<論 文>

土壤別 地表, 地下排水間 土壤水分 變化에 대하여

The soil moisture fluctuation between surface and subsurface drained plots in the different soil characteristics

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摘 要

本試驗은 灌漑 및 排水 設計를 爲한 基礎資料 提供을 目的으로 土壤水分 및 地下水位의 變化狀態를 究明하고자 하는 것으로 카나다 퀴벡(Quebec) 地方 低地帶의 代表的인 2種의 土壤인 粘土와 砂質 로움土壤에 對해서 一次的으로 地表, 地下排水間의 土壤水分과 地下水位의 變化를 硏究分析한 것으로 그 結果를 要約하면 다음과 같다.

1. 2種의 土壤(粘土, 砂質로움)에 있어서 共히 土壤水分은 地表로 부터 地下로 내려갈수록 增加되는 狀態를 나타냈으면 이는 下層土로 내려감에 따라 팽창된 치밀한 土壤 組織을 가지고 있음을 시사하며

2. 冬期에 있어서는 지표로부터 12inch 깊이의 土壤水分이 더 깊은 18 inch 나 24 inch 깊이의 土壤水分 보다 增加된 狀態를 維持하였다. 이는 土壤內의 빙결막이나 地表面의 눈 또는 어름에 영향으로 생각되며 이 傾向은 粘土質 土壤에서 보다 土壤內 빙결막으로의 水分 移動을 助長해주는 透水 係數가 큰 砂質로움 土壤에서 더 높았다.

3. 兩試驗區 共히 地表에서 얕은 地下 0~3inch 以內의 土壤水分은 降雨를 前後해서 급격한變化를 가져왔다. 여기에서 水分의 急上昇은 豪雨時나 表層土가 下層土의 土壤水分에 影響을 주는 降雨以前에 圃場容水量(Field capacity)에 達했기 때문이며 急降下는 地表面의 물 分子가 熱에너지에 依해 蒸發散되고 淺層에 散在한 草, 樹根에 依해 消費되는 때문인 것으로 思料된다.

4. 地下水位下의 土壤水分은 飽和에 達하여 거의 一定 할것으로 期待되었지만 實際로 많은 變化를 가져왔다. 이들 變化에는 部分的으로 土壤死隙이 地下水位下이라도 체워지지 않았거나(Capillary pressure가 작을 時) 혹은 관측기간 中에 土壤의 융기와 收縮에 基因된다고 생각된다.

5. 地下排水區가 地表排水區에 比해 地下水位降下가 빨랐음은 勿論 砂質로움 土壤에서는 보다 높은 透水係數로 因해서 地下水位의 降下가 粘土質 土壤에서 보다 휠씬 빨랐음을 보여주고 있다.

I. Introduction

The importance of soil moisture measurements was recognized long ago from the point of view of water balance and crop production. Especially soil moisture, soil temperature, size and amount of aggregates and plant nutrient availability are most important for crop production. The quantity of water present between the field capacity and the wilting point is the moisture available to plants.

Knowledge of soils ability to hold available moisture is of particular importance in planning and operating irrigation systems.

Several indirect methods have been developed during the last forty years to obtain the moisture content of soil easily, corectly and quickly.

The major objective of the research described in this paper is to obtain informations on the movement

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of soil moisture content in the soil throughout the year on the two flat land soils with subsurface drained and without subsurface drained system in the St. Lawrence lowlands which can provide a background for assessing:

1. Water availability for consumptive use
2. Rates of extraction of water from soil
3. Changes of groundwater levels
4. Times of recharge of ground water
5. Extent of drought periods
6. Possible effect of subsurface drains on the water supply
7. To give data for an efficient irrigation and drainage design

Ⅱ. Method of measuring soil moisture

Neutron scattering method

This method is based on the principle that fast neutrons are slowed down most rapidly by particles near the size of neutrons. Hydrogen atoms are very close to the same mass as neutrons, and an abundance of hydrogen atoms exists in the soil, primarily in the soil water. the neutron advice essentially consists of two parts, the neutron probe and the scaler.

The neutron probe contains a source of neutrons. The water content in the soil on a percentage by volume basis is obtained indirectly by counting the number of slow neutrons reaching the detector per minute.

Except when strong neutron absorbers (such as cadium, chlorine, boron, lithium) are substantially present, it is claimed by several workers (Gardner and kirkham,(6) 1952; Van Bavel(12) *et al.*, 1956) that one calibration curve is sufficient for measuring water content of all types of soils. Two types of assessment have been achieved for the precision of measurements. One is on the degree of reproducibility by repeating determinations. The other assessment consists of comparisons with moisture determinations by the conventional oven drying technique.

Measurements of reproducibility indicate a standard error of about 0.5 per cent water by volume for the depth-moisture gage in the range of 15 per cent to 35 per cent moisture.

Using the ratementer, Van Bavel(13) *et al.* (1956) mentioned a precision equivalent to a standard error of about 0.1 per cent of moisture by volume basis. Stewart and Taylor(12) (1957) used the term "water ratio" (R). R represents the ratio of the volume of water in the sample to its bulk volume. He also defined the term "Count ratio" as the ratio of counts taken in soil to standard counts. The correlation coefficient calculated between count ratio and water 'ratio was 0.95.

Bowman and king(2) (1965), in their studies of evapotranspriation, concluded that this method is accurate to 0.15 inch water for one week, or 0.62 inch over a three-month period.

The zone of measurement of a depth-neutron probe is infinite, therefore an effective zone of measurement is that within which occurs about 90-95 per cent of all neutron interactions.

An approximate formula for the effective zone radius has been worked out by Van Bavel *et ail.*(1956).

$$R=15\left(\frac{100}{\text{moisture content in per cent by volume}}\right)1/3$$

where

R=efective radius of zone of measurement, Cm.

Usually the centre of measurement is considered at the centre of the BF_3 tube, however, since the diameter of the zone of measurement varies with the moisture content, it becomes diffcult to define precisely the centre of measurement at moisture contents above 40 per cent by volume (Troxler, 1968). Hanks and Bowers18)(1960) concluded that an access tube influences the soil temperature within a radius of 10cm from the access tube and, to a depth of 10cm from the surface of the ground, but this change has no influence on soil moisure measurement.

The temperature efftect on the depth-neutron probe has been reported by Davidson[4] *et al.* (1959). The major effects were due to the temperature on electrical components of the preamplifier of the probe. Stewartand Taylor[12] (1957) found that it takes nearly 60 seconds to bring the neutrons into a steady state condition.

Ⅲ. Materials and methods

1) Description of experiment site

a) Location

The field measurements presented in this thesis were made on the farms of Mr. Jean Paul Martineau and Mr. Paul Emile Vincent in Soulanges County of Quebec. A map showing the locations of these farms is given in Figure 1.

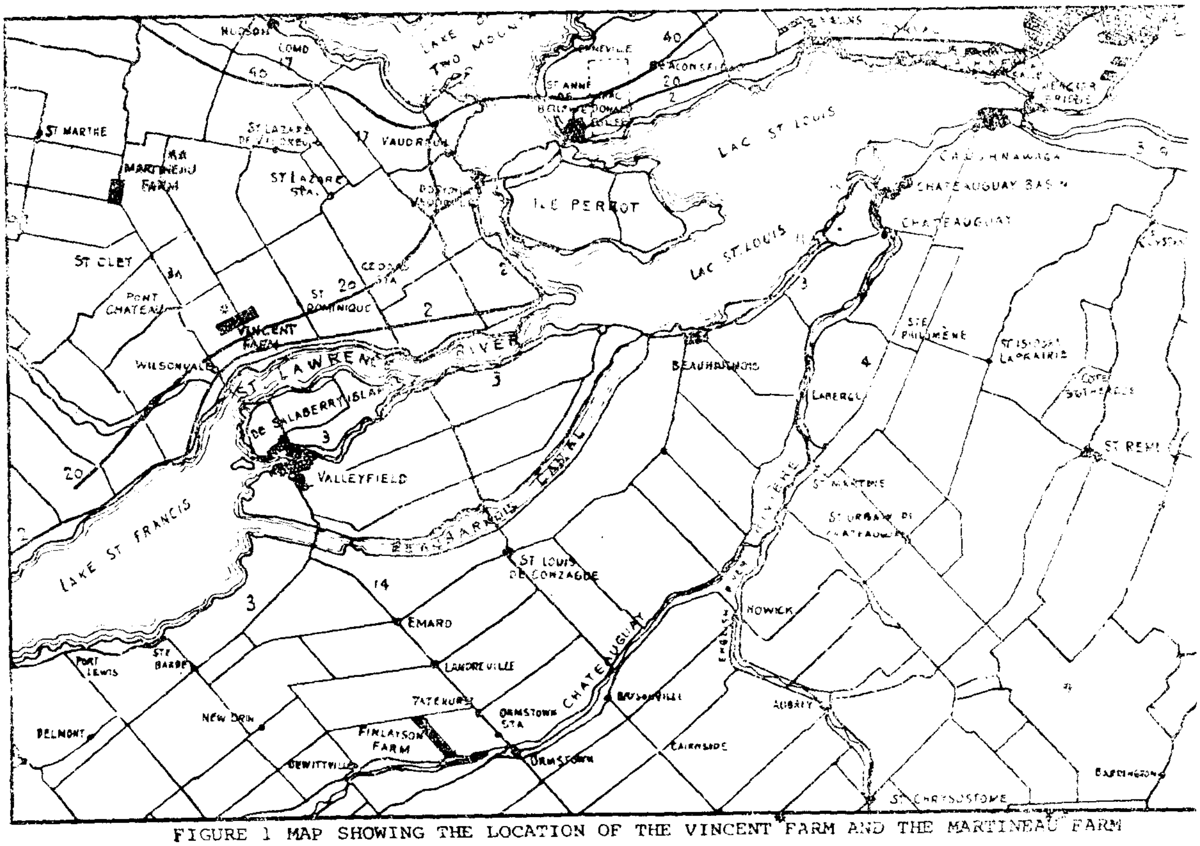

FIGURE 1 MAP SHOWING THE LOCATION OF THE VINCENT FARM AND THE MARTINEAU FARM

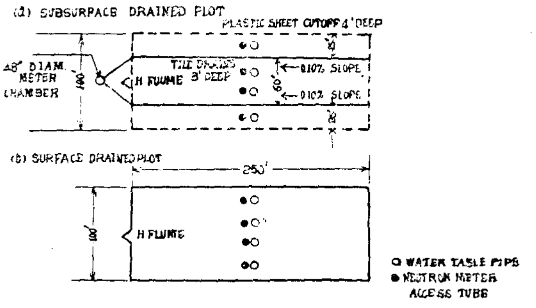

FIG 2 LAYOUT OF THE WATER BALANCE PLOTS IN THE SOULANGES FINE SANDY LOAM FARM.

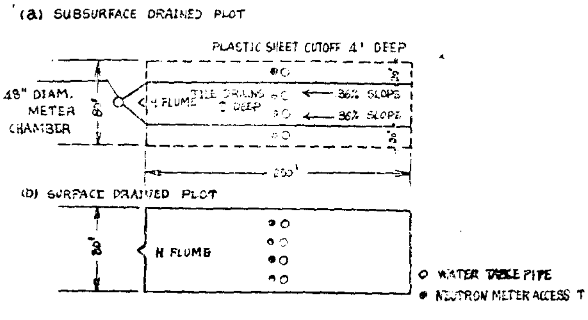

FIG. 3 LAYOUT OF THE WATER BALANCE PLOTS IN STE. ROSALIE CLAY FARM

b) Experimnetal field

The experimental measurements were made in the water balance plots on Ste. Rosali clay and soulanges fine sandy loam soils on the Martineau and Vincent farms respectively. At each site there were two plots; One with surface drainage and the other was supplemented with subsurface drainage. The detailed layout for the water balance plots is given in Figure 2 and Figure 3.

c) Particle size analysis and Bulk densities

The results in the Table 1 were obtained from the particle size analysis using the hydrometer method. Bulk density values for the following depths were obtained at each plot by using a core sampler of $2\frac{3}{4}$ diameter (see Table 2).

Table 1. Particle size analysis

(1) Subsurface drained plot at Vincent farm

Depth (In.)	Clay (%)	Silt (%)	Sand (%)
0~6	13.0	12.0	75.0
9~15	3.5	9.5	87.0
18~24	11.5	9.0	79.5
30~36	62.0	30.0	8.0

(2) Surface drained plot at Vincent farm

Depth (In.)	Clay (%)	Silt (%)	Sand (%)
0~6	14.0	15.0	71.0
9~15	9.5	7.5	83.0
18~24	3.1	3.5	93.4
30~36	60.5	27.0	12.5

(3) Subsurface drained plot at Martineau farm

Depth (In.)	Clay (%)	Silt (%)	Sand (%)
0~6	40.5	30.5	29.0
9~15	50.5	29.5	20.0
18~24	46.0	33.0	21.0
30~36	48.0	31.5	20.5

(4) Surface drained plot at Martineau farm

Depth (In.)	Clay (%)	Silt (%)	Sand (%)
0~6	34.0	32.0	34.0
9~15	43.0	31.0	26.0
18~24	47.0	28.0	25.0
30~36	38.0	29.5	32.5

Table 2. Dry bulk density values (gm/c.c)

Depth (In.)	Vincent farm			
	SB.D.P.	S.D.P.	SB.D.P.	S.D.P.
0~4	1.30	1.34	1.18	1.07
4.5~7.5	1.33	1.37	1.29	1.11
7.5~10.5	1.50	1.37	1.51	1.36

SB.D.P.=Subsurface drained plot
S. D.P.=Surface drained plot

d) Weather summary

Weather stations were installed on both farms and provided climatic data for use in this experiment. Table 3. and Table 4. show the weather summary of the Martineau and the Vincent field in 1970.

Table 3. Weather summary of Martineau field (1970)

Month	Precipitation (In.)	Mean temp. (OF)	Max. temp. (OF)	Min. temp. (OF)
March	2.75	24.5	46.0	2.0
April	3.23	41.5	79.0	15.0
May	2.64	52.4	64.5	64.2
June	2.05	69.2	85.0	38.0
July	2.54	68.4	79.3	57.6
Aug.	1.41	66.6	78.9	54.3
Sep.	4.26	57.5	83.0	37.0

Table 4. Weather summary of Vincent field (1970)

Month	Precipitation (In.)	Mean temp. (OF)	Max. temp. (OF)	Min. temp. (OF)
March	2.45	24.8	45.0	−5
April	2.62	41.5	78.0	18
May	2.54	51.2	67.4	43.6
June	1.72	56.3	73.7	51.9
July	1.73	66.8	78.7	62.7
Aug.	1.85	68.4	78.7	57.3
Sep.	4.90	58.2	83.0	37.0

e) Measuring techniques

(1) Soil moisture measurements

The neutron method was selected because it is reputed to be inherently very accurate and also, it allows repeated measurement at the same location in the field. The moisture content on a volume basis is obtained directly without the need of bulk density measurements. The neutron probe (Model 104) and the scaler (Model 200b) made by Troxler Electrical laboratory, Raleigh, North carolina, U.S.A. were used for the measurements of soil moisture content.

Along the center line of each plot, four acess tubes, 10 feet long, were inserted 7 feet into the ground. A two inch soil auger was used to drive these into the ground. These access tubes were made from standard 2.00-inch O.D. and 1.9 inch I.D. seamless aluminium irrigation tubing. Bottoms of the tubes were sealed by welding on a circular aluminium plate. Rubber stoppers were placed in the top of the tube to prevent ingress of rain. The measurements were taken approximately once a week with the center of the probe at the following depths; 6, 12, 18, 24, 30, 36, 42, 48, and 60 inches.

(2) Water table measurements

Water table measurements were made by direct observations taken from water table access pipes. Half-inch standard (0.84 in. O.D.) iron pipes were used with diametrically opposite holes at three inch intervals throughout the length of pipes.

A two inch diameter auger was used for inserting these tubes in the ground. A cotton cloth filter was placed around the tubes to prevent ingress of soil into the holes.

The water table level was measured with a blow pipe once a week. The blow pipe was made of one-quarter inch copper tube with an extension of plastic tube. Rubber corks were placed in the top of the water table access pipes to avoid the direct entering of rain or dust from the top.

Ⅳ. Results and discussion.

Referring to Figures 4 and 5, it can be seen that the changes in soil moisture content in the top 3 inches are more abrupt than the changes in the deeper layers, The more rapidly descending moisture content in the top 3 inches is due largely to the direct energy available at the ground surface for evaporation and transpiration. The concentration of roots in the top 3 inches helps to dry out that layer faster.

Similar results were obtained for the Ste. Rosalie clay soil. The moisture content of the top 3 inches increases more rapidly after rainfall than it does at greater depths, because the upper soil must theoretically be brought nearly to field capacity before the wetting front descends. It is only when there is a large rainfall or when the top soil is near field capacity prior to rain that the lower soils increase in moisture content. From Figures 4 and 5, it can be seen that on almost all occasions where the moisture content in the top 3 inches has risen abruptly after a rain, the moisture content at all lower depths has also risen slightly. This observation confirms laboratory findings which show that when the whole profile is moist, water moves gradually down through the profile after a rain rather than proceeding as an abrupt wetting front, as it does when the soil is dry before the rain. Since the regular moisture measurements were taken at approximately weekly intervals, in most cases there was a period of 24 hours or more after a rain before the moisture measurements were made.

This time would allow gradual distribution of water down through the profile. It is noted that except for the winter months the moisture content increases as the depth from the surface increases.

Near or beneath the water table, the soil moisture content should be at the saturation point and might and might be excepected to be constant. But during the investigation it was found that the moisture content of soil below the water table changed a considerable amount. Some of the variations may be due to all the pores not being filled even if they are below the water table. For the largest pore to fill,a very low negative pressure, i.e., a pressure from the curvature of the air-water meniscus, is required. This is a manifestation of hysteresis which is influenced by the history or revious treatment of the soil. Some variation in water content below the water table may be due to the soil swelling or shrinking over a period of time between field observations.

The variation may also be due to partly to the loss in the neutron probe sensitivity at the higher moisture contents. Considering Figures 4 and 5, it can be said in general that moisture content increases as the depth from the surface increases in almost all cases except during the winter time when the temperature goes down below the freezing point.

It was observed that the moisture content in winter at the 18-inch depth was less than the moisture content at the 12-inch depth. No remarkable changes in soil moisture contents were observed in deeper layers of the soils. The increases in moisture content at the 12-inch depth during freezing weather was greater in the Soulanges fine sandy loam soil than in the Ste. Rosali clay soil. This may be due to the higher hydraulic conductivity of the Soulangesfine sandy loam soil which offers greater opportunity of migration of water to freezing lenses in the soil.

The question might be asked whether the higher moisture content at the 12-inch depth is due to ice lenses in the soil or to the accumulation of snow or ice on the surface of the ground. It is difficult to say precisely which was the major cause of obtaining the higher moisture content in winter time at the

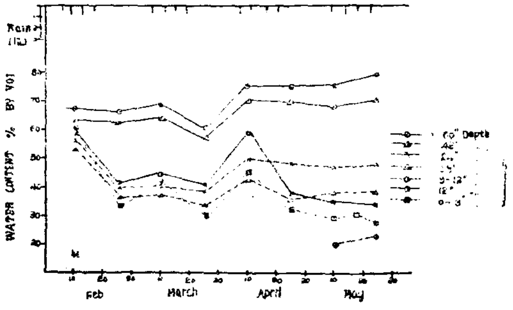

FIG 4 SOIL MOISTURE OBSERVATIONS, SURFACE DRAINED PLOT SOULANGES FINE SANDY LOAM SOIL, 1970

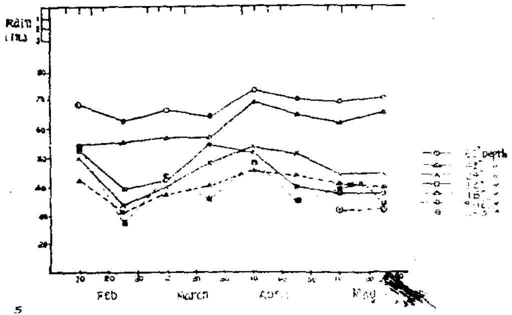

FIG 5 SOIL MOISTURE OBSERVATIONS SUBSURFACE DRAINED PLOT SOULANGES FINE SANDY LOAM SOIL 1970

12-inch depth. Further research is needed to investigate the effect of snow accumulation on the neutron meter readings for top layers of soils. Similar result as Figure 4 and Figure 5 even in the plot of clay isol was obtained.

Only the water content was found more in the Soulanges fine sandy loam than in the Ste. Rosali clay soil.

It can be seen from Figures 6 and 7 that the water table recedes faster in the subsurface drained plot than in the surface drained plot in both soils. This was expected because a large quantity of water was removed by the tile drains. The water table recession characteristics of the two soils were found to be different. In the Soulanges fine sandy loam soil the water level moved faster and went down to almost four feet due to high hydraulic conductivity. In the Ste. Rosali clay soil, the water level did not move as quickly as in the Soulanges fine sandy loam soil.

Considering the recession, it appears that the hydraulic conductivity of the soils is a governing factor. A faster rate of recession occured in the sandy loam soil which had a higher hydraulic conductivity than in the clay soil.

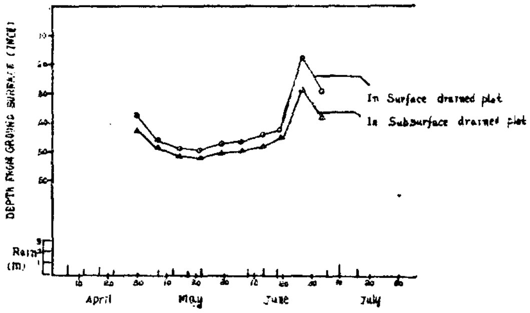

FIG. 6 WATER TABLE FLUCTUATIONS IN SOULANGES FINE SANDY LOAM SOIL. 1970

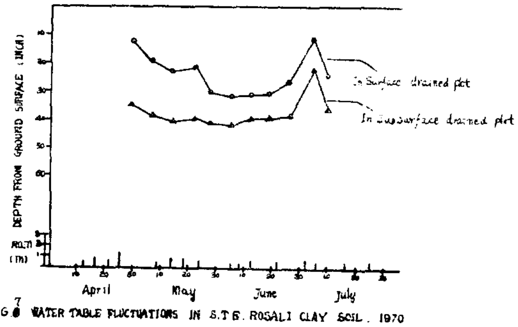

FIG 7 WATER TABLE FLUCTUATIONS IN S.T E. ROSALI CLAY SOIL. 1970

V. Summary and conclusions

Soil moisture observations in the plots with and without subsurface drained system were made approximately at weekly intervals for acquiring some basic data to provide backgrounds of water availability for consumptive use, changes of groundwater levels, and an efficient irrigation and drainage design. The experiment sites were located near St. clet in Soulanges County, Quebec, Canada, about twenty miles southwest of Macdonald College.

The neutron scattering method was used for the soil moisture measurements. Through this experiment, following results are obtained.

1. Soil moisture increases as the depth from the surface increases in almost all cases.
2. The moisture content of the top 12 inches was found to increases during the winter weather. This increase in frozen water content was found more in the fine sandy loam than in the clay soil.
3. Abrupt changes in soil moisture content were noted at the depth of 0~3 inches from the surface.
4. It was found that the moisture content of soil below the water table changed a considerable amount.
5. A faster rate of recession of ground water table was noted in the fine sany loam than in the Rosali clay soil.
6. It was found the water table recedes faster in the subsurface drained plots than in the surface drained plots.

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