maintenance of soil organic carbon (Xiang et al. 1998; Zinati et al. 2001; Dorado et al. 2003; Rivero et al., 2004). Researchers have observed increases in soil organic matter content in gravelly (Hornick, 1988; Zinati et al., 2001), sandy (Foley and Cooperband, 2002; Negm and Zaki, 2004), silty (Borken et al., 2002; Tsegaye et al., 2003), and clayey (Rivero et al., 2004; Yuksel, 2004) soils following compost applications. Filip and Kubát (2001) concluded that increased soil organic matter content observed in long-term organically

amended soils could be attributed to the increased resistance of humic acid fractions to microbial degradation.

Compost May Increase Soil Water Holding Capacity

A reduction in soil water holding capacity is considered by some to be the major factor contributing to reduced yields in eroded, low organic matter soils (Bauer and Black, 1992). The addition of organic amendments has been documented to increase soil water holding capacity (Hernando et al., 1989; Shiralipour et al., 1992; Curtis and Claassen, 2005; Konomi et al., 2005). Soil water holding capacity is operationally defined as water held at specific tensions (i.e., “field capacity” or “wilting point”) or the total amount of water held between two tensions. It is often considered an indirect measurement of plant available water. However, a plant's ability to extract water from a particular soil is also species dependent. An increase in carbon decreases soil bulk density through increased aggregation of soil particles and the relative number of smaller pores (Khaleel et al., 1981; Martens and Frankenberger, 1992; Warren and Fonteno, 1993; Canarutto et al., 1996; Grandy et al., 2002; Elsharawy et al., 2003). This shift in pore size distribution (i.e. smaller pores), increases the tension required for pore drainage (Khaleel et al., 1981). Humic substances in organic amendments have been documented to bind soil microaggregates (Elsharawy et al., 2003).

The greatest improvements in soil water holding capacity have been documented in the coarse-textured soils (Abdel-Sabour et al., 1997; Stepkowska et al., 2001; Foley and Cooperland, 2002; Hangarge et al., 2002; Elsharawy et al., 2003; Newman et al., 2005). Researchers have observed that the addition of organic material increases the number of smaller pores and surface area of sandy soils; thus, more water is held in amended soils at lower tensions. The amount of water retained in organically-amended soils is greater than that retained in unamended soils as soil-water tension increases (Khaleel et al., 1981; Elsharawy et al., 2003), and the overall water holding capacity of the soil is increased. Improvements in soil water holding capacity with the addition of organic amendments are typically less significant or simply not observed in finer-textured soils (Khaleel et al., 1981; Reynolds et al., 2003; Jiménez et al., 2004) although researchers have observed increases in water holding capacity at very high application rates (ShengoGao and Lei, 2004). The addition of organic matter in finer textured soils

results in a slight increase in moisture holding capacity at low tensions (i.e., field capacity) and no change at higher tensions (i.e., wilting point) (Khaleel et al., 1981; Carter et al., 2004). Nearly all pores are air filled at higher tensions, and the moisture content is determined by the specific surface area of soil particles and the thickness of water films (Khaleel et al., 1981). Finer soil particles have a very large surface area. The addition of organic amendments, therefore, does not improve water holding capacity at higher tensions.

Pooling data from several studies, Khaleel et al. (1981) observed that 80% of the variability in water holding capacity at low tensions (i.e. 0.03 MPa) and high tensions (i.e. 1.5 MPa) could be explained by soil texture and organic carbon content. Bauer and Black (1992) observed that variations in percent water holding capacity of sandy, medium, and fine textured soils could be based on sand content with 75% certainty.

Although increases in soil water capacity cannot be directly associated with increased crop yield, it is generally accepted that increases in water holding capacity between 0.03 and 1.5 MPa is beneficial to crop growth. Increased “plant water availability” has been considered the causal factor for increased crop yields in organically amended soils (Serra-Wittling et al., 1996; Hangare et al., 2002; Curtis and Claassen, 2005). Interestingly, some researchers have demonstrated that organic amendments may produce 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) recorded 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 cuticular conductances of the leaves were lower in these plants than in inorganically-fertilized plants.

An understanding of the processes that affect leaf photosynthesis - the primary determinant of yield - and how drought stress can impair the photosynthetic process is

essential to the elucidation of the mechanism of drought stress amelioration in crops grown in organically amended soils.

Impact of Drought Stress on Photosynthetic Electron Transport

During photosynthesis, green leaf tissues absorb solar energy and convert it into organic compounds. The process requires proper electron transfer throughout the thylakoid membrane. For every one photon of energy, two electrons from Photosystem II (PSII) oxidize water to oxygen, and reduce NADP^+ to NADPH via Fd-NADP reductase. ATP is also synthesized by the passage of H^+ from the lumen to the stroma (Figure 2.1). NADPH and ATP serve as reducing equivalents for the reduction of CO_2 to sugars in the stroma.

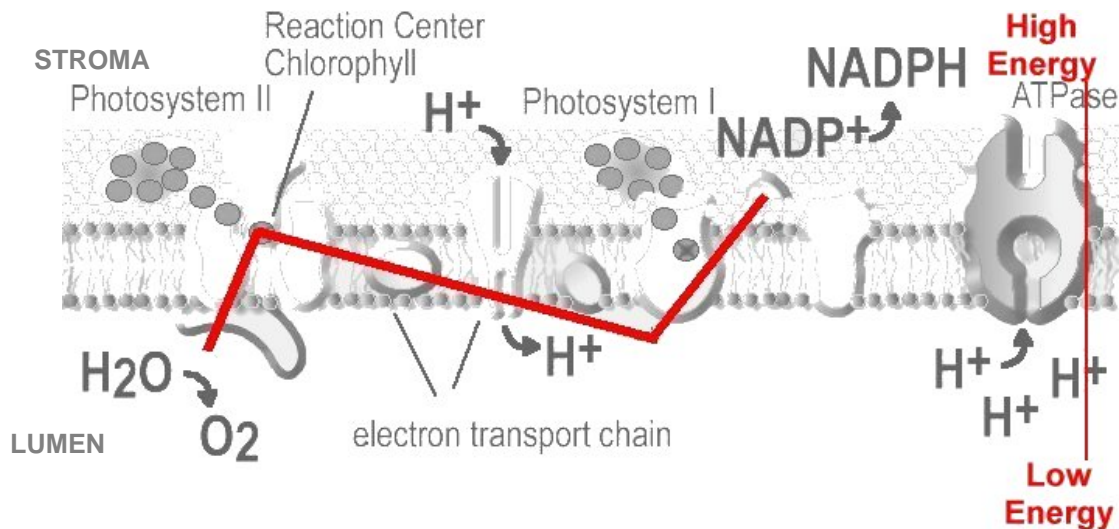


Figure 1.1. The transfer of electrons and protons in the thylakoid membrane. Water is oxidized and protons are released in the lumen by Photosystem II. Photosystem I reduces NADP^+ to NADPH in the stroma. Protons transported into the lumen by the cytochrome b_6f complex contribute to the electrochemical proton gradient. These protons then diffuse to the ATP synthase enzyme where ATP is synthesized in the stroma. Both ATP and NADPH are used to form sugars in the dark reaction of the stroma. The solid line represents electron transfer. ©2005 from http://bioweb.wku.edu/courses/Biol120/images/z-scheme_grey.jpg by Robert Wyatt. Reproduced by permission of Robert Wyatt.

At the onset of moisture stress, stomatal openings close due to the decreased turgor pressure in the guard cells and/or the upregulation of abscisic acid (ABA) synthesis in the roots (Desikan et al., 2003). Stomatal closure is beneficial as it decreases transpiration and temporarily increases water use efficiency (Taiz and Zeiger, 1998). Prolonged closure, however, limits CO_2 influx and photochemical efficiency creating an over-reduced environment in the chloroplasts (Bray et al., 2002). Moisture stress during

high light conditions inevitably causes improper transfer of electrons to oxygen resulting in excessive reactive oxygen species (ROS) formation (Bray et al., 2002).

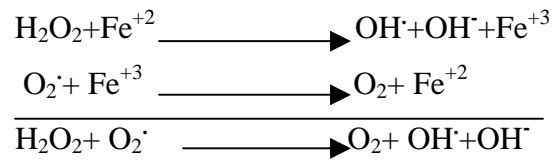
Reactive oxygen species are naturally generated due to the intrinsic inefficiencies of photosynthetic electron transport. Under saturating CO₂ conditions, 10-20% of electrons are still transferred to intracellular oxygen (Asada and Takahashi, 1987). Plants have evolved a scavenging mechanism to maintain steady-state levels of ROS as high concentrations can cause membrane lipid peroxidation, gene mutation and inactivation, and senescence (Asada, 1994).

Formation of Reactive Oxygen Species

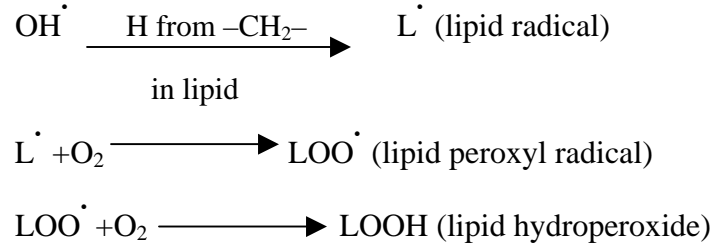
Photosystem I (PSI) is the primary site of ROS formation (Mano, 2002). In the overreduced environment of the chloroplast, NADPH concentrations are much greater than NADP⁺. Newly accepted electrons by PSI, therefore, are less likely to be properly transferred to NADP⁺. Instead, the abundant intracellular oxygen found in the chloroplast serves as a reducible substrate. The reduction of oxygen to superoxide (O₂^{•-}) occurs via the Mehler reaction. Superoxide is a free radical that is highly reactive with the thiol and iron-sulfur clusters of peptides and DNA bases (Mano, 2002). Superoxide dismutase (SOD), an O₂^{•-} scavenger, is contained in the chloroplast at a concentration of 50 μM (Asada, 1994). The enzyme is located adjacent to PSI on the stromal side of the thylakoid membrane or free floating in the stroma (Asada, 1994). Although total concentrations are low, the high affinity for O₂^{•-} and the strategic location of the antioxidant renders great efficiency to reduce O₂^{•-} to H₂O₂.



Peroxide is not a free radical, *per se*, but it is highly water soluble and easily diffuses across membranes. Peroxide can serve as both a reductant or oxidant in forming other free radicals, the most dangerous of which is the hydroxyl radical (OH[•]) which is formed via the Haber-Weiss reaction (Perl-Treves and Perl, 2002).

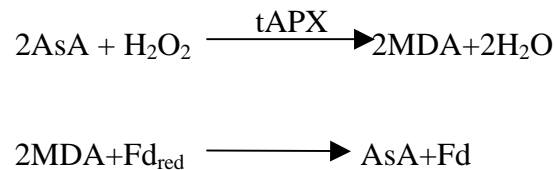


The hydroxyl radical is extremely reactive, oxidizing everything in its vicinity as it has no specific targets (Mano, 2002). Hydroxyl destroys membrane integrity by producing lipid peroxides.



Due to its high toxicity, there are no antioxidants specific to scavenge OH^\bullet (Wolff et al., 1986). Instead, leaf health is protected by maintaining OH^\bullet substrates at low levels (Perl-Treves and Perl, 2002). Superoxide dismutase is arguably the most important first response antioxidant as it determines the concentration of O_2^\bullet and H_2O_2 available for reaction (Perl-Treves and Perl, 2002).

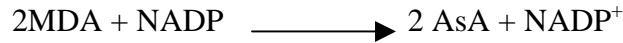
Peroxide is reduced to water by ascorbate peroxidase (APX). Total concentrations are low (70 μM), and the enzyme is strategically located on the stromal side of the thylakoid membrane or free floating in the stroma (Foyer, 2002). Ascorbate peroxidase reduces H_2O_2 in one of two reactions: the water-water cycle or the Halliwell-Asada cycle, also known as the ascorbate-glutathione cycle (Foyer, 2002). In the water-water cycle, electrons released by the oxidation of intracellular water are used to regenerate ascorbate (AsA), the reducing substrate that is catalyzed by thylakoid bound APX (tAPX) to reduce H_2O_2 to H_2O .



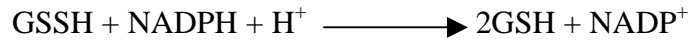
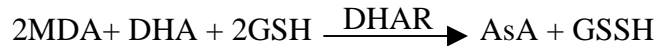
where MDA= monodehydroascorbate, Fd=ferredoxin, Fd_{red} =reduced ferredoxin

In the ascorbate-glutathione cycle, stromal APX (sAPX) catalyzes the reduction of H_2O_2 to H_2O using AsA and glutathione (GSH) as reducing substrates.





OR



Where MDA= monodehydroascorbate, MDAR= monodehydroascorbate reductase,
DHA=dehydroascorbate, GSH=glutathione, GSSH=oxidized glutathione

Both cycles are advantageous as electrons are used directly from the photosynthetic apparatus (reduced Fd and NADPH) as reducing power. This not only scavenges ROS produced in the environment, but removes the factors that created conditions conducive for ROS formation (Mittler, 2002). Figure 2.2 provides a comprehensive view of the thylakoid antioxidants involved in ROS quenching.

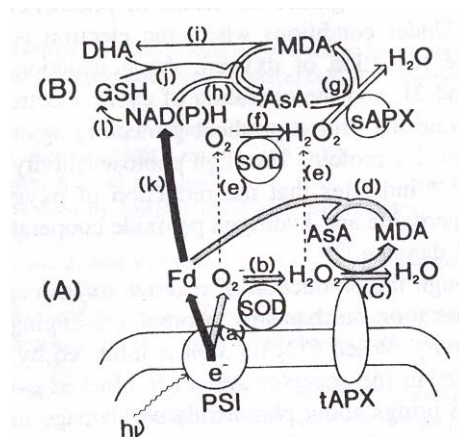


Figure 1.2. Thylakoid in stromal scavenging systems of superoxide and hydrogen superoxide in chloroplasts. (A) thylakoid scavenging system: (a) diffusion to the stroma of superoxide radicals generated within the membrane, (b) disproportionation of superoxide catalyzed by thylakoid bound SOD, (c) reduction of hydrogen peroxide by ascorbate (AsA) catalyzed with thylakoid-bound ascorbate peroxidase (tAPX) localized on the stroma thylakoids, (d) reduction of monodehydroascorbate radical (MDA) by reduced ferredoxin (Fd) in PS I. (B) stromal scavenging system: (e) diffusion of superoxide and hydrogen peroxide to the stroma from the thylakoid periphery, (f) disproportionation of superoxide catalyzed by stromal SOD, (g) reduction of hydrogen peroxide catalyzed by stromal ascorbate peroxidase (sAPX), (h) reduction of MDA by NAD(P)H catalyzed by MDA reductase, (i) spontaneous disproportionation of MDA to dehydroascorbate (DHA) and ascorbate (AsA), (j) reduction of DHA to AsA by glutathione (GSH) catalyzed with DHA reductase, (k) reduction of NADP⁺ by the reduced Fd catalyzed with Fd-NADP reductase and production of NADH catalyzed by transhydrogenase, (l) reduction of oxidized glutathione (GSSH) by NADPH catalyzed by glutathione reductase. ©1994 from Production and action of active oxygen species in photosynthetic tissues. By C.H. Foyer and P.M. Mullineaux Reproduced by permission of Routledge/Taylor & Francis Group, LLC.

Another antioxidant that scavenges H₂O₂ is catalase (CAT). Located exclusively in the peroxisome, CAT is found in high concentrations (~4mM), some of which is in

crystalline form (Asada, 1994). Although it requires no reducing equivalents, CAT is only stimulated by mM concentrations of H₂O₂ making it less responsive than APX to oxidative stress (Asada, 1994).



Tolbert et al. (1969) conducted a survey of leaf peroxisome activity in 10 plant species and observed that in C₃ plants, the oxidation of glycolate, a product of photorespiration, accounted for most of the H₂O₂ scavenged by CAT. Lyu-bimov and Zastrizhnaya (1992) observed that CAT activity in C₄ plants was not driven by the production of glycolate, but by the formation of H₂O₂ from SOD activities.

Humic Substances May Ameliorate Crop Drought Stress

There are a few studies that document increased drought tolerance of creeping bentgrass (*Agrostis stolonifera*) (Waddington et al., 1978), tall fescue (*Festuca arundinacea*) (Zhang et al., 2005), soybean (*Glycine max*) (Heckman et al., 1987), and corn (*Zea mays*) (Sahs and Lesoing, 1985; Hornick, 1988; HuiLan et al., 1998; Mamo et al., 2000; Xu, 2000) in compost amended soils. Most interesting are the improvements in crop drought stress tolerance when there were no apparent differences in soil water holding capacity among treatments (HuiLan et al., 1998; Mamo et al., 2000; Xu, 2000; Zhang et al., 2005).

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). Frankenberger and Arshad (1995) summarized research that documented the alteration of plant development by external hormones. Zhang et al. (2005) applied nine differently processed biosolids based on agronomic nitrogen needs to tall fescue planted in calcined clay and observed increased SOD among the drought stress treatments. Interestingly, the plants with the greatest drought tolerance (i.e., greatest SOD activity) were planted in biosolids treatments that contained the greatest auxin content. Zhang and Ervin (2004) foliarly applied humic acid derived from leonardite to two mature field grown bentgrass cultivars. The researchers observed that unashed samples of the compound contained the cytokinin sugar, zeatin riboside, and that the application of this material increased the

zeatin riboside content of both cultivars. An increase in cytokinin has been linked to increased antioxidant activity and drought tolerance (Musgrave, 1994).

Other studies have documented improved crop drought stress tolerance following foliar applications of humic substances (Mladenova et al., 1998). Xudan (1986) foliarly applied fulvic acid to pot grown wheat (*Triticum aestivum*) 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 (*Poa pratensis*), and observed an increase in leaf water status and antioxidant activities relative to the control.

In the preceding experiments, humic substances were foliarly applied to the crop. 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.

Summary and Conclusions

Composted organic amendments are frequently applied to land as a means of environmentally sound waste management. Their application to land is often based on estimated nitrogen mineralization rates for the materials. The use of composts have consistently shown to be a viable means of improving soil quality parameters including soil water holding capacity, organic and humified carbon contents, and soil macro- and micronutrient status. Researchers have observed that the use of composted organic amendments may improve plant health beyond the fertility value. Of particular interest is the apparent ameliorating effect of organic amendments on drought-stressed crops.

Researchers speculate that the hormonal properties of humic substances within composts play a causal role in ameliorating drought stress. Humic substances are biologically active compounds formed during the composting process that are resistant to microbial degradation.

Most experiments exploring the potential ameliorating effects of humic substances on crop growth are carried out in pot studies where humified materials are foliarly applied to seedlings. 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.

References

- Abdel-Sabour, M.F., C.B. Ogden, and R.W. El-Gendi. 1997. Conditioning effect of organic waste compost on hydro-physical properties of Inshas sandy soils. Egypt. J. Soil Sci. 37:355-366.
- Abreu Junior, C.H., T. Muraoka, and F.C. Oliveira. 2001. Exchangeable cations, cation exchange capacity and base saturation in Brazilian soils amended with urban waste compost. Scientia Agricola. 58:813-824.
- Agehara, S., and D.D. Warncke. 2005. Soil moisture and temperature effects on nitrogen release from organic nitrogen sources. Soil Sci. Soc. Am. J. 69:1844-1855.
- Asada, K. 1994. Production and action of active oxygen species in photosynthetic tissues. p. 78-99. *In* C.H. Foyer and P.M. Mullineaux (eds.) Causes of photooxidative stress and amelioration of defense systems in plants. CRC Press, Inc., Boca Raton.
- Asada, K., and M. Takahashi. 1987. Production and scavenging of active oxygen in photosynthesis. p. 227-260. *In* D.J. Kyle, C.B. Osmond, and C.J. Arntzen (eds.) Photoinhibition. Elsevier Science, Amsterdam.
- Atiyeh, R.M., N.Q. Arancon, C.A. Edwards, and J.D. Metzger. 2000a. Influence of earthworm-processed pig manure on the growth in yield of greenhouse tomatoes. Biores. Tech. 81:103-108.
- Atiyeh, R.M., C.A. Edwards, S. Subler, and J.D. Metzger. 2000b. Earthworm-processed organic wastes as components of horticultural potting media for growing marigold and vegetable seedlings. Compost Sci. Util. A: 215-223.
- Atiyeh, R.M., C.A. Edwards, S. Subler, and J.D. Metzger. 2001. Pig manure vermicompost as a component of horticultural bedding plant medium: effects on physiochemical properties in plant growth. Biores. Tech. 78: 11-20.
- Atiyeh, R.M., S. Lee, C.A. Edwards, N.Q. Arancon, and J.D. Metzger. 2002. The influence of humic acids derived from earthworm-processed organic wastes on plant growth. Biores. Tech. 84:7-14.

- Ayuso, M., T. Hernández, C. Garcia, and J.A. Pascual. 1996. Stimulation of barley growth and nutrient absorption by humic substances originating from various organic materials. *Biores. Tech.* 57:251-257.
- Baddi, G., H. Mohamed, V. Gilard, and J. Revel. 2003. Characteristics of humic acid produced during composting of olive mill waste: elemental and spectroscopic analyses (FT-IR and ^{13}C -NMR). *Agronomie.* 23:661-666.
- Badran, N.M., M.E.A. Khalil, and M.A.A. El-Emam. 2000. Availability of N, P, and K in sandy and clayey soils as affected by the addition of organic materials. *Egypt. J. Soil Sci.* 40:265-283.
- Bauer, A., and A.L. black. 1992. Organic carbon effects on available water capacity of three soil textural groups. *Soil Sci. Soc. Am. J.* 56:248-254.
- Benitez, C., E. Bellido, J.L. Gonzalez, and M. Medina. 1998. Influence of pedological and climatic factors on nitrogen mineralization in soils treated with pig slurry compost. *Bioresource Tech.* 63:147-151.
- Blezinger, 2001. Taking a look at liquid feeds for growing cattle. [Online]. *Cattle Today*. Available at www.cattletoday.com/archive/2001/November/CT179.shtml (verified 9 Oct. 2005).
- Borken, W., A. Muhs, and F. Beese. 2002. Changes in microbial and soil properties following compost treatment of degraded temperate forest soils. *Soil Bio. Biochem.* 34:43-412.
- Boyd, S.A., and L.E. Sommers. 1990. Humic and fulvic acid fractions from sewage sludges and sludge-amended soils. p. 203-220. *In* McCarthy et al., (eds) *Humic substances in Soil and Crop Sciences: selected readings*. ASA and SSA, Madison WI.
- Bray, E.A., Bailey-Serres, and E. Weretilngk. 2002. Responses to Abiotic Stresses. *In*: B. Buchanan (ed.) *Biochemistry and molecular biology of plants*. Am. Soc. Plant Path., Rockville.
- Brunetti, G., C. Plaza, and N. Senesi. 2005. Olive pomace amendment in the Mediterranean conditions: Effect on soil and humic acid properties and wheat (*Triticum turgidum*) yield. *J. Agric. and Food Chem.* 53:6730-6737.
- Brye, K.R., N.A. Slaton, R.J. Norman, and M.C. Savin. 2004. Short-term effects of poultry litter form and rate on soil bulk density in water content. *Comm. Soil Sci. Plant Anal.* 35:2311-2325.
- Buckerfield, J.C., T. Flavel, K.E. Lee, and K.A. Webster. 1999. Vermicompost in solid and liquid form as a plant-growth promoter. *Pedobiologia.* 43:753-759.

- Bulluck, L.R., III, M. Brosius, G.K. Evanlyo, and J.B. Ristaino. 2002. Organic and synthetic fertilizer amendments influence soil microbial, physical, and chemical properties on organic and conventional farms. *Appl. Soil Ecol.* 19:147-160.
- Cabrera, M.L., D.E. Kissel, and M.F. Vigil. 2005. Nitrogen mineralization from organic residues: research opportunities. *J. Environ. Qual.* 34:75-79.
- Canarutto, S., A. Pera, M. la Marca, and G. Vallini. 1996. Effects of humic acid some compost-stabilize green waste or leonardite on soil shrinkage and microaggregation. *Compost Sci. Util.* 4:40-46.
- Carter, M.R., J.B. Sanderson, and J.A. MacLeod. 2004. Influence of compost on the physical properties and organic matter fractions of a fine sandy loam to route the cycle of a potato rotation. *Can. J. Soil Sci.* 84:211-218.
- Chang, T., and J. Cheng. 2000. Effects of cattle and Goldman newer composts on forage yield and quality of pangolagrass pasture. *J. Taiwan Live. Res.* 33:225-233.
- Chaoui, H.I., L.M. Zibilske, and T. Ohno. 2003. Effects of earthworm pass and compost on soil microbial activity and plant nutrient availability. *Soil Bio. Biochem.* 35:295-302.
- Chefetz, B., F. Adani, P. Genevini, F. Tambone, Y. Hadar, and Y. Chen. 1998. Humic-acid transformation during composting of municipal solid waste. *J. Environ. Qual.* 27:794-800.
- Chen, L.W., A. Dick, J.G. Streeter, and H.A.S. Hoitink. 1996. Ryegrass utilization of nutrients released from composted biosolids and cow manure. *Compost Sci. Util.* 4: 73-83.
- Chen, Y., M. de Nobili, and T. Aviad. 2004. Stimulatory effects of humic substances on plant growth. p. 103-129. *In* F. Magdoff, and R.W. Ray (eds.) *Soil organic matter in sustainable agriculture.*
- Clark, M.S., H.R. Horwath, C. Shennan, and K.M. Scow. 1998. Changes in soil chemical properties resulting from organic and low-input farming practices. *Agron, Sci.* 90:662-671.
- Cuevas, G., R. Blázquez, F. Martinez, and I. Walter. 2002. Composted MSW effects on soil properties and native vegetation in a degraded semiarid shrubland. *Compost Sci. Util.* 8:303-309.
- Curtis, M.J., and V.P. Claassen. 2005. Compost incorporation increases plant available water and drastically disturbed serpentine soil. *Soil Sci.* 170:939-953.

- Davis, J.G., M. Young, and B. Ahnsted. 1997. Soil characteristics of cropland fertilized with feedlot manure in the south Platte river basin of Colorado. *J. Soil and Water Conser.* 52:327-331.
- Desikan, R., C. Mankim, J. Bright, D. Henson, J.T. Hancock, and S.J. Neill. 2004. ABA, hydrogen peroxide, and nitric oxide signaling in stomatal guard cells. *J. Exp. Bot.* 55:205-212.
- Dorado, J., M.C. Zancada, G. Almendros, and C. Lopez-Fando. 2003. Changes in soil properties and humic substances after long-term amendments with manure and crop residues in dryland farming systems. *J. Plant Nutr. Soil Sci.* 166:31-38.
- Douglas, J.T., M.N. Aitken, and C.A. Smith. 2003. Effects of five non-agricultural organic ways on soil composition, and on the yield and nitrogen recovery of Italian ryegrass. *Soil Use. Mngmt.* 19:135-138.
- Economic Research Service. 2001. Confined animal manure and nutrient data system. [Online] Available at www.ers.usda.gov/data/manure (verified 27 Sept. 2003).
- Egelkraut, T.M., D.E. Kissel, and M.L. Cabrera. 2000. Effect of soil texture on nitrogen mineralized from cotton residues and compost. *J. Environ. Qual.* 29:1518-1522.
- Eghball, B. 2002. Soil properties influenced by phosphorus and nitrogen-based manure and compost applications. *Agron. J.* 94:128-135.
- Eghball, B., B.J. Wienhold, J.E. Gilley, and R.A. Eigenberg. 2002. Mineralization of manure nutrients. *J. Soil Wate Conserv. (Ankeny).* 57:470-473.
- Eghball, B., D. Ginting, and J.E. Gilley. 2004. Residual effects of manure and compost applications on corn production and soil properties. *Agron. J.* 96:442-447.
- Elsharawy, M.A.O., M.A. Aziz, and K.M. Ali Laila. 2003. Effect of the application of plant residues composts on some soil properties in yield of wheat and corn plants. *Egypt. J. Soil Sci.* 43:421-434.
- Epstein, E. 1997. *The science of composting.* Technomic Publishing Company, Lancaster, PA.
- Eneji, A.E., S. Yamamoto, T. Honna, and A. Ishiguro. 2000. Characterization of organic matter in nutrients during composting of livestock manure. p. 632-639. *In* J.A. Moore. (ed.) *Animal, agricultural and food processing waste. Proceedings of the eighth international symposium, Des Moines, Iowa, 9-11 October, 2000.*
- Faulker, D. 2001. Applying biosolids: issues for Virginia agriculture. USDA/Natural Resources Conservation Service. p. 1-13.

- Filip, Z., and J. Kubát. 2001. Microbial utilization and transformation of humic substances extracted from soils of long-term field experiments. *Eviron. J. Soil Biol.* 37:167-174.
- Flavel, T.C., D.V. Murphy, B.M. Lalor, and I.R.P. Fillery. 2005. Gross nitrogen mineralization rates . after application of composted grape marc to soil. *Soil Biol Biochem.* 37:13 97-1400.
- Foley, B.J., and L.R. Cooperband. 2002. Paper mill residuals and compost effects on soil carbon and physical properties. *J. Environ. Qual.* 31:2086-2095.
- Foyer, C.H. 2002. The contribution of photosynthetic oxygen metabolism to oxidative stress in plants. p. 217-246. *In: D. Inzè and M.V. Montague (eds.) Oxidative stress in this plants.* Taylor and Francis, New York.
- Frakenberger, W.T., and M. Arshad. 1995. *Phytohormones in soils.* New York, NY. Marcel Dekker.
- Gagon, B., and Z. Ziadi. 2004. Value of paper mill sludge in agriculture: crop yield, soil properties, and environmental impacts. p. 1-10. *In S.G. Pandalai (ed.) Recent research developments in crop science.* Vol. 1 Part 1.
- Gao, G., and C. Chang. 1996. Changes in CEC and particle size distribution of soils associated with long-term annual applications of cattle feedlot manure. *Soil Sci.* 161:115-120.
- García-Gil, J.C., S.B. Ceppi, M.I. Velasco, A. Polo, and N. Senesi. 2004. Long-term effects of amendment with municipal solid waste compost on the elemental and acidic functional group composition and pH-buffer capacity of soil humic acids. *Geoderma.* 121:135-142.
- Giardina, C.P., M.G. Ryan, R.M. Hubbard, and D. Binkley. 2001. Tree species and soil textural controls on carbon in nitrogen mineralization rates. *Soil Sci. Soc. Am. J.* 65:1272-1279
- Gigliotti, G., A. Macchioni, C. Zuccaccia, P.L. Giusquiani, and D. Businelli. 2003. A spectroscopic study of soil fulvic acid composition after six-year applications of urban waste compost. *Agronomie.* 8:719-724.
- Giusquiana, P., G. Gigliotti, D. Businelli, and A. Macchioni. 1994. Spectroscopic comparison between humic and fulvic acids from urban waste compost and soil. p. 1303-1310. *In N. Senesi, T.M. Miano (eds.) Humic substances in the global environment, and implications on human health: Proceedings of the six international meeting of the international humic substances society, Monopoli (Bari),Italy, September 20-25, 1992.*

- Glenn, J. 1992. On farm handling of organic residuals. *BioCycle* 33:34-36.
- Grandy, A.S., G.A. Porter, and M.S. Erich. 2002. Organic amendment and rotation crop effects on the recovery of soil organic matter and aggregation in potato crop in systems. *Soil Sci. Soc. Am. J.* 66:1311-1319.
- Griffin, T.S., C.W. Honeycutt, and Z. He. 2002. Effects of temperature, soil water status, and soil type on swine slurry nitrogen transformation. *Biol. Fert. Soils.* 36:442-446.
- Guster, R., T. Ebertseder, A. Weber, M. Schraml, and U. Schmidhalter. 2005. Short-term and residual availability of nitrogen after long-term application of organic fertilizers on arable land. *J. Plant Nut. Soil Sci.* 168:439-446.
- Hangarge, D.S., R.S. Raut, S.D. More, R.R. Birajdar, and P.L. Pholane. 2002. Effective vermicompost and soil conditioner on some physical properties of soil under chilli-spinach system. *J. Soils Crops.* 12:41-45.
- Heckman, J.R., J.S. Angle, and R.L. Chaney. 1987. Residual effects of sewage sludge on soybeans: II. Accumulation of soil and symbiotically fixed nitrogen. *J. Environ. Qual.* 16:118-124.
- Hernando, S., M.C. Lobo, and A. Polo. 1989. Effect of the application of the municipal refuse composts on the physical and chemical properties of a soil. *Sci. Total Environ.* 81 & 82:589-596.
- Hornick, S.B. 1988. Use of organic amendments to increase the productivity of sand and gravel spoils: Effect on the yield and composition of sweet corn. *Am. J. Alt. Ag.* 3:156-162.
- HuiLan, X., N. Ajiki, W. XiaoJu, C. Sakaibara, and H. Umemura. 1998. Corn leaf water retention as affected by organic fertilizations and effective microbes applications. *Pedosphere.* 8:1-8.
- Jiménez, L., N. Noguera, and M. Larreal. 2004. Productivity changes in a degraded Ultisol of the Machiques Colón by the application of cattle dung. *Rev. Fac. Agron., Univ. de Zulia.* 21:246-259
- Kegley, E.B. 2001. Role of trace minerals and vitamins in optimizing immune function of cattle. *J. Dairy Sci.* 86(suppl.):1.
- Kessel, J.S. van, and J.B. Reeves, III. 2002. Nitrogen mineralization potential of dairy manures and its relationship to composition. *Biol. Fert. Soils.* 36:118-123.
- Khaleel, R., K.R. Reddy, and M.R. Overcash. 1981. Changes in soil physical properties

- due to organic waste applications: a review. *J. Environ. Qual.* 10:133-141.
- Khalil, M.I., M.B. Hossain, and U. Schmidhalter. 2005. Carbon and nitrogen mineralization in different of plant soils of the subtropics treated with organic materials. *Soil. Biol. Biochem.* 37:1507-1518.
- Khatik, S.K., and P.R. Dikshit. 2001. Integrated use of organic materials and inorganic fertilizers on yield, quality, economics and nutrition of sunflower grown in Haplustert clay soil. *Ag. Sci. Digest.* 21:87-90.
- Kingery, W.L., C.W. Wood, D.P. Delaney, J.C. Williams, and G.L. Mullins. 1994. Impact of long-term land application of broiler litter on environmentally related soil properties. *J. Environ. Qual.* 23:139-147.
- Konomi, K., M.R. Savabi., D. Shinde, K. Jayachandran, P. Nkedi-Kisa, and S.T. Reed. 2005. Water and atrazine movement in a calcareous compost applied during soil simulated multiple storms events. *Water, Air, Soil Polltn.* 165:365-377.
- Kulikova, N.A., A.D. Dashitsyrenova, I.V. Perminova, and G.F. Lebedeva. 2003. Auxin-like activity of different fractions of coal humic acids. *Ecol. Future- Bulg. J. Ecol. Sci.* 2:55-56.
- Kumar, K. and K.M. Goh. 2003. Nitrogen release from crop residues and organic amendments as affected by biochemical composition. *Comm. Soil Sci. Plant Anal.* 34: 2441-2460.
- Kumar, P.S.S., and K. Kumaraswamy. 2000. Effect of manure-fertilizer schedules on soil properties in different forms of potassium in a permanent manurial experiment. *Res. Crops.* 1: 94-14.
- Kumar, P.S.S., and K. Kumaraswamy. 2003. Soil potassium as affected by long-term application of fertilizers and cropping with rice on an Alfisol. *Indian. Agric.* 47:121-124.
- Kuo, S. 1995. Nitrogen and phosphorus availability in groundfish waste and chitin-sludge Cocomposts. *Compost Sci. Util.* 3:19-29.
- Ladd, J.N., J.W. Parsons, and M. Amato. 1977. Studies of nitrogen immobilization and mineralization in calcareous soils-I: Distribution of immobilize nitrogen amongst soil fractions of different particle size and density. *Soil Biol. Biochem.* 9:319-318.
- Leifeld, J., S. Siebert, and I. Kogel-Knabner. 2002. Changes in the chemical composition of soil organic matter after application of compost. *Euro. J. Soil Sci.* 53:299-309.
- Lin, Y., T. Liu, and C. Wang. 2003. Study on nitrogen mineralization characteristics of organic materials. *J. Agric. Res. China.* 52:178-190.

- Lund, Z.F., and B.D. Doss. 1980. Residual effects of dairy cattle manure on plant growth and soil properties. *Agron. J.* 72:123-130.
- Luo, A., C. Shi, X. Sun, Y. Zhou, D. Qiu. 2005. Transitional phosphorus components in swine manure during composting course. *Acta Agric. Zhejiangensis.* 17:296-299.
- Lyu-bimov, V. Yu., and O.M. Zastrizhnaya. 1992. Role of hydrogen in photorespiration of C₄ plants. *Soviet Plant Physiol.* 39:454-460.
- Mano, J. 2002. Early events in environmental stresses in plants: Induction mechanisms of oxidative stress. p. 217-246. *In: D. Inzè and M.V. Montague (eds.) Oxidative stress in plants.* Taylor and Francis, New York.
- Martens, D.A., and W.T. Frankenberger, Jr. 1992. Modification of infiltration rates in an organic-amended irrigated soil. *Agron. J.* 84:707-717.
- Mittler, R. 2002. Review: Oxidative stress, antioxidants, and stress tolerance. *Trends Plant Sci.* 7:405-410.
- Mladenova, Y.I., P. Maini, C. Mallegni, V. Golstev, R. Vladava, K. Vinarova, and S. Rotcheva. 1998. Siapton- and amino-acid-based biostimulant reducing osmotic stress metabolic changes in maize. *Agro. Food. Industry Hi-Tech.* 9:18-22.
- Motavalli, P.P., K.A. Kelling, and J.C. Converse. 1989. First-year nutrient availability from injected dairy manure. *J. Environ. Qual.* 18:180-185.
- Mugwira, L.M. 1979. Residual effects of dairy manure on millet and rye forage and soil properties. *J. Environ. Qual.* 8:251-255.
- Muñoz, G.R., K.A. Kelling, J.M. Powell, and P.E. Speth. 2004. Comparison of estimates of first-year dairy manure nitrogen availability or recovery using N¹⁵ and other techniques. *J. Environ. Qual.* 33: 719-727.
- Musgrave, M.E. 1994. Cytokinins and oxidative processes. p. 167-178. *In D.W.S. Mok, and M.C. Mok (eds.) Cytokinins: Chemistry, activity, and function.* CRC Press, Inc., Boca Raton, FL.
- Nardi, S., F. Morari, A. Berti, M. Tosoni, and L. Giardini. 2004. Soil organic matter properties after 40 years of different use of organic and mineral fertilizers. *Europ. J. Agron.* 21:357-367.
- Negm, M.A., and R.N. Zaki. 2004. Influence of town refuses compost and potassium applications to a sandy soil on soil properties along with groundnut yield and composition. *Egypt. J. Agric. Res.* 82:1031-1046.

- Newman, C.M., D. Rotenberg, and L.R. Cooperband. 2005. Paper mill residuals and composts effects on particular organic matter and related soil functions in a sandy soil. *Soil Sci.* 170:788-801.
- Nishio, T., and N. Oka. 2003. Effect of organic matter application on the fate of ¹⁵N-labeled ammonium fertilizer in an upland soil. *Soil Sci. Plant Nut.* 49:397-403.
- Omay, A.B., C.W. Rice, L.D. Maddux, and W.B. Gordon. 1997. Changes in soil microbial and chemical properties under long-term crop rotation and fertilization. *Soil Sci. Soc. Am. J.* 61:1672-1678.
- Ouatmane, A., V. D'Orazio, M. Hafidi, N. Senesi. 2002. Chemical and physiochemical characterization of humic acid-like materials from composts. *Compost Sci. Util.* 10:39-46.
- Paré, T., and E.G. Gregorich. 1999. Soil textural effects on mineralization of nitrogen from crop residues and the added nitrogen interaction. *Comm. Soil Sci. Plant Anal.* 30:145-157.
- Park, M., O. Singvilay, W. Shin, E. Kim, J. Chung, and M. Sa. 2004. Effects of long-term compost and fertilizer application on soil phosphorus status under paddy cropping system. *Comm. Soil Sci. Plant Anal.* 35:1635-1644.
- Perl-Treves, R., and A. Perl. 2002. Oxidative stress: An introduction. p. 1-33. *In:* D. Inzè and M.V. Montague (eds.) *Oxidative stress in plants*. Taylor and Francis, New York.
- Preusch, P.L., P.R. Adler, L.J. Sikora, and T.J. Tworowski. 2002. Nitrogen and phosphorus availability and composted and on composted poultry litter. *J. Environ. Qual.* 31:2051-2057.
- Quaggiotti, S., B. Ruperti, D. Pizzeghello, O. Francioso, V. Tugnoli, and S. Nardi. 2004. Effect of low molecular size humic substances on nitrate uptake and expression of genes involved in nitrate transport in Maize (*Zea mays* L.). *J. Exp. Bot.* 55:803-813.
- Reddy, S.S., B. Shivaraj, V.C. Reddy, and M.G. Ananda. 2005. Direct effect of fertilizers and residual effect of organic manures on yield and economics of maize (*Zea Mays* L.) in groundnut-maize cropping system. *Crop Res. (Hisar)*. 31:1-5.
- Reynolds, W.D., X.M. Yang, C.F. Drury, T.Q. Zhang, and C.S. Tan. 2003. Effects of selected conditioners and tillage on the physical quality of a clay loam soil. *Can. J. Soil Sci.* 83:31-393.

- Rivero, C., T. Chirenje, L.Q. Ma, G. Martinez. 2004. Influence of compost on soil organic matter quality under tropical conditions. *Geoderma*. 123:355-361.
- Rodriguez, F., C. Guerrero, R. Moral, H. Ayguade, and J. Mataix-Beneyto. 2005. Effects of composted and non-composted solid waste of pig slurry on nitrogen, phosphorus, and potassium contents into Mediterranean soils. *Comm. Soil Sci. Plant Anal.* 36:635-647.
- Sahs, W. W., and G. Lesoing. 1985. Crop rotations and manure versus agricultural chemicals in dry land grain production. *J. Soil Water Cons.* 40:511-516.
- Schlegel, A.J. 1992. Effect of composted manure on soil chemical properties and nitrogen use by grain sorghum. *J. Prod. Agric.* 5:153-157.
- Senesi, N. 2004. Humic acids in composted materials and in compost-amended soils. p.433-436. *In* L. Martin-Neto et al. (ed.) Humic substances and soil and water environment. International Meeting of the International Humic Substances Society, 12th, São Pedro, São Paulo, Brazil. 25-30 Jul. 2004. Embrapa Instrumentação Agropecuária, São Carlos, Brazil.
- Serra-Wittling, C., S. Houot, and E. Barriuso. 1996. Modification of soil water retention and biological properties by municipal soil-waste compost. *Compost Sci. Util.* 4:44-52.
- Serdyuk, O.P., L.D. Smolygina, E.P. Ivanova, O.E. Trubetskaya, O.A. Trubetskoi, R.F. Obertur. 1999. Phytohormonal activity of humic acid is isolated from soil and compost. *Doklady, Bio. Sci.* 365:163-165.
- ShengGao, L., and Z. Lei. 2004. Effective fly ash on physical properties of Ultisols from subtropical China. *Comm. Soil Sci. Plant Anal.* 35:703-717.
- Shiralipour, A., D.B. McConnell, and W.H. Smith. 1992. Physical and chemical properties of soils as affected by municipal solid waste compost application. *Biomass Bioenergy.* 3:261-266.
- Sikora, L.J., and V. Yakovchenko. 1996. Soil organic matter mineralization after compost amendment. *Soil Sci. Soc. Am. J.* 60:1401-1404.
- Sims, J.T. 1990. Nitrogen mineralization and elemental availability in soils amended with co-composted sewage sludge. *J. Environ. Qual.* 19:669-675.
- Singer, J.W., K.A. Kohler, M. Liebman, T.L. Richard, C.A. Cambardella, and D.D. Buhler. 2004. Tillage and compost effect the yield of corn, soybean and wheat, and soil fertility. *Agron. J.* 96:531-537.

- Singh, S.K., and B.C. Ghosh. 1999. Effect of organic and chemical sources of nitrogen on yield in nitrogen uptake of jute and rice grown in rainfed lowlands. *Oryza*. 36:270-280.
- Sørensen, P., and E.S. Jensen. 1995. Mineralization of carbon and nitrogen from fresh and in aerobically stored sheet manure in soils of different texture. *Biol. Fert. Soils*. 19:29-35.
- Stepkowska, E.T., C. Maqueda, E. Morillo R. López, and R.L. Pérez-Rodríguez. 2001. Changes in physio-chemical properties of soils fertilized by agro-industrial residues. *Fres. Environ. Bultn*. 10:300-304.
- Stevenson, F. 1994a. Organic matter in soils: pools, distribution, transformations, and function. p. 1-23. *In: Humus chemistry: genesis, compositions, reactions*. John Wiley and Sons, New York, NY.
- Stevenson, F. 1994b. Biochemistry of the formation of humic substances. p. 188-211. *In: Humus chemistry: genesis, compositions, reactions*. John Wiley and Sons. New York, NY.
- Subler, S., C.A. Edwards, and J.D. Metzger. 1998. Comparing vermicompost and compost. *BioCycle*. 39:63-66.
- Sullivan, D.M., A. I. Bary, T.J. Nartea, E.A. Myrhe, C.G. Cogger, and S.C. Fransen. 2003. Nitrogen availability seven years after a high-rate food waste compost application. *Compost Sci Util*. 11:265-273.
- Taiz, L., and E. Zeiger. 1998. Photosynthesis: physiological and ecological considerations. p. 228-249. *In: Plant physiology*, 2nd ed., Sinauer Associates, Sunderland, Mass.
- Tester, C.F., L.J. Sikora, J.M. Taylor, and J.F. Parr. 1982. Nitrogen mineralization by tall fescue from sewage sludge compost amended soils. *Agron. Journ*. 74: 1013-1018.
- Thomsen, I.K. and J.E. Olesen. 2000. Carbon in nitrogen mineralization of composted in an aerobically stored ruminant manure in differently textured soils. *J. Agric. Sci*. 135:151-159.
- Tiquia, S. 2003. Evaluation of organic matter and nutrient composition of partially decomposed and composted spent pig litter. *Environ. Tech*. 24:97-107.
- Tolbert, N.E., A. Oeser, R.K. Yamazaki, R.H. Hagemane, and K. Kasaki. 1969. A survey of plant peroxisomes. *Plant Physiol*. 44:135-147.
- Tomati, U., E. Madejon, E. Galli, D. Capitani, and A. Segre. 2001. Structural changes of humic acids during olive mill pomace composting. *Compost Sci. Util*. 9:134-142.

- Tsegaye, T.D., T.D. Ranatunga, and K.C. Reddy. 2003. Variation of soil dielectric, moisture holding capacity, and nitrate-nitrogen as influenced by application of fresh and compost poultry litter on a Decatur silt loam soil. *J. Sustain. Agric.* 22:55-73.
- Unsal, T., and S.S Ok. 2001. Description of characteristics of humic substances from different waste materials. *Bioresource Tech.* 78:239-242.
- U.S. Environmental Protection Agency. 1999. Biosolids generation, use, and disposal in the United States. USEPA 530-R-99-009 (Available online at www.epa.gov/epaoswer/non-hw/compost/biosolid.pdf)
- U.S. Environmental Protection Agency. 2005. Municipal solid waste basic facts. [Online] Available at www.epa.gov/msw/facts.htm (verified 24 Jan 2006).
- Vadiraj, B.A., S. Siddagangaiah, and N. Potty. 1998. Response of coriander (*Coriandrum sativum* L.) cultivars to graded levels of vermicompost. *J. Spices Aromatic Crops.* 7:141-143.
- Valdrighi, M.M., A. Pera, M. Agnolucci, S. Frassinetti, D. Lunardi, and G. Vallini. 1996. effects of compost-derived humic acids on vegetable biomass production and microbial growth within a plant (*Cichorium intybus* L.)-soil system: a comparative study. *Agric. Eco. Environ.* 58:133-144.
- Veen, J.A. van, J.N. Ladd, and M. Amato. 1985. Turnover of carbon in nitrogen to the microbial biomass in a sandy loam and clay soil incubated with [¹⁴C(U)] glucose and [¹⁵N](NH₄)₂SO₄ under different washer régimes. *Soil Biol. Biochem.* 17:747-756.
- Velasco, M.I., P.A. Campitelli, S.B. Ceppi, J. Havel. 2004. Analysis of humic acid from compost of urban wastes in soil by fluorescence spectroscopy. *AgriScientia.* 21:31-38.
- Waddington, D.V., T.K. Turner, J.M. Duich, and E.L. Moberg. 1978. Effect of fertilization on Penncross creeping bentgrass. *Agron. J.* 70:713-718.
- Waksman, S.A. 1932. *Humus*. Williams and Wilkins, Baltimore, MD.
- Walker, D. J., and M.P. Bernal. 2004. Plant mineral nutrition and growth in a saline Mediterranean soil amended with organic wastes. *Comm. Soil Sci. Plant Anal.* 35:2495-2514.
- Warren, S.L. and W.C. Fonteno. 1993. Changes in physical and chemical properties of a loamy sand soil when amended with composted poultry litter. *J. Environ. Hort.* 11:186-190.

- Wolff, S.P., A. Garner, and R.T. Dean. 1986. Free radicals, lipids, and protein degradation. *Trends in Biochemical Sciences*. 11:27-31.
- Xiang, Z., Z. Hongxun, and S. Chunhe. 1998. Effects of long-term fertilizer application on soil microorganisms and humus compositions. *Acta. Ag. boreali-sinica*. 13:87-92.
- Xu, H. 2000. Effects of a microbial inoculant, organic fertilizer, and chemical fertilizer on water stress resistance of sweet corn. *J. Crop Prod.* 3:223-233.
- Xudan, X. 1986. The effects of foliar application of fulvic acid on water use, nutrient uptake, and wheat yield. *Aust. J. Agric. Res.* 37:343-350.
- Yakimenko, O., D. Orlov, and Y. Ammosova. 1995. Humic substances of ligno-compost, and its effect on the properties of a medium podzolic soil. *Agrokhimiya*. 9:17-24.
- Yan, J., and R.E. Schmidt. 1993. Effects of fortified seaweed extract on cell membrane lipids and drought tolerance in ryegrass. In. 1993 *Agronomy Abstracts*. American Society of Agronomy, Madison, Wisconsin, USA.
- Yogananda, S.B., V.C. Reddy, and K. Sudhir. 2004. Effect of urban compost and inorganic fertilizers on soil nutrient status and grain yield of hybrid rice. *Mysore J. Agric. Sci.* 38:454-458.
- Yona, C. 2003. NMR, infrared and pyrolysis: applications of spectroscopic methodologies for maturity determination of composts. *Compost Sci. Util.* 11:152-168.
- Young, C.C., and L.F. Chen. 1997. Polyamines in humic acid and their effect on radical growth of lettuce seedlings. *Plant Soil*. 195:143-149.
- Yusel, O. 2004. Effect of municipal waste compost on some chemical characteristics of clay soils. *J. Agron.* 3:43-45.
- Zhang, X.Z., and R.E. Schmidt. 1999. Antioxidant response to hormone-containing product in Kentucky bluegrass subjected to drought. *Crop Sci.* 39:545-551.
- Zhang, X.Z., and R.E. Schmidt. 2000. Hormone-containing products' impact on antioxidant status of tall fescue and creeping bentgrass subjected to drought. *Crop Sci.* 40:1344-1349.
- Zhang, X.Z., and E.H. Ervin. 2004. Cytokinin-containing seaweed and humic acid extracts associated with creeping bentgrass leaf cytokinins and drought resistance. *Crop Sci.* 44:1737-1745.
- Zhang, X.Z., E.H. Ervin, G. Evanylo, C. Sherony, and C. Peot. 2005. Biosolids impact on tall fescue drought resistance. *J. Residuals Sci. and Tech.* 2:173-180.

Zinati, G.M., Y.C. Li, and H.H. Bryan. 2001. Utilization of compost increases organic carbon and its humin, humic, and fulvic acid fractions in calcareous soils. *Compost Sci. Util.* 9:156-162.