Chemical and Physical Properties of Soil Amended with Pecan Wood Chips

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Abstract. The pruning wood of pecan [*Carya illinoensis* (Wangenh.) K. Koch] is often burned. Chipping and soil incorporation of pruning wood is becoming more popular as a result of environmental constraints on burning. The objective of our research was to determine how pecan wood incorporation into soil affects the soil chemical and physical properties. Pecan wood chips were incorporated into a silty clay soil at rates of 0, 4484, 8968, 13,452, and 17,936 kg·ha⁻¹ in Summer 2002, 2003, and 2004. Some plots received nitrogen at a rate of 0, 15.2, 30.5, 45.7, and 61.0 kg·ha⁻¹ to adjust the C : N ratio of trimmings to 30 : 1. Ammonium sulfate, as a nitrogen source to balance the C : N ratio of pecan wood chips, reduced soil pH. However, the wood chip amendments alone did not reduce soil pH. Soil salinity (as determined by electrical conductivity) and bulk density were unaffected by wood chip incorporation regardless of application rate or number of applications. Incorporation of pecan chips had little effect on soil moisture content, but the soil had an inherently high waterholding capacity. Pecan wood chip incorporation significantly increased soil organic matter content and aggregate stability, particularly at the higher application rates and with repeated amendment. The incorporation of pecan pruning wood into the soil appears to improve soil tilth and aggregation while providing growers with an environmentally acceptable means of disposal.

Regular additions of organic materials such as animal manures and crop residues are important in maintaining the tilth, fertility, and productivity of soils, protecting them from wind and water erosion and preventing nutrient losses through runoff and leaching. Organic amendments improve soil physical properties by increasing waterholding capacity, soil aggregation, soil aeration, and permeability and decreasing soil crusting and bulk density (Oades, 1984; Tisdall and Oades, 1982). Soil chemical properties are improved by organic amendments through their contribution to soil cation exchange capacity, enhancing the ability of soils to buffer pH changes, and cation complexation (Magdoff, 1992; Wallace et al., 1990). Soil organic matter enhances soil biological properties. Studies have shown that organic farming leads to higher soil quality and more soil

biological activity than conventional farming by increasing soil organic matter content, microbial biomass, diversity, respiration, and dehydrogenase enzyme activity (Boggs et al., 2000; Drinkwater et al., 1995; Reganold, 1993).

In Doña Ana County, NM, alone, an estimated 25,500 t of pecan pruning wood is produced annually (Cabral, 2005). Much of the pruning wood is burned as an economic means of disposal. However, pruned wood is increasingly chipped and incorporated into the soil as an environmentally viable method of handling the waste. Although more expensive than burning, chipping and soil incorporation avoid burning controls recently imposed by the New Mexico Environment Department and the U.S. Environmental Protection Agency. Burning regulations will probably become more restrictive in the future (New Mexico Air Quality Bureau, 2003).

Chipping and incorporation of pruning wood as an alternative to burning has gained acceptance in areas of the San Joaquin Valley, CA (Holtz, 1999) where environmental regulations have forced growers to adopt alternative ways to deal with the waste. The addition of almond wood chips lowered soil pH, increased soil carbon, and organic matter contents and enhanced water infiltration in soil planted with almond trees in the San

Joaquin Valley, CA (Holtz et al., 2004). However, the application rate was unrealistically high ($\approx 410,000$ kg·ha⁻¹ or one-third of soil weight) and resulted in initial immobilization of soil inorganic nitrogen. In a previous report (Tahboub et al., 2007), we found no significant effect of wood chip incorporation on plant-available nitrogen, phosphorus, or potassium at application rates up to 17,936 kg·ha⁻¹ and concluded that wood chip incorporation was a viable means of wood disposal.

Wood chip incorporation should increase the organic matter content of soils and improve soil chemical and physical properties. The continuous use of hardwood chips for a period of 15 years at an application rate of 7000 kg·ha⁻¹·yr⁻¹ in the northeast United States increased organic matter content, aggregate stability, and moisture retention and reduced soil bulk density, pH, and soil erosion (Free, 1971). Sanborn et al. (2004), while studying the effect of wood chip incorporation on the rehabilitation of older landings and roads constructed on fine-textured soils in British Columbia, Canada, found that soil bulk density at 7 to 14 cm was lowest in the wood chip-amended soil when compared with the topsoil amendments. The wood chip treatment had also the highest 3-year growth rates of hybrid white spruce. Based on these promising results, the authors recommended silviculturists to use chipped wood wastes in the rehabilitation of disturbed lands.

Although our previous report showed that nutrient immobilization was not a concern with pecan wood chip incorporation, the potential beneficial aspects of wood chip incorporation on soil organic matter and the effects on soil chemical and physical properties were not included.

The influence of pecan wood chip incorporation must be viewed over several years and with repeated applications for a clear picture of the beneficial and detrimental effects of this disposal method. Therefore, the objective of this study is to determine how pecan wood incorporation into the soil would affect soil organic matter content, chemical and physical properties, and whether this practice might present an alternative to burning.

Materials and Methods

As previously described (Tahboub et al., 2007), a field experiment was established at the Leyendecker Plant Science Research Center, New Mexico State University, Las Cruces, NM, in May 2002. The experimental site (lat. 32°12.309'N, long. 106°45.058'W) is located 14.5 km south of Las Cruces at an elevation of 1172 m. The mean annual precipitation is 20.3 cm. The soil was a well-drained Glendale clay loam [fine-silty, mixed (calcareous), thermic Typic Torrifluent] that formed in alluvium. The surface soil (0 to 30 cm) had an average pH of 8.7 (saturated paste extract) and electrical conductivity (EC) of 2.24 dS·m.

Pruning wood was ground in a tub grinder and the resulting chips were generally long

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Table 1. Sampling dates of soil characteristics for each number of pecan wood chip applications.

Number of applications	Sampling date			
	pH and EC	Organic matter	θ_v and Db	Aggregate stability
One application in 2002	Dec. 2002	May 2003	Aug. 2003 (1 d after irrigation)	May 2005
	Dec. 2003	May 2004	Aug. 2003 (20 d after irrigation)	
	Oct. 2004	May 2005	Aug. 2005 (30 d after irrigation)	
Two applications in 2003 and 2004	Dec. 2003	May 2004	Aug. 2003 (1 d after irrigation)	May 2005
	Oct. 2004	May 2005	Aug. 2003 (20 d after irrigation)	
			Aug. 2005 (30 d after irrigation)	
Three applications in 2002, 2003, and 2004	Dec. 2003	May 2004	Aug. 2003 (1 d after irrigation)	May 2005
	Oct. 2004	May 2005	Aug. 2003 (20 d after irrigation)	
			Aug. 2005 (30 d after irrigation)	

EC = electrical conductivity; θ_v = volumetric moisture content; Db = bulk density.

(2.5 to 5.0 cm in length) and narrow (2.4 to 7.9 mm in diameter). A more thorough description of wood chips was previously given (Tahboub et al., 2007). Pecan wood chips (C : N ratio of 143 : 1) were incorporated (disked to 10 cm) in May 2002, June 2003, and May 2004 to achieve one application, two applications, or three applications.

Experimental treatments were arranged in a control plus a two-way factorial of four rates of wood chips and two inorganic nitrogen fertilizer treatments (an unfertilized treatment (N0) and a fertilized (N1) treatment to adjust the C : N ratio of wood chips to 30 : 1) in four blocks. Wood chip application rates were 4484 (C1), 8968 (C2), 13,452 (C3), and 17,936 (C4) kg·ha⁻¹ and corresponded to the amount of pruning wood typically observed on the ground from light to heavy pruning. The inorganic nitrogen (ammonium sulfate) treatment (N1) included rates of nitrogen at 15.2, 30.5, 45.7, and 61.0 kg·ha⁻¹ to adjust the C : N ratio of wood chips to 30 : 1. The experimental design was a randomized complete block with nine treatments and three application times (one application in 2002; two applications, one in 2003 and one in 2004; or three applications, one in 2002, one in 2003, and one in 2004) and each treatment combination was replicated four times. The first set of plots received treatments in May 2002 only, the second set received treatments in June 2003 and May 2004, and the third set received treatments in May 2002, June 2003, and May 2004. Plots were 2.5 × 2.5 m and 2.0 m apart from each other within each block. A more complete description of the experimental site, design, wood chip amendments, and treatment application were previously described (Tahboub et al., 2007).

Parameters measured included soil reaction (pH), soluble salts as determined by EC, volumetric moisture content (θ_v), bulk density (Db), organic matter (OM), and aggregate stability. Soil samples for pH, EC, and OM were taken at a depth of 0 to 20 cm. Three soil subsamples were taken from each treatment combination and mixed into one composite sample. Representative samples taken from each composite sample were immediately air-dried for 72 h, ground to pass through a 2.0-mm sieve, and stored at 4 °C until analysis.

Soil pH and EC were determined from soil-saturated paste extracts (Rhoades, 1982) and measurements were taken in Dec. 2002,

Fig. 1. Soil reaction (pH) as influenced by the nitrogen treatments averaged overall other treatments. Treatments were applied in summer of 2003 and 2004 (A) and summer of 2002, 2003, and 2004 (B). Error bars represent $\pm$ SE. Means within each sampling date with the same letter are not significantly different at $\alpha = 0.05$.

Dec. 2003, and Oct. 2004 for the set of plots that received one wood chip application in May 2002. For the plots that received two and three wood chip applications, soil pH and EC were measured in Dec. 2003 and Oct. 2004 (Table 1). Soil OM analysis was by the Walkley-Black method (Nelson and Sommers, 1982) and measurements were taken in May 2003, 2004, and 2005 for the first set of plots that received one application in May 2002. For the plots that received two and three treatment applications, soil organic matter was measured in May 2003 and 2004 (Table 1).

A surface moisture-density gauge (Troxler Model 3440; Troxler Electronic Laboratories, Research Triangle Park, NC) was used to determine the soil Db and the θ of all treatment combinations at a depth of 0 to 15 cm. The gauge was calibrated for the θ_v using the technique described by Topp and Ferre (2002). Eighteen random field core samples were taken at a depth of 0 to 15 cm and at various soil moisture levels to determine the gravimetric moisture content (θ_g) and mean Db of the soil. The θ_v was determined by multiplying the calculated θ_g by the mean Db. The θ_v were plotted against preliminary measured moisture count ratios (gauge readings) to obtain the calibration curves as well as the regression equation.

The surface moisture-density gauge uses gamma radiation backscattering to non-destructively sample relatively large volumes of soil to estimate the wet bulk density (Dbw), which is a function of Db and water content. The gauge was calibrated for the Db using the technique described by Blake (1965) and involved measurements on large containers containing soils that had been compacted artificially to a desired Dbw. The Dbw were calculated from the mass and volume of wet soils and were plotted against preliminary measured density count ratios (gauge readings) to obtain the calibration curve and the regression equation. The Db was predicted from the Dbw by the following equation:

$$Db = Dbw / (1 + \theta_g / 100).$$

Soil Db and θ_v of all three sets of plots that received one, two, and three treatment applications in May 2002, June 2003, and May 2004 were measured 1 d and 20 d after irrigation in Aug. 2003 and 30 d after irrigation in Aug. 2005 (Table 1).

Soil samples for aggregate stability measurements were taken at a depth of 5 cm from each experimental plot and were immediately air-dried until measurements were taken. Soil aggregate stability was measured for all experimental plots in May 2005 (Table 1). Aggregate stability was determined using the technique described by Herrick et al. (2001). Nine aggregates of 6 to 8 mm in diameter from each plot were rated on a scale of 1 to 6 based on a combination of visual observations of slaking during the first 5 min after immersion in deionized water and the percent remaining on a 1.5-mm sieve after five dipping cycles.

Fig. 2. Soil volumetric moisture content twenty days after irrigation in Aug. 2003 as influenced by the wood chip rates averaged overall other treatments. Treatments with C1, C2, C3, and C4 received chips at 4484, 8968, 13,452, and 17,936 kg·ha⁻¹ in May 2003, respectively. Error bars represent $\pm$ SE. Means with the same letter are not significantly different at $\alpha = 0.05$.

Fig. 3. Soil organic matter content 1 year after two treatment applications as influenced by the wood chip rates averaged overall other treatments. Treatments with C1, C2, C3, and C4 received chips at 4484, 8968, 13,452, and 17,936 kg·ha⁻¹·yr⁻¹, respectively. Error bars represent $\pm$ SE. Means within each set of amendment years with the same letter are not significantly different at $\alpha = 0.05$.

Soil measurements were analyzed by each set of plots and sampling time separately using analysis of variance by the Mixed procedure of SAS (SAS Institute Inc., 1997). Proc Mixed was used to calculate F statistics for the overall treatment effect and for contrasts for the wood chip main effect, the nitrogen fertilization main effect, and for the wood chip simple effects with no nitrogen. The simple effects of the wood chips with no added nitrogen are comparisons among C1N0, C2N0, C3N0, and C4N0. In addition, means with ses were calculated for the nine treatments and estimate statements were used to calculate wood chip and nitrogen main effect means and ses. Least significant differences were used to carry out pairwise comparisons of the nine treatments to determine if they were significant at a significance level of $\alpha = 0.05$.

Results and Discussion

At the end of the growing season, most of the applied wood chips had entirely degraded, and the remaining larger chips were degraded to the point that no brittle wood remained to interfere with mechanical harvest. One year after application, some wood chips were still evident in the soil, particularly at the higher application rates (13,452 and 17,936 kg·ha⁻¹), but the remaining chips were degraded to the point of flexible shreds. Wood chips remaining tended to be short lengths of woody twigs that had passed unscathed through the tub grinder.

No statistical differences ($P > 0.05$) for soil pH among all treatments were observed for the single wood chip application measured in Dec. 2002, Dec. 2003, and Oct. 2004. One treatment application of pecan wood chips did not influence soil pH for a period of three seasons after treatment application.

For the plots that received two treatment applications in May 2003 and 2004, soil pH was measured after one application in Dec. 2003 and after two treatment applications in Oct. 2004. Similar to the plots that received only one treatment application in May 2002, soil pH measured after one treatment application in Dec. 2003 was not statistically ($P > 0.05$) different among treatments (Fig. 1A). The addition of ammonium sulfate to balance the C : N ratio of pecan chips decreased soil pH after two treatment applications (Fig. 1A). Soil pH in the control and chip-amended soil was not statistically different. Furthermore, no tendency was observed ($P > 0.05$) for soil pH to change with increasing wood chip application rate (data not shown).

A similar tendency of decreasing soil pH with the addition of nitrogen to adjust the C : N ratio of pecan wood chips was observed [$F(8,24) = 3.18$, $P = 0.0132$] for the plots that received three treatment applications in May 2002, 2003, and 2004 when measured after three seasons in Oct. 2004 (Fig. 1B). The decrease in soil pH with addition of ammonium sulfate is attributed to the acidifying effect of ammonium sulfate. The addition of

Fig. 4. Soil organic matter content 1 year after three treatment applications as influenced by the wood chip rates averaged overall other treatments. Treatments with C1, C2, C3, and C4 received chips at 4484, 8968, 13,452, and 17,936 kg·ha⁻¹·yr⁻¹, respectively. Error bars represent $\pm$ SE. Means with the same letter are not significantly different at $\alpha = 0.05$.

ammonium fertilizers (such as ammonium sulfate) has a strong acidifying effect on the soil (Havlin et al., 1999; Krishna, 2002). Ammonium sulfate has three times the acidifying effect on soil pH compared with ammonium nitrate, urea, or urea ammonium nitrate solution. On the conversion of ammonium to nitrate, the ammonium ion produces 5.35 pounds of acidity per pound of nitrogen applied, which in turn makes ammonium sulfate the most acidifying of these N sources (Sartain and Kruse, 2001).

Incorporation of pecan chips had no significant effect ($P > 0.05$) on soil EC for the plots that received one, two, or three treatment applications. This lack of response on soil EC was expected and was attributed to the low salt content in pecan wood. The ash content of pecan wood is 0.4% on an oven-dried weight basis (Pettersen, 1984). On the other hand, Patriquin et al. (1993) indicated that soil EC is tightly linked to nitrate nitrogen concentration in the soil. The authors, while studying the effect of various organic amendments on soil pH, EC, and nitrate, indicated that the growth of plants reduced soil nitrate and EC to a greater extent than the incorporation of immobilizing residues. Furthermore, Werner (1997) observed relatively stable EC levels under organic compared with conventional systems.

Incorporation of pecan chips had little effect on soil θ_v . The effect of one wood chip treatment application was only significant in Aug. 2003 for the plots that received treatment in May 2003 and 2004. Pecan chips applied in 2003 statistically [$F(8,24) = 2.87$,

$P = 0.0217$] increased soil θ_v at the three highest wood chip rates (Fig. 2). The positive effect of one treatment application on soil θ_v in Aug. 2003 was also noticed on the soil θ_g for the same plots (data not shown). However, pecan wood chips applied in 2003 increased soil θ_g only at the highest wood chip rate. The incorporation of pecan wood chips had no significant effect ($P > 0.05$) on soil θ_v for the plots that received two or three treatment applications.

The lack of influence of pecan wood chip incorporation on soil θ_v was attributed to the fine texture of the soil ($\approx 46\%$ clay). The results of this study agree with the results obtained by Bauer and Black (1992) who indicated that the effect of organic amendments on soil water availability is generally positive, but whether the effect is significant depends on other soil parameters such as texture. The authors found that the effect of soil organic matter on soil water availability tends to be more pronounced in coarse-textured than fine-textured soils.

In this study, the application of pecan wood chips had little effect on soil θ_v . However, the silty clay soil at the research site has a high waterholding capacity and pecan wood chip incorporation was not expected to greatly increase water retention. Pecan chip amendment would be more likely to increase the waterholding capacity of coarser textured soils.

Incorporation of pecan chips had no significant effect ($P > 0.05$) on soil Db regardless of application rates or number of applications. Numerous studies have addressed

the beneficial effect of organic amendments on decreasing soil bulk density (Nemati et al., 2000; Webber, 1978; Weil and Kroontje, 1979). The insignificant effect of pecan wood chip incorporation on soil Db was attributed to the lack of readily decomposable organic constituents of pecan wood. Nemati et al. (2000) indicated that the lack of response on Db from a compost treatment compared with the deinking and secondary sludge amendments was probably the result of the lack of readily decomposable organic constituents that were entirely consumed during the composting process. The beneficial effects of deinking sludge and secondary sludge amendments might have resulted from the rapid increase in aggregate stability. Paper sludge amendments as a source of carbon for microorganisms can also stimulate the production of binding agents (polysaccharides, ill-humidified organic materials, or lipids) that rapidly aggregate soil particles.

Soil organic matter content 1, 2, or 3 years after one treatment application was not significantly ($P > 0.05$) different in the experimental plots that received one treatment application in May 2002. The incorporation of pecan wood chips increased soil organic matter content 1 year after two treatment applications at the two highest wood chip rates [$F(8,24) = 2.97$, $P = 0.0185$] in May 2004 and at the second and third highest rates [$F(8,24) = 2.97$, $P = 0.0184$] in May 2005 (Fig. 3). Although a similar trend of increasing soil organic matter content occurred with increasing pecan wood chip rates, soil organic matter 1 year after three treatment applications was not statistically different ($P = 0.06$) among all treatments (Fig. 4).

Soil organic matter content increased as pecan wood chips input increased. The increase in soil organic matter was attributed to the high content of recalcitrant constituents such as lignin in pecan wood that contribute much more to soil organic matter (humus) than organic materials composed of hydrophilic constituents such as protein and plant tissue polysaccharides. Schnitzer (1978) indicated that organic residues rich in recalcitrant constituents such as lignin and other polyphenols decompose more slowly and contribute much more significantly to soil organic matter (humus) than proteins and sugars. Furthermore, Lal (2003) indicated that the use of high-lignin recalcitrant amendments increased soil organic carbon.

Soil aggregate stability 3 years after one treatment application was not significantly ($P > 0.05$) different in the experimental plots that received treatments in May 2002. Soil aggregate stability 1 year after two and three treatment applications was statistically higher at the two and three highest wood chip rates averaged overall other treatments, respectively (Fig. 5A–B). Although the increase in soil aggregate stability with increasing pecan wood chip inputs was significant, the increase in soil aggregate stability was slow and the aggregate stability values did not exceed 2.75 on the 1 to 6 aggregate stability scale. The increase in aggregate stability was attributed

Fig. 5. Soil aggregate stability 1 year (May 2005) after two treatment applications (A) and three treatment applications (B) as influenced by the wood chip rates averaged overall other treatments. Treatments with C1, C2, C3, and C4 received chips at 4484, 8968, 13,452, and 17,936 kg·ha⁻¹·yr⁻¹, respectively. Error bars represent $\pm$ SE. Means within each set of treatment applications with the same letter are not significantly different at $\alpha = 0.05$.

to the high content of hydrophobic constituents such as lignin in pecan wood that are likely to be more effective and longer-lasting aggregate-binding agents than organic materials composed of hydrophilic constituents such as root exudates and plant tissue polysaccharides.

The results of this study agree with the results obtained by Martens (2000) who found that aggregate stability increased in organic residue-amended soil, and the process was related to the biochemical composition of the plant residues. Residues with high carbohydrate and amino acid contents

decomposed quickly and resulted in quick but short-term aggregate stability, but longer-term aggregation was noted from residues with slower decomposition rates and higher concentrations of phenolic acids. Furthermore, Tisdall and Oades (1982) found organic residues with slower decomposition rates such as wood resulted in persistent soil aggregation accompanied by an increase in soil organic carbon. Kong et al. (2005) found that aggregate stability increased linearly with both carbon inputs ($r^2 = 0.75$) and soil organic carbon ($r^2 = 0.63$). Piccolo and Mbagwu (1999) found that as organic carbon

inputs increased aggregate stability increased. The authors indicated that soil amendments with exogenous humified or hydrophobic organic constituents appear to be most suitable for improving soil physical quality. The positive effect of hydrophobic materials on aggregate stability has been also observed by Capriel et al. (1990), who found a high correlation coefficient ($r^2 = 0.91$) between aggregate stability and the aliphatic (hydrophobic) fraction of organic residues.

The chipping and incorporation of wood chips is an alternative to the burning of waste wood if environmental constraints do not allow burning. Chipping and incorporation is expensive. Depending on the size and quantity of wood and the type of self-propelled chipper, the estimated cost for chipping and incorporation in New Mexico is \$296 to 493/ha (\$120 to 200/acre) whereas dragging the pruned wood to the end of the field costs \$74 to 123/ha (\$30 to 50/acre).

Conclusions

Wood chip amendments had no effect on soil pH, EC, or bulk density after one, two, or three treatment applications. Incorporation of pecan wood chips only significantly affected soil volumetric moisture content on one sampling date. Pecan chip amendment would likely increase the waterholding capacity of coarse-textured soils that have lower waterholding capacities than the silty clay soil used in the current study. Pecan wood chip incorporation enhanced soil organic matter and aggregate stability at the higher application rates. The incorporation of chipped pecan pruning wood into the soil appears to improve soil tilth while providing growers with an environmentally benign means of disposal.

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