Soil and crop management aspects of water table control practices

By W. J. Busscher, E. J. Sadler, and F. S. Wright

HIGH average annual rainfall, high solar radiation, and warm temperatures could make the Southeast Coastal Plain of the United States an ideal place to grow crops. But, other geographic areas consistently outproduce it. A fundamental problem in the region is variable rainfall during the growing season (*24*). At times, flooding and aeration problems occur; at other times there is drought, and crops cannot thrive because the sandy soils have a low water-holding capacity (*7*). These factors are worse in soils with shallow rooting zones caused by subsurface hardpans.

These problems are not confined to the Southeast Coastal Plain. However, the regional climate and soil characteristics combine to require unique solutions. One such solution, water table management by controlled drainage-subirrigation, can ameliorate variability of crop water supply (*9, 14, 33, 39*).

Climatic effects

The Southeast Coastal Plain is known for high humidity, heat, and a long growing season. Humidity, represented as dewpoint temperature, has a mean annual value in excess of 52°F. Average daily extreme temperatures for July, the hottest month of the year, range from 70° to 91°F. Similar values for January, the coldest month of the year, range from 34° to 66°F. With the mild winter temperatures, there is an evaporative demand throughout the year, which averages 0.1 inch per day, and ranges from nearly zero in winter to 0.3 inch per day in the summer. Total evapotranspiration for the year varies from 16 to 28 inches.

With 43 inches of rainfall per year (*24*), water would not appear to be a limiting factor for crop production. But rainfall distribution is not uniform. For example, the drought of 1986 was so intense that feed for cattle had to be shipped into the area from the Midwest. However, annual rainfall in 1986 was within 10 percent of that for 1987, a relatively good growing year; but the timing and the intensity of rainfall in 1986 were unfavorable for even moderate corn yields. During the drought, two rains of 3.7 and 4.2 inches fell in 52 minutes on May 30 and 51 minutes on July 21, respectively, in Florence, South Carolina. These storms were preceded and followed by long dry periods.

In other years, winter rains and relatively low winter evapotranspiration can cause high spring water tables. It was because of

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these conditions that drainage with deep ditches has been used to carry off excess water in many areas of the Coastal Plain. However, water tables near the ditches often dropped far below the root system. Controlled drainage-subirrigation has been used to maintain the water level in the ditches and in the soil, saving some of the water for use by crops (*13*). This stored water also has been pumped from the ditches for surface irrigation. The shallow water tables that result from controlled drainage-subirrigation leave fields vulnerable to flooding. To prevent this, systems have been designed to link controlled drainage-subirrigation to weather predictions. In one study, researchers stopped subirrigation at or above the 55 percent rainfall probability (*18*). They also recommended free drainage of the soil in advance of predicted storms, although care must be taken not to drop the water table so much that reestablishment of the desired level would be difficult (*12, 15*).

Effects on the rhizosphere

In a region where soils have a large water-holding capacity, a few large rainfalls might provide adequate available water for plant growth. In the Southeast Coastal Plain, however, many of the soils are coarse- or fine-loamy siliceous, aquic Utilsols or Entisols. They are sandy and hold little water, often as little as one inch per foot of soil depth. Soil water storage is reduced further in some Coastal Plain soils by shallow subsurface pans that restrict root growth to the upper eight inches, or essentially the plow layer (*7*). At summer evapotranspiration rates, this may limit available water to three days or less. It is necessary to understand how controlled drainage-subirrigation affects the rhizosphere as a growth medium in these sandy soils to develop controlled drainage-subirrigation management techniques for crop production.

Controlled drainage-subirrigation affects water supply, aeration, and temperature. Such systems can buffer high temperatures by increasing the soil heat capacity because of increased soil water content and by decreasing canopy temperatures because of increased evapotranspiration. Lower soil temperatures can decrease respiration of root and soil microorganisms, increase the soil oxygen concentration, and decrease carbon dioxide.

Research establishing the relationship of oxygen and carbon dioxide concentrations to controlled drainage-subirrigation could help improve the rooting environment. High water tables lead to aeration problems because water-filled pores disrupt the diffusive supply of oxygen to the roots. Lack of aeration also increases the presence of soluble phytotoxins (*1*). Tolerance of excess water varies widely, depending on species and growth stage (*8, 21*). There is an extensive body of literature on aeration and its effect on plant growth, but its application to controlled drainage-subirrigation is limited.

For controlled drainage-subirrigation systems to be successful, the depth of the water table must be low enough to prevent aeration problems and high enough to permit capillary rise into the root zone for plant root uptake. Uptake becomes less effective as the water table drops further below the root zone. When it is 2.5 feet below the bottom of the root zone in a sandy soil, or three feet in a clay soil, the capillary water contribution to root uptake is negligible (*36*).

Controlling the water table can provide adequate water to row crops for many soil conditions (*10, 11, 16, 22, 25, 29, 31*). Recommended ranges of water table depths that are best for plant growth vary with soil type, crop, and location. Follet and associates worked with corn (*Zea mays* L.), sugarbeets (*Beta vulgaris* L.), and alfalfa (*Medicago sativa* L.) in North Dakota on sandy soils (*17*). They found that a shallower water table (28 to 35 inches) resulted in greater yields than a deeper one (more than 55 inches), even if the deeper water table was supplemented with irrigation.

In a companion study for the same crops, Benz and associates found that it was important to maintain the water table higher than a 51-inch depth (*2*). Even a small drop in the water table significantly increased the surface irrigation requirement.

Working on the sands and sandy loam soils in the Coastal Plain, Doty found the best water depth for corn was between 30 to 35 inches (*10*). Visser, studying water table depths of 28 to 51 inches, found the highest yield from fruit trees over the deepest water tables (*37*).

Because capillary rise is greater for clay soils than for sandy soils, the recommended depth to the water table is three to five feet for clay soils (*38*) and two to four feet for sandy soils. The crop type and climate determine where within this range the target water table should be set. Shallow-rooted crops, such as grasses, require a higher water table than deep-rooted crops, such as alfalfa.

Natural fluctuations in the water table

Yield of crops (in percent) irrigated from only controlled water tables at varying depths

Crop and Reference	Crop Yield by Water Table Depth: 15 cm	30 cm	40-50 cm	60-65 cm	75-80 cm	80-90 cm	90-100 cm	100-110 cm	120 cm	200 cm	240 cm	Soil*
	%											
Ladino clover (*20*)	100	99	92									sl
Orchardgrass (*20*)	100	70	92									sl
Fescue (*20*)	100	50	72									sl
Alfalfa (*35*)				100					92		86	cl, l, sl
Alfalfa (*17*)									100	62	55	sl, ls
Soybeans (*38*)	14	63	78	100		86						fsl
Grain sorghum (*38*)	73	86	93	100		93						fsl
String beans (*38*)	45	100	75	65		70						fsl
Corn (*17*)									100	78	66	sl, ls
Corn (*38*)		41	82	85		100	85	45				l
Corn (*39*)						95	100					fsl
Cabbage (*38*)	65	80	100	90	80							fsl
Sugarbeets (*17*)									100	42	35	sl, ls
Peanuts (*39*)					65	100	82					sl

*C-clay, l-loam, s-sand.

complicate specific depth recommendations. The major factors influencing fluctuations are plant withdrawal and rainfall. This is especially true in the Southeast Coastal Plain, with its high summer evapotranspiration rates and heavy rains. Bloemen (*3*) found that rye yields decreased with increasing fluctuations. This was true until the water table apparently became deep enough—below four feet—that the fluctuations brought otherwise unavailable water into the root zone.

Transferring controlled drainage-subirrigation technology from one location to another has been difficult because of climatic differences. In a humid climate, the depth at which a water table is maintained should be lower than it would be in a dry climate to aid in drainage. Even at the same location, adjustments would be required from one year to another because a lower water table would be needed in a wetter year than in a drier year.

Within a field, the distance from the drainage tile results in changes of depth to the water table. (This makes it difficult to transfer the technology from lysimeter studies to the field.) To reduce these depth changes, recommended tile spacings for controlled drainage-subirrigation systems are about 65 percent of that for drainage alone (*12, 15, 32*). However, Wright and Adamsen controlled a water table in a field originally designed for drainage alone (*39*). In this case, the cost of retrofitting a drainage system to a controlled drainage-subirrigation system was reduced. The drain tiles were 130 percent farther apart than recommended for controlled drainage-subirrigation. The average water depth varied between tile lines from one to four feet below the soil surface. Yields decreased with increasing depth to the water table. More work needs to be done to determine the depth of control of the water table for the optimum management of retrofitted drainage systems.

Soil effects on management

Suitable sites for controlled drainage-subirrigation systems are relatively flat, with normally high water tables and/or impermeable layers. This eliminates or minimizes water losses to deep percolation. If the ratio of deep percolation to infiltration is greater than one to 10, a water table will not perch adequately (*28*). Such a site is unsuitable for a controlled drainage-subirrigation system. Although water loss to deep percolation is an important factor, other limitations, such as irrigation efficiency or leaching of nutrients and pesticides into the groundwater, may be an overriding concern.

Drainage during wet periods may be just as important for soil management as irrigation. It can help maintain trafficable conditions during wet springs and prevent aeration problems during wetter parts of the growing season. This is especially true of areas with poor surface drainage—those areas suitable for controlled drainage-subirrigation. Controlling the water table may make it more difficult to get into the field after a rain because the water table remains high and rains can more easily saturate the profile (*12*).

Some work has been done to integrate specialized management, such as vegetable production, with controlled drainage-subirrigation. For example, because organic soils subside when they are drained, Shih and associates controlled the water table to both irrigate the crop and reduce subsidence (*30*). They recommended different water table depths for different crops and different times of the year to maintain production while reducing the loss of soil.

Other specialized management techniques, such as minimum tillage, and their interaction with controlled drainage-subirrigation need more work. In some areas of the Southeast Coastal Plain, tillage management has focused on the amelioration of strength in shallow subsurface hardpans (*4*). Some of this work applies to subsurface sources of water. In some early work, Reicosky and associates showed the advantage of combining deep tillage with controlled water table depth (*26*). Their tillage broke up a hardpan at the 8- to 16-inch depth to permit the roots to grow to the 30-inch-deep water table. Recently, Camp and associates showed that daily water management provided high yields without deep tillage despite root-restricting subsoil layers (*5*). They used buried trickle tubes instead of a controlled water table. Nevertheless, their subsurface source of irrigation maintained high water contents within and above the subsurface hard pan. This has the potential for alleviating strength problems (*6*) and providing a shallow source of water for roots. Relationships among the hardpans, water table, and root growth need to be developed.

Management research needs

Most of the above discussion relates to research for water tables maintained at optimum depths and to how they vary with crop, climate, and soil. There are other questions pertinent to controlled drainage-subirrigation-system development for crop management. For example, because the controlled drainage-subirrigation surface is dry, relative to surface irrigation, fewer nutrients may leach into the water table. Geraldson found that because water is pumped into the

Crop type and climate determine recommended depth to water table in controlled drainage systems.

soil below the surface, nutrients placed on the surface move into the root zone depending on rainfall and concentration gradient (*19*). However, there is still a need to determine the best method of nutrient placement or incorporation in controlled drainage-subirrigation systems for environmental safety (*34*) and plant uptake.

The depth of the water table also interacts with nutrient availability. For example, Visser found a harmful interaction between high water tables and high nitrogen fertilization levels, decreasing the quality of apples grown on a calcareous clay soil (*37*). Fertility work with controlled drainage-subirrigation on agronomic crops is needed to develop management practices with effective nutrient uptake.

In some years, weeds or winter cover affect crop seed germination and soil temperature by drying out the soil. Germination decreases with a dryer, cooler surface. Killing back the winter cover before depletion of available water can help to provide water for crop germination and growth. The best time to do this in controlled drainage-subirrigation systems needs to be determined. Also, a deeper water table will have larger, quicker swings of temperature because of reduced heat capacity. However, the water table depth for optimal management of soil thermal conditions has yet to be determined.

Presumably, there would be less evaporation from the surface with a controlled drainage-subirrigation system than with a surface irrrigation system (*5*); however, this has not been directly studied and the amount of evaporation is not known. Physical properties of the soil would be affected by wetting and drying or lack of wetting and drying when compared to surface irrigation. Some of these research needs for controlled drainage-subirrigation could be aimed at the integrity of the little structure that exists in the kaolinitic Coastal Plain soils; tractor wheel compaction with relatively dry, drained surface; soil settling under saturated conditions; and how all of this affects root growth and yield.

Pest management needs

There is scant literature on pest management with controlled drainage-subirrigation systems, and a significant effort is needed to understand pest control in these systems. The fact that the surface would be dry relative to surface irrigation can affect insect populations, either benefically or detrimentally. For example, heliothis will drown in a wet surface (*27*) while mosquitos will flourish. Also, alternate flooding and draining would reduce leafhopper and planthopper populations (*23*). This would be more prevalent under surface irrigation than under controlled drainage-subirrigation. Insect control specifically aimed at controlled drainage-subirrigation management has yet to be addressed.

The relatively dryer surface, compared to conventional irrigation, would conceivably be less susceptible to the spread of disease. Subirrigation should also help crops by making them healthier.

Weed control in controlled drainage-subirrigation systems could benefit when compared with conventional irrigation systems. A dryer surface would discourage germination throughout the growing season. Research on weed control in controlled drainage-subirrigation and its comparison to conventional management systems is needed.

Pesticide leaching should be less in controlled drainage-subirrigation systems than in surface irrigation systems, depending on seasonal rainfall. Also, a dryer surface under controlled drainage-subirrigation may render pesticides less effective. Research in this area is needed.

Conclusion

Water table management can help to reduce the fluctuations between too much and too little water for the sandy soils of the Southeast Coastal Plain by maintaining a more constant depth to the water table. Water can move upward from the water table to the root zone by capillary action where it is taken up by the root. Because many areas in the Coastal Plain need to be drained, these areas could benefit from controlled drainage-subirrigation with a closer tile spacing than for drainage alone. Optimum depths of controlled water tables appear to be three to five feet for clay soils and two to four feet for sandy soils. More specific depths depend on crop and climate.

Research needs to be done on controlled drainage-subirrigation in soil and crop management as well as water management. Research needs to include the areas of nutrient availability, differences in soil surface physical properties when compared to surface irrigation or rainfed culture, differences in evapotranspiration and soil water extraction when compared to other management systems, and pesticide effectiveness and leaching.

REFERENCES CITED

1. Armstrong, W. 1975. *Waterlogged soils.* In J. R. Etherington [ed.] *Environment and Plant Ecology.* John Wiley and Sons, New York, N.Y.
2. Benz, L. C., G. A. Reichman, E. J. Doering, and R. F. Follett. 1978. *Water-table depth and irrigation effects on applied-water-use efficiencies of three crops.* Trans., ASAE 21(4): 723-728.
3. Bloeman, G. W. 1951. *Two aspects of level groundwater.* Landbouwvoorlichting 8: 387-390.
4. Busscher, W. J., R. E. Sojka, and C. W. Doty. 1986. *Residual effects of tillage on Coastal Plain soil strength.* Soil Sci. 141(2): 144-148.
5. Camp, C. R., E. J. Sadler, and W. J. Busscher. 1989. *Subsurface and alternate-middle micro irrigation for the southeastern Coastal Plain.* Trans., ASAE 32(2): 451-456.
6. Campbell, R. B., and C. J. Phene. 1977. *Tillage, matric potential, oxygen, and millet yield relations in a layered soil.* Trans., ASAE 20: 271-275.
7. Campbell, R. B., D. C. Reicosky, and C. W. Doty. 1974. *Physical properties and tillage of paleudults in the southeastern Coastal Plains.* J. Soil and Water Cons. 29(5): 220-224.
8. Carter, C. E., B. Halverson, and V. McDaniel. 1985. *Effects of excess water on wheat yields.* Paper No. 85-2569. Am. Soc. Agr. Eng., St. Joseph, Mich.
9. Carter, C. E., and J. M. Floyd. 1973. *Subsurface drainage and irrigation for sugarcane.* Trans., ASAE 16(2): 279-281, 284.
10. Doty, C. W. 1980. *Crop water supplied by controlled and reversible drainage.* Trans., ASAE 23: 1,122-1,126, 1,130.
11. Doty, C. W., and J. E. Parsons. 1979. *Water requirements and water table variations for a controlled and reversible drainage system.* Trans., ASAE 22(3): 532-536, 539.
12. Doty, C. W., K. R. Cain, and L. J. Farmer. 1986. *Design, operation, and maintenance of controlled drainage/subirrigation (CD-DI) systems in humid areas.* Applied Eng. Agr. 2(2): 114-119.
13. Doty, C. W., and L. J. Farmer. 1983. *Considerations for the design and operation of control drainage-subirrigation (CD-SI) systems.* Paper No. 83-2566. Am. Soc. Agr. Eng., St. Joseph, Mich.
14. Doty, C. W., S. T. Currin, and R. E. McLin. 1975. *Controlled subsurface drainage for the Southern Coastal Plains soil.* J. Soil and Water Cons. 30(2): 82-84.
15. Evans, R. E., and R. W. Skaggs. 1985. *Operating controlled drainage and subirrigation systems.* Publ. AG-356. N. Car. Agr. Ext. Serv., Raleigh.
16. Fausey, N. R. 1983. *Shallow subsurface drain performance in Clermont soil.* Trans., ASAE 26(3): 782-784.
17. Follett, R. F., E. J. Doering, G. A. Reichman, and L. C. Benz. 1974. *Effect of irrigation and water-table depth on crop yields.* Agron. J. 66: 304-308.
18. Fouss, J. L., and J. R. Cooper. 1988. *Weather forecasts as a control input for water table management in coastal areas.* Trans., ASAE 31(1): 161-167.
19. Geraldson, C. M. 1987. *Control of the ionic composition of the rhizosphere in the transition to soil-based hydroponic systems.* J. Plant Nutrition 10: 1,205-1,211.
20. Gilbert, W. B., and D. S. Chamblee. 1964. *Effect of depth of water table on ladino clover, orchardgrass, and tall fescue.* J. Am. Soc. Agron. 51: 547-550.
21. Joshi, M. S., and N. G. Dastane. 1966. *Studies in excess water tolerance of crop plants.* Indian J. Agron. 11: 70-79.
22. Kanwar, R. S. 1988. *Stress-day factor and stress-day index as indicators of drainage needs of soils.* Trans., ASAE 31(5): 1,423-1,429.
23. Karuppuchamy, P., and S. Uthamasamy. 1984. *Influence of flooding, fertilizer and plant spacing on insect pest incidence.* Int. Rice. Res. Newsletter 9(6): 17.
24. National Oceanic and Atmospheric Administration, U.S. Department of Commerce. 1983. *Climatic atlas of the United States.* Nat. Climatic Data Center, Ashville, N. Car.
25. Nemon, N. A., B. von Hoyningen Huene, J. Gillichand, and R. S. Broughton. 1987. *Subsurface irrigation and drainage on sandy soil in southern Quebec.* Can. Agr. Eng. 29(2): 137-142.
26. Reicosky, D. C., R. B. Campbell, and C. W. Doty. 1976. *Corn plant water stress as influenced by chiseling, irrigation, and water table depth.* Agron. J. 68: 499-503.
27. Roach, S. H., and A. R. Hopkins. 1979. Heliothis *spp.: Behavior of prepupae emergence of adults from different soils at different moisture levels.* Environ. Ent. 8: 388-391.
28. Schneider, A. D., and J. N. Luthin. 1978. *Simulation of groundwater mound perching in layered media.* Trans., ASAE 21(5): 920-923, 930.
29. Schwab, G. O., N. R. Fausey, E. D. Desmond, and J. R. Holman. 1985. *Tile and surface drainage of clay soils.* Res. Bull. No. 1166. Ohio Agr. Res. and Develop. Center, Wooster.
30. Shih, S. F., D. E. Vandergrift, D. L. Myhre, G. S. Rahi, and D. S. Harrison. 1981. *The effect of land forming on subsidence in the Florida everglades' organic soil.* Soil Sci. Soc. Am. J. 45(6): 1,206-1,209.
31. Skaggs, R. W. 1973. *Water table movement during subirrigation.* Trans., ASAE 16: 998-993.
32. Skaggs, R. W. 1979. *Water movement factors important to design and operation of subirrigation systems.* Paper No. 79-2543. Am. Soc. Agr. Eng., St. Joseph, Mich.
33. Skaggs, R. W., G. J. Kriz, and R. Bernal. 1972. *Irrigation through subsurface drains.* In Proc., Nat. Water Resources Eng. Meeting. Am. Soc. Civil Eng., New York, N.Y.
34. Thomas, D. L., P. G. Hunt, and J. W. Gilliam. 1991. *Water table management for water quality improvement.* J. Soil and Water Cons. 47(1): 65-70.
35. Tovey, R. 1964. *Alfalfa growth as influenced by static and fluctuating water tables.* Trans., ASAE 7: 310-312.
36. Verhoeven, B. 1953. *Over de zout en vochthuishouding in geinundeerdegronden.* Thesis. Netherlands Agr. College, Wageningen, The Netherlands.
37. Visser, J. 1985. *Effect of the ground-water regime and nitrogen fertilizer on the yield and quality of apples.* Netherlands J. Agr. Sci. 33(3): 310-313.
38. Williamson, R. E., and G. J. Kriz. 1970. *Response of agricultural crops to flooding, depth of water table and soil gaseous composition.* Trans., ASAE 13: 216-220.
39. Wright, F. S., and F. J. Adamsen. 1987. *Peanut and corn yield response to water table level.* Paper No. 87-2550. Am. Soc. Agr., Eng., St. Joseph, Mich. □