THERMAL MOISTURE TRANSFER IN SOIL

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Abstract
One of the main mechanisms for supplying moisture to the upper layers of soil is its capillary-sorptive transfer, caused by moisture loss due to evaporation from the soil surface and transpiration by plants. Very complex alternatives arise for plant roots under conditions of deep plowing. They must:
- either "catch up" with the moisture as the upper soil horizons dry out rapidly (as is observed in nature); - or wait for the moisture to rise upward.
However, deep plowing hinders both of these processes, as it destroys the capillary properties of the plowed soil horizon, contributes to its rapid drying, and at the same time creates a plow pan beneath it. This impedes both root penetration into deeper layers and the upward movement of moisture.

Keywords: Thermo-moisture transfer, capillary-sorptive, creeping (moisture movement), depth gradients, condensation-related, plant roots.

Introduction

In addition to the movement of moisture in liquid form, the transfer of moisture in vapour form is also observed in soil. Noticeable vapour-phase moisture movement occurs in unsaturated soils, from warmer zones to colder ones. This typically happens during frosts, when the soil surface is significantly colder than the underlying layers, causing moisture to move upward toward the surface.

In contrast, during the summer period, the temperature of the upper soil layer is much higher than that of the lower layers, and vapour-phase moisture moves downward.

Additionally, moisture from the air condenses at night on the cooled soil surface, since although the surface temperature may be warmer than that of the lower soil layers, it is much lower than the ambient air temperature.

It should be noted that in summer, thermo-moisture transfer occurs in a direction opposite to that of capillary-sorptive moisture transfer. That is, under the effect of solar-induced drying of the upper soil layers, moisture films "creep" upward, whereas vapour phase moisture tends to condense in the deeper, cooler layers.

The contribution of thermo-moisture transfer and atmospheric moisture to the wetting of the upper soil layers remains a controversial and under-researched issue. According to estimates by E. I. Ovsinsky [7], this contribution is quite significant. However, Ovsinsky also refers to capillary-sorptive transfer, which suggests that he may have been referring to the combined effect of both mechanisms.

According to R. Schleicher, the contribution of thermo-moisture transfer and condensation-derived moisture is minor. Chubarov [2] estimates the intensity of vapour-phase transfer in soils to be an order of magnitude lower than that of liquid moisture.

In any case, our experiments using a 2-meter-high column of loose medium loamy soil placed indoors (i.e., in the absence of temperature gradients with depth) demonstrated a high rate of restoration of equilibrium moisture content when the groundwater table was at a depth of 2.0 meters. This indicates the dominant role of capillary-sorptive transfer.

In Lecture No. 7, we schematically presented the magnitude of the moisture-driving forces in soils and plants of arid zones, without providing justification or explanation.

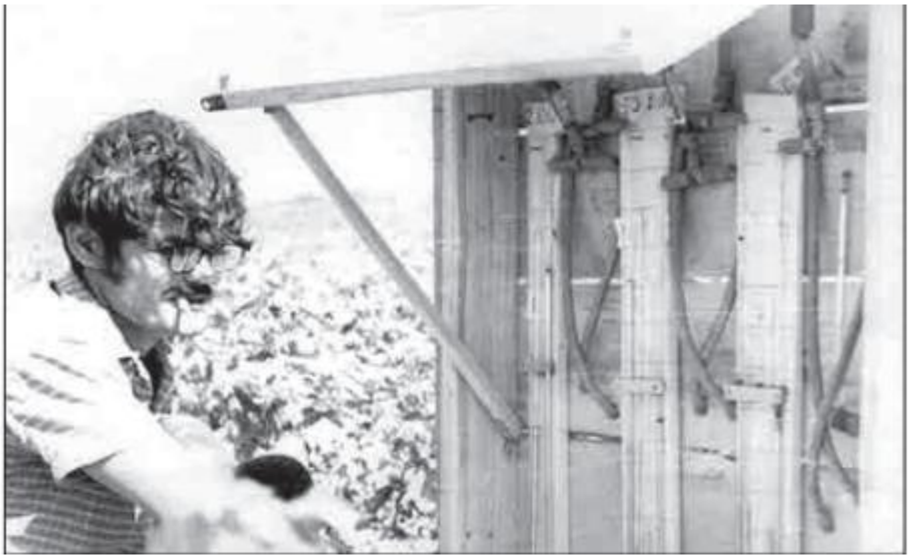

Figure 1. Measurement stand with mercury vacuum gauges in field conditions on soils of Agricultural Site No. 11 of the Karshi Steppe.

However, the basis for the statements made in the lecture was both the analysis of existing literature and our direct observations under field conditions. Our attempts at round-the-clock measurement of soil moisture tension in the root-inhabited layer during summer in the conditions of the Karshi Steppe (semi-desert) using tensiometers (Figures 1 and 2) showed that the soil in this layer significantly restores its moisture content overnight, and loses it during the daytime.

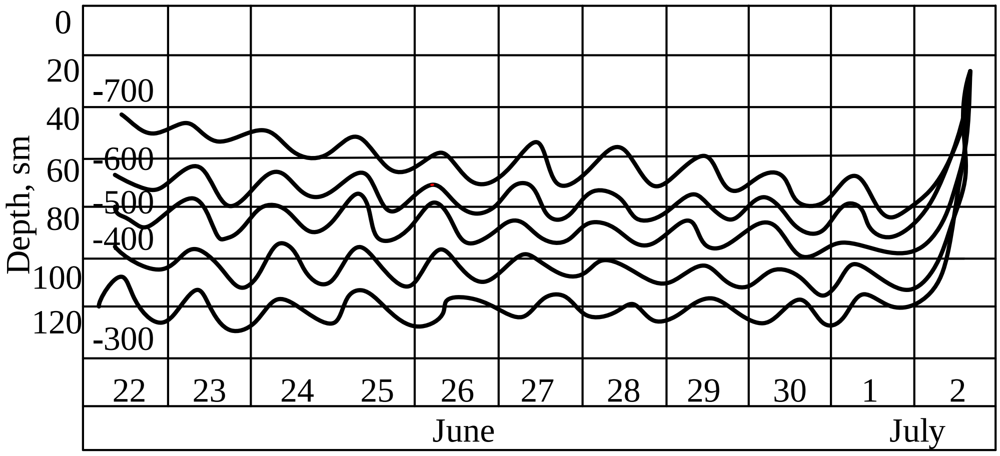

Figure 2. Results of soil suction pressure measurements (cm H_2O) in a cotton field

At State Farm No. 11 of the Karshi Steppe (the curved lines in the figure represent isobars of soil suction pressure, which gradually decrease in the upper soil layer during the inter-irrigation period, despite some recovery during nighttime hours). By comparing the statements made in the lecture with the patterns of soil moisture pressure variation shown in the figures, we can generally understand the types of pressure gradients that are formed between the air and the soil, as well as between different soil layers. It should be noted that these gradients could vary significantly from season to season and throughout the day.

Let us now recall the key factors for preserving soil moisture under natural conditions. These include the presence of a turf layer, which acts as a blanket protecting the soil from drying out while also serving as a source of fertility.

To retain moisture, it is necessary either to preserve the natural turf or at least to create something similar to it on the soil surface.

In the soil cultivation systems proposed by E. I. Ovsinsky [6], E. Faulkner, and others, this is achieved through the constant loosening of the top 5 cm soil layer (after rainfalls or snowmelt) without disturbing the deeper layers, and by incorporating organic matter into this upper layer.

This approach ensures:

• Weed control;

• Normal soil formation processes;

• Preservation of soil moisture by preventing excessive evaporation, while simultaneously maintaining strong capillary-sorptive support to the root zone within a substrate of undisturbed structure;

• The possibility of additional atmospheric moisture absorption by the uppermost, biologically active and essential soil layer located beneath the artificial turf.

Thus, a thin, loose topsoil layer of the substrate, especially when enriched with organic matter, can to some extent replace natural turf!

The practice of shallow surface tillage has long been used in Central Asia and is known as "moisture sealing", though it is mainly applied to row crops and occasionally before the sowing of winter cereals, mostly under rainfed conditions.

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As summer sets in, daytime solar heat input increases significantly, and the moisture content of soil layers — even those located beneath a "blanket" — gradually decreases. If capillary-sorptive inflow from below and condensation-derived moisture from above do not compensate for moisture losses due to evaporation and transpiration, irrigation becomes necessary, as the cost of irrigation may be far lower than the potential loss in yield.

If we compare the water needs of major agricultural crops with the plant-available reserves of moisture in the soil, we can draw important conclusions:

If we learn to effectively utilize annually renewable reserves of soil moisture, the need for irrigation could be drastically reduced.

It seems this is precisely why I. E. Ovsinsky was able to achieve average crop yields even in catastrophically dry years (during the growing season).

In any case, testing his method would be worthwhile both on rainfed and irrigated fields in Uzbekistan — and not only in Uzbekistan.

In Table 1, we have attempted to compare the available natural reserves of moisture in equilibrium (e.g., during early spring) with established crop water requirements. These reserves, in most cases (excluding acutely dry years), can be considered guaranteed, provided we are able to manage them properly through appropriate agrotechnical practices.

Table 1. Plant water requirements and available moisture reserves in the 1-meter soil layer (BZ1) under groundwater table conditions of 1.5–2.0 meters.

Crops	Water requirement, m³/ha	BZ1, m³/ha	% of requirement
Cotton	4000–9000	2220–2510	25–50%
Perennial grasses	9000–12000	2220–2510	20–25%
Winter cereals	2500–3500	2220–2510	70–100%
Vegetable and gourd crops	5000–10000	2220–2510	25–50%
Potato	4000–9000	2220–2510	25–50%

In the next lecture, we will examine the methods used by great agronomists to preserve soil moisture, as well as the modern possibilities for applying these techniques.

Conclusions

One of the main mechanisms for supplying moisture to the upper soil layers is capillary-sorptive transfer, which is driven by evaporation from the soil surface and transpiration by plants.

Very challenging alternatives arise for plant roots under deep plowing conditions.

They must:

• either “catch up” with the moisture as the upper soil horizons dry out rapidly (as they sometimes manage to do in natural conditions),

• or wait for the moisture to rise up to them (most often, if there is no rainfall, the plants cannot wait and die).

Both scenarios are hindered by deep plowing, which destroys the capillary properties of the plowed soil horizon, accelerates its drying, and at the same time creates a plow pan beneath it — a compacted layer that obstructs both root growth downward and moisture rise upward.

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