THE CURRENT STATUS ON THE SELECTION AND MANAGEMENT OF VEGETATION FOR SLOW RATE AND OVERLAND FLOW APPLICATION SYSTEMS TO TREAT MUNICIPAL WASTEWATER IN THE NORTH CENTRAL REGION OF THE UNITED STATES

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INTRODUCTION

The 1977 Clean Water Amendments to Public Law 92-500 were enacted to strengthen the original policy of encouraging the utilization of innovative, alternative management techniques for the treatment and disposal of municipal wastewater. These alternative techniques include spray irrigation and overland flow land treatment systems which can be used individually or combined with lagoons. The lagoons serve as pre-treatment systems for settling, microbial degradation of BOD, and/or for storage during periods of cold or wet weather. The proper selection and management of vegetation is critical for the efficient renovation of municipal wastewater by slow rate, overland flow, or spray irrigation systems.

A number of major research projects have been underway in the north central region of the United States for several years. Among them are: the Michigan State University Water Quality Management Facility (WQMF), the Muskegon County Land Treatment Facility at Muskegon, Michigan, land application on crops in Minnesota in a joint U.S. Department of Agriculture/U.S. Army Corps of Engineers study, and land application on forests in the north central region by the U.S. Forest Service. When supplemented with findings from other projects in adjacent regions, such as The Pennsylvania State University system and the overland flow system at the U.S. Army Cold Regions Research and Engineering Laboratory (CRREL) in Hanover, New Hampshire, these projects have resulted in the accumulation of sufficient data to formulate guidelines to improve present wastewater renovation and vegetation management concepts. Nonetheless, until now very few attempts have been made to compile the results into a set of guidelines to select and manage vegetation.

SITE CHARACTERISTICS AND SYSTEM OPERATING PARAMETERS

The selection of land treatment relative to other methods depends on the size of the community and the expertise of local system operators, as well as the cost, quantity, and type of land available. The necessary expertise requires less formal training and emphasizes agronomic skills that are more apt to be available in small rural communities than the specialized skills needed to operate an advanced, centralized system. However, these land treatment techniques may not be economically feasible for large communities with limited access to reasonably priced rural land.

Once land treatment has been determined to be feasible, guidelines to operate and manage the system can be recommended based on local soil conditions and appropriate types of vegetation. Protecting the groundwater is a primary consideration. Over the past 18 years, land application has been studied on various research sites that span a broad range of soil types from spodosols to alfisols and mollisols with an array of cation-exchange capacities and organic matter.

To date, spray irrigation has been the most common land treatment method adopted in the north central United States. A wide variety of application techniques have been used, but center-pivot rigs or solid set distribution systems are most common. These systems can be used on flat, extensively undulating, and very steep land if the soil is moderately to highly permeable and the location has appropriate borders to protect the public from wind drift and/or spray aerosol. Flood irrigation, ridge and furrow, or other such practices may be more appropriate if borders are not available, or if the topography and soils are more suitable for these practices.

The responses of crops to slow rate wastewater application has been quite similar on all types of soil as long as the infiltration rate was not routinely exceeded. On sites with slow infiltration rates, for example fine textured soils that are only slowly permeable, an overland flow system may be more suitable depending on the topography. The land should be graded so that the water spreads uniformly, and the soil surface should be inspected frequently for incipient downslope channeling.

MANAGEMENT RECOMMENDATIONS FOR NITROGEN REMOVAL

Extensive research has been conducted on the relative quantities of phosphorus and nitrogen that can be removed by the soil and vegetation during various periods of the growing season. Whereas renovating the wastewater so as to preserve the quality of the groundwater is the primary goal, it sometimes conflicts with the secondary consideration of maximizing agricultural yields and profits. Frequently, recommendations for the land application of wastewater have been based on nitrogen mass balance data because nitrate-nitrogen can be readily leached from these systems at levels in excess of the drinking water standard. Therefore, the nitrogen application rates must be correlated with the levels of removal by the plant systems and soils to prevent excess nitrate-nitrogen from leaching into the groundwater.

While municipal wastewaters normally contain high levels of nitrogen, low nitrogen wastewaters are sometimes available through dilution (i.e., from paper mills) or effluents from lagoon systems. Low nitrogen wastewaters, containing less than

10 mg/l of total nitrogen, can safely be applied to land to remove the phosphorus and solids and also to enhance crop production and groundwater recharge. High nitrogen wastewaters, those with more than 10 mg/l of total nitrogen, can be applied to the land if precautions are taken to assure nitrogen removal. Because of the close relationship to vegetation management, separate guidelines may be needed for low and high nitrogen wastewater systems. High nitrogen wastewaters were used to grow corn (Zea mays L.), forage grasses, and legumes in The Pennsylvania State, Michigan State, Minnesota, and Muskegon projects. Because the Muskegon wastewaters were low in nitrogen, they were supplemented with commercial fertilizers to bring the levels to more than 10 mg/l to increase yields.

Application was usually restricted to the period from late spring to early fall, but the potential for winter irrigation was investigated at Michigan State University, Minnesota, and CRREL. During winter irrigation, the recharge volumes were greatest, and high nitrogen wastewaters were most likely to leach out of the root zone and into the groundwater aquifers. The greatest nitrogen losses coincided with periods of reduced plant growth or were prior to the development of significant root biomass for annual crops. Therefore, during the application of high nitrogen wastewater, actively growing vegetation with a well developed root biomass is required if nitrate-nitrogen leaching is to be reduced significantly. If irrigation is restricted to the growing season, nitrogen losses will be minimal because the leaching volumes are low during winter. Nevertheless, the limited amount of leachate which does occur may contain nitrate concentrations greater than 10 mg/l as nitrogen because of the absence of plant growth.

AGRONOMIC CROP MANAGEMENT SYSTEMS

Cultivars of major grain, forage, food, and fiber crops are bred specifically for different regions of the United States because of variations in growing seasons, moisture availability, soil type, incidence of plant diseases, and other factors. Therefore, a regional approach is essential to select and manage vegetation at land treatment facilities. Considerable data have been generated for slow rate systems in the north central region. However, only limited data are available on seeded crop yields and nutrient uptake at overland flow sites.

Because information about selecting and managing vegetation on overland flow slope systems is quite limited, research must be directed toward identifying, managing, and improving the functions that vegetation can perform. With proper study, this method of treating municipal wastewater should advance dramatically in the next few years. The overland flow process holds great promise because vegetation can perform multple functions such as controlling erosion, delaying runoff (settling solids and promoting time-dependent phosphorus-soil reactions), entrapping solids, removing nutrients by plant uptake. It can also serve as a denitrification medium, improve the aesthetics, and provide low cost treatment of wastewater, often with an economic return.

The vegetation management system must be selected to optimize wastewater renovation first and then the net economic return from various crops that might be grown on the site. Several cropping systems are adaptable, and their sale offers an opportunity to lower the overall cost.

ROW CROPS

Row crops such as corn are attractive because of their potentially high rate of economic return as grain or silage. However, the limited root biomass early in the season and limited period of rapid nutrient uptake can present problems. As a result, corn can remove extensive amounts of nitrogen only for a short period of time (four to six weeks) from approximately the fourth to the ninth week after the plants emerge. High nitrogen wastewater applied at other times often results in leachates containing nitrate levels greater than 10 mg/l as nitrogen. Prior to the fourth week, root biomass is too low to renovate the wastewater effectively, and after the ninth week plant uptake slows. However, during the rapid uptake period, corn efficiently in removes nitrogen from percolating wastewater. In some studies, the corn yields were low unless other nitrogen fertilizers were applied during the critical uptake period. Conversely, if high nitrogen fertilizers were added, the possibility of nitrogen leaching into the groundwater was increased. If the wastewaters were low in nitrogen, however, corn was an excellent choice for wastewater renovation. For example, in the Muskegon studies, corn was grown year after year with no problem of excessive nitrate in the drainage water nor any interdrain leachate problems because the applied wastewater contained less than 10 mg/l nitrogen. Although not much nitrate was taken up by the corn, not much was leached either. Other row crops like soybean (Glycine max Nerr.) and sunflower (Helianthus annuus L.) are potential alternatives, but they have not been sufficiently studied to determine their relative value.

The management guidelines for the spray irrigation of high nitrogen (>10 mg/l) wastewater have to be very specific for corn. Either the application rate has to be adjusted to prevent leaching during low uptake periods, or there must be intercropping with annual or perennial forages. Intercropping may represent a suitable alternative to growing this grain alone. A dual system of rye (Secale cereale L.) intercropped with corn to maximize the period of nutrient uptake was tested in Minnesota and Michigan. For such dual corn-ryegrass cropping systems, rye can be successfully seeded in the standing corn in August, or after the harvest in late September. The growth of rye in the spring, before the corn is planted, allows early the application of high nitrogen wastewater. While planting the corn, a herbicide can be applied in strips to kill some rye so corn can be seeded in the killed rows. With the remaining rye absorbing nitrogen, less is leached during the early growth of the corn. Such intercropping allowed the successful use of corn as a high value crop. However, nitrate-nitrogen in excess of the drinking water standard was leached during the period that corn was being established in the partially killed rye if more effluent was applied per week than was lost through evapotranspiration. The corn-rye system is acceptable from a nitrogen renovation standpoint, and with careful attention to application rates, the technology is available for this option; but managing an intercropping system is more difficult than growing either crop alone. Perennial grasses and legumes can also be grown in a grass-corn intercrop system, but the practice requires careful control of the forage grasses and weeds. Where grasses are overkilled, the system behaves like a single corn crop; and the nitrogen renovation is ineffective. When too much grass remains, good nitrogen renovation occurs; but the corn yield is lowered.

Planting corn into the killed sods can also be beneficial because the sod serves as a winter cover to control erosion. The sod can be irrigated with wastewater in the spring before it is killed and again in the fall if the growth is sufficient. During the corn growing season, however, the problem remains that corn monoculture is inadequate to remove the nitrogen.

When both corn and hay are available for wastewater treatment, applications can be tailored to produce high corn yields by supplying water and a nitrogen supplement as needed. When the corn cannot use the water or when irrigation would increase nitrogen leaching, the wastewater can be diverted to the hay fields. Because such a system requires larger land areas, a primary consideration in the initial planning stage is land cost.

NON-ROW FORAGE CROPS

The tradeoff between good renovation and a cash return can best be attained by mixing corn and forage crops. However, by themselves, forage grasses and old field vegetation[1] can provide high levels of renovation with less operational and maintenance costs than corn. Grasses are suitable for overland flow as well as spray irrigation, and excessive leaching of nitrate-nitrogen is relatively easy to prevent.

Special care is necessary for overland flow systems. To prepare for a successful operation, the tract should be land-planed, and the soil must be finely graded to avoid channeling and to provide a firm seed bed. For rough grading, the equipment should follow the land's contour to minimize the potential for erosion; however, the final grading should be uniform for each section. The seeding equipment should also be operated on the contour to minimize the formation of downslope runnels, rills, and channels. Equipment with wide tires is strongly recommended to minimize rutting, both for planting and harvesting. For spray irrigation systems, typical agronomic practices for the region are usually satisfactory.

Before seeding, soil tests should be performed to determine the initial need for fertilization to establish the grass and to ensure its rapid growth. The rate of seeding for overland flow systems should be greater than for conventional hay fields and should follow the recommendations of the Soil Conservation Service for establishing sod in grassed waterways. For spray irrigation systems, a rate of seeding somewhere between typical agronomic practices and the procedure for grassed waterways should be suitable.

The seeding mixture for overland flow systems should include water-tolerant perennial grasses such as orchardgrass (Dactylis glomerata L.), reed canarygrass (Phalaris arundinacea L.), tall fescue (Festuca arundinacea Schreb.), or Kentucky bluegrass (Poa pratensis Leyss.), along with a "nurse" grass that will establish itself quickly and insure the stability of the surface of the soil while the other grasses become established. Perennial ryegrass has performed the nursing function well in many overland flow systems. Annual weeds also must be controlled to avoid

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1. The old field vegetation described here was a mixture of perennial grasses and weeds (mostly broad-leaved weedy perennial species) which volunteered in the area after the growth of crops of corn, clover (Trifolium spp.), grass, and alfalfa (Medicago sativa L.) were discontinued.

competition with the beneficial grasses. For spray irrigation systems, the most economical species or mixture should be chosen from the four water tolerant species listed above. In this case, a "nurse" grass is not usually necessary.

After seeding the overland flow site, a mulch should be applied to hold the soil and maintain its moisture until the new grass is established and can be irrigated. Smaller sites can be sodded and the application of wastewater can begin immediately. Enough lead time should be allotted to establish the vegetation before irrigation begins unless conditions allow a light sprinkling to assist in establishing the plants. Also, less than normal loading rates should be applied initially to test the stability of the freshly planted slopes. Subsequently, the grasses should be inspected frequently and analyzed periodically to detect losses of vigor or other health problems. Mulching is unnecessary on spray irrigation sites with slopes less than 6 percent, but care should be taken to assure that a good stand is established before higher irrigation rates are initiated.

In spray irrigation systems, nitrogen is removed from the wastewater by the roots of the plants. Therefore, root depth is very important; and proper drainage is needed to assure an adequately aerated soil volume for deep rooting. About 30 cm appears to be adequate for water tolerant grasses such as reed canarygrass. The less tolerant grasses, as well as alfalfa and corn, require deeper rooting if renovation is to be successful. The preferred maximum aerated depth of soil is about 40 to 60 cm for corn and 100 cm for alfalfa to allow adequate wastewater retention for nitrogen uptake in the root zone. To minimize leaching, the amount of wastewater can be reduced to lower the net downward movement out of the root zone. Good aeration also minimizes root disease in the crop.

Land application systems have given excellent removals of phosphorus and nitrogen. In the U.S. Army CRREL experiment at Hanover, New Hampshire, nitrogen and phosphorus removals were between 210 and 332 kg/ha and 27 and 48 kg/ha, respectively. These results demonstrate that, with careful management, significantly higher crop yields can be obtained on overland flow sites than on land used for normal forage agriculture. Similar yields and removal rates have been achieved on spray irrigation sites.

Another tradeoff that has to be considered is whether harvesting the forage crop enhances removal enough to justify the cost, as opposed to leaving the field unattended. Some studies indicate that excellent renovation of wastewaters can be achieved on unharvested fields of planted grasses or volunteer old field vegetation, at least for the first few years. Studies were not continued beyond 5 yr; however, it is likely that nitrogen renovation will decrease as soil nitrogen levels increase over time. Thus, harvesting to remove nutrients from the site is recommended in the long term.

Forage crops other than grasses can also be used for slow rate irrigation systems. For example, alfalfa is more valuable than grasses; but it does not tolerate excess water as well, particularly on fine textured soils. Root rot resistant varieties of alfalfa are acceptable to renovate wastewater, and they persist on artificially tiled or naturally well drained soils. However, increasing the rates of water application above the total amount lost through evapotranspiration and percolation may reduce the long term survival rate. Thus, re-establishment may be required more often, every 2 to 3 yr, rather than the 3 to 5 yr which is a standard agronomic practice in the region. As long as the alfalfa persists, however, the nitrate leaching levels should be acceptable. More nitrogen is leached from alfalfa than from grasses but less than from corn. Also, removing the cut forage as hay or greenchop assures that a major portion of the wastewater nitrogen is permanently removed from the land application system.

Harvesting schedules are important for forage crops. Maximum crop yields and nutrient removals result when forage grasses are harvested three or more times per year with the first harvest in late May or early June at the "early heading" or flower stage of spring growth. Alfalfa survives well on this system with the second harvest in mid-July or early August and a third harvest in September or early October. Old field vegetation also offers excellent renovation when it is cut and removed on this schedule. For all of the forage crops, the irrigated fields have to be dried for approximately one to two weeks before each harvest so the soil can support the harvesting equipment without damage from rutting and puddling. Therefore, the number of cuttings must be weighed against the cost of additional land to accommodate the down time during harvest. In addition, alfalfa has a lower nutrient uptake for two weeks following harvest, so the irrigation rate should not exceed the total amount lost through evapotranspiration and percolation. This consideration adds to the land required to irrigate this species.

Grasses or old fields offer the possibility of minimum management because they remove nitrogen from high nitrogen water even when left unharvested. In this case, the time of safe renovation is related to the period of biomass accumulation. After the growth of biomass peaks each year, nitrogen leaching increases. Cutting or mowing the fields, even without removing the cut biomass, can increase the period of active growth and effective renovation. However, because the nitrogen is not physically removed from the field as it is with hay, the long term nitrogen removal of such a mowing system is less certain.

Mowed old fields have adequately renovated nitrogen over many years. These and some of the overland flow systems have been dominated by quackgrass (Agropyron repens L.). Quackgrass can be an acceptable volunteer to replace the plantings of other grasses because it takes up large quantities of nitrogen, and if cut frequently, provides good quality feed for animals, and forms a thick sod. Quackgrass, however, is a noxious weed and can only be established by sodding or natural selection because the sale of quackgrass seeds is illegal.

An alternative to the high cost to purchase land for even minimal management systems is to supply local farmers with wastewater for crop irrigation when privately owned farms are nearby. When the amounts of applied wastewater are near the evaporative losses from the crop, nitrogen leaching is reduced to a tolerable level as field crops of all kinds are usually able to tolerate more water than their evaporative losses. Under these circumstances, either high or low nitrogen wastewaters can be safely applied to any row or forage crop. Thus, more wastewater may be supplied to farmers than the minimum required for their crops without reducing the yield. However, excessive rates of irrigation must be avoided as the extra water increases the leachates, especially when nitrogen fertilizer is being added.

RESEARCH NEEDS FOR SLOW RATE AND OVERLAND FLOW SYSTEMS

OVERLAND FLOW SYSTEMS

To supply more precise information for cost balancing, additional research on overland flow systems is needed to determine: (1) the optimum vegetation and soil management procedures to remove the most phosphorus and nitrogen, (2) the effects of various plant species on wastewater residence time in overland flow systems, (3) the bioaccumulation of toxic organics by plant uptake and the effects of these organics on the quality of forages removed for animal feed or maintaining viable crop-soil systems, (4) the water tolerances, yields, and uptake of nutrients by various types of forages, and (5) the seasonal constraints on overland flow systems.

SLOW RATE SYSTEMS

Corn

Corn has not reliably removed high concentrations of nitrogen in wastewaters. Yet, because of its economical desirability, research is needed to explain the following: (1) why corn roots are not able to take up nitrogen when the concentrations in the soil solutions are low; (2) why the inefficiency of corn in using nitrogen is affected by the methods of application, soil aeration, and root structure; and (3) what the maximum application rates are for corn before the yields are lowered and/or excessive nitrogen leaching occurs.

Other Crop Systems

Information is needed on all crop systems to determine: (1) the extent to which diseases lower the capacity of cropping systems to renovate wastewater; and (2) how diseases can be managed through variety selection, crop rotation, and irrigation frequency.

New Crop Systems

Because only a limited number of crop systems have been investigated for use on land treated with wastewater, additional research is needed to identify new plant species such as wheat, soybeans, dry beans, and others of economic importance to this region.

FORESTED SYSTEMS

Since the pioneering research began at The Pennsylvania State University in the early 1960's, interest has increased in utilizing forested sites for the renovation of wastewater. The early work indicated that coniferous and hardwood forest ecosystems could be effective living filters to improve the quality of wastewater by removing the nutrients. Generally, forest productivity was also increased by this process. Subsequent research in Pennsylvania, Michigan, New Hampshire, Washington, Georgia, and other states examined a wide variety of forest cover types and sites.

Their diversity necessitates consideration of the vegetation, soil, hydrology, and climate unique to each. However, a similar pattern of response was common to most of them.

The greatest benefit was observed with tree seedlings. Irrigation increased their survival in abnormally dry years and, on some sites, made it possible to establish tree species that would not normally survive. As a group, Populus species and hybrids demonstrated the greatest growth response whereas pines demonstrated the least. Irrigation of established stands resulted in changes in soil nutrient and hydrological characteristics. Accelerated decomposition and elevated pH in litter, humus, and the A_1 soil horizon were nearly universal. The normal levels of BOD, suspended solids, phosphorus, pathogens, heavy metals, and trace refractory organic compounds in biologically treated effluent did not appear to be detrimental to growth. On deep, well-drained sandy soils, the only detrimental effects of wastewater irrigation have been boron toxicity in red pine and rapid weed growth in new plantings. Extensive ice breakage and blowdown occurred in one irrigated stand of pole-sized red pine growing on a heavy soil.

Slow-rate irrigation is the only application technique that has been successfully used in forest ecosystems. A modification of overland flow was tried in fully mature mixed hardwoods; but extensive tree mortality occurred, and the wastewater phosphorus concentrations were not adequately reduced. Christmas trees have been irrigated on a trial basis with a center pivot irrigator, but solid set systems are more common. Winter irrigation of forest lands has been attempted on a limited scale in the northern United States. In addition to The Pennsylvania State University facility where special nozzles were developed and are still being used effectively, winter irrigation has also been carried out at Greenville, Maine; Wolfboro, New Hampshire; West Dover, Vermont; Milton, Wisconsin; and Pack Forest, Washington, to name a few.

Wastewater irrigation rates and schedules should be managed so as to meet treatment criteria, with fertilization of vegetation to increase yields as a secondary objective. In forest ecosystems, the control of nitrate-nitrogen discharges to groundwater is usually the foremost design constraint. Forest stands of rapidly growing trees and understory flora most effectively remove nitrogen from wastewater. The intensively cultured hybrid and eastern cottonwood have been tried in the north central region, and they compare favorably with corn and forage grasses with regard to wastewater renovation. In addition, ten species of seedlings have been investigated on the Michigan State University WQMF with eastern cottonwood, white ash, and Scotch pine showing the most favorable growth responses.

Uptake in very young plantations of any species is low because they do not fully occupy the site. During this stage of development, vegetation other than trees serves as an important nutrient sink. Until the stand closes, a high level of management, approaching that for agronomic crops, is required to maintain the herbaceous ground cover without reducing tree survival or growth.

The optimum management for forest ecosystems irrigated with high nitrogen effluent utilizes rapidly growing tree species and hybrids that are intensively managed in short rotations. Changes in the hydrologic characteristics expected as a consequence of adding wastewater at each application site should be addressed in the design, operation, and maintenance procedures for the irrigation system. At some locations there may be no market for products of short rotation silviculture in small quantities, but a favorable cost-benefit ratio might be achieved by developing local uses for whole-tree wood chips such as for energy production and sludge composting. Growing Christmas and ornamental trees for community beautification is another management option. As previously mentioned, ground cover enhances the nutrient uptake, so intercropping is a possible management method to achieve additional cash return as well as to renovate high nitrogen effluents effectively.

Acquiring the necessary level of expertise for a program of intensive management is a major cost element. This may not be justified for small community systems unless this expertise can be acquired through local public service agencies or private service contracts and the part-time employment of individuals with the required skills and expertise.

To manage small volume wastewater treatment facilities (<0.5 MGD) utilizing forest land, it is preferable to minimize the operational costs and skill levels of the personnel by adopting an extensive rather than intensive vegetation management strategy. Typically, lagoon facilities with seasonal storage provide an effluent with minimum nitrogen concentrations during the growing season. An irrigation rate of 2.5 to 5.0 cm/wk, applied only during the growing season, would result in nitrogen loadings of 56 to 112 kg/ha/yr, depending upon the wastewater nitrogen concentration.

High nitrogen wastewater should not be applied to forests with little or no net accumulation of biomass, such as predominantly evenly-aged stands of mature trees. However, because the soil can remove phosphorus adequately, these stands are acceptable for low nitrogen-high phosphorus wastewater applications. The forests might be made acceptable for the application of high nitrogen wastewaters by modification to introduce herbaceous plants and young trees. Red pine should not be irrigated with wastewater unless it occupies the only available site. If red pine is irrigated, it should be managed to accelerate conversion to more suitable species.

Reduced wind velocity in forests, visual screening by trees, and non-product values should be considered in selecting stands, specifying buffer zone dimensions, and controlling human access. Foresters' advice and assistance are helpful in formulating plans to develop wind and visual barriers and to optimize the distribution of species of appropriate sizes on and around the application site.

The forest ecosystem has little capacity to remove nitrogen when the plants are dormant. Therefore, if high nitrate wastewater is applied in winter, the nitrate concentrations in the leachate are likely to exceed those allowable under the drinking water standard. The difficulty and costs of winter irrigation vary with climatic conditions within the region. Therefore, the choice of year-round or warm-weather-only irrigation should be based on the requirements for nitrogen removal and a comparison of costs for wastewater storage versus operation and maintenance of the system during cold weather.

RESEARCH NEEDS FOR FORESTED SYSTEMS

Most research has focused on wastewater renovation in forest stands that are not managed or where standard silviculture procedures have been practiced to increase yields. The establishment and manipulation of stands to maximize nitrogen uptake has been only indirectly addressed. Except for the work at The Pennsylvania State University, studies of wastewater have been carried on for only 5 yr or less, a short time relative to the rate of change in natural ecosystems. A lack of long-term studies severely limits the opportunities to evaluate the effect of wastewater irrigation on species composition and sustained product yields.

Mismanagement of wastewater irrigation on forest land cannot be entirely avoided because the current knowledge of the process and its limitations is incomplete. Furthermore, facilities are sometimes not operated within appropriate design limits. The loss of the renovative capacity may not be recognized until major changes have taken place in the ecosystem. Then a collapse can result in the unacceptable discharge of pollutants. Some facilities have so little excess application area that the damaged system must be rehabilitated while it is still being utilized.

The kinds of research needed to solve these problems are listed below in three groups that indicate their relative urgency. First: (1) compare the amount and timing of nitrogen uptake by native herbaceous plant, brush, and tree species grown under existing forest stands; and (2) manage old field vegetation to maximize its nitrogen uptake while establishing tree plantations. Second: (1) develop operation and management procedures to rehabilitate ecosystems overloaded to the point of collapse; and (2) modify silviculture practices in existing stands to establish and maintain the mixture of herbaceous plants, brush, and tree species that will maximize nitrogen uptake. Third: (1) develop methods to harvest tree crops while maintaining nitrogen uptake, and (2) establish, manage, and harvest forage crops under natural stands and tree plantations.

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