ROOT DEVELOPMENT, WATER UPTAKE AND GROWTH OF SPRING WHEAT AND PERENNIAL RAY GRASS ON THREE PROFILES

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Although it is well known that a crop takes up water from the soil, it is probably less known from which layers this water is withdrawn. CONRAD and VEIHMEYER (1929) found a relation between the amount of roots of *Sorghum* and the water content of the soil at a distinct moment. The present author has made an attempt to study the root development of two crops in two different profiles, and the desiccation of several soil layers during the whole growth-period of these crops.

For this purpose, in 1956 an experiment has been performed with spring wheat and perennial ray grass upon profiles consisting of a top soil of light marine clay of 25, 50 or 75 cm. and a sandy subsoil of 75, 50 or 25 cm. respectively. A number of uncropped profiles were included (fig. 1). These profiles were built up artificially by careful filling in concrete tubes with a height of 100 cm. and an inner diameter of 30 cm.

The density of the subsoil was about 1.45.[1]) This is much lower than VEIHMEYER and HENDRICKSON (1948) found to impede root penetration. The subsoil sand was mixed with 0.8 g. lime per kg. moist soil. The pH-KCl was made approximately 5.0 in this way.

In order to vary the amount of roots in the soil without changing the physical

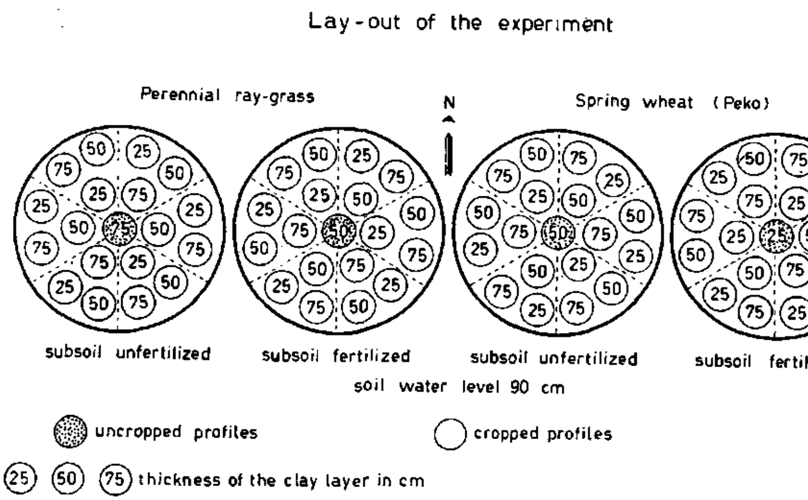

FIG. 1.

[1]) kg. per litre soil.

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conditions, half of the profiles were given a fertilized subsoil, by mixing it with 0.07 g. N, 0.1 g. P_2O_5 and 0.15 g. K_2O per kg. moist soil (GOEDEWAAGEN, 1932). The fertilizers used were ammonium nitrate, superphosphate and potassium sulphate. The subsoil in the other profiles was not fertilized.

The water table was fixed at 90 cm. below soil level. This was verified regularly. In case the water level was too high due to rainfall, the superfluous water was pumped out. In the reverse case water was supplied. These amounts of water were measured (fig. 6).

For the determination of the amounts of roots in the soil layers at distinct moments, a periodical sampling was carried out. Simultaneously the water content of these samples was determined by drying and weighing. Afterwards the pF-curve of both soils was determined, showing that the water content in the clay at pF 2 was about 26 %, at pF 4.2: 8 %; in the sand at pF 2: 8 %, at pF 4.2: 1 % (percentages of dry weight of the soil). Moreover the oven dry weights of the tops of the plants were determined.

Each profile obtained a top soil dressing of ammonium nitrate, superphosphate and potassium sulphate in amounts that depended upon the height of the clay layer. These amounts were calculated in kg/ha:

	N	P_2O_5	K_2O
25 cm. loam upon sand	60	80	120
50 ,, ,, ,, ,, ...	50	70	100
75 ,, ,, ,, ,, ...	45	60	80

RESULTS

a. Growth of the crop

The seeds were sown on April 4 and had germinated in the end of April. The first ears of the spring wheat appeared on June 22; on July 2 the whole crop had formed ears. Flowering occurred some days later. The ripening of the wheat started July 27; on August 20 the whole crop was mature. The growth was therefore very regular, as was the case with the perennial ray grass (fig. 2).

The first differences between the profiles with fertilized and unfertilized subsoil could be observed on June 12 in the wheat and on July 3 in the ray grass. Later these differences became even more significant.

Only small mutual differences were present in the oven dry weights of the tops of the profiles with unfertilized subsoil. These may be attributed to the different amounts of topsoil dressing. Much greater differences were found between the profiles with fertilized subsoil, where the highest yield was obtained from the profile with 25 cm. loam. This was evidently due to the subsoil fertilization. Large differences were found between the corresponding profiles with and without subsoil fertilization, in favour of the first.

b. Root development

The root weights were determined in soil cores with a height of 10 cm., taken with an auger having a diameter of 7 cm. (GOEDEWAAGEN, 1948). The samples consisting half of sand and half of loam were divided in these two

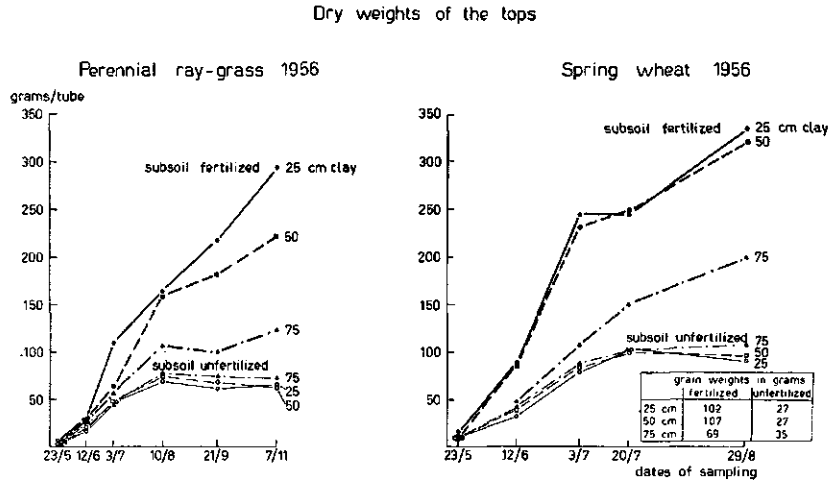


FIG. 2.

parts. Later the results of several layers were added up. These data are given in the figs. 3, 4 and 5.

From fig. 3 it appears that the total amount of roots of spring wheat in the profiles with unfertilized subsoil had already reached its maximum at about the 12th of June. This was shortly before the ears became visible. Similar results were already found with cereals by SCHULZE (1906), KÖNEKAMP (1953) and GOEDEWAAGEN (unpublished data). The maximum was not influenced by the profile. After the 12th of June the amount of roots decreased, especially in the subsoil, although there were some irregularities.

On June 12 the roots already deeply penetrated into the sandy subsoil. The relatively highest amount of roots was, however, developed in the clayey subsoil of the profile with 75 cm. loam. Further it was clear that by far the greatest amount of roots was formed in the toplayer of 0 to 10 cm.

The maximum amount of roots in the profiles with fertilized subsoil was reached on July 3. At that moment the ears had already been formed. After July 3 the amount of roots rapidly decreased. There were only slight differences between the maxima in the different profiles, although the smallest amount was found in the profile with 75 cm. clay. The maxima were considerably higher than those found in the unfertilized profiles.

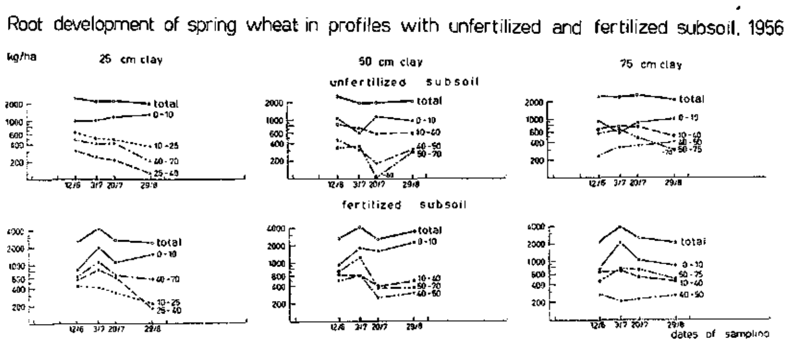
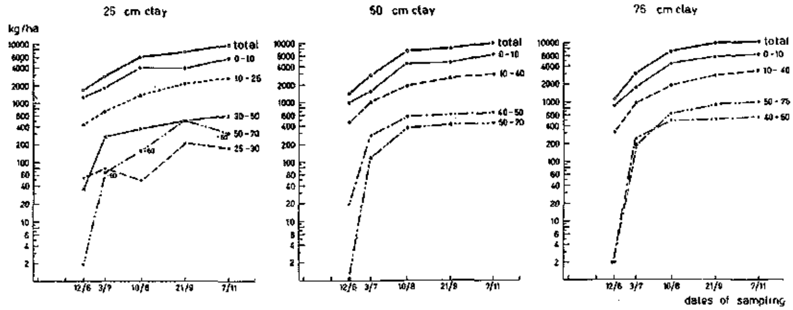


FIG. 3.

Root development of perennial ray-grass in profiles with unfertilized subsoil, 1956 FIG. 4.



In these profiles the roots penetrated deeply into the subsoil sand too. The amount of roots in the top soil and in the sand of the fertilized profiles with 25 and 50 cm. loam exceeded that of the unfertilized ones.

The total amount of roots of the perennial ray grass in the profiles without subsoil fertilization increased until the end of the experiment in November. There were again only small differences between the profiles (fig. 4). At the time of the first sampling, when the length of the leaves was about 15 cm. the roots penetrated already to a depth of 70 cm. The amounts of roots in the subsoil were at that date, however, exceedingly small but they increased rapidly so that finally rather important quantities of roots had been developed in the subsoil.

The root development in the fertilized profiles resembled that of the unfertilized ones (fig. 5). Again the total amount of roots increased to the end of the experiment. Ultimately, only the amount of roots in the profiles with 25 and 50 cm. clay exceeded that of the corresponding unfertilized profiles. The profiles with 75 cm. loam showed the reverse. These differences were principally found in the subsoil. The root development in the subsoil took place in the later period of growth, similar to that in the unfertilized profiles.

A comparison of spring wheat and perennial ray grass did show that there were important differences in root growth of these crops:

1. Root growth of spring wheat attained an early maximum, the root growth of perennial ray grass continued until November.

Root development of perennial ray-grass in profiles with fertilized subsoil, 1956

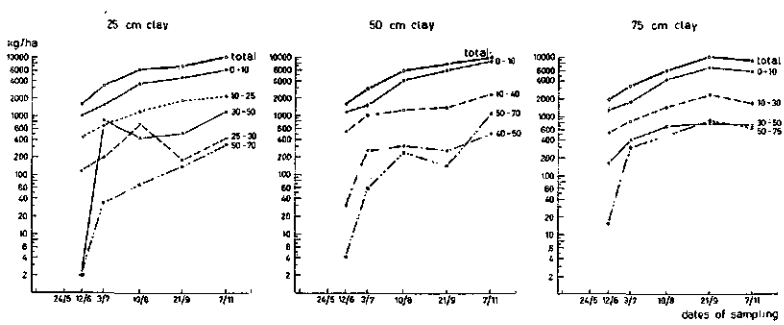


FIG. 5.

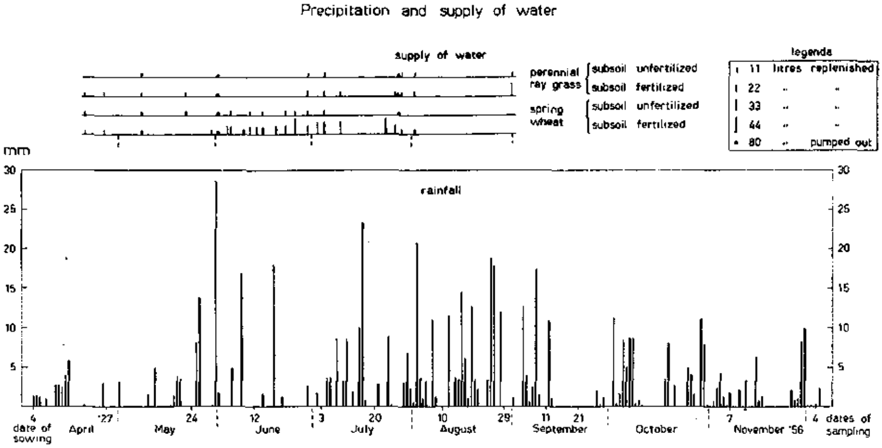


FIG. 6.

2. The ultimate quantity of roots of perennial ray grass exceeded that of spring wheat.
3. The speed of the root formation of spring wheat exceeded that of ray grass.
4. In both crops the greater majority of roots was formed in the top soil. This was the most pronounced in ray grass.

c. The moisture content of the soil

The large differences in growth between the crops on the profiles with unfertilized and fertilized subsoil suggest that there may have been considerable differences in water absorption by these crops.

The data in fig. 6 show that indeed the greater amount of water has been absorbed from the profiles with fertilized subsoil. The total quantities of water supplied were:

perennial ray grass	subsoil unfertilized	66 litres
	subsoil fertilized	143 ,,
spring wheat	subsoil unfertilized	110 ,,
	subsoil fertilized	462 ,,

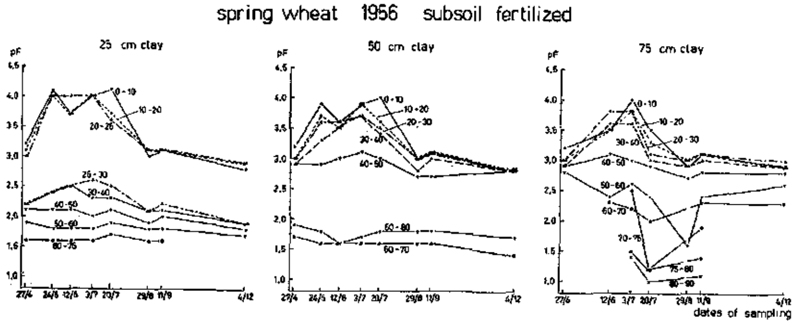
From these data it may also be concluded that water consumption of the wheat exceeded that of ray grass.

The question arises from which soil layers this water has been absorbed.

The moisture tensions in the various layers of the profiles of all samples are summarized in the figs. 7, 8, 9, 10.

It appears from these graphs that the moisture contents of the soil layers were not constant during the experiment. Theoretically this can be caused by several factors. In the first place the evaporation, especially in the top soil, will have given some losses. We cannot determine this amount, since there are only data from uncropped profiles at the beginning and at the end of the experiment. It may be assumed, however, that the heavy losses of moisture have not been principally caused by evaporation from the soil, nor have they been caused by drainage of the water. The major cause of the decrease of moisture in the soil must have been the absorption by the plants.

FIG. 7.



We first may pay attention to the results of the spring wheat on the profiles with unfertilized subsoil. The graphs in fig. 7 show that the pF in the clay of the uncropped profiles on April 27 reached a value of about 3. The pF in the subsoil was about 2. At this time the young wheat plants had developed the first leaf. It may be assumed that the water conditions in the cropped soil were conform with those in the uncropped ones. After this date the moisture content in the top soil of the cropped profiles decreased rapidly.

This was followed by an increase on June 12, probably due to heavy rainfall in the preceding period. After this date the moisture content decreased again and remained low for the greater part of July. After July 20 the soil moisture content did show a definite increase to the value of April 27.

The deeper layers followed this course more or less. The increase of moisture on June 12 reached only to a depth of about 20 cm. The increase of moisture in July started earlier moreover.

The maximum depth, where decrease of moisture could be determined was dependent on the thickness of the clay layer. With a clay layer of 25 cm. loss of moisture was determined with certainty in the layer of 25 to 30 cm., in the upper 5 cm. of the sandy subsoil, and on July 3 probably also in the layer of 30 to 40 cm. In the profiles with 50 and 75 cm. clay, the moisture decrease reached a depth of 50 cm.

From this it is clear that the period of major moisture absorption by the spring wheat lasted from about May 24 to July 3.

The absorption of water by spring wheat from profiles with fertilized subsoil resembled that of the unfertilized ones (fig. 8). The main difference was that the uptake in the profiles with 25 and 75 cm. clay reached a depth of 40

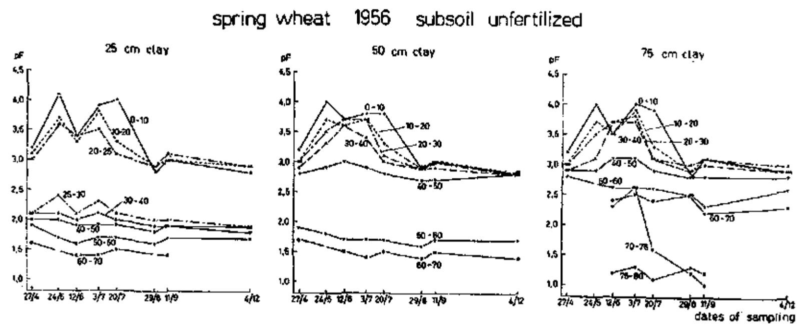
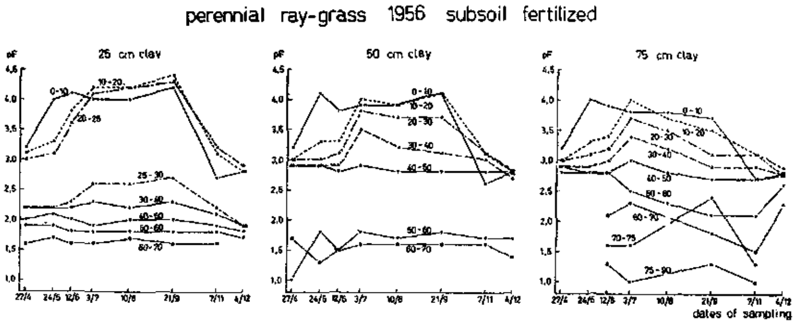


FIG. 8.

FIG. 9.



and 60 cm. respectively, instead of 30 and 50 cm. Moreover the rate of absorption in the top soil of the fertilized profiles was higher, especially in the profile with 25 cm. clay.

The water absorption by the perennial ray grass on the profiles with unfertilized subsoil started also after April 27. This was most pronounced in the upper 10 cm. (fig. 9). The maximum decrease of moisture was found in the period from May 24 to July 3. The increase of moisture after this date may have been caused by heavy rainfall. It must be assumed that water absorption had not stopped at that date since there was a substantial decrease of moisture thereafter. Only after September 21 the moisture content of the top layer increased towards the value of April 27.

This trend was followed more or less by the lower layers. The maximum depth was again dependent to a certain degree on the thickness of the clay layer, reaching 30, 50 and 40 cm. in the profiles with 25, 50 and 75 cm. clay respectively. It is clear that the desiccation in the lower layers started less vigorously or later and stopped earlier.

The course of the water contents in the profiles with fertilized and unfertilized subsoil did show a large conformity (fig. 10). It appears, however, that the desiccation in the fertilized profiles, especially in the profile with 25 cm. loam was more vigorous than in the unfertilized ones. Moreover the rate of desiccation in the fertilized profiles was higher and there was hardly an increase in moisture in the period of July 3 to August 10, showing an uninterrupted period of absorption from May 5 to September 21. The maximum depth where pF

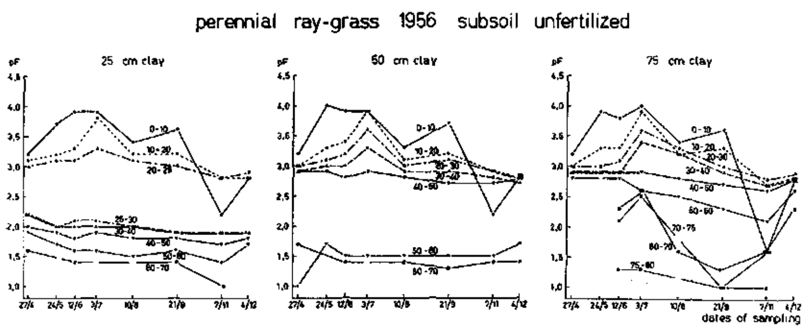


FIG. 10.

changes in the fertilized profiles with 25 and 75 cm. clay occur, exceeds that of the unfertilized ones with 10 cm.

Some general remarks may be made here about the figures 7 to 9. There exists always a striking difference in pF between the bottom layer of the clay and the top layer of the sand. This indicates that the vertical upward transport of water through the soil is hampered considerably near the boundary of sand and clay.

The fact that the pF of the top soil of clay was continually above 2.7 to 3 means that water transport in these layers was merely possible by diffusion and in consequence unimportant.

d. The relation between the root development and the moisture content of the soil

There exist two possibilities of relation between soil moisture content and roots, i.e. 1. with the quantity of roots and 2. with the velocity of uptake by the roots due to transpiration. We now will see which were the relations with the root quantities of spring wheat in the various soil layers.

This crop germinated in the end of April. At that moment water absorption was small and must have been restricted to the top layer. During the sampling on May 24 the crop had a height of 20 to 25 cm. There are no data available of the root development on that date. It may, however, be assumed that the plants had already a well-developed root system on that date. In accordance herewith a strong decrease of moisture was found to a depth of 30 or 50 cm. in the unfertilized as well as in the fertilized profiles.

The root mass in the unfertilized profiles increased probably up to June 12 when the crop had a height of about 50 cm. On this date the roots had attained a depth of 70 cm. This corresponds with a desiccation of the deeper soil layers, especially in the profiles with 50 and 75 cm. clay. After June 12 the total root mass decreased slightly, especially in the deeper layers. This, however, did not affect the absorption since the desiccation increased in several of these layers until July 3. On that day the ears of the wheat had appeared. The increase in moisture in the soil, the top layer excepted, in the following period shows no distinct relation with the root quantity. Probably this increase is mainly a consequence of the heavy rainfall in the period from 5 to 16 July. Moreover, decreasing transpiration rather than a decreasing root quantity may have influenced the moisture content especially after July 20, when the crop started ripening. It is evident from the figures that the absorption of water had already ceased before August 29. VAN DER PAAUW (1949) also found a decrease of transpiration of oats after the appearance of the panicles.

Contrary to the unfertilized profiles, the root mass in the fertilized ones still increased after June 12, mainly in the top layer but also deeper in the soil. This may explain why the rate of desiccation in many layers on July 3 exceeded that of May 24. After July 3 there was a decrease of root mass that corresponded with an increase of water in the soil, this again may be caused by the rainfall between 3 and 16 July together with decreasing transpiration especially after July 20.

Comparing the crops on the profiles with fertilized and unfertilized subsoil it may be stated that the first difference in growth of the tops was visible first on June 12. This was most pronounced on the profile with 25 cm. loam. Parallel with this, the root mass in the fertilized profiles exceeded that in the unfertilized ones and this resulted in an increased water absorption that could be ascertained by the different amounts of water supplied.

The perennial ray grass was sown on April 4. It germinated at the end of April. During the sampling on May 24 the plants had a height of about 10 cm. Root data on that date are not available, but water absorption had already reached a considerable height since the moisture content in the soil had decreased materially in the top layer and to a lesser extent in the lower layers. There was a more distinct difference in the rate of desiccation between the top layer and the other ones than with spring wheat. However, in the later stages of growth this difference diminished.

The growth of the plants on the unfertilized subsoil continued up to August 10. After that date no more increase of dry matter was found. The root development, on the other hand, continued after this date, although slowing down and probably becoming unimportant in the deeper soil layers. The maximum of desiccation of the soil was already reached at July 3. This was followed by an increase of moisture in the period up to August 10, this may be attributed to a very heavy rainfall in the period up to August 8. It must be assumed that the absorption of water had not yet stopped on that date since there followed a desiccation in the period up to September 21 that cannot be ascribed to evaporation of the soil. The absorption must, however, have decreased. This was certainly the case in the period after September 21, when the soil moisture content rapidly increased to the point of April 27.

The growth of the plants on the fertilized profiles with 25 and 50 cm. loam continued until the end of the experiment, the root development showed a similar picture. Up to July 3 the moisture decrease followed the same trend, after that date the increase in roots did not enhance the water absorption. After September 21 the absorption by the roots apparently ceased.

Comparison of the crops on the fertilized and the unfertilized profiles shows that the growth on the first was much better, although the root development did not show important differences. Nevertheless the desiccation of the soil was considerably stronger in the fertilized than in the unfertilized profiles, showing that the absorption per weight-unit of the roots must have been higher. This is in accordance with the fact that the quantity of supplied water also was much higher.

There is still one question that is worth mentioning. The fact that the soil layers below 50 cm. did not show any desiccation, although there were many roots present in these layers, might suggest that these roots did not contribute to the absorption. This, however, may be explained as follows, although the moisture decrease in a soil layer is certainly related to the root activity, this, however, does not imply that a diminution of moisture in a distinct layer must be attributed only to the roots present in this layer. Moisture that is absorbed from a soil layer may be replenished by capillary flow from the underlying layer, if replenishment of that layer is possible in the same manner. In an extreme case, moisture may be replenished from the soil water with such a velocity that there is only a very short-lasting decrease of the water content. It may be assumed that this was the case in the layers below 50 cm. The quantity absorbed below 50 cm. cannot be calculated from the available data. The uptake of water by roots in the deeper soil layers is now studied in an experiment with profiles without a groundwater table.

Summary

Root growth and top growth of perennial ray grass and spring wheat on three profiles were studied. Simultaneously, data were collected on the uptake of water from various soil layers.

The results found were:

1. Root growth of spring wheat reached a maximum early in the spring. Subsoil fertilizing resulted in a considerable increase of roots, mainly in the top layer of the soil.
2. Root growth of perennial ray grass continued up to November, although the rate of increase was slowing down. Subsoil fertilization did not materially influence the total amount of roots.
3. The dry matter in the tops increased in both crops up to the end of the growth period.
4. Subsoil fertilization caused a strong increase of the growth.
5. In consequence of the stronger growth the total water uptake by the plants on the profiles with fertilized subsoil exceeded that of those on the unfertilized ones.
6. The water absorption by spring wheat remained high from May 24 up to July 20. The maximum depth was dependent to a certain degree on the profile, but water absorption could not be demonstrated below a depth of 50 cm., although there were roots present in these layers.
7. The water absorption by perennial ray grass remained high from approximately May 24 to September 9. There was again a certain relation between the maximum depth of absorption and the composition of the profile. With this crop also, water absorption could not be demonstrated with certainty below a depth of 50 cm., notwithstanding the presence of roots in these layers.
8. It is assumed that moisture has been absorbed from depths below 50 cm. but that this water was replenished with a high velocity by capillary flow.

Résumé

La croissance des racines et des parties aériennes du ray-grass anglais et du froment de printemps a été étudiée sur trois profiles. Simultanément des données furent recueillies sur le prélèvement d'eau dans les différentes couches du sol.

Voici les résultats trouvés:

1. La croissance des racines du froment de printemps atteignit un maximum au début du printemps. La fumure du soussol stimulait fortement le développement des racines, spécialement dans la couche arable du sol.
2. La croissance des racines du ray-grass anglais continua jusqu'en novembre, quoique le degré de croissance allait en diminuant. La fumure du soussol n'a pas influencé de façon importante la quantité totale des racines.
3. La matière sèche dans les parties aériennes des deux végétaux allait croissant jusqu'à la fin de la période de croissance.
4. Les fumures du soussol occasionnèrent une forte augmentation des parties aériennes.
5. A la suite de cette augmentation de croissance le prélèvement d'eau par les végétaux sur les profiles avec un soussol fertilisé dépasse celui des profiles avec soussol non fertilisé.
6. L'absorption d'eau par le froment de printemps resta élevée du 24 mai au 20 juillet. La profondeur maximum dépendait jusqu'à un certain degré du profil, mais l'absorption d'eau ne put être démontrée à une profondeur de plus de 50 cm, quoiqu'il s'y trouvèrent quand même des racines.
7. L'absorption d'eau par le ray-grass anglais resta élevée du 24 mai au 9 septembre. Ici également il y avait une certaine relation entre la profondeur maximum d'absorption et la composition du profil. Avec ce végétal il ne fut également pas possible de démontrer qu'il y eut une absorption d'eau dans les couches plus profondes que 50 cm, malgré la présence de racines dans ces couches.
8. Il fut présumé qu'il y eut peut être une absorption d'humidité des couches plus profondes que 50 cm mais que cette eau a été rapidement remplacée par voie capillaire.

Zusammenfassung

Das Wachstum der Wurzeln und der oberirdischen Teile von Englischem Ray-gras (Winter-Lolch) und von Sommerweizen wurde beobachtet. Zugleich wurden Bestimmungen der Wasseraufnahme durch diese Gewächse aus verschiedenen Bodenhorizonten durchgeführt.

Die wichtigsten Ergebnisse dieser Forschung waren:

1. Das Wurzelwachstum des Sommerweizens erreichte sein Maximum bereits früh im Frühling. Düngung des Untergrundes förderte das Wurzelwachstum bedeutend, hauptsächlich in der obersten Bodenschicht.
2. Das Wurzelwachstum des Ray-grases hielt bis in November an, obgleich das Tempo des Wachstums almählich abnahm. Die Düngung des Untergrundes beeinflusste kaum die Gesamtmasse der Wurzeln.
3. Die Trockensubstanz der oberirdischen Teile nahm bei beiden Pflanzen bis zum Ende der Vegetationsperiode zu.
4. Die Untergrunddüngung begünstigte in hohem Masse das Wachstum der oberirdischen Teile.
5. In Übereinstimmung mit dem üppigeren Wachstum entzogen die auf Profilen mit Untergrunddüngung erwachsenen Pflanzen dem Boden im gesamten mehr Wasser als die auf ungedüngten Profilen erzogenen.
6. Die Wasseraufnahme blieb beim Sommerweizen hoch vom 24. Mai bis zum 20. Juli. Die Tiefe des maximalen Wasserentzuges hing gewissermassen vom Profilaufbau ab. Tiefer als bei etwa 50 cm konnte aber kein Wasserentzug nachgewiesen werden, obgleich da noch Wurzeln vorhanden waren.
7. Beim Ray-gras hielt sich die Wasseraufnahme auf hohem Niveau ungefähr vom 24. Mai bis zum 9. September. Und auch hierbei hing es gewissermassen vom Profilaufbau ab in welcher Tiefe die Wasseraufnahme maximal war. Wie beim Sommerweizen, so auch beim Ray-gras konnte unter 50 cm keine merkbare Wasseraufnahme nachgewiesen werden, obgleich da wohl Wurzeln vorhanden waren.
8. Man könnte daher annehmen, dass die Pflanzen auch unter dem 50 cm-Niveau dem Boden Wasser entzogen haben, das aber sehr schnell aus den tieferen Bodenschichten durch kapillaren Aufstieg ersetzt wurde.

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