Community Shade Tree Leaves: Beneficial Uses for Agriculture

Joseph R. Heckman[1], Uta Krogmann[2], and Christian A. Wyenandt[3]

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Summary. **Every autumn an abundance of leaves from various species of shade trees [e.g., oak (*Quercus* sp.), maple (*Acer* sp.)] are collected from urban landscapes. In 1988, shade tree leaves were banned from landfills and combustion facilities in New Jersey because it was an unsustainable practice. Composting and mulching leaves and using them as a resource was proposed. The purpose of this review is to summarize studies of mulching and amending soils with shade tree leaves and their potential to benefit agricultural production. Research sponsored by New Jersey Agricultural Experiment Station on soils and crops found that land application of shade tree leaves was beneficial for building soil organic matter content, protecting against erosion, and controlling weeds when used as a mulch. In general, crop yields and quality were improved with leaf mulch. Collected shade tree leaves on average have a relatively high carbon-to-nitrogen (N) ratio and the potential to cause a temporary deficiency of soil N availability. However, with good agronomic practices and well-timed N fertilization, crops perform well after shade tree leaves have been applied without increasing the recommended N fertilizer application rate.**

In 1988, shade tree leaves were banned from landfills and combustion facilities in New Jersey. The initial reason was that siting of new landfills and combustion facilities was difficult and existing landfill capacity had sharply decreased. Additional reasons included leaves in landfills and combustion facilities were lost as a valuable resource but also contributed to gas and leachate emissions in landfills. Furthermore, landfilling and combustion of leaves was costly. Thus, composting and mulching were proposed alternatives, with composting currently being the most common alternative. However, collected shade tree leaves can be a valuable resource as mulch and soil amendment for many agricultural purposes. Every autumn, New Jersey municipalities collect ≈290,000 tons of shade tree leaves. If spread as a mulch in a 6-inch layer, this is enough to cover 14,000 acres (nearly 22 square miles).

When leaves were banned from disposal facilities, the Rutgers New Jersey Agricultural Experiment Station (NJAES) was called upon to develop best practices for on-farm uses of shade tree leaves. Over the last 35 years many studies have been conducted in the state of New Jersey with autumn leaves to understand their composition and chemical properties of shade tree leaves, effect on soil properties and potential uses as an agricultural resource. This review summarizes studies of mulching and amending soils with shade tree leaves and their potential in agricultural production. The review includes studies using shade tree leaves not only as a surface mulch but rather as a soil amendment tilled into the soil.

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[1]Department of Plant Biology, Rutgers University, 59 Dudley Road, New Brunswick, NJ 08901, USA

[2]Department of Environmental Sciences, Rutgers University, 14 College Farm Road, New Brunswick, NJ 08901, USA

[3]Department of Plant Biology, Rutgers University, 121 Northville Road, Bridgeton, NJ 08302, USA

J.R.H. is the corresponding author. E-mail: heckman@njaes.rutgers.edu.

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New Jersey regulations of leaf mulching on farmland

Farms accepting shade tree leaves for mulching and amending soils are required to notify the New Jersey Department of Environmental Protection (NJDEP), Division for Sustainable Waste Management regarding such activity along with the municipality and the county solid waste and recycling coordinators.

Leaf mulching activities on land deemed actively devoted to agricultural or horticultural use, as defined in the Farmland Assessment Act of 1964, N.J.S.A. 54:4–23.5, provided that the activity is consistent with the State Agriculture Development Committee rule at N.J.A.C. 2:76–2A.7 (natural resource conservation agricultural management practice which covers the implementation of a farmland conservation plan), are exempt from obtaining recycling center approval given three stipulations: 1) leaves delivered for mulching are removed from bags, boxes, or similar containers before spreading; all discarded bags, boxes, and similar containers are placed in a suitable refuse receptacle in a staging area for removal to an off-site disposal facility; 2) within 7 d of delivery, the leaves are spread onto the field in a thin layer no higher than 6 inches; and 3) no later than the next tillage season, the leaves are incorporated into the soil.

Composition and chemical properties

Developing beneficial on-farm uses for natural materials should begin with information about its composition. Toward this objective, we sampled shade tree leaves that had been collected by 100 communities across New Jersey (Heckman and Kluchinski 1996). Each sample was visually inspected for leaf species composition, then dried and passed through a grinder before being sent off to an ag-

Units

To convert U.S. to SI, multiply by	U.S. unit	SI unit	To convert SI to U.S., multiply by
0.4047	acre(s)	ha	2.4711
2.54	inch(es)	cm	0.3937
1.1209	lb/acre	$kg \cdot ha^{-1}$	0.8922
2.5900	$mile^2$	km^2	0.3861
0.001	ppm	$g \cdot kg^{-1}$	1000
1	ppm	$mg \cdot kg^{-1}$	1
2.2417	ton(s)/acre	$Mg \cdot ha^{-1}$	0.4461

ricultural laboratory for mineral nutrient analysis. On visual inspection, it appeared that various species of oak (*Quercus* sp.) and maple (*Acer* sp.) were the most common shade tree leaf sources. American sycamore (*Platanus occidentalis*) and sweet gum (*Liquidambar* sp.) leaves and sometimes pine (*Pinus* sp.) needles were occasionally present but not common.

Shade tree leaves may be collected from landscapes by hand raking, lawn mowers with a bagging attachment, leaf blowers, and leaf vacuums. The method used influences the composition of the collected material. For example, lawn mowers may mix in some grass clippings, and raking and vacuuming probably picks up some soil, all of which may influence the composition of the collected material. The inclusion of grass clippings may be expected to increase the nitrogen (N) content (Krogmann et al. 2001). Besides plant materials, community-collected shade tree leaves can be expected to contain some types of trash or litter, such as soda cans or plastic wrappers. This garbage needs to be removed by hand by the farm crew after spreading in the field. Community education programs emphasizing "leaves only" have helped to minimize contamination with trash. Some farmers in New Jersey have worked closely with the communities they accept leaves from to help educate the collectors as well as the homeowners.

The mean chemical composition, based on the 100 samples of community collected shade tree leaves was determined (Heckman and Kluchinski 1996). The laboratory analysis (Table 1) reveals that the material typically has 50 parts carbon (C) to 1 part N. Knowing this ratio is key to understanding how readily a plant residue will decompose and influence N availability in soil. When plant materials have C-to-N ratios much greater than 25:1 they are slower to decompose and in the process of decomposition they initially reduce the availability of N in soil. This was also confirmed in a 25-week laboratory mineralization rate study of leaves with a C-to-N ratio of 35:1 applied to soils from two soil series, Adelphia sandy clay loam (Aquic Hapudults) and Sassafras sandy loam (Typic Hapludults) with and without supplemental ammonium sulfate (Rogers et al. 2001).

Crops growing on soils recently amended with materials rich in C and containing little N often exhibit N deficiency. This is because microorganisms feeding on the energy-rich materials use and deplete the soil of soluble N to balance their metabolism. With time, as metabolism proceeds, carbon dioxide is released to the atmosphere. As the C-to-N ratio shifts to a more favorable balance, more N becomes newly available for crop uptake. Because crops may initially suffer N deficiency from land application of high C-to-N materials, farmers need to be prepared to prevent this from happening.

Although shade tree leaves are rich in C compounds, which build soil organic matter content, the material is relatively low in concentrations of essential plant nutrients (Table 1). On average, community shade tree leaves (dry matter basis) contain as a percentage: 1.0% N 1.0, 0.1% phosphorus (P) [0.23% phosphorus pentoxide (P_2O_5)], 0.38% potassium (K) [0.46% potassium oxide (K_2O)], 0.1% sulfur (S), 1.6% calcium (Ca), and 0.2% magnesium (Mg).

Approximately half of New Jersey soils test above for P fertility levels, which, with nutrient management planning, limits application rates for livestock manures (Heckman et al. 2006). In contrast to manures, the relatively low concentration of nutrients in shade tree leaves may be considered a beneficial attribute for building soil organic matter content. Thus, shade tree leaves can generally be applied at relatively high rates to build soil organic matter without as much concern for excessive application rates of N, P, or K.

A typical land application rate for shade tree leaves is 3-inch layer, which is equivalent to ≈10 tons/acre (dry). This amount can normally be applied with one pass of a manure spreader (Fig. 1). At 10 tons/acre (dry), this applies about (lb/acre) 200 N, 20 P, 75 K, 328 Ca, 48 lb Mg, 0.76 lb boron (B), 29 lb iron (Fe), 11 lb manganese (Mn), 1.6 lb zinc (Zn), 2.2 lb sodium (Na), 25 lb chlorine (Cl), 0.2 lb copper (Cu), 0.06 lb cobalt (Co), and 0.14 lb nickel (Ni).

Table 1. Chemical composition of 100 municipal leaf samples collected in New Jersey in 1993 and 1994. Adapted from Heckman and Kluchinski (1996).

Component	Minimum	Maximum	Median	Mean
Carbon-to-nitrogen ratio	26.8	71.8	48.5	50.0
	($g·kg^{-1}$)[i]			
Carbon	362.8	516.1	480.1	472.7
Nitrogen	6.6	16.2	9.4	10.0
Phosphorus	0.2	2.9	1.0	1.0
Potassium	0.9	8.8	3.6	3.8
Calcium	1.3	30.4	17.3	16.4
Magnesium	0.2	4.6	2.4	2.4
Sulfur	0.1	2.1	1.1	1.1
	($mg·kg^{-1}$)[i]			
Boron	7	72	38	38
Iron	46	9,800	733	1,461
Aluminum	58	10,554	602	1,200
Manganese	19	1,845	406	550
Zinc	22	392	67	81
Sodium	36	325	90	110
Chlorine	68	3,995	1,083	1,264
Copper	2.8	31.5	8.1	9.2
Cobalt	0.9	10.9	2.7	3.1
Cadmium	0.1	6.8	1.3	1.7
Lead	3.1	399.9	18.0	28.4
Nickel	1.1	57.9	5.3	7.2

[i] 1 $g·kg^{-1}$ = 1000 ppm; 1 = $mg·kg^{-1}$ = 1 ppm.

Fig. 1. Two passes with manure spreader applies a 6-inch (15.2-cm) layer of shade tree leaves. This operation was performed in advance of planting pumpkin in plots mulched with shade tree leaves.

As previously indicated by the high C-to-N ratio, the applied N from the shade tree leaves is mostly unavailable for crop uptake in the first growing season. However, the applied N can benefit crops in subsequent years because it is released from soil organic matter decomposition. Much of the applied K is soluble and readily available to crops because release of this mineral is much less dependent microbial decomposition.

Besides essential plant nutrients, collected shade tree leaves also contain some heavy metals (28 ppm lead and 1.7 ppm cadmium). When the concentrations of heavy metals are occasionally elevated, it is likely caused by urban soils that may get mixed in with the collected shade tree leaves (Heckman and Kluchinski 1996).

If soil concentrations of heavy metals increase over time, it depends on the application rate of the leaves and the heavy metal concentration of the initial soil and the leaves. An example calculation of yearly applications of various soil amendments for 100 years can be found at Krogmann et al. (1999).

Soil properties

Land application of shade tree leaves can be expected to increase soil organic matter content and influence soil fertility. Field research was initiated to study changes in soil properties and influence crop production at the Rutgers Snyder Research and Extension Farm, Pittstown, NJ, in 1990 (Heckman and Kluchinski 2000a).

The soil was a Quakertown silt loam: fine-loamy, mixed, active, mesic typic Hapludults. It was amended with collected shade tree leaves at 0, 10, and 20 tons/acre per year for a period of 3 years. Field corn (*Zea mays*) and soybean (*Glycine max*) were grown to test crop response to shade tree leaves.

In the fourth year of the study (after 3 years of land application), soil organic matter content levels had increased from 2.4% in unamended soil to 2.9% in soil amended annually at 10 tons/acre, and to 3.9% in soil amended annually at 20 tons/acre. Thus, a significant amount of the organic carbon that was added to the soil as shade tree leaves for 3 years annually was still present 1 year after the practice was discontinued.

An increase in soil organic N content was also associated with the increase in soil organic matter; organic N increased from 0.1% in the unamended soil to 0.2% in the 20 tons/acre amended soil. This N associated with organic matter may be expected to be released by microbial activity and become slowly available for crop uptake in future years.

Soil test fertility levels as measured by the Mehlich-3 extract showed no changes for most nutrients except for increases in Ca and B levels. Exchangeable Ca saturation increased from 54% in the unamended soil to 60% in the 20 tons/acre-amended soil.

Some farmers (personal communications) have expressed a concern that using shade tree leaves will cause soils to become acid. Although changes in soil pH were not statistically significant, trends (pH 6.2 for the unamended soil, 6.3 for the 10-tons/acre rate, and 6.4 for the 20-tons/acre rate) did not showed evidence for shade tree leaves causing soil acidification.

Another study was conducted assessing the chemical, physical, and biological soil properties after long-term applications of multiple organic wastes including leaves on a commercial farm. Values of soil properties of the sandy loam soil varied systematically from the edge to the center of the fields, suggesting that spatial variation resulting from uneven application of a waste should be considered when assessing amended fields (San Miguel et al. 2012).

Soybean crop response

A legume (Fabaceae) that can furnish itself with N from the atmosphere would seem to be a wise crop choice to grow when limited N availability from soil is a concern. Soybean is an important crop grown on ≈100,000 acres in New Jersey. Although soybean is capable of biological N fixation, soil conditions that make the crop entirely dependent on this process draws on photosynthetic energy that might otherwise boost yield. Also, during the first few weeks before legumes are colonized and fully nodulated with N fixing bacteria, the early plant growth could suffer from N deficiency.

Another concern with legumes is that residues from some tree species may contain allelopathic chemicals with the potential to inhibit plant growth and the biological N fixing process. To investigate this concern (Heckman and Kluchinski 1995), soybean was grown in pots with soils amended with various types of plant residues [composted leaves, as well as individual treatments consisting of red oak (*Quercus rubra*) leaves, sugar maple (*Acer saccharum*) leaves, sycamore (*Platanus occidentalis*) leaves, eastern black walnut (*Juglans nigra*) leaves, rye (*Secale cereale*) straw, field corn stover, or unamended soil].

Early soybean growth exhibited temporary N deficiency with all types of amendments until plants had access to biologically fixed N. Nodulation of the soybean plants was not adversely affected by any of the residue amendments. Soybean plants grown on plant residue–amended soils were more dependent on symbiotically fixed N, and this was associated with lower dry matter yield. This study, conducted with potted plants, demonstrated that when shade tree leaves were composted before amending soil, the problem of N deficiency stress causing harm to soybean biomass yield could be avoided. The study also found no evidence for allelopathic harm to biological N fixation from soils amended with shade tree leaves of various species (Heckman and Kluchinski 1995).

Soybean was also grown in a field environment on a Quakertown silt loam amended (shade tree leaves at 0, 10, and 20 tons/acre per year) during 1990 to 1993 (Heckman and Kluchinski 2000b). The leaves were tilled into the soil in the fall before planting using a chisel plow. Yields on amended soils were comparable or better than on unamended soils. Nodulation of plants was enhanced when grown on shade tree amended soils. Although N deficiency of soybean might be expected when grown on shade tree leaf–amended soil, adding supplemental N fertilizer to the crop did not increase yield on unamended or amended soil. Research suggests field-grown soybean is a crop that performs well on soils amended with collected shade tree leaves using normal agronomic practices. In a field environment, in contrast to potted plants (Heckman and Kluchinski 1995), soybean has access to a larger volume of soil and is apparently less vulnerable to N deficiency.

Field corn crop response

Field corn was grown in the same field and under the same treatments as described for soybean except that N rates of 140 to 240 lb/acre were also compared (Heckman and Kluchinski 2000b). Grain yields generally increased with amending soil with shade tree leaves, but applying more N fertilizer beyond the normal recommended rate did not further increase yield. In one of the growing seasons with an unusually wet spring, field corn plant population and grain yield were reduced on shade tree leaf amended soil.

During summer dry weather periods soil moisture was measured in the field corn plots. Soils amended with shade tree leaves held more moisture than unamended soils. This difference in soil moisture availability was exhibited by more severe leaf rolling in the field corn plants growing on unamended soil.

In the preceding section on soil properties, it was reported that amending soils with leaves increased the levels of exchangeable Ca. Plant tissue samples collected from both soybean and field corn found increased concentrations of Ca in both crop species.

Pumpkin crop response

Pumpkin (*Cucurbita pepo*) was grown in a field environment that would simulate a pick-your-own operation (Wyenandt et al. 2008a). The soil was a Quakertown silt loam mulched with shade tree leaves at 0 or 20 tons/acre in 2006 and 2007. The leaf mulch was applied immediately before seeding the pumpkin in mid-June. The leaf mulch had been stockpiled the previous autumn. Using two passes of a manure spreader a 6-inch layer of leaves provided a thick layer of mulch. Seeds were hand planted in the soil by brushing the leaf mulch aside (Wyenandt et al. 2008a).

Pumpkin fruit yields where leaf mulch was applied were equivalent to or better than the typical bare soil production system using herbicide. The leaf mulch provided excellent control of annual type weeds. Leaf mulch plots tended to produce fewer but larger fruit. One special benefit of this production system is that the fruit sides and bottoms were kept clean by the mulch. In contrast, bare ground allowed soil to splash on to pumpkins, and it adhered to the fruit. Other work evaluating the use of different cover crops as mulches during the production season to help reduce disease development and improve fruit cleanliness have shown similar results in pumpkin and processing tomato (*Solanum lycopersicum*) (Wyenandt et al. 2008b, 2009, 2010).

Applying more than the usual recommended rate of N fertilizer did not increase fruit production. Early season N deficiency is a concern for pumpkin grown with leaf mulch. However, as long as the crop is given an application of N fertilizer alongside the crop row on a timely basis, N deficiency can be prevented (Fig. 2).

Crop rotation after a legume cover crop is another strategy to prevent early season N deficiency when pumpkin is grown with leaf mulch (unpublished data). Findings from this field study demonstrated that the leaf mulch was effective in suppressing weeds, controlling soil erosion, and keeping pumpkin fruit clean (Fig. 3). The leaf mulch was also observed to provide an attractive, mud-free surface for families that might want to walk into such fields as part of a pick-your-own operation. Thus, leaves left on the soil surface without tillage can serve as a mulch with multiple benefits.

Sweet corn (*Z. mays*) crop response to leaf mulch residue

The year after pumpkin was grown with leaf mulch or bare ground, the plots were planted to sweet corn (Heckman et al. 2011). After sweet corn harvest, the plots were planted to a rye cover crop. Before the plots were tilled to prepare the soil for planting sweet corn, there remained a thin layer of leaf mulch residue on the soil surface. This mulch layer protected the soil from erosion and conserved soil moisture. In the previous field experiment with pumpkin, the 20 tons/acre of leaf mulch applied ≈400 lb/acre N. Even with this considerable amount of added N, crops grown shortly after application of leaves are vulnerable to N deficiency due to immobilization of soil N supply. However, in growing seasons after the initial leaf mulch application, most of the carbon-rich leaf residue was already metabolized. In the process, much of the N associated with that carbon was released and available for crop uptake. The sweet corn and rye cover crops following the mulched pumpkin captured and used the N.

Sweet corn yield and ear size was increased when grown on land that had been mulched for pumpkin production in the previous year. Adding

Fig. 2. Pumpkin plot (front) mulched with 6-inch (15.2-cm) layer of shade tree leaves and pumpkin plot with bare soil (back). Note pumpkin plants with leaf mulch exhibited an early season deficiency of nitrogen (N) until supplemental N fertilizer was side dressed along each row.

supplemental (sidedress) N fertilizer did little to increase yield or ear size further. Thus, the residual N from the leaf mulch was able to supply a substantial portion of the N required for sweet corn production. When sweet corn was grown on the land that never received the leaf mulch, yield and ear size was responsive to supplemental (sidedress) N fertilizer. In general, sweet corn crop performance was better on land following leaf mulch compared with bare ground.

Rye cover crop response to leaf mulch residue

A rye cover crop seeded in the fall after harvest of sweet corn exhibited growth responses in the spring to leaf

Fig. 3. Pumpkin (top) harvested from bare ground plots have soil clinging to the fruit. Pumpkins (bottom) harvested from mulched plots are relatively clean except for a small amount of leaf residue.

mulch used 2 years previously for pumpkin production (Heckman et al. 2011). The rye cover crop biomass, N uptake, and plant height measurements demonstrated that a large amount of N applied as shade tree leaves can provide agronomically useful amounts of available N for at least 2 years after its application.

Lima pole bean (*Phaseolus lunatus*) crop response to leaf mulch

In 2011, lima pole bean plants were transplanted into Sassafras sandy loam (Fine-loamy, siliceous, semiactive, mesic Typic Hapludults) soil at the Rutgers Horticulture Farm-3, New Brunswick, NJ. Half of the plots were mulched with a 6-inch layer of shade tree leaves and compared with bare ground that was hand hoed for weed control. The leaf mulch was applied immediately after transplanting. The mulch provided good weed control. However, the leaf mulch seemed to slow the early growth of the lima pole bean plants. Because the lima pole bean trellis was not strong enough to support the crop, data were compromised and never published. Shade tree leaves appear to be useful as a mulch between rows of lima pole beans, but the mulch should not be applied too close to the new transplants.

Peach (*Prunus persica*) orchard response to leaf mulch

A peach orchard was established on a Sassafras Sandy soil (US Department of Agriculture, Sustainable Agriculture Research and Education 2002) at a farm near Richwood, NJ. Transplanted trees were mulched with a 6-inch layer of shade tree leaves and compared with bare-ground culture. After the first growing season, the trunk cross-sectional area was 10% greater than where trees were not mulched. By the end of the second growing season, the trunk cross-sectional area was 13% greater for the mulched trees. Adding supplemental N fertilizer further increased tree growth over mulch alone. Soil under mulched trees had better moisture retention compared with trees with bare ground. Although yield was not measured, trunk and tree size are generally associated with increases in peach yield.

Animal bedding with shade tree leaves

An alternative to direct application of shade tree leaves to farmland is to use it as a bedding material for livestock (Fig. 4). Farmers have reported (personal communications) that animals seem to find shade tree leaves as comfortable bedding. Leaves that are relatively dry and rich in carbon help to soak up urine and fecal material and improve animal hygiene. The used bedding, a mix of leaves and manure, should have a more favorable C/N ratio for composting or more rapid decomposition when land applied.

Fig. 4. Collected shade tree leaves may be used for livestock bedding. Note that bold instructions on bag are an educational effort to keep out trash.

Conclusions

Research at Rutgers NJAES has identified many ways to use community collected shade tree leaves as a beneficial resource on local farms. Agricultural uses for shade tree leaves keeps this material out of landfills and builds community relationships between urban centers and farmers (Heckman 2013). In the process nutrients are recycled to restore fertility and soil organic matter content and soil health is enhanced.

The NJDEP requires that land applied shade tree leaves be incorporated into soil with tillage. This regulation should be reconsidered given that surface mulching with shade tree leaves can benefit many crops. Leaf mulch on the surface can provide excellent weed control without herbicides, enhance orchard tree establishment, prevent soil splash onto crops, and protect against soil erosion.

Because collected shade tree leaves have a C-to-N ratio of 50:1, they have the potential to cause N deficiency in crops in the first year after application. Having legumes in the crop rotation or planting a N-fixing crop after shade tree land application should mitigate concerns with N deficiency. However, research shows that even nonlegumes such as corn can perform well in the first year after shade tree leaves land application when given the usual recommended N fertilizer rate. Pumpkin also performs well with the usual recommended N fertilizer rate so long as the supplemental sidedress N application is applied early enough to prevent N deficiency. In general, there appears to be no need to increase the rate of N fertilizer when using shade tree leaves in crop production. Shade tree leaves add substantial amounts of N to soil that slowly becomes available to crops in the second and third years after application. This slow-release N benefits subsequent crops in rotation and may reduce the need for supplemental N fertilizer. Beyond crop production, shade tree leaves also may be used for livestock bedding. The urine and fecal soaked bedding material should have a more favorable C-to-N ratio for compost or land application as manure.

References

Heckman, J.R. 2013. Soil fertility management a century ago in farmers of forty centuries. Sustainability 5:2796–2801, https://doi.org/10.3390/su5062796.

Heckman, J.R. and D. Kluchinski. 1995. Soybean growth and nodulation on soil amended with plant residues. Biol. Fertil. Soils 20:284–288, https://doi.org/10.1007/bf00336091.

Heckman, J.R. and D. Kluchinski. 1996. Chemical composition of municipal leaf waste and hand-collected leaf litter. J. Environ. Qual. 25:355–362. https://doi.org/10.2134/jeq1996.00472425002500020019x.

Heckman, J.R. and D. Kluchinski. 2000a. Agronomics of land application of municipal collected shade tree leaves, I. Soil properties. J. Sustain. Agric. 17:33–40, https://doi.org/10.1300/J064v17n02_05.

Heckman, J.R. and D. Kluchinski. 2000b. Agronomics of land application of municipal collected shade tree leaves, II. Soybean and corn production. J. Sustain.

Agric. 17:41–52, https://doi.org/10.1300/J064v17n02_06.

Heckman, J.R., W. Jokela, T. Morris, D. Beegle, T. Sims, F. Coale, S. Herbert, T. Griffin, B. Hoskins, J. Jemison, M. Sullivan, D.K. Bhmumla, G. Estes, and W.S. Reid. 2006. Calibration of soil test phosphorus for corn in the northeast USA. Agron. J. 98:280–288, https://doi.org/10.2134/AGRONJ2005-0122.

Heckman, J.R., C.A. Wyenandt, and M. Provance-Bowley. 2011. Residual effects of leaf mulch on sweet corn and rye. J. Sustain. Agric. 35:639–649, https://doi.org/10.1080/10440046.2011.586592.

Krogmann, U., J.R. Heckman, and L.S. Boyles. 2001. Nitrogen mineralization of grass clippings - A case study in fall cabbage production. Compost Sci. Util. 9: 230–240, https://doi.org/10.1080/1065657X.2001.10702040.

Krogmann, U., J. Heckman, L. Boyles, and C. Wielderhold. 1999. Land application of sewage sludge (Biosolids) #6: Soil amendments and heavy metals. Rutgers New Jersey Agric Exp Sta Fact Sheet 956.

Rogers, B.F., U. Krogmann, and L.S. Boyles. 2001. Nitrogen mineralization rates of soils amended with nontraditional organic wastes. Soil Sci. 166:353–363, https://doi.org/10.1007/s004420050157.

San Miguel, C., D. Giménez, U. Krogmann, and S.W. Yoon. 2012. Impact of land application of cranberry processing residuals, leaves and biosolids pellets on a sandy loam soil. Appl. Soil Ecol. 53:31–38, https://doi.org/10.1016/J.APSOIL.2011.11.001.

US Department of Agriculture, Sustainable Agriculture Research and Education. 2002. Utilization of community leaves for improving orchard soil quality. Project Rep LNE99-129. https://projects.sare.org/project-reports/lne99-129/ [accessed 10 Aug 2022].

Wyenandt, C.A., J.R. Heckman, and N.L. Maxwell. 2008a. Pumpkin fruit size and quality improves with leaf mulch. HortTechnology 18:361–364, https://doi.org/10.21273/HORTTECH.18.3.361.

Wyenandt, C.A., L.H. Rhodes, M.A. Bennett, and R.M. Riedel. 2008b. Cover crop mulch and fungicide program affect development of septoria leaf spot and marketable yield in processing tomato production. HortScience 43:807–810, https://doi.org/10.21273/HORTSCI.43.3.807.

Wyenandt, C.A., L.H. Rhodes, M.A. Bennett, and R.M. Riedel. 2009. Control of fruit rots of processing tomato using cover crops and Tom-Cast. HortTechnology 19:511–517, https://doi.org/10.21273/HORTSCI.19.3.511C.

Wyenandt, C.A., R.M. Riedel, L.H. Rhodes, M.A. Bennett, and S.G.P. Nameth. 2010. Fall and spring-sown cover crop mulches affect yield, fruit cleanliness, and fusarium fruit rot development in pumpkin. HortTechnology 21:343–354, https://doi.org/10.21273/HORTTECH.21.3.343.