# Demonstration of an agroforestry system to minimize pollution hazards from land application of treated municipal sludge

***Abstract:*** *Iowa has over 700 communities that generate municipal biosolids by various treatment means. These biosolids contain valuable nutrients. In this study, municipal biosolids are applied to trees, perennial grasses, and corn/soybean crops in an alley cropping (repeated tree strips combined with crops) system. The goal is to produce economical quantities of biomass and grains with reduced use of fossil fuel-based fertilizers and minimal environmental impacts.*

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**Budget:**
$20,000 for year one
$20,000 for year two
$20,000 for year three

## Background

In 1990 the Iowa State Agroforestry Research Team (IStART), a multidisciplinary team of scientists from ISU's departments of agronomy, geological and atmospheric sciences, forestry, and mechanical engineering started the Ames Agroforestry Project with the City of Ames Water Pollution Control Facility (AWPCF) and the Iowa Department of Natural Resources (IDNR)—Energy Bureau.

The goal was to develop a renewable energy, alley cropping system, using municipal biosolids to increase the biomass production of woody and nonwoody, perennial, and annual plants for generating electricity. An alley cropping system consisting of fast-growing trees, herbaceous crops, and corn/soybean strips has been established on 40 ac of land adjacent to the City of Ames WPCF.

Biosolids, according to the U.S. EPA, are solid, semi-solid, or liquid residue generated during the treatment of domestic sewage in a treatment works. Biosolids are that portion of the wastewater solids stream which meets federal and state regulations for beneficial use by land application or other methods.

Biosolids are used as fertilizer for the alley cropping systems. The products (woody biomass and grass biomass) are designed to be used as energy feed-stock or as fiber for manufactured biocomposite products such as medium-density fiberboard.

While municipal biosolids are recognized as a potential source of crop nutrients, and are applied as a soil amendment to crop and forest land, public concern about the fate of transition and heavy metals in biosolids has been great. Amid the awareness of the potential for groundwater contamination, current national regulations limit annual land application of sewage sludge on the basis of the assumed utilization of nutrients by crops and total loading of metals in the soils. Phosphorus is known to contribute to degradation of surface water quality, and it is found in biosolids at fully half the concentration of the nitrogen content.

Objectives of the project were to:
- compare corn and soybean yields in the traditional row-crop system, with and without municipal biosolids amendments, with corn, switchgrass, and tree yields in an agroforestry system with and without biosolids applications,
- quantify perennial and annual crop utilization versus translocation below the root zone or leaching to groundwater of nitrogen, phosphorus, and heavy metals applied with the municipal biosolids in an agroforestry system, and
- develop a signed, self-guided educational trail in the agroforestry system, develop two extension bulletins, one directed at

farmers and one a municipal managers, and hold two field days at the project site, one directed at farmers and one at municipal managers.

## Approach and methods

*Design.* Six replications of alley crops of trees, herbaceous biomass, and crops were planted from 1990 to 1992. Two replicates located together along a 1200 A long strip are subdivided into three equally long plots which are assigned three different biosolids application rates. Zero (0) X is the control with no biosolids applied, 1X stands for application of approximately 150 lbs/ac/yr of available nitrogen, and 2X is twice the 1X rate.

Within each replication are three sets of closely planted rows of hybrid poplar trees. Each replication contains three non-tree crops; switchgrass (reed canarygrass in replications 5 and 6), corn, and soybean. The woody biomass and the herbaceous biomass or crops are planted alternately within each replication.

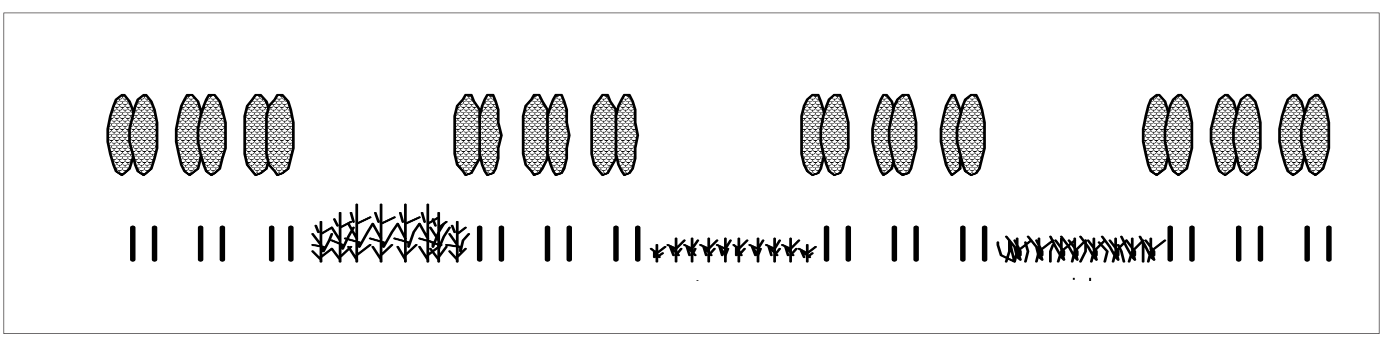
*Corn and soybean yields in the alley cropping system.* In 1995, within replications 1 and 2 where the oldest and tallest poplar trees were, test plots for corn and soybean yields within and across the alleys were established. The crop yield test plots were in the 0X and 2X treatment plots. The corn and soybean yields were taken to assess the impact of the trees in terms of shade and root competition on the annual crops. In 1996, the focus shifted to determination of the microclimatic impacts within and across the tree and crop alleys. Crop yields were to be taken as in 1995 but, due to a miscommunication with the farmer, all alleys were harvested before the researchers were able to obtain corn and soybean measurements.

In 1997, soybean yields were sampled in replications 1 and 2. The farmer who worked the land and the City of Ames decided to plant only soybeans in all replications because of the very strong market prices for beans.

*Microclimatic variations in the alley cropping system.* Crop yield data from 1995 show a classic curvilinear response in the alley cropping systems across the alley with a maximum corn or soybean yield in the center rows and a minimum at the edges close to the trees. The literature has suggested that this could be the result of root competition between the trees and the crops or reduction of light nearest the trees resulting in lower photosynthetic activity and biomass production.

*Economics of the alley cropping system.* An economic model was developed that includes market products, and assumes constant prices and costs only for the biosolids biomass agroforestry system. Thus, extra market benefits such as wildlife value, and benefits associated with producing renewable energy crops are not included in this study.

***Typical layout of tree strips and crop alleys for a replication.***



Twelve agroforestry designs of hybrid poplar, switchgrass, reed canarygrass, and soybean following corn at four different rotation lengths (seven to ten years) for the trees were evaluated. The study and continuing research will select the best system in terms of annual equivalent value, and do sensitivity analyses on the system.

Three basic agroforestry systems were compared:

- hybrid poplar with reed canarygrass
- hybrid poplar with switchgrass
- hybrid poplar with corn/soybean

Four rotation ages (the interval length for production of woody biomass) were considered. For each of the three basic agroforestry systems four rotation age variants were applied: 7,8,9, or 10 years. Twelve models were evaluated in terms of annual equivalent value (AEV), the net return per acre per year from each model.

*Effects of biosolids amendments on total phosphorus in soil and water.* Accumulation of phosphorus (P) in soil drainage waters in response to biosolids application has been reported in this study. When the biosolids application rate is based on the potentially available nitrogen in the sludge biosolids, the total P applied is generally much greater than the crop needs. Once soil P levels become excessive, the potential for P loss in runoff and drainage water could be a disadvantage greater than any agronomic or biomass benefit.

Researchers here studied the mobility of P derived from surface-applied municipal biosolids in the soil, to observe the effect of biosolids amendment on P in the mobile soil water, and to examine if P would threaten groundwater after biosolids are applied to a soil with high soil total P.

Four replications of three treatments were studied. The three biosolids target application rates were control (zero pounds of N per acre

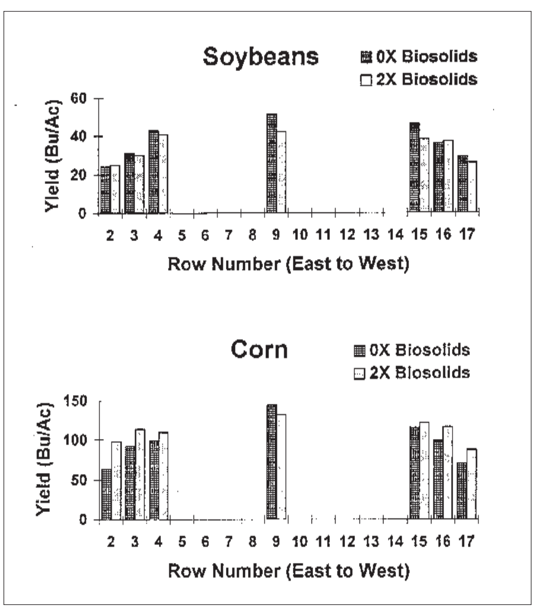
***In 1997, the crop fields to the north (bottom of picture) and east (left) were planted with soybeans as well all alleys in Replications 1 and 2 and the easternmost alleys in Replications 3 and 4 shown on the right***

per year), low (about 150 lbs. per acre per year) and high (twice the low rate). The biosolids rates are based on the plant uptake of nitrogen. Actual application rates averaged 107 and 196 lb available N/A/year for the 1X and 2X biosolids treatments, respectively. The biosolids were surface-applied to the poplar trees and switchgrass plots.

Soils were sampled each fall at depths of 0 to 2 and 2 to 10 in. Soil samples were composited from four grid-point locations in each plot and checked for organic carbon and total nitrogen, pH, phosphorus, and four trace metals.

*Trace metals in biosolids-amended soils under perennial crops.* High levels of trace metals in sewage biosolids could be detrimental to vegetation as well as to human and animal health. This research was conducted to examine the effects of biosolids application on accumulation of trace metals in soils under the herbaceous and woody biomass crops (switchgrass and poplar hybrid) at the Ames Water Pollution Control facility.

Ames biosolids do not contain high concentrations of trace metals. A typical analysis is: lead, 0.015%; copper, 0.070%; nickel, 0.004%; and zinc, 0.089%. These concentrations are well below the current regulatory concentration limits for application of Class II biosolids.




***Soybean and corn yields as influenced by proximity to the tree alley in Replications 1 and 2 for the 1995 crop year.***

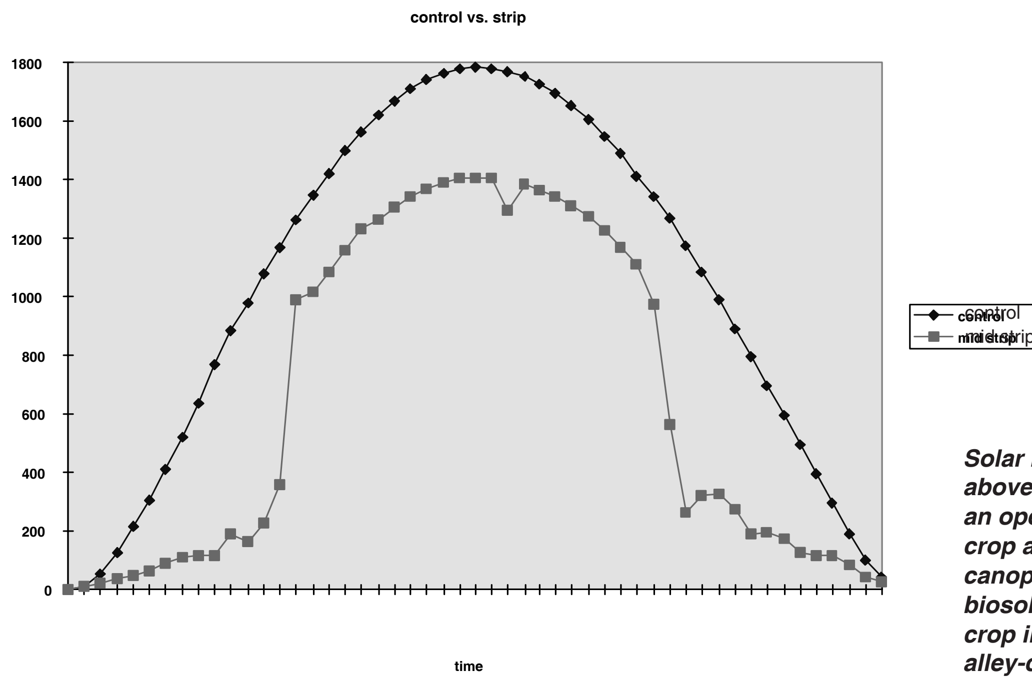
*Educational activities.* An informational kiosk was built and placed near the main administration building at the AWPCF. A 12- to 15-panel poster was developed to explain the project at field days and open houses. A ten- to 12-station self-guided trail was created along with a pamphlet to allow visitors to understand the agroforestry system, the use of biosolids, and the expected benefits from the study. Field days, sponsored tours, and on-demand site visits have been held.

## Results and discussion

*Corn yields in the alley cropping system.* In 1995, the corn crop yield from the unsheltered eastern field was 132 bu/acre, whereas corn yield in replications 1 and 2 from the 1X treatment plots was 115 bu/acre, and for the 2X treatment plots 120 bu/acre. Because of different varieties planted and crop management tactics by the farmer, this is not a direct comparison and serves only to suggest that corn yield in the alley cropping system may be reduced by about 10 to 15 percent.

The 1997 crop yields for corn and soybean from unsheltered fields to the east and north of the alley cropping system were 132 bu/acre and 47 bu/acre, respectively. The corn field received about 1X application of biosolids whereas the soybean plot received an application of potassium (KCl) to achieve a desired macronutrient level.

*Soybean yields in the alley cropping system.* In 1995, the soybean production in replications 1 and 2 averaged 41 bu/acre. The yield from the 0X (control) treatment plots was greater at 44 bu/acre than the 38 bu/acre from the 2X biosolids application plots. For soybeans in 1995, the alley yields were 20 to 33 percent lower compared with the southern




***Solar radiation just above the canopy of an open-field corn crop and above the canopy of the 1X biosolids-treated corn crop in a four-year old alley-cropping system.***

unsheltered soybean field. The greatest yields were in the center rows and the lowest yields occurred in the outside rows near the trees.

In 1997, the soybean yields in replications 1 through 4 were determined in the 0X and 2X treatment plots. Two alleys in each replication, except on replications 1 and 2, were sampled. The eastern-most alley in replication 1 and 2 was converted from switchgrass to soybean in spring 1997 and soybean production was affected by the residual switchgrass plants and sod. Mean grain yields for the 0X plots (39 bu/acre) were greater than those from the 2X plots at 34 bu/acre. Yields were greater in the center row and lower in the outer rows.

*Microclimatic variation in the alley cropping system.* Based on preliminary data in 1996, there were no significant differences in the microclimatic variables between the biosolids treatments within the alleys. This is expected as only canopy surface conditions were monitored and only slight differences in crop height existed at the time of the measurement.

There were significant differences in solar radiation between the alley treatments and the open-field control. The preliminary results showed strong trends which help explain the differences in yield and which could be used to help determine the optimum width of the alleys to maximize crop production.

Wind, temperature, and humidity show only average differences between the alley and the open-field control plots. Wind speed in the top of the canopy of open-field plots was most often higher than in the alley. The humidity in the upper canopy of the open-field control plots was higher early in the morning, but there were no differences between the two treatments in humidity during the rest of the day. Average temperatures in the top of the crop canopies were higher in the open-field control for most of the day. During the peak of solar radiation, from about noon to 4 pm, temperatures did not differ between the two treatments. Solar radiation differences in the open field control canopy and the alley canopy were significantly different. Even with the benefits of higher humidities and lower wind and temperatures, however, the shorter period of radiation inputs resulted in yield reductions for the alley crops.

*Soil quality.* Concentrations of organic carbon and N were greater at the soil surface than in the subsurface zone. As the rate of biosolids application increased, the difference in surface and subsurface concentrations of C, N, and P increased. In the 0 to 2 inch zone, the total P contents were greater than those at the 2 to 10 inch zone of plots with biosolids application, but no consistent differences were found in total phosphorus with depth in plots where no biosolids were applied. The amounts of extractable nitrate-N were positively correlated with the levels of biosolids application.

*Total soil phosphorus.* After five years of biosolids amendment, total P in the soil of the poplar plots was significantly different between any two of the three treatments at the 0 to 2 inch depth. At the 2 to 10 inch depth of the poplar plots, total P was significantly different between the control and high-rate applications. Biosolids amendments to the switchgrass plots were stopped after 1993, but total P was still significantly different between any two of the three treatments at the 0 to 2 inch depth of soils sampled in 1995. At the subsurface depths, there was no difference in soil total P among the three treatments of the switchgrass plots. This was in contrast to the poplar plots were continuous, heavy biosolids amendments resulted in some transport of P below the 2-inch depth.

***Harvesting corn in October 1995 in the ailey in Replications 1 and 2. Note the height variation on the eastern half of the rows within the alley.***

*Total phosphorus in the poplar plots over time.* Because of the biosolids amendments, total P at the 0 to 2 inch depth of soils increased dramatically year by year since 1991 in both low and high biosolids amendment plots, except in 1994 when no biosolids were applied.

*Effect of biosolids amendments on P in mobile soil water.* The greatest mean P concentration was found in the mobile soil water samples collected from the low-rate biosolids plots rather than from the high-rate plots. It is believed that the higher salt content of the high-rate plots increased sorption of P from the biosolids.

Conclusions on soil quality were:

- Biosolids amendments at either the low or high level had a significant impact on total P in the 0 to 2 inch of soils under both poplars and switchgrass. In the poplars, part of the added P moved below the 2-inch depth. At the 2 to 10 inch depth, in the high-rate poplar plots, total P increased significantly.

- Biosolids amendments increased P concentrations in mobile soil water (collected with zero-tension lysimeters at the 20 inch depth). P concentrations were greater in mobile soil water collected from the low-rate plots than from high-rate plots.

- Biosolids amendment had little effect on P concentration in groundwater, even when total soil P was high.

*Trace metals in biosolids-amended soils under perennial crops.* The total concentration of Zn, Cu, and Pb increased as a result of biosolids applications, but there was no significant change in soil Ni concentrations due to applied biosolids. Available Cu and Zn at the soil surface increased under both crops in the biosolids treated plots. There was a slight increase in available Pb as a result of biosolids application. Although soil pH decreased due to biosolids application, the concentrations of available metals (especially Zn and Cu) were well below phytotoxic (poisonous to plants) levels. For the present trace metal studies are complete.

Even though the pH of the biosolids-treated plots decreased, most of the metals added to the soil with the biosolids under each crop remained in the upper 0 to 2 inch depth after six years, implying limited translocation. The high clay and organic C contents of the soils provided a large retention capacity for metals. In addition, less than 15 percent increase in the extractable metals confirmed that major portions of the added metals were precipitated or sorbed to the soil solid phase in unavailable forms. These factors probably prevented subsurface translocation of trace metals.

## Conclusions

Based on the corn and soybean yields from 1995 and 1997, the trees lowered yields by 10 to 15 percent for corn and 20 to 33 percent for soybeans within the 50 ft. wide alley when compared to the open-grown production from fields to the north and east.

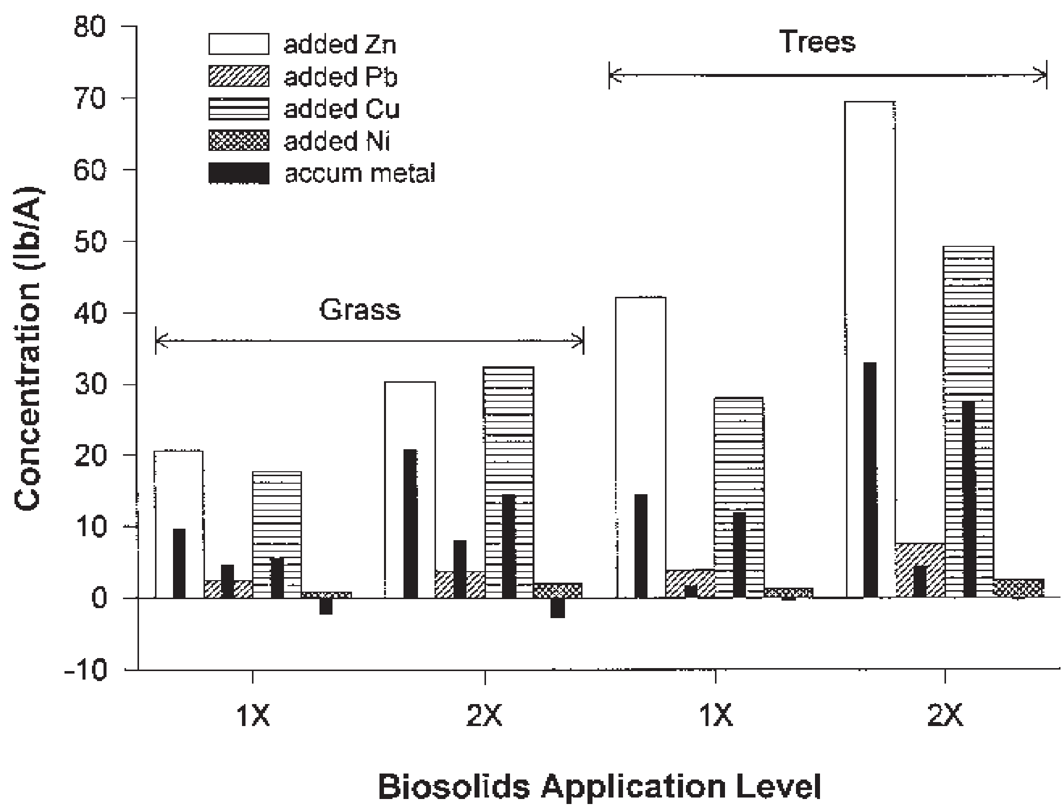
As for microclimatic changes within the top of canopy of the alley crops, wind speed is reduced, humidity is higher in the morning, and temperatures are lower throughout the rest of the day. Solar radiation inputs were as much as three to four hours less in the alleys than in the open-field control plots. Root competition between the trees and the crops does exist but is reduced with distance away from the trees and with higher biosolids inputs. These results suggest that alley width could be optimized to increase average yield of the alley. While a reduction in yield will always be expected in the first several rows near the trees, an increase in yield should be likely for the remaining rows as the alley is widened to an optimal width.

On the economic side, all models, except hybrid poplar/reed canarygrass when the rotation length is seven years and land cost is assumed to be $0 per acre, are profitable. The most profitable system in terms of annual equivalent worth (AEV-$/acre/year) is the hybrid poplar/soybean following corn year. Its AEVs vary from a low of about $75/acre/year to over $87/acre/year.

The concentration of nitrate-N in mobile soil water (sampled with the zero-tension lysimeters installed at about 20 inches depth in the research plots) was positively correlated with the level of biosolids applied to the soil. The concentrations of nitrate in soil water in or near the root zone are below levels that would raise environmental concerns. Nitrate-N occurs in the groundwater below the site at concentrations of less than 1 mg $mL^{-1}$.

Biosolids amendments at both the high and low levels increased the concentration of total phosphorus in the 0 to 2 inches of soils under both the poplars and switchgrass. In the poplars, part of the added P moved below the 2 inch depth. At the 2 to 10 inch depth in the high-rate poplar plots, total P increased significantly. Biosolids amendments increased P concentrations in mobile soil water (collected with zero-tension lysimeters) at the 20 inch depth. Phosphorus concentrations were greater in mobile soil water collected from low-rate plots than from high-rate plots. Biosolids amendment had little effect on P concentrations in groundwater.

*Trace metals.* The total concentration of Zn, Cu, and Pb increased as a result of biosolids applications, but there was no significant




***Additions and accumulations of biosolids-borne metals at the 0-2 inch depth of soil under each crop at the research site.***

change in soil N concentrations due to applied biosolids. Available Cu and Zn at the soil surface increased under both crops in the biosolids treated plots. There was a slight increase in available Pb as a result of biosolid treatment. Although soil pH decreased due to biosolids application, the concentrations of available metals (especially Zn and Cu) were well below phytotoxic levels.

Even though pH decreased on most of the biosolids treated plots, the bulk of the metals added to the soil with the biosolids under each crop remained in the upper 0 to 2 inch depth after six years, implying limited translocation. The high clay and organic C contents of the soils provided large retention capacity for metals. The results also suggest that pH management of biosolids-amended soil is important. Since only one soil type was studied at the WPCF, we cannot extrapolate to other soils. Over the long term, increasingly, acidic conditions in amended soil increase the mobility and bioavailability of the trace metals.

*Information.* The kiosk and 12-panel poster have been used frequently and to good effect. The self-guided tour proved to be less viable given the small number of people who choose to visit the Ames WPCF. Several successful field tours for the general public, farmers, scientists, and the staff of the Ames WPCF have been staged since 1995.

## Impacts of results

- There was a yield reduction for corn and soybeans grown in 50 ft. wide alleys between 40 ft. tall hybrid poplar trees. Based on other shelterbelt research, we know that the crop alleys in the Ames system are too narrow to optimize yield.
- Application of biosolids with N, P, and K increased the tree biomass production. The tree biomass is enhanced by over 40 percent when about 200 lb/acre of available N is applied annually in the biosolids compared with no application of nitrogen.
- There was no significant "leakage" of N from the system below the trees, grass, or annual crops. There was a buildup of soil P, but with effective above-ground management including protection from erosion at harvesting, this should not be a problem.
- There was no measurable negative impact on the groundwater quality.
- This alley cropping system with between 100 to 200 lbs/acre/year of available N added from the municipal biosolids can serve as a model system for farmers who are considering establishment of a tree shelterbelt on their swine farms. The trees respond to high rates of nutrient loading. Where soils have high organic matter and clay contents and are protected from erosion, off-site impacts of biosolids applications are likely to be minimal.

## Education and outreach

**1995**: Groups of scientists and administrators from the People's Republic of China toured the project site in September and November. The dean of environmental studies at a Cairo, Egypt university visited the agroforestry research plots in November and was guided by Carl Mize. A Town and Country Tour of the Ames Water Pollution Control Facility was held in August and about 50 people attended to hear members of the team give presentations about the tree and annual crop production and soil and water quality. Joe Colletti presented a paper on the project and the economic aspects at the Fourth North American Agroforestry Conference in Boise, Idaho during the summer of 1995.

**1996**: A group of Illinois farmers interested in sustainable agriculture toured the site in spring 1996. As part of the ISU Agronomy Days event, tours were arranged for participants to

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view the Ames WPCF project site. The Town and Country Tour of the Ames Water Pollution Control Facility was once again held in August and about 50 people visited the facility and research plots.

**1997**: A tour of the project was arranged for the participants at a regional biomass conference held in Des Moines in fall 1997. Tours of the project site were again offered to those who attended the September ISU Agronomy Days. The Ames WPCF was one of the tour options for participants at the Leopold Center's tenth anniversary conference in July.