SOIL SCIENCE
Copyright © 1972 by The Williams & Wilkins Co.

Vol. 114, No. 3
Printed in U.S.A.

A SELF-DRAINING SUBSURFACE RAINFALL CONSERVATION SYSTEM; ITS EFFECT ON THE SOIL WATER STATUS AND PRODUCTIVITY OF COASTAL PLAINS SANDS

D. A. RUSSELL

USDA, Florence, S. C. and South Carolina Experiment Station, Clemenson, S. C.[1]

Received for publication January 28, 1971

The productivity of deep sands and sandy soils is often limited by low 0.1 to 15 bar water retention, very low exchange capacity, and high final infiltration rates. Even in a humid climate, such as the southeastern U.S.A., crop growth and yield can be severely limited by the very low capacity of these soils for buffering the plant against periodic adverse environmental conditions. The situation is complicated by the fact that the rainfall regime during the growing season is characterized by short periods of high intensity rain, often followed by drought periods.

The object was to establish a water control system which would provide simultaneously for both rainfall and nutrient conservation and drainage of excess water, with the capability of providing for crop needs over the growing season. A subsurface system was decided on, as meeting these requirements.

The approach adopted was to establish a perched water table, which would be self-draining to a predetermined level when the free-water level rose above that mark. For this reason, and because of the steeply rolling topography, a continuous subsurface barrier such as that developed by Erickson et al. (1) was not considered suitable.

LABORATORY MODEL TEST

To achieve the desired conditions the system consisted of a U-shaped subsurface trough, with the top of the U set about 20 cm. below the ground surface. Preliminary tests showed that this system effectively retained precipitation; the trough filled during rainfall, and self-drained to a level below the lip of the trough when rainfall ceased. This self-drainage feature operated in a manner analagous in some respects to the wick-siphon principle (Richards 2, 3).

The design was modelled in the laboratory using a 60-cm. high, 42-cm. wide Plexiglas trough set inside and against one wall of an 80-cm. high, 72-cm. wide, 60-cm. deep Plexiglas-fronted box (fig. 1). A rigid screen was set in the trough 12 cm. in from the side of the box to provide a well. Thus the trough and the section of profile outside it were both 30 cm. wide. That part of the box base not covered by the trough was perforated to allow for drainage. The whole container, except for the well, was filled with wet, washed sand. The trough was supplied via the well with water to which a dye had been added. The results are shown in figs. 1 and 2.

The water table was initially maintained at 1 cm. below the trough lip. In fig. 1, the position of the wetting front advancing from the trough is shown at two times.

Subsequent to this, the water supply to the trough was shut off. Drainage from the trough continued and the water table decline was traced with time. This is shown in fig. 2. It is evident that drainage is fairly rapid initially, but the water out-flow rate and hence the free-water surface, declines in a logarithmic fashion with time.

The equilibrium level of the free-water surface below the trough lip depends on the hydraulic characteristics of the particular soil. In this laboratory test it was 25 cm. In a pilot trough on a Lakeland sand it was approximately 40 cm. The total quantity of water conserved depends on the trough depth below this equilibrium level, as well as on the soil porosity and superficial coverage of the troughs.

[1] This work is a contribution from the Coastal Plains Soil and Water Conservation Research Center, Florence, S. C., Soil and Water Conservation Research Division, ARS, USDA, in cooperation with the South Carolina Experiment Station, Clemson, S. C. The author was formerly with the USDA, ARS-SWC, Florence, S. C., and is now with the department of Agriculture, University of Rhodesia, Salisbury, Rhodesia.

Consultations with Doyle Peters, USDA-ARS, Urbana, Illinois, are gratefully acknowledged.

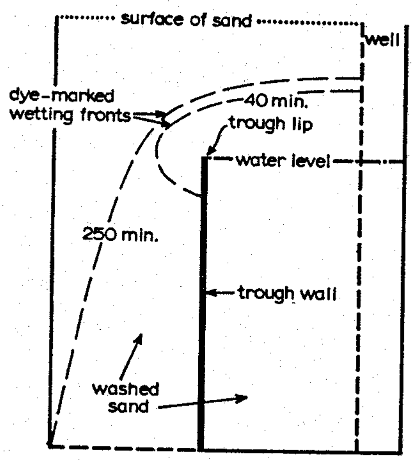

FIG. 1. Schematic of model of sub-surface trough, showing wetting front position after specified period of flow from constant level watertable.

FIELD TEST

The pilot trough demonstrated the effectiveness of the system with regard to water control *per se* in the field. A trial was then designed to test its behaviour under a plant cover and its efficacy with respect to plant growth and crop production.

The field experiment was located on a transition Lakeland-Eustis soil with a 1% slope and a profile comprising 1.83 m. of sand overlying a sandy clay. The relevant soil physical properties are shown in table 1.

The subsurface troughs were formed by lining trenches with .02-cm. polyethylene, and backfilling. Dolomitic lime and superphosphate were added to the backfill in quantities equivalent to 6750 kg/ha and 69.2 kg P/ha (784 kg 0-20-20/ha), respectively, per 15.00-cm. depth increment below plow depth.

The troughs were .61 m. wide, with the bottom 1.22 m. and the top 15–23 cm. below the soil surface. They were laid on the contour across the width (4.27 m.) of the plots on 1.22-m. centers, giving 50% superficial coverage. Treatments were:

1) Subsurface rainfall impoundment plus subsurface irrigation, through perforated pipe laid

TABLE 1

Soil physical characteristics

	Mechanical Composition					Soil Water
Depth* (*cm.*)	(*% by wt.*) Size (*mm.*)			Bulk Density (*g. cm* $^{-3}$)	C.E.C. *meq./ 100 g.*	0.1–15 bar (*% by vol.*)
	2–.2	.20–.02	.02			
0–15	58	29	13.0	1.6	1.87	10
15–60	54.6	28.5	16.9	1.5	0.02	

* Because of their small differential the mean was taken of the values for both zones.

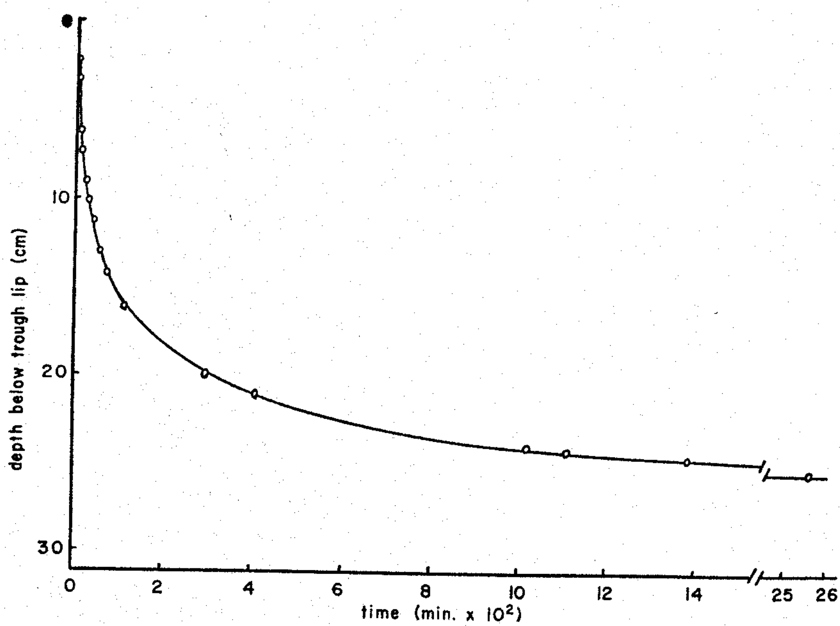

FIG. 2. Drop in water-table with time.

on the bottom of the trough during construction. This supplemental irrigation was provided to maintain the water table at the desired level during times of high ET.

2) Subsurface rainfall impoundment only.

3) Trenching. This comprised trench excavation with backfill and fertilization as detailed above, but no trench lining was laid.

4) No treatment (check).

A randomized complete block design was used, with three replication. The plot dimensions were 4.27 × 6.1 m. Thus each plot treatments 1 and 2 contained five troughs, each 4.27 m. long.

Agronomic practices were selected so that growth - limiting factors other than climate and water supply were eliminated. Except for the initial cultivation, all operations were done by hand. Corn (S. C. 236) was planted March 13, using a population of 46, 102 plant/ha. Each row was planted directly over and in line with a trough. The area was limed with 6750 kg/ha dolomitic lime, and fertilized with 135 kg N/ha, 119 kg P/ha, 224 kg K/ha (2240 kg 6-12-12/ha) broadcast at planting. Later, the corn was side-dressed with 112 kg N/ha (336 kg 33-0-0/ha). Rootworm, weeds and earworm were chemically controlled.

The water-table level in the trough was measured, using wells set to the bottom of one trough in each plot. Samples of water were withdrawn from the troughs in the experimental area and from an identical trough outside the experimental area; the electrical conductivity was measured to trace the variation in salt concentration of the conserved water with time. Tensiometers were installed in the center of each treatment in the second replicate. One set of five tensiometers were installed in the row to monitor the 15, 30, 45, 60, 90-cm. depths, and an identical set placed opposite in the center of adjacent inter-row space. All measurements, including plant height and soil water tension measurements were made weekly.

RESULTS AND DISCUSSION

The troughs were installed on January 20–23 and filled by the late winter and early spring rains. The variation in water table level through the season is shown in fig. 3 together with the rainfall. The water table level stabilized at 61 cm. below the soil surface, approximately 40 cm. below the trough lip. This resulted in 61-cm.-deep water table in the trough, representing 122 mm.ha. of water conserved. The one recorded time the free-water level exceeded the 61-cm. mark was on April 18, when the measurement was made immediately after a thunderstorm.

It is evident from fig. 3, that the water table level variation depends on rainfall and plant

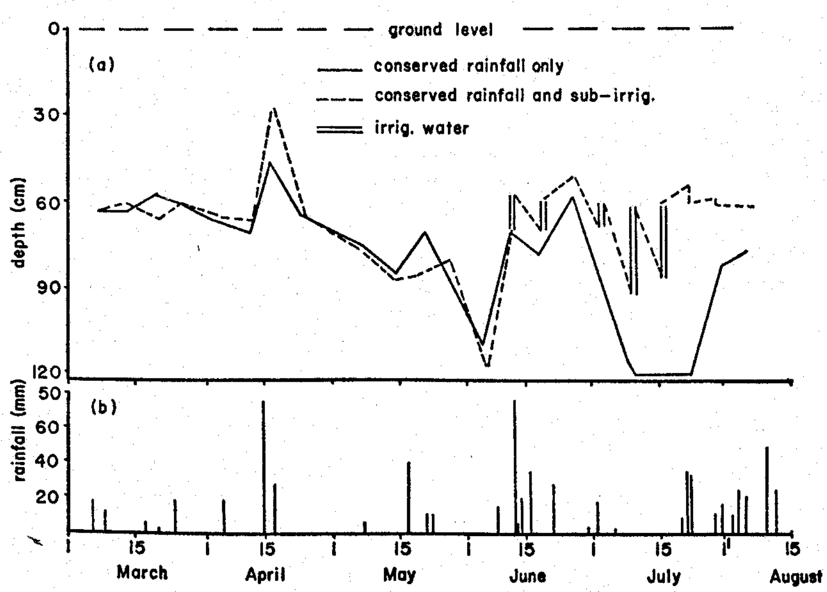

FIG. 3. (a) Water-table height; (b) rainfall.

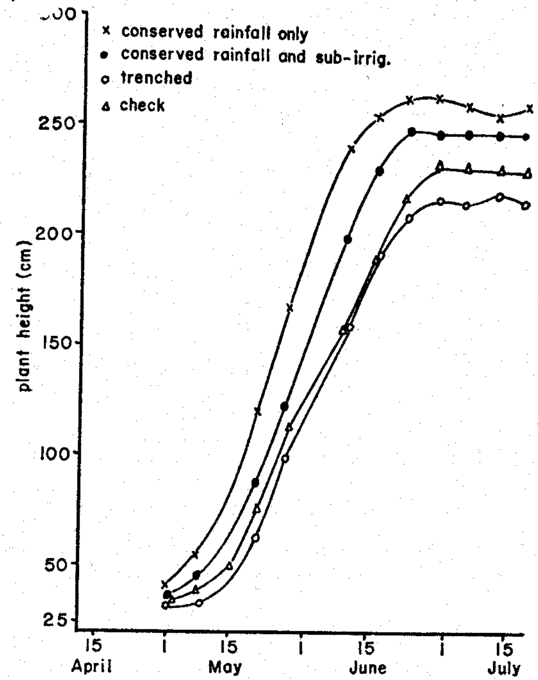

FIG. 4. Plant height cumulative growth curve.

demand. The rainfall record shows that three drought periods occurred during the test, covering three different stages in the growth cycle of the crop (fig. 4). The first, of 21 days duration, occurred in late April and May; the second, of 12 days, lasted from May 25 through June 8; the third was most severe because of very high temperatures, lasting 20 days from July 3 through 23. The rate of water table decline for each drought period reflects the demand at the particular stage of growth. During the first period, which spans the early vegetative growth stage, the water table showed a slow but steady decline. The rate of decline was considerably greater in the second period, which covered the middle of the vegatative growth cycle. ET calculated from the water table data was 1.75 and 6.1 mm./day for the first and second periods, respectively. Tensiometric data showed that the soil water tensions between the rows in both sub-irrigated and non-irrigated trough plots did not exceed 25 cb. at depths greater than 30 cm., indicating that most of the water loss through ET was from the trough water table, not from the soil profile. In contrast, toward the end of the second drought period, the non-trough plots showed tensions in excess of 30 cb. to a depth of 76 cm. Severe wilting occurred at this time, and the resulting growth lag is reflected in fig. 4.

During the last drought, which encompassed the period of final vegetative growth, maturity of reproductive organs, fertilization, and ear development, the rate of water table decline was highest. The ET was calculated to be 7.6 mm./day. The free water held in the trough was exhausted, and although low tension water was present in the lower part of the trough, by July 17 soil water tension between the troughs increased to approximately 70 cb. at the 45-cm. depth. Evidently the plant water demand ex-

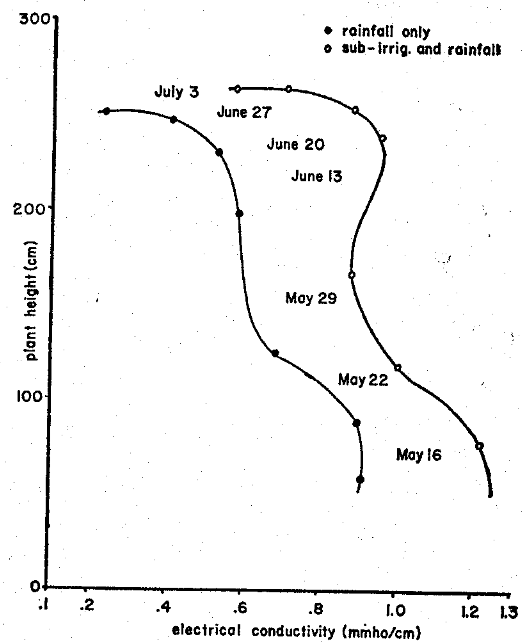

FIG. 5. Relationship of plant growth (height) and change in electrical conductivity.

TABLE 2

Yield of shelled corn (15.5% moisture) (t/ha.)

Treatment	Yield
Rainfall + sub-irrigation	7.24 a
Rainfall	7.45 a
Deep cultivation (trenched)	2.42 b
Check	2.44 b

Note: Treatment means labelled with different letters are significantly different at 1% level; those labelled with the same letters are not significantly different at the 5% level.

ceeded that available from the root system in or near the trough. In the non-trough plots, tensions exceeded 40 cb. to the 90-cm. depth and all the plants "fired" severely, some dying.

Measurements of electrical conductivity of water samples from the troughs were made weekly from May 16 to July 3, covering the major portion of the cumulative growth curve. The conductivity declined from an initial reading of about 1 mmho./cm. to a final figure of .5 mmho./cm. Samples from an identical trough on unfertilized fallow ground declined from 0.24 to 0.06 mmho./cm. This indicates that fertilizer salts were conserved in the trough plots along with the infiltrating rainfall.

Figure 5 shows the variation of electrical conductivity of the conserved water due to plant growth and rainfall. The curves for the sub-irrigated and non-irrigated treatments are parallel. The initial small net decline in conductivity was probably due partly to dilution by conserved rainfall (fig. 3), and partly to plant use. During the ensuing dry period from May 25 through June 13, relatively little change in electrical conductivity occurred although the water table continued to fall; this indicated that water and nutrients were taken up simultaneously by the plant. Subsequently the electrical conductivity of the conserved water showed a continuing sharp decline, which was apparently little influenced by variation in the water table level. Evidently salt uptake was particularly high during this period of tasselling and early ear growth.

Root distribution studies just prior to harvest showed that the root system extended to the bottom of the trough in the rainfall-only trough plot and to the 1.22 m. depth in the trenched plot. However, the bulk of the root system was in the top 45 cm in these treatments, as well as the sub-irrigated and check plots. The fluctuating water table apparently did not sufficiently affect the root system to cause any effect on plant growth and development. The self-drainage feature was probably responsible for this, as well as minimizing root damage during periods of high rainfall.

The net effect of this root zone environment modification is shown by the corn yield data in Table 2. The subsurface conservation treatment tripled the mean grain yield from 2.44 metric tons/ha., which is typical for the area, to 7.45 metric tons/ha. There was no significant difference between treatment means for either of the water conservation treatments, or for the non-conservation treatments.

The present cost of materials makes this possible practice quite expensive. Using a reasonably sturdy grade (0.152 mm.) of polyethylene film in the above configuration would cost approximately $3336/ha ($1350/ac) for materials alone. Fluidized grouting material commonly used for engineering purposes, which can be laid down by injection, costs even more. However, for selected crops such as peaches (seedlings), where much less material would be needed, or for high-valued crops such as strawberries, the practice would likely be both agronomically and economically feasible.

CONCLUSION

These results show that by applying the principles of soil water movement to a subsurface trough design, water and nutrient conservation, and excess water drainage can be incorporated in a single practice. This reduces drought damage hazard to crops and provides a marked increase in the productivity of sand soils. However, at present, the cost of material would limit use of this practice to high-valued crops and to crops which would not require massive amounts of material such as orchard establishment.

REFERENCES

(1) Erickson, A. E., Hansen, C. M. and Smucker, A. J. M. 1968. The influence of subsurface asphalt barriers on the water properties and productivity of sand soils. Trans. 9th Int. Cong. Soil Sci. 1: 331–336.

(2) Richards, L. A. 1950. The laws of soil moisture. Trans. Am. Geophys. Union 31: 750–756.

(3) Richards, L. A. 1955. Retention and transmission of water in soil. Yearbook of agriculture "Water", 144–151.