*How field drainage is managed on cropland has important implications for the quality of surface and shallow groundwater resources*

# Water table management for water quality improvement

By D. L. Thomas, P. G. Hunt, and J. W. Gilliam

WATER quality in streams and groundwater is among the most critical environmental concerns in the United States and elsewhere. The U.S. Department of Agriculture's Agricultural Research Service (ARS), U.S. Geological Survey (USGS), Experiment Station Committee on Organization and Policy (ESCOP), and other institutions have research and extension priorities directed toward protecting surface water and groundwater resources. In the mid-1980s, ESCOP commissioned a task force to establish a groundwater quality initiative for the entire United States (*13*). In the report of that task force, groundwater quality issues were separated by region: West, South, North Central, and Northeast. In all areas, the top research and extension priorities included the evaluation of the source, fate, remedial treatment, and impacts of agricultural pesticides and nitrates.

Agriculture is considered a major contributor to water quality problems (*4, 5, 25, 35, 38, 41, 43, 51*). Improved surface and subsurface drainage has been associated with water quality problems in streams and lakes (*2, 9, 18, 28, 36*). Research indicates that nitrogen losses increased due to drainage of relatively heavy agricultural soils in Ohio, but sediment and other nutrient losses decreased (*42*). Studies on a Commerce silt loam in southern Louisiana showed that subsurface drainage reduced surface runoff 33 percent (*3*). There were corresponding reductions in total sediment, nitrogen, potassium, and phosphorus losses of 21, 23, 29, and 33 percent, respectively. These results relate directly to the heavier textured soils and high rainfall conditions characteristic of the Lower Mississippi Valley.

In the Eastern Coastal Plain of the United States, surface and groundwater resources are tremendously valuable. Agriculture has played a major role in this region because of the favorable climatic conditions, long growing season, and high annual rainfall. Most of the lower Coastal Plain, however, needs some form of improved drainage to maximize the agricultural land use potential.

The effects of improved surface and subsurface drainage on water quality are a major concern, and research programs have addressed this issue. With the introduction of more intensive water table management systems, such as controlled drainage and controlled drainage-subirrigation (*8, 46, 52*), surface and shallow groundwater quality is affected differently than with conventional drainage.

The Eastern Coastal Plain is not unique in the use of water table management systems. But the combination of climate, predominantly sandy soils, coastal impacts, rural shallow groundwater use, and water table management potential does provide a unique region for evaluation.

## Water quality in the area

As in other regions, water quality has been and continues to be a concern in the Eastern Coastal Plain (*1, 11, 14, 22, 24, 32, 39, 45, 48*). Improved surface and subsurface drainage of agricultural land has been necessary on a majority of the soils because of the relatively flat topography, high annual rainfall, sandy surface soils, and typically poor natural drainage. The poor natural drainage is usually an indication of a confining layer within the soil profile or a high water table that restricts vertical water movement. In the Flatwoods region of the Eastern Coastal Plain, a confining layer usually exists that limits water movement into deep aquifers. This perched water table system helps to protect the major water supply aquifers in the region; however, water will move laterally and resurface in streams and lakes.

The leaching of nutrients, primarily nitrates, to shallow groundwater and return flow through riparian zones has received some attention (*17, 29*). Studies on the movement of nitrates in the Coastal Plain have been described (*23*). One of the typical hydrologic characteristics of the Coastal Plain includes an upland agricultural area bordering heavily vegetated, seasonally wet riparian zones, also described as floodplains or seasonal wetlands. Shallow groundwater from the upland areas enters these poorly drained riparian zones through seepage. The riparian areas can be effective filters for nitrate-nitrogen (*34*). Research has shown that cropped upland areas bordered by riparian forests used, retained, or transformed 96 percent of the nitrate-nitrogen (*58*).

As the Coastal Plain approaches the coast (Lower Coastal Plain or Flatwoods region), the slope of the upland areas decreases, and the soils are poorly drained. Riparian areas still occur naturally; however, improved

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drainage systems can bypass and incorporate these zones. In the North Carolina Coastal Plain, loss of riparian wetlands and the associated loss of nutirent removal capacity has been identified as a major contributor to coastal eutrophication by phosphorus and nitrogen enrichment (*10*).

Soils in the lower region of the Eastern Coastal Plain lend themselves to drainage and water table management because of the sandy nature of surface layers and the clay confining layer.

## Drainage

The impacts of drainage on water quality, especially nutrient movement, have been evaluated in many studies. In most cases, drainage has been assumed to increase the losses of mobile chemicals, such as nitrates, to surface water resources. This assumption also applies to the movement of mobile pesticides; however, few data are available to evaluate or model the effects of drainage on pesticide movement in Eastern Coastal Plain soils.

Nitrate-nitrogen losses ranging from 9 to 50 pounds per acre per year have been measured from well- and moderately well-drained soils in the Middle Coastal Plain (*29*). The same study found that fields containing subsurface drainage tubes with outflow into open ditches lost more nitrogen than fields without improved subsurface drainage.

Nitrogen application rates with swine lagoon effluent has been studied on a sandy loam soil in the Coastal Plain of North Carolina (*13*). Results indicate that the uptake ability of Coastal bermudagrass in combination with denitrification may allow application of up to 356 pounds of nitrogen per acre per year without exceeding the 10-parts-per-million drinking water standard in the shallow groundwater beneath the field. Phosphorus application, in all the nitrogen combinations, greatly exceeded recommended rates, and the measured results indicated a gradual increase in phosphorus movement in subsurface drainage. Phosphorus losses could be a problem if not taken into account during application.

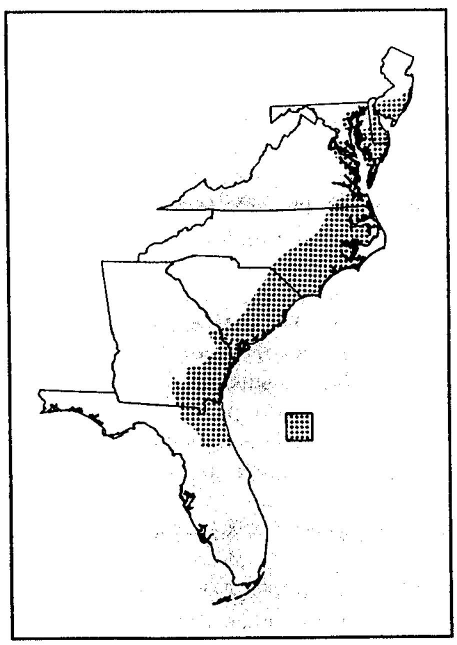
The hydrologic and water quality effects of drainage and land development have been investigated in the North Carolina Tidewater region (*48*). Researchers found that agricultural development on the organically rich soils produced a significant increase in inorganic nitrogen in drainage water. The developed, highly organic soils also lost significantly higher levels of phosphorus, whereas the developed mineral soil had little effect on phosphorus loss.

Nitrate-nitrogen concentrations in in-field shallow well samples and tubing effluent from a drained Flatwoods soil have been evaluated in the Georgia Coastal Plain (*53*). The tubing effluent was fairly representative of the in-field nitrate-nitrogen concentrations following an application of 22 pounds of nitrogen per acre. However, the potential for lateral intrusion from adjacent areas intc the drained fields can distort the results following rainfall events. Well-drained agricultural conditions with high oxidation-reduction potential and a high nitrate-nitrogen to chlorine ratio indicates that denitrification has not occurred. Thus, under well-drained conditions, excess fertilizer nitrogen has a strong potential to move to shallow aquifers and surface water (*14*).

Researchers have found evidence of alachlor persistence in the organic soils of the Tidewater region of North Carolina (*48*). Alachlor disappeared rapidly from the soil in the first four weeks after application, but low concentratins of nonphytotoxic alachlor persisted from one season to another. The concentrations of alachlor in drainage water appeared to be greatly affected by the quality and timing of the application. The outflow ditch contamination was attributed to direct spraying over ditches and drift of sprays into ditches rather than from surface runoff.

One research study has evaluated the movement of the nematicide fenamiphos and its metabolites (f. sulfone and f. sulfoxide) on a drainage system in the South Georgia Coastal Plain (*49*). Fenamiphos, f. sulfone, and f. sulfoxide have soil degradation half-lives of about 4, 18, and 42 days, respectively (*55*). The parent compound fenamiphos degraded rapidly, and little was measured in the drainage outflow. The metabolite f. sulfone was much more persistent and mobile, with concentrations in the drainage outflow approaching 180 parts per million. The metabolite f. sulfoxide was less mobile than f. sulfone, but the sampling period may have been too short to detect the movement of most of the f. sulfoxide.

***The Atlantic Coast Flatwoods region of the Eastern Coastal Plain where water table management practices may have potential.***



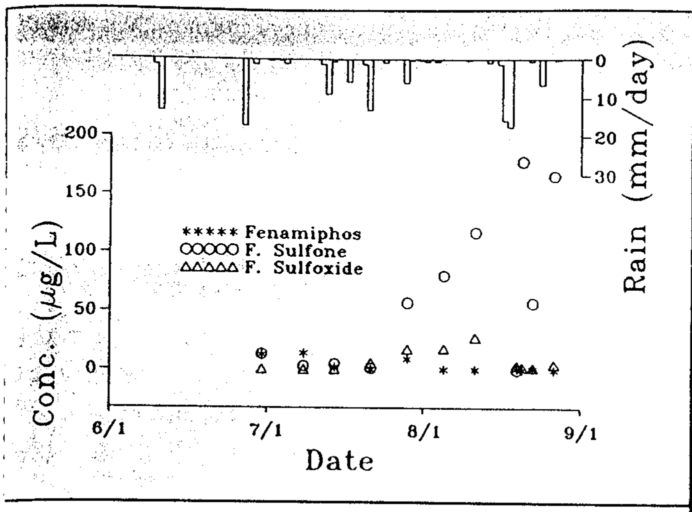
## Controlled drainage

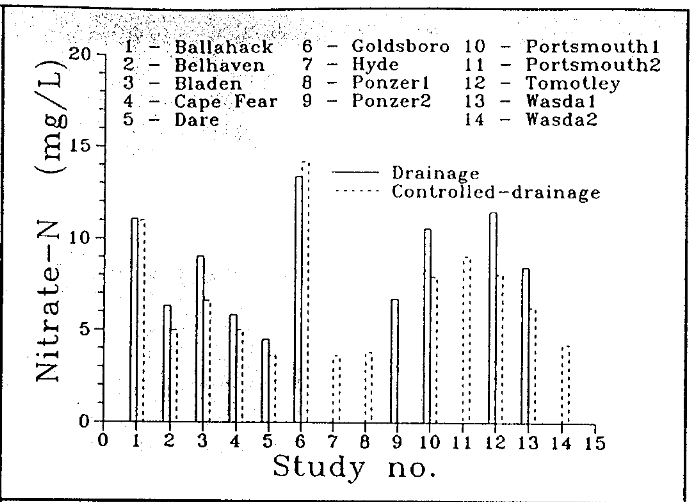
Controlled drainage is accomplished by regulating drainage depth with some water-level control device. Controlled drainage, which effects water quality quite differently than conventional drainage, has been shown to effectively reduce the loss of nitrate-nitrogen from drainage systems. However, the loss of phosphorus may increase under controlled drainage as compared to drainage alone. Few data are available to evaluate the effect of controlled drainage on pesticide movement.

Researchers have studied the effects of water-level control structures, such as flashboard risers, on water quality in tile mains and outlet ditches on a farm in the North Carolina Coastal Plain (*17*). They found a reduction of about 50 percent in nitrate-nitrogen movement into the drainage ditches. The reduction was attributed to enhanced water movement into and through deeper soil horizons, which had low oxidation-reduction potential and sufficient organic carbon to reduce the nitrate. They found no apparent decrease in the oxidation-reduction potential or denitrification in the surface soil. One study indicated that drainage systems with good subsurface drainage lost about 10 times more nitrate-nitrogen than systems with primarily surface drainage (*16*). The system with good surface drainage lost about twice the amount of phosphorus that the good subsurface drainage system did. However, controlled drainage may increase the total phosphorus efflux compared to conventional surface and subsurface drainage.

One of the important characteristics of controlled drainage is the reduction in total drainage outflow on a yearly basis compared to conventional drainage (*11*). Holding water in the system enhances evapotranspiration and vertical seepage. The timing of rainfall events and potential nutrient and pesticide applications can have a more severe effect on chemical and sediment losses because of the higher water table during the rainy season.

There is one noteable characteristic of studies on the effects of controlled drainage

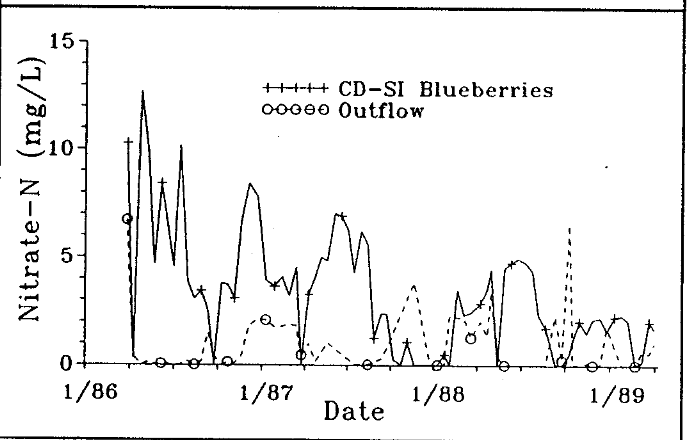



*bove left: Average concentrations of the nematicide enamiphos and its two metabolites (f. sulfone and f. sulfoxide) n drainage outflow (four drainage plots) on a Georgia 'latwoods soil (49).*

*bove right: Nitrate-nitrogen concentrations in subsurface rainage outflow as affected by conventional and controlled rainage (11).*

*ight: Comparison of nitrate-nitrogen concentrations from hallow wells in a controlled drainage/subirrigated field as ompared to outflow in the Georgia Coastal Plain (50).*




›n water quality in the Eastern Coastal Plain *11*). Average nitrate-nitrogen concentrations n the controlled drainage outflow remained ›elow 10 parts per million in 11 of 13 studies. Concentrations in the outflow from controlled drainage were only slightly lower han the outflow values with conventional lrainage. This probably was a result of the lecreased outflow under controlled drainage.

We are unaware of any research results on he effects of controlled drainage on pesticide movement along the Eastern Coastal Plain. Studies are being instigated in several tates, but data are not currently available.

## Controlled drainage-subirrigation

Controlled drainage-subirrigation is imilar to controlled drainage but includes supplemental water supply to maintain a vater table level sufficient to supply crop vater requirements. This practice potentially an reduce outflow chemical concentrations ›ecause of the addition of water from below luring nutrient and pesticide application ›eriods.

In gravity flow controlled drainage-ubirrigation systems, water is supplied at he highest elevation in the field and distributed through ditches or mainlines that are attached to the perforated laterals. Except ınder high rainfall conditions, supplemental water is added during the crop growth stage, which is also during the period of nutrient and pesticide applications. The water supply, primarily groundwater, usually does not contain high concentrations of nitrate-nitrogen or other chemicals. During subirrigation, therefore, water in the distribution ditches or mainlines also does not contain high concentrations of chemcials. The limited overflow at the outlet of the distribution system (to maintain a particular water level) is similar in quality. The operational characteristics of controlled drainage-subirrigation systems can reduce potentially high concentrations of chemicals in the outflow during the time of application. When rainfall occurs during the subirrigation period and the system reverts to drainage to remove excess water, the rainfall and water supply dilute the chemical concentrations, but do not reduce the mass load.

One research study compared nitrogen and phosphorus losses under potato production from a water-furrow system and a controlled drainage-subirrigation system on a sandy soil in Florida (*6*). The water-furrow system employs a similar water table management technique, but uses primarily surface drainage and has no improved subsurface drainage. Results indicated that the enhanced surface runoff characteristics of the water-furrow system increased the nitrate-nitrogen and phosphate-phosphorus losses in runoff compared with drain outflow from the controlled drainage-subirrigation system. The average weekly nitrate-nitrogen concentrations in subsurface drainage outflow remained below three parts per million during the 13-month study even though 133 pounds of nitrogen per acre were applied at planting, followed by 36 pounds of nitrogen per acre 40 days later.

The effects of controlled drainage-subirrigation on in-field and outflow water quality under blueberry production as compared to adjacent cleared and forested areas were evaluated in the Flatwoods of the Georgia Coastal Plain (*54*). First-year results indicated that the shallow subsurface nitrate-nitrogen concentrations in the controlled drainage-subirrigation area exceeded 10 parts per million following fertilizer application. But nitrate-nitrogen concentrations in the outflow samples were below that level. After three years of biweekly sampling, the results did not change. Nitrate-nitrogen concentrations in in-field samples exceeded 17 parts per million, while outflow samples remained below 10 parts per million.

The foregoing research results and other water quality studies indicate the potential for agriculturally induced increases in nitrate-nitrogen concentrations in shallow groundwater, whether using a controlled drainage or a controlled drainage-subirrigation system. This increase may not be a problem in some areas. But in Georgia, a major cross-section of the rural population—more than 120,000 wells—uses shallow groundwater (less than 80 feet) for its primary drinking water supply (*27*). Past research and current regulatory programs in Georgia and in other states have not addressed the extent of shallow groundwater use or the quality of this supply.

The effects of controlled drainage subirrigation systems on pesticide losses has not been addressed extensively in the Eastern Coastal Plain. Research is underway in North Carolina to address some of these issues, but results are not available, and additional research is needed throughout the region.

## System design and management

The design and management of drainage and water table management systems, whether controlled drainage or controlled drainage-subirrigation, does have an effect on water quality. Spacing of the drains, quality of the installation, crop and system management capabilities of the owner, buffer zones around the system, and depth to the water table can have impacts on the quality of the shallow subsurface and outflow water. In addition, new model developments should help to predict the long-term effects or benefits of particular design and management decisions.

One research study indicated that undersized drainage canal outlets can prevent subsurface drainage systems from removing water at the drainage capacity. Consequently, runoff rates from developed and undeveloped land may differ very little (*48*). Controlled drainage and controlled drainage-subirrigation systems usually are designed with closer drain spacings than conventional drainage systems. This increases the rate of water movement into the soil to maintain the desired water table elevation. This decreased spacing can increase the outflow rates and nutrient transport and reduce the residence time of pesticides when in the drainage mode. Optimization of the design, to provide the widest drain spacing to meet design and management criteria, is essential to reduce a system's cost and water quality impacts (*11*).

One of the most important considerations when designing and installing a water table management system is the ability of the system to handle large rainfall events. For example, one critical situation is an anticipated large rainfall event during the crop growth stage. A system that is poorly designed (or is assumed to be poorly designed) will reduce the confidence of the operator and may induce poor decisions, such as "pulling the plug" (allowing free drainage) prior to an anticipated extreme rainfall event. This type of practice may create a severe water quality problem, especially if the rainfall event does not occur. A well-designed system in the Eastern Coastal Plain where sandy soil conditions predominate should promote owner operator confidence and would not require the operator to anticipate rainfall events. The operator should be able to adjust the drain outlet during or immediately following a large rainfall event because the high potential outflow rates from the sandy soils should remove excess water before crops stress occurs.

One additional consideration in the design of a system is the maintenance of a forested or grassed buffer zone between streams or lakes and the drainage, controlled drainage, or controlled drainage-subirrigation system. For outflow and ditch management, this may not be practical. But research indicates that riparian-type areas adjacent to water table management systems can reduce the potential movement of chemicals and sediment to surface waters. The denitrification ability of forested buffer areas can reduce substantially the lateral movement of nitrate-nitrogen to adjacent water bodies (*29*). Where surface runoff is a problem, maintenance of a buffer zone is recommended.

Research indicates that "discharging agricultural drainage water into wetland buffer areas is expected to remove nitrogen, phosphorus, and sediment and to attenuate peak flow rates of freshwater into saline receiving waters" (*7*). Wetland areas can be extremely effective in removing nitrogen, phosphorus, and sediment before the water reaches the wetland outlet (*15*). The effectiveness of wetland filtering depends upon hydrologic conditions, but for the drainage events studied, the wetland area removed a minimum of 70 and 90 percent of the phosphorus and sediment, respectively.

Besides the degradation of surface water quality, an additional problem associated with improved drainage in North Carolina is the concern over increased freshwater influx into the saline marshes and its potential effects on fish and shellfish populations. Additional research is needed to quantify the extent of the potential problem across the region.

The management of controlled drainage and controlled drainage-subirrigation systems requires a desired water table depth, or acceptable depth range, in the field. Maintaining a deep water table, which still achieves optimum crop growth, is desirable from the standpoint of water use (pumping costs) and reducing potential surface runoff. As the water table rises, the soil air volume available for water storage decreases, the infiltration rate decreases, and the potential for additional surface runoff increases. Unfortunately, this desired depth range may not be known for many of the crops being grown with water table management systems.

In North Carolina, the recommended starting depth for sandy loam soils is about two feet for most crops, based on past studies. A majority of the crops studied can tolerate a water table fluctuation of plus or minus six inches (*11*). Water tables maintained at one foot or five feet produced similar crop yields for soil and crop conditions in one study (*57*). Optimum water table depths for the growth of many crops and for maintaining water quality are not known.

The need to evaluate the potential water quality impacts of water table management systems and their operation has lead to computer simulation programs. Modeling tools have been developed to evaluate management effects on water quality for Flatwood soils in Florida (*20, 21*). These tools use the original CREAMS (*30*) model to describe the effects of management on surface hydrology, runoff, and erosion from field areas and basins. The model developments currently are designed for undeveloped (undrained) fields and basins. But they do represent a method of quantifying the varying hydrologic and water quality characteristics of areas with high water tables.

A combined model has been developed that uses CREAMS and DRAINMOD (*46, 47*) to evaluate water table management effects on soil erosion for North Carolina climatic conditions (*37*). Results indicate that design and management options for water table management systems can be evaluated for their effects on sediment loss as well as crop production.

A vadose zone model has been developed to route percolation water and pesticides, as calculated in the GLEAMS model (*33*), from the root zone to the water table (*44*). Additional data are needed to validate the results and to evaluate the preferential flow contribution.

Whether water table management is used or not, the reduction of nutrient losses requires crop and soil monitoring and an application schedule that provides nutrients only when they are needed. Increased split applications of nitrogen have been shown to reduce the total leaching losses of nitrate-nitrogen in modeling studies (*31, 55*). The potential exists to reduce phosphorus losses by the same technique.

Elimination of excessive fertilization through intensive soil and crop monitoring will help in any environment. In the midwestern United States, the potential to reduce excessive fertilization is high because of the grain-oriented crop production systems (56). However, control of nitrogen fertilization in the southeastern United States will require closer monitoring because of the legume cropping systems typical in the region. Legume crops often add more nitrogen to the soil through dinitrogen fixation than is removed in the seed. Annual increases in nitrogen levels may be more than 90 pounds per acre for some crops (*19, 26, 40*).

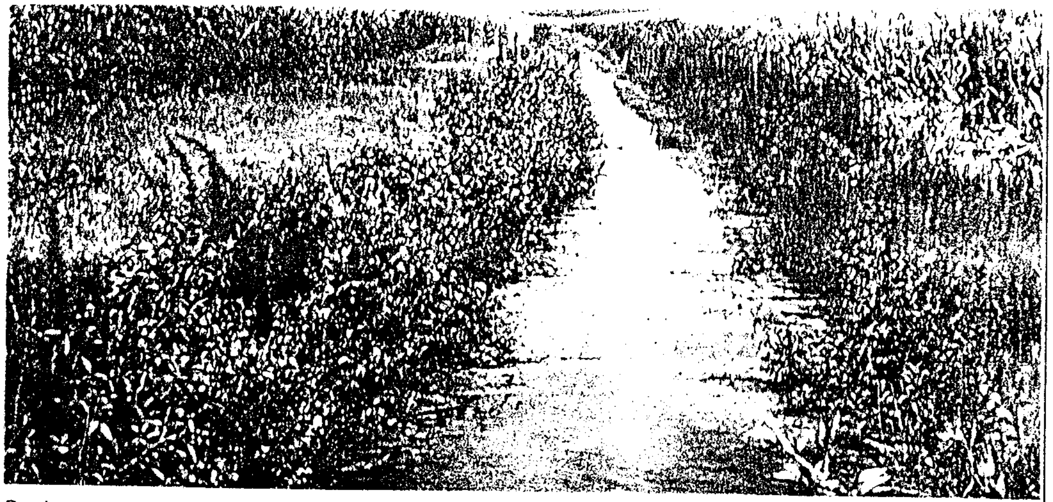
The availability of soil water dramatically affects dinitrogen fixation in leguminous plants. This consequently has impacts on the accumulation of nitrogen in dry matter and seed (*26*). Peanut plants were estimated to have both negative and positive net annual accumulations of nitrogen, depending upon seasonal rainfall and soil nitrogen level. And nitrogen accumulations were more positive for peanuts grown over water table depths of two feet versus four feet (P. G. Hunt, Florence, unpublished data).

Operating water table management systems for the benefit of surface and subsurface water quality requires an understanding and appreciation by the farmer of the environmental consequences and benefits. In most cases, management decisions are not made to maintain water quality, but are an integral component of crop production. System operators must be aware of all the impacts of their management decisions. Research and extension personnel must understand the impacts of particular decisions and provide this information to system owners and operators.

## Potentials and needs

The potential exists for improving and expanding agricultural production areas in the Eastern Coastal Plain as other production areas decline because of resource depletion. Most of the Flatwoods region does, however, need some form of improved drainage to maximize the agricultural land use potential. Surface and subsurface drainage effects on water quality are a major concern. In most cases, conventional drainage has been assumed to enhance or increase the losses of mobile chemicals, such as nitrates, to surface water resources.

This assumption would also apply to the movement of mobile pesticides. However, few data are available to evaluate or model the effects of drainage on pesticide movement in Eastern Coastal Plain soils, and additional research is needed. Specific research needs include field data on pesticide movement as affected by tillage operations and the impact of different pesticide and nutrient application techniques, such as banding and broadcasting, and formulations, such as slow release, on pesticide movement. The enhancement and verification of water quality and management models to include drainage impacts on nutrient and pesticide movement are needed for improved drainage management across the entire region.



***Design and management of water table management systems can help land managers improve water quality in surface water and groundwater.***

Controlled drainage effects water quality quite different than conventional drainage. Controlled drainage can decrease the loss of nitrate-nitrogen from drainage systems. However, the loss of phosphorus may increase under controlled drainage compared with drainage alone. Few data are available to evaluate the effect of controlled drainage on pesticide movement. Additional information is needed with respect to varying climatic and soil conditions through the other states in the region. The research needs mentioned above for drainage are also needed for controlled drainage systems.

Controlled drainage-subirrigation can potentially reduce outflow chemical concentrations because of the addition of water from below during nutrient and pesticide application periods. Unfortunately, few data also are available to evaluate the water quality benefits of controlled drainage-subirrigation. More precise field data, with discrete samples throughout the rainfall events, are needed to justify these assumptions. Additional research is needed to evaluate the influence of controlled drainage and controlled drainage-subirrigation systems with good nutrient management practices, such as split nutrient applications, on shallow groundwater quality.

The design and management of drainage and water table management systems does have an effect on water quality. Spacing of the drains, quality of their installation, crop and system management capabilities of the owner, buffer zones around the system, and depth to the water table can have impacts on the quality of the shallow subsurface and outflow water.

Additional field research is needed to evaluate the potential practice of directing outflow water into riparian zones and pumping into other types of vegetated filters.

Controlled drainage and controlled drainage-subirrigation systems do have beneficial water quality characteristics that only can be maximized by proper design and management. Unfortunately, all the questions on the best design and management scenarios for improved water quality have not been answered, especially those questions on pesticide movement. The development of design and management tools (models) that can be used to evaluate the alternatives are needed. Modeling structures, with water table management and water quality components in a user-friendly operating system, are required for widespread application. Specific investigations on the psychology of management decisions would be beneficial in developing user-oriented management guidelines. These tools must also be sufficiently validated with laboratory and field data before widespread application.

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