SOME CONSIDERATIONS FOR DRAINAGE OF FLATWOODS
SOILS USED IN VEGETABLE PRODUCTION

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In a recent national survey made by the Agricultural Research Service in cooperation with Federal and State Extension Service subject-matter specialists, 62 percent of the states indicated a need for publication of farmers bulletins on "How to Have Irrigation Mains and Laterals." For bulletins on "Development of Drainage Systems for Irrigated Lands," 68 percent of the states indicated a need; while 95 percent indicated a need for farmers bulletins on "Irrigation Requirements for Specific Crops."

Florida ranked fourth in the Nation in 1959 in net farm income ($6,681), outranked by only Arizona, California and Nevada according to U.S. Department of Agriculture's final revised figures. Total cash receipts from Florida products in 1959 were $806,233,000—an increase of almost $106 million over the previous year. Of this total, agricultural crops accounted for $558,772,000. Vegetable crop receipts for Florida for 1959 were in excess of $185,000,000.

In the educational, commercial and service fields, we find ourselves in a quandary for lack of information of benefit to those growers who insist that Florida keep its rank in vegetable production.

The intent of this paper is to furnish information on drainage and irrigation not readily available to vegetable farmers, commercial interests and educational personnel, and to provide a general outline on the proper use of drainage criteria for Florida Flatwoods soils which, by virtue of environment, are imperfectly or poorly drained.

Soils referred to as Flatwoods soils (see appendix) are described by Byron (1) and are generally suitable for vegetable crop production with adequate drainage and irrigation.

SOIL, WATER AND PLANT RELATIONSHIPS

Most vegetable crops grown in Florida require either furrow or seepage drainage and irrigation. The method used is mainly dependent on the soil-sub-strata beneath the root zone, the source and availability of water, and individual crop response. Regardless of how applied for irrigation, the water must be sufficient to keep the top 2 feet of soil near field capacity—a condition which exists when all but gravitational water remains in the soil. The water must be applied regularly in rainfree periods to supply the daily Evaporation-Transpiration (ET) of the soil and crop.

Preliminary data from Soil and Water Research in Florida have given some promising leads to unanswered questions on soil-water and plant use relationships (Table 1).

There is a 30 percent reduction in water used by crops grown at a 36-inch water table over those at 12-inch water table. Plant nutrient losses are decreased with increasing depth to water table due to a decrease in percolation rates. Optimum depth to water table for vegetable crops grown on Davie fine sand was 2.0 feet. This soil type has characteristics similar to other soils used in vegetable crop production. Based on years of observations in the field, a depth to water table of 2.0 feet is considered to be optimum for most vegetable crops grown in Florida with sub-irrigation.

Table 1. Daily Moisture Requirements for Maximum Yields of Beans, Peppers, Field Corn and St. Augustinegrass Grown on Davie Fine Sand at Ft. Lauderdale, Florida.

<table>
<thead>
<tr>
<th>Crop</th>
<th>Early Growth Water Requirement (in./day)</th>
<th>Mid-season Water Requirement (in./day)</th>
<th>Average Water Used - Crop Life (in./day)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Snap Beans</td>
<td>0.06</td>
<td>0.25</td>
<td>0.18</td>
</tr>
<tr>
<td>Bell Peppers</td>
<td>0.09</td>
<td>0.19</td>
<td>0.13</td>
</tr>
<tr>
<td>Field Corn</td>
<td>0.13</td>
<td>0.33</td>
<td>0.22</td>
</tr>
<tr>
<td>Grass</td>
<td>0.05</td>
<td>0.25</td>
<td>0.13</td>
</tr>
</tbody>
</table>

1Cooperative research with the Soil and Water Conservation Div, ARS, USDA; the Florida Agric. Exp. Sta. and Central and Southern Florida Flood Control District.

2Assistant Agricultural Engineer, Soil Scientist and Engineering Aid; Agricultural Extension Service, University of Florida, Gainesville, and Soil and Water Conservation Division, Agricultural Research Service, USDA, Plantation Field Laboratory, Fort Lauderdale, Florida respectively.

3Lysimeter tests at Plantation Field Laboratory, USDA, ARS, Soil and Water Conservation Research Division, Fort Lauderdale, Florida.
Water requirements (ET) for most vegetable crops grown in Florida will range from 0.10 to 0.20 inches per day. They will be greater in the summer months when the temperature and solar energy are highest and the evaporation is greatest (3).

Soil Moisture Characteristics

Soil moisture retention and release by Flatwoods soils depend to a large extent on their textural and structural qualities. These soils represent land in Florida which is characteristically level to gently sloping. Surface drainage, depth to water table and internal drainage characteristics are important factors in their development for vegetable crop production. Most of these soils have a fine sandy texture to a depth of 2 to 3 feet with varying amounts of organic matter in the surface layers. The permeability or hydraulic conductivity of the sandy layers permits an adequate drainage rate in most instances. The permeability factor (k) of these sandy layers may be expected to be 2-inches per hour minimum.

Shallow soils with normally high water tables over imperfectly drained sandy clay subsoils present the greatest obstacle to adequate drainage. Examples of soil series of this type are Charlotte, Felda, Keri, Manatee, Ruskin and Sunniland. Soils with somewhat impermeable hardpans such as Leon, Immokalee, Pomello and St. Johns present similar problems depending on the depth to hardpan and amount of drainage required.

Most of these Flatwoods soils have more than 40 percent pore space, and when completely saturated will contain as much as 10-inches of total water in the 0 to 24-inch zone. In order to lower the free water table from the surface to 24-inches, approximately 20 percent of the water or 2-inches will need to be drained from the soil. This will leave about 8.3 percent of the volume of the 24-inch profile as air space. Since a larger part of this air space will be in the upper 12 inches of the soil which contains the important rooting zone, this is well within the minimum requirement of soil aeration for most vegetable crops.

Designs of ditches and tile drains must be made and used to conform with the time limit requirement necessary to remove expected surface and soil water to a safe level. Soils with a sandy texture 3 to 6 feet deep usually do not have internal drainage problems. They will drain readily with adequate spacing of ditches and/or tile drains. However, these soils may present a problem in the maintenance of ditch banks and open drains. Areas of saturated fine sand may have fluid properties which cause severe bank caving or tile siltation and failure.

The drainage or draw-down rate of a water table may be assumed to be limited by the permeability of the soil layer having the lowest permeability rate in that part of the soil profile through which the water passes. If the drain tiles or active drainage areas of the drain ditches are within the sandy clay subsoils the rate of drainage will be much lower than in a sandy soil. Several of the Flatwoods soils such as Bladen, Charlotte, Leon, Manatee, Ona and Scranton series may have sandy clay layers within 2 to 3 feet of the surface with permeability ranging from 0.2 to 2.0 inches of water per hour.

Formulas are available that are designed to determine depth and spacing of drain laterals based on soil permeability measurements, non-capillary porosity and hydraulic gradient. Homogeneity in the horizontally stratified layers, permeability, and porosity are generally assumed although known to be quite variable in many cases. An acute shortage of such data for these problem soils make it difficult to design drainage systems that will do the job and at the same time not be over designed or be economically feasible. Assuming a permeability of 2-inches per hour, water table recession rate of 1.0 feet per day for the 0-12-inch depth and non-capillary porosity of 14.7 percent, one set of formulas (4) indicate a needed tile spacing of 218 and 327 feet respectively for tile drains placed 2.5 and 3.5 feet deep. Similar calculations with a permeability of only 0.2 inch per hour indicate needed spacing of drain laterals of 22 and 33 feet respectively for 2.5 and 3.5 foot depth drains. These data probably demonstrate the extremes in design requirements.

Some soil moisture data of several of the Flatwoods soils are listed in Table 2. Total pore space, amount of water released, or degree of aeration at the various moisture tensions may be readily determined from these data. Moisture retained at 15 atmospheres tension is generally accepted as the wilting point for most crops. Field capacity, defined as the amount of water held in the soil after the excess gravitational water has drained.
away and after the rate of downward movement of water has materially decreased," is probably within the range of 0.05 and 0.1 atmosphere tension. Water available for plant growth is normally considered as that amount held by the soil between field capacity and the wilting point. The relatively uniform moisture content among these soils at the same tensions may aid in determining the drainage and irrigation requirements of a large number of the other Flatwoods soils as needed information is collected.

Table 2. Soil Moisture Characteristic Data of Some Flatwoods Soils

<table>
<thead>
<tr>
<th>SOIL TYPE</th>
<th>Water content of 21-inch soil profile, inches of free water</th>
<th>Soil Moisture Tension*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Adamsville fine sand</td>
<td>1.0</td>
<td>1.0</td>
</tr>
<tr>
<td>Felda fine sand</td>
<td>1.0</td>
<td>1.0</td>
</tr>
<tr>
<td>Isomokalee fine sand</td>
<td>1.0</td>
<td>1.0</td>
</tr>
<tr>
<td>Leon fine sand</td>
<td>1.0</td>
<td>1.0</td>
</tr>
<tr>
<td>Ona fine sand</td>
<td>1.0</td>
<td>1.0</td>
</tr>
<tr>
<td>Plumasr fine sand</td>
<td>1.0</td>
<td>1.0</td>
</tr>
</tbody>
</table>

* Moisture content based on same moisture tension throughout the 21-inch profile.

**Drainage Requirements for Removal of Excess Water**

Open Ditch Spacings, Depth and Design:

The impracticability of designing any drainage-irrigation system that will keep interior soil moisture contents at continuous optimum levels during all conditions of weather has long been recognized by drainage engineers and farmers. This problem of design in the areas occupied by Flatwoods soils becomes especially acute because of many factors such as almost level topography, normally high water tables from sub-tropical rainfall, and sandy soils that flow almost like water into tile and ditches under the hydraulic gradients necessary to move the desired amount of water.

The velocities of flow required through flat sandy soils to prevent excessive erosion of ditch side slopes not only creates a drainage problem, but provides an excellent environment for aquatic weed growth which would be flushed out periodically if higher velocities were permissible. Ditches must be designed to remove surface waters of storm rainfall without excessive erosion and silting in sandy soils. The probability of having growth-rates of lowering of the water surface in the ditches which would promote excessive infested drainage channels calls either for additional channel cross section because of increased restriction to flow, or a strict adherence to a weed eradication program.

Soils are not homogeneous nor of uniform depth above impervious or semi-impervious strata and do not have the same permeability characteristics.

The general topography, though usually referred to as "flat," is not actually level, and may vary enough within small areas to exceed the water table range considered to be optimum for crop production. This would create a problem of maintaining uniform soil moisture content throughout a given cropped area without surface ponding unless adequate controls were incorporated into the general design, or unless land-leveling techniques were employed.

The entire area is subject to torrential rainfall and extended periods of drought.

An ideal drainage system may be visualized as a series of primary canals channeling storm runoff smoothly and effectively to a pump or series of pumps with a gradual lowering of stage that provides for a non-eroding flow of surface water and ground water into the canals. These primary canals are fed by a secondary system of smaller ditches all operating under the same conditions as the primary canals. These secondary ditches are in turn fed by field laterals or a system of tile drains. Controls in the system are at a minimum, and serve only to keep canal, ditch, and lateral levels of flow at a depth parallel to ground surface over the entire area.

The size, geometry, and slope of each water channel is designed to transport a certain amount of design storm runoff as it is routed overland as surface flow, and through the soil as base flow. This amount never exceeds a rate of supply from the soil that would produce scouring velocities or sand bar formations at confluence points.

Field laterals are so placed, in conjunction with tile drains, that design storm rainfall is removed within the time limit determined for initial crop damage by inundation or soil saturation.

For use in irrigation, this drainage system is more than adequate in "reverse." By merely
supplying the irrigation water in the upper elevation reach of the system, water is routed through the system in a descending order of elevation supply and in the higher lands a moisture deficit is made up as quickly as in the lowland.

Idealized? Possibly, but achievable within limits that permit a successful agriculture if proper design use is made of soil moisture retention and release characteristics. The first step to be made is the determination of the economic factors that set the frequency with which a crop can be lost to flooded fields. It would be foolish, for example, to design a drainage system to adequately handle storm rainfall that would probably occur only once in twenty-five years when the additional cost would vastly exceed the cost of the crop to be lost.

In the region under consideration, a 24-hour rain totalling 6.5 inches will probably occur once in ten years (5). With an initial water table of 24-inches below ground surface, the soil profile will absorb a minimum of 2-inches of this amount, leaving 4.5 inches of surface water to be removed. As permanent damage to healthy vegetable crops apparently occurs after they have been flooded from 36 to 48 hours, according to observations made at Plantation Field Laboratory, surface water should be removed in 36 hours. This procedure introduces a slight safety factor inasmuch as no surface flooding will occur until the soil profile has become completely saturated, while pumping has removed a portion of this profile water during the initial part of the storm.

Having arrived at a drainage modulus of 3-inches in 24-hours, a system of levees and primary canals is designed to best fit the topographic relief. Ditch gradients are established to provide the “drive” or head that causes flow throughout the system without producing scouring velocities. Canals, ditches, and laterals are designed with proper side slopes and width-depth ratios consistent with the eroding characteristics of the soils through which they are to transport storm waters. Sufficient cross-section is provided in the design to carry the predetermined soil water flow below a “free-board” water surface elevation below ground surface of about 24-inches.

Control structures are placed at strategic locations throughout the system to establish water table levels in conformity with changing land surface elevations. These controls do not restrict drainage flow, but do produce a head loss that keeps drainage flow in approximate parallelism with ground surface.

There are many available formulas in the literature that contain design procedures for this phase of planning. No effort will be made in this paper to present criteria for primary and secondary ditches. Usually, primary canals are excavated parallel to the slope of the land, while secondary ditches (field laterals) are excavated normal to the slope. Within limits, this aspect of the design usually creates but few problems. Spacing of field laterals to adequately intercept soil water flow at a rate commensurate with a desired water table recession increment presents a complex problem. Design can be successfully made only by the use of techniques to characterize the hydraulic conductivity and moisture release of the soils indigenous to the area.

Walker (4) has derived a practical method for determining this spacing of field laterals from 3-inch length soil core sample analysis using standard engineering data, soil permeability, soil porosity and rate of desired water table fall.

Minimum permeabilities of 2-inches per hour for the Flatwoods soils above the underlying semi-impervious strata, and 0.2 inches per hour for the underlying strata, with a non-capillary porosity of 15 percent for both soils were used as a basis of design. The water table recession increment at 0.5 foot depth was taken as 1 foot in 24-hours. The depth of the laterals was assumed to be 3 feet with a depth of flow 1 foot deep (24-inches below ground surface). Using Walker’s method, laterals spaced at 160 foot intervals, 3 feet deep, flowing at a depth of 1 foot would lower the water table from ground surface to a depth of 12-inches in 24-hours.

Where the impermeable layer came close to the surface and soil water was assumed as having to flow through a soil with a permeability of only about .2 inches per hour, ditch spacings required for adequate drainage were so close that little land remained for agricultural crops. In these areas the only solution would be tile drains installed in ditches that were backfilled with more permeable soil through the impermeable layer.

A suggested method of checking the design spacings of field laterals is to first determine
from moisture release characteristics of the soil the volume of water in the soil profile to be drained from the center of the drained field to the lateral (gravitational water in cubic content). This volume of water has to drain through a definite ditch surface below the flow line elevation producing the head that is moving soil water. If this effective surface area is sufficient to transmit water to the ditch at a velocity that does not exceed the velocity of flow per unit area commensurate with permeability of the soil, at the mean head producing flow, design drawdown can occur. This means simply that if there is more water in the soil profile to be drained than the design ditch depth can transmit, this volume of water will have to be decreased by closer spacings of ditches. This is further complicated by the depth of the impermeable layer in relation to ditch depth, or the restriction placed on effective drain surface.

In any discussion of ditch spacings there are factors of economics that will not permit a generalized design. Such questions as the minimum spacing of field ditches allowable before drainage will have to be accomplished by tile because of the large surface areas taken up by ditches, and the value of land leveling for more uniform soil moisture control can be answered only by a survey of individual units to be developed.

**Drain Tile Spacings and Depth:**

Under average conditions the depth of tile lines should be such that the maximum head of water would be at least one foot below the surface. Neal (2) has shown that the spacing and depth of any tile drainage system has a direct relation to the non-capillary pore space of the soil; however, since the pore space is a direct function of the moisture equivalent, it is reasonable to assume the spacings and depth of tile lines to be a function of the moisture equivalent. The most effective tile spacings and depth were tried by Neal (2) and a nomograph evolved from the equations developed. Table 3 has been abstracted from Neal's nomograph for Florida conditions and should be useful as a general guide in locating tile spacings and depths in the Flatwoods soils of Florida.

When vegetable crops are grown in the Flatwoods soils of Florida, the desirable depth to water table is 2-3 feet. With the current cost of tile materials and installation at $0.40-$0.60 per linear foot, tile drainage in most cases is not economical. For example, in fields requiring a 2-3 foot water table, tile lines must be 2.5 to 3.5 feet deep and spaced 25 to 70 feet apart. This would require an initial capital outlay of some $355-$750 per acre.

**Summary**

Drainage or irrigation criteria depend on such factors as crop moisture requirements, soil topography and moisture characteristics, expected rainfall, and the economics of the various systems. For optimum production, vegetable crops require a soil environment in the rooting zone of near field capacity. A 2-foot water table is generally considered to be best for most vegetable crops grown on Fl. flatwoods soils with sub-irrigations. Flooding these crops for longer than 26 hrs. may seriously damage healthy plants. Moisture removed from the soil as evapo-transpiration under normal vegetable cropping conditions will probably range from 0.1 to 0.2 inches per day.

Data on soil moisture retention and release by these soils are essential for determining drainage requirements. Generally, 2 to 3 inches of free water will need to be removed from these soils to lower the water table from the surface to 24 inches. Soils having a sandy texture to the depth of the drains usually have good internal drainage, but may present problems of ditch or drain-tile maintenance. Sandy loam or sandy clay subsoils usually have hydraulic conductivity rates much lower than fine sands. Whether to use ditch or tile drains largely depends on the hydraulic conductivity of the soils and the economics involved in land use and field operations resulting from open ditch construction.
A well designed ditch and tile drainage system for level to gently sloping land may be used in reverse as an effective sub-irrigation system. The irrigation system selected should be designed to supply sufficient water to bring the soil moisture to near field capacity in the plant rooting zone.

The first step in design of drainage is the determination of economic factors that set up the frequency which a crop can be lost to flooded fields. Permanent drainage normally means flooding from 36 to 48 hours. In the central and southern Florida area, a 24-hour rain totaling 6.5 inches has a probability of once in 10 years. Since 2 inches of this total will be absorbed in the soil profile when using a 2-foot water table, only 4.5 inches of surface water must be removed; therefore, it would have been sheer foolish business to place our design criteria on an amount in excess of 3 to 4 inches per hour.

In conclusion, water content of most of our Flatwoods soils at field capacity will range from approximately 3.0 to 3.8 inches per 2 feet of depth.

LITERATURE CITED

EFFECT OF FUNGICIDE DRENCHES APPLIED IN THE FURROW AT PLANTING TIME ON CONTROL OF DAMPING-OFF OF SNAP BEANS

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Damping-off and root rots of snap beans in south Florida are caused principally by Rhizoctonia solani Kuhn and species of Pythium. The most obvious damage caused by these fungi occurs during germination and shortly thereafter in the form of damping-off. Later invasions usually result in lesions on the stem at the soil level or on the root system under the soil surface, and perhaps less frequently result in death of the plant by damping-off. Loss of plants by damping-off has been reduced by the use of fungicides applied as drenches in the furrow at plant time (2,3,4,