SOIL SCIENCE AND SPRINKLER IRRIGATION

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If it should be asked to what extent the practice of overhead irrigation may benefit from applied soil science, the answer must be either fully positive or mildly negative, depending on the education and training of the person in charge of such operations.

The simplest soil test i.e., the taking of soil samples with the aid of a soil borer to establish the moisture content visually with in mind the alternatives: irrigation at once called for, or irrigation not necessary at all, may after some practice be performed with success by any duly instructed person with a thorough knowledge of the field concerned.

A more intricate type of analysis is based on a judicious use of the pF-curve and a knowledge of the relevant instructions concerning the way to prepare soil samples with a moisture content of known pF by mixing dry soil with water. Here too, estimation of the moisture content of the samples drawn is, either visually or by touch, comparing the artificially obtained moisture conditions in the various samples with the moistness of the natural soil, but in this case the conclusion may be expressed in both moisture content and pF. If the pF is known the possibility exists of estimating the rate of evaporation of the crop with reference to this pF, so the time that will expire before a degree of dampness will have been reached below one does not wish the soil to drop, or before a pF will have been reached one does not want to exceed, may be tentatively predicted. This method is already in a lesser degree confined to a single type of soil profile, but it requires the availability of pF-curves for all strata of the profile under investigation.

Really large-scale advisory operations call for a comprehensive range of pF data for each profile and a soil map showing extent and limits of the various profiles.

A step further again may be achieved by those field officers who, for certain regions and on the basis of visual observations, are capable of drawing a pF-curve from the lithologic data supplied by examining the soil profiles. Regional surveys covering such data as influence of silt and humus content, relative coarseness of the sand and similar information on the shape of the pF-curve, may enable irrigation experts with an adequate training in soil engineering to set up a tentative pF-curve. If now the moisture content of the soil is determined by inspection, it is possible to establish at what level the moisture content may be expected to range between the wilting point and the field capacity.

A closer consideration of the methods to obtain an adequate advice on irrigation available to date reveals them to consist of three stages. The first of these covers an estimation of the moisture content, the second the additional estimation of the corresponding pF and the third the estimation of the relevant rate of evaporation.

The pF alone may provide indications on the desirability of instantaneous

irrigation. The relation between the established moisture content and the lowest admissible one divided by the evaporation rate – deduced from the pF – may indicate by how many days irrigation may eventually be safely delayed.

The first stage represents the development of a more accurate estimate of the moisture conditions with respect to moisture holding capacity and quantity of moisture. The second stage deals with a characterization of the milieu of the crop with respect to its requirements regarding the availability of moisture. The third stage investigates the length of time in which both the drop in moisture content per layer and the depth of the desiccated zone will have reached a limit that, from the agricultural point of view, must be considered as representing the limit of the admissible loss of moisture from the profile.

In considering the proper function of soil science in this vast field, taking into account the aspects which are still lagging behind and consequently deserving more attention, and the present-day trend of research, it will in the first place be necessary to provide a delineation of limits within which this knowledge is to be applied.

The experimental farm and the large estate, being both of them assured of adequate scientific assistance, may be safely left to themselves. Problems of quite a different nature in advisory work present themselves, however, in the case of large areas with the usual variation in soil profiles. These areas may comprise some thousands of irrigated fields belonging to a large number of small holdings. Any assistance, in as far as management of sprinkler installations is concerned, can in that case of necessity no longer be on an individual scale. In such a case more general methods must be resorted to, such as the use of pF-curves constructed on the basis of visual soil estimates, the estimation of moisture contents through comparison with standard samples, etc.

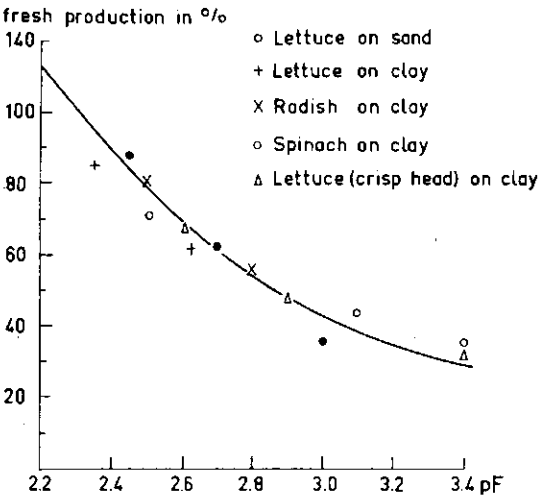
At this stage the question arises, which part of this chain of considerations and procedures may already today be made to yield tolerably accurate results and which part is sufficiently tried out and studied, requiring only a very restricted amount of scientific attention.

On the other hand it ought to be possible to point out the weakest link with the greatest error, as this would enable investigators to concentrate their joint efforts on its improvement or solution.

THE REQUIREMENTS OF THE CROP

Present-day research into the moisture requirements of the crop is done mainly along two lines. Partially, attempts are made to characterize the relative humidity of the soil on the basis of the pF. Their aim is, to determine the pF at which the largest yield is obtained, as well as the magnitude of possible declines in the yield ascribable to moisture conditions which deviate from the optimum value of the pF. This should be done for various crops and types of soil. Figure 1 provides an example of such a study. A striking feature in this diagram is the occurrence of the same relation between crop yield and pF for the different soil types and crops. The number of tests in this field of study the world-over, has probably been so far not very high. However, what research there has been should be enough to provide us with an idea of the nature of the result to be expected. The probability exists that at the optimum pF the soil moisture content falls below the field moisture content (see figure 2) so in the event of field irrigation tests, yields are usually found on that part of the curve where

FIG. 1.
The fresh yields of various crops react in an identical manner to the pF of the soil, quite independent of the soil profile. After BIERHUIZEN



the yield declines through desiccation, whereas, the field moisture content never reaches the level required for the optimum yield. The soil cannot hold that quantity of water against gravity.

A true optimum in production with respect to the factor water is in all probability not entirely attainable through the expedient of overhead irrigation alone, it being impossible to get beyond conditions which are just somewhat too dry.

In case of a prevailing water scarcity, watering will be started only at a high pF, whereas with the availability of cheap water this will already be done at a much lower pF. Watering of expensive crops, including horticultural crops, will, even on soils with a relatively large moisture holding capacity, start earlier than will be the case with the less expensive cereal crops. The point of lowest admissable moisture content will therefore have to be fixed separately for each individual case, the shape of the growth reaction curves must have been determined in advance however. This doubtless calls for further research, though it does not seem to represent the worst lacuna in our present knowledge.

Another direction of research operates with evaporation as a standard for

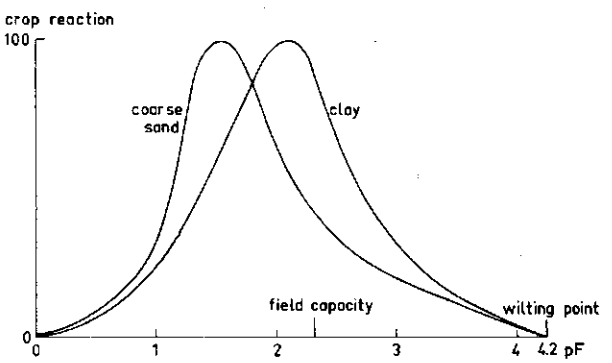


FIG. 2.
The reaction of the crop to the pF for various types of soil will, in view of the present state of our knowledge, present a picture as indicated. The optimum pF lies below the field capacity

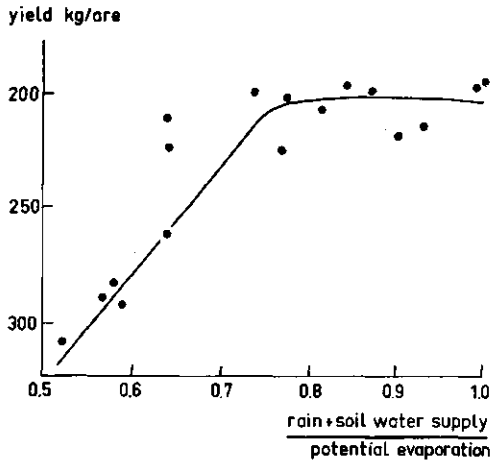


FIG. 3.
Crop yield of potatoes in relation to the ratio available moisture to potential evaporation. After VAN DUIN and SCHOLTE UBING

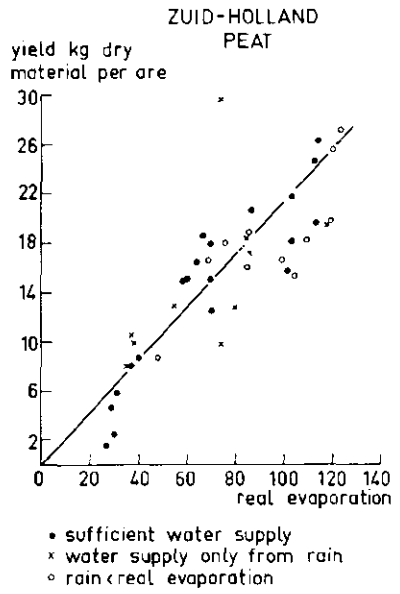


FIG. 4.
Grass yields show in relation to the estimated evaporation a simple reaction. After WIND

growth. The simple relations found in this way are certainly very attractive (see the figures 3 and 4). This type of research, however, is preferably concentrated on evaporation as observed over longer periods of time and this, on account of the relatively short periods involved in sprinkling, tends to lay considerable difficulties in the way of investigations concerned with the nature of critical periods or preferential moments of application of water occurring during the growth process, where research has shown sudden changes in reaction of the crop. It may be presumed that research of this type – even though it is still in its initial stage – may soon yield practical results and that at the cost of a comparatively inconsiderable amount of work.

DETERMINATION OF MOISTURE CONTENT

The energy with which investigators have attempted to design a convenient method for determining the moisture content of the soil is truly amazing. The number of methods now available certainly runs into scores, varying from methods which are complicated and hard to perform to the extremes of simplicity. Nevertheless they all are apparently still too intricate to be useful in practice. As to the standards of accuracy to be achieved with them, these too, in view of the important variations in moisture content in the soil profile from place to place, are lower than is generally assumed.

Any study of this type must invariably make use of a large number of samples. For the purpose of soil analysis a wide use has so far been made of estimated soil data, whilst also the accuracy with which the soil moisture content can be estimated today is such, as to make it a matter of some surprise that no trouble

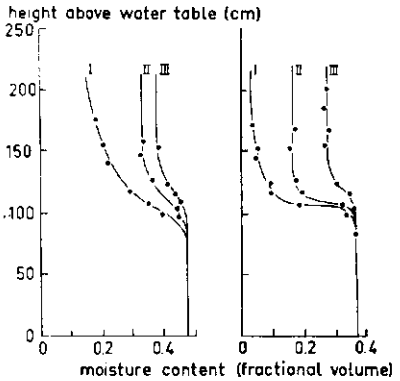


FIG. 5.
Moisture profile, for moisture equilibrium and two rates of infiltration intensity, showing how the infiltration water causes an increase in the moisture content of the soil. After YOUNGS

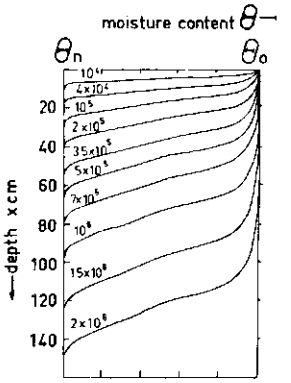


FIG. 6.
The accumulated moisture remains available for the crop many days after the infiltration process itself has ceased. After PHILIP

has been taken by scientists to develop any methods for estimation of the moisture content by eye or hand and also that the method of determining the moisture content by estimation has found so few adherents.

In attempting to deduce from these moisture content data how much water the plant is capable of extracting from a given soil profile or, for that matter, how much moisture is still to be added to such a profile, some recent results of study present themselves for consideration which are still rather less well-known. The rate of moisture extraction tends to decrease with depth. It is customary to assume a certain depth for the root zone of any crop and furthermore to suppose that of the total amount of moisture available for the plant in all layers, the part that is present in the surface layer is taken up in its entirety, whilst that present in the lowest layers is left untouched and that on the average from each layer a share proportionate with its depth is removed by the roots. In homogeneous soil profiles this would come to half the amount of moisture which should be available, if all the water above wilting point is computed from the pF-curve.

The possibility of supplementation of the moisture content is computed by subtracting the moisture content as observed in the field from the moisture contents obtained from the pF-curve, taking as a maximum the moisture content at field capacity. But here too, a large number of different influences makes itself felt, such as air inclusions, irregular moisture distribution – with the result of subsoil drainage in the presence of non-saturated sections – whilst finally more moisture may be temporarily retained by the soil, which will be available to the crop during the length of the period required for the water to sink beyond the reach of the roots. With a regular use of the field irrigation system, or in the event of casual natural showers, this extra amount of moisture may be not inconsiderable.

Laboratory tests by YOUNGS (figure 5) tend to show that a rate of infiltration equal to some 10 % or 20 % of what will be transmitted through the soil at a fall of 1 : 1, will fill up a major share of the available air volume and increase the moisture content, as prevailing during conditions of equilibrium, by a fair

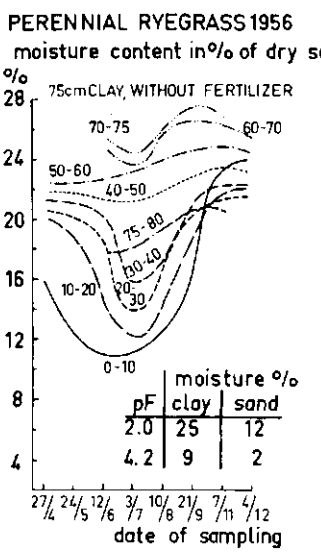


FIG. 7.
Samples repeatedly taken show from which layers moisture is derived by the crop as well as the rate at which soil moisture is consumed in the process. After SCHUURMAN

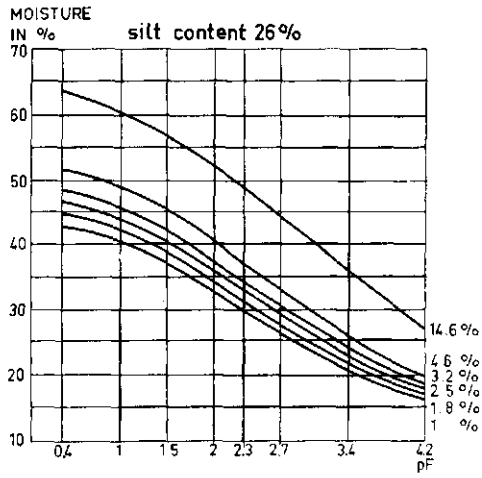
proportion. It has been demonstrated by PHILIP (fig. 6), that the time required for the excess moisture to drain away will amount to several days. From this it would appear that under certain given circumstances, fairly important quantities of water will be retained for by no means inconsiderable periods of time.

A considerable deepening of our understanding of the problem of moisture extraction may be expected from the result of a combined root and moisture content research. An impression of the results to be obtained from such a type of research is provided by figure 7, which tends to demonstrate that the moisture depleted zone will only very gradually expand downwards. By SCHUURMAN, a wide fund of material has been collected on this subject, from which a clear outline of the laws governing the rate of infiltration into the capillary zone, the elimination of moisture from the soil profile and the evaporation rate of crops may be obtained.

The aspects of the problem presented by the amount of moisture available for consumptive use, have for some time been the subject of thorough investigation by a large group of workers, who all aim at a deduction of the moisture distribution pattern from the non-stationary capillary flow, the pattern that will, under certain marginal conditions, arise through the influence of moisture extraction by the crop or supplementation of the moisture content through irrigation and sprinkling.

Since in the presence of unsteady conditions of capillary flow, amounts of moisture are concerned which may be far in excess of the quantities arrived at by computation from pF-curve and plant root depth, a field of investigation which will prove to be of decisive importance is undoubtedly opened up. It is, however, to be anticipated that the difficulties that will have to be overcome will be formidable. This would seem to point to the desirability of the use of a parallel statistical research, to be carried out in conjunction with the fundamental investigation, so the trend and the magnitude of the forces at play may be already known to some degree even before the final difficulties of the physical – mathematical stage will have been fully mastered.

FIG. 8.
A relation appears to exist between pF-curve and humus and silt content, which may be deduced from the data for a number of samples analysed for the pF



MOISTURE TENSION AND SOIL MOISTURE CONTENT

For advisory work it will be necessary to derive the pF from estimated moisture contents. As the, before mentioned, more refined type of research is making a large use of the moisture tension of the soil and for a simpler type of interpretation the pF-curve may be expected to become increasingly indispensable also, it will be impossible to avoid the complication of the conversion of moisture content into moisture stress. Henceforward one of the aims of future work will mainly consist in the determination of many hundreds of pF-curves. Both from a technical and a financial point of view this will not be a simple matter.

It seems therefore more probable that in future, scientific advice on irrigation problems will become based increasingly on some type of hydrologic soil mapping. One may imagine that the individual statistical units involved will be defined by hydrologic standards and will be delimitated in the field with an accuracy that is compatible with the visual method of estimation. These hydrological units will have to be calibrated against the corresponding pF-curve and other physical constants that are possibly available.

Yet another, certainly also attractive, possibility is to set up the pF-curve as a function of the silt and humus content and further properties of the soil. For each field a curve may then be constructed with the aid of these properties. A relevant example for clay soil is provided in figure 8. A closer study of those soil constants that lend themselves best as a characteristic of the hydrologic properties might be of major importance. Such characteristics will enable one to obtain a better grasp on the nature of the relationship between these soil constants and the pF-curve. Little mention has so far been made of this type of investigations in international literature, yet this would be of the greatest value for irrigation engineering.

EVAPORATION

Research into the cause and effects of evaporation has been enormously stimulated by the investigations of THORNTHWAITE, PENMAN, HAUDE, TURC and others. To such an extent, that it has acquired a quite different character in

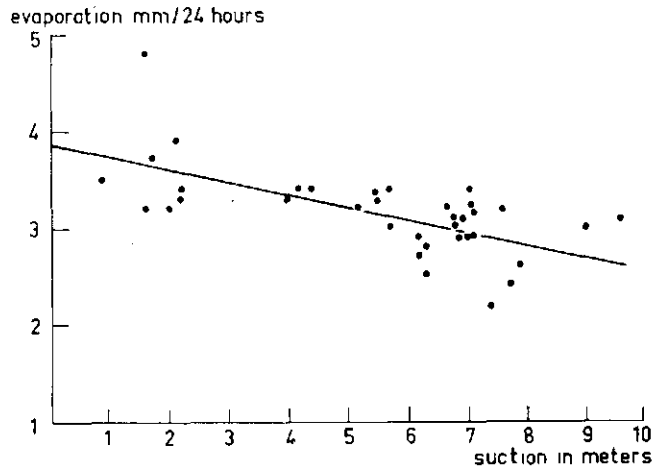


FIG. 9. Evaporation is indicated by MAKKINK as a linear function of capillary tension in meters

a comparatively short time. As far as sprinkler-type irrigation is concerned, it may be safely stated that future studies will be concerned chiefly with the influence of evaporation on soil moisture conditions and on the growth of the crop.

Investigations with the use of a lysimeter, by MAKKINK (see fig. 9) and field studies by WIND (see fig. 10), have demonstrated a distinctly decreased evaporation with an increase in pF. Actually, if one would like to establish the total amount of evaporation for any given day, pF-determinations or estimations might give a solution. But here too, the rule holds good that a solution for any given test-field is not necessarily a sound over-all solution for general practice. It seems probable that the summation of the daily evaporation values could preferably be achieved by calculation and not by moisture determination. To

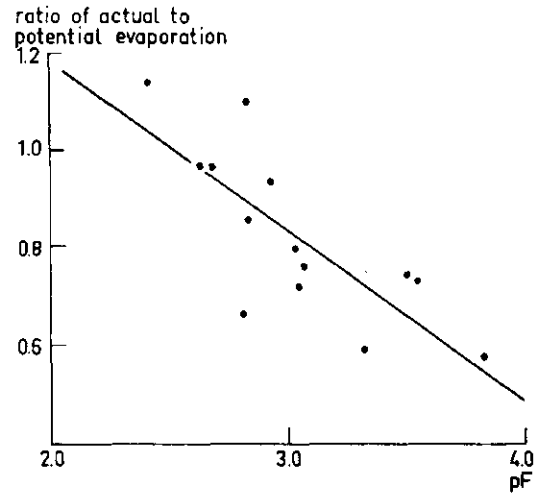
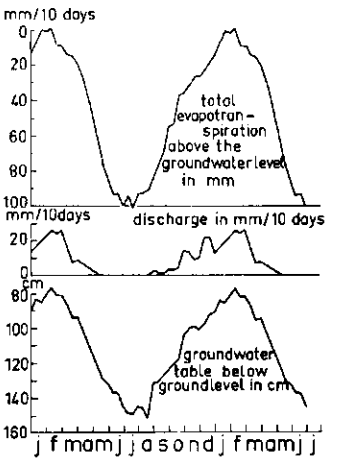


FIG. 10.
WIND assumes a linear relation between evaporation ratio and pF

FIG. 11.

An analysis of groundwater depth may provide an insight into many aspects of the water balance and the moisture content of the soil to examplify this, the amount of discharge and the rate of moisture depletion from the profile are indicated



this end, however, the relation of evaporation to pF will have to be further amplified by data covering the relation between evaporation, depth of ground water and recent rainfall, respectively amount of irrigation water applied, together with the amount of time which will have elapsed since the rain fell or water was applied. Furthermore, the moisture content of the soil profile concerned is important in this respect.

In reviewing the various degrees of accuracy attainable in computing the rate of evaporation by the various methods now available, it would seem that PENMAN'S evaporation formula is more than sufficiently accurate, even though the error of the reduction factor is slightly on the high side. For the purpose of a single irrigation the latter inaccuracy is still well within admissible limits, but taken over the entire irrigation season, this error will tend to add up, so after several irrigations it would be beyond the capacity of any continuous moisture registration of this type to predict the time of the next irrigation with a reasonable measure of accuracy. In spite of this, the keeping of moisture records computed by adding up daily rainfall and evaporation data, will be of importance in many cases since a correct and regular evaluation of the current water balance, however simple, will always be hard to achieve if a large number of irrigated plots should be concerned.

Finally the attention should be drawn to the influence of natural rainfall, which will tend to provide complications if occurring immediately following a period of artificial rain. Part of this natural rain water will drain away into the subsoil, but the laws governing this type of drainage are at the moment not entirely clear. The simple notion of the soil first becoming filled to saturation and the excess amount draining down into the subsoil is, as pertinent investigations have demonstrated, not correct. Actually, water already starts seeping away into the lower strata when the maximum saturation point of the surface soil has not yet been reached by a far stretch (see fig. 11). To obtain a good insight into the moisture balance of soil profiles with a view to irrigation, it would therefore seem to be of the highest importance that the discharge of moisture into the deeper strata of the subsoil should equally be made the subject of exhaustive investigation. Soil science may provide a contribution in this respect by supplying a clearer picture of the maximum water-holding

capacity of a given soil profile, since the laws governing this factor are obviously more complicated than has been supposed so far.

Trends in soil physics with respect to irrigation

If one is to set oneself a purpose in the study of irrigation research, it would seem to be relevant to aim at a standardized method of computation, by means of which it would be possible to establish day-by-day alterations in the moisture balance for a given number of soil types and also in the amounts of artificial rain that would be required, whilst duly accounting for the naturally occurring precipitation. To this end a few test-fields should be available, for the purpose of regularly checking up with the results of these computations. In this manner it would be possible to give an irrigation advice which might serve as a guide for a large number of farms. This would appear to provide a firmer basis for a rational irrigation policy for each farm, than would be achieved if the performance of moisture studies or estimates were to be left to the farmer's own initiative.

With a view of putting this type of research on a firmer basis and, more particularly, to get a better insight into the various soil characteristics, water balance studies should preferably be carried out on a world-wide scale and with sufficient precision. This would certainly be invaluable since climatological variations, particularly in the smaller countries, would be too insignificant to warrant adequate over-all results, whilst the long periods of time spent in waiting for an extremely wet or an extremely dry year would tend to render research of this type too laborious and too expensive.

A nucleus of a similar type of international collaboration is already available in the form of the „Working Party on Supplemental Irrigation" of the FAO, which might issue the necessary directives with regard to this kind of studies.

Equally important results might be expected to follow from combined investigations concerning root growth and the progressive depletion of moisture from the soil. Both the very large number of crops and the equally wide variation in soil types will tend to make such a study a major task, which might be advantageously tackled at various different places simultaneously and after that be integrated by suitable mutual consultation.

Much indeed is still to be done in the field of soil engineering that will give the so very necessary support to better moisture provisions for the crop.

May, therefore, full attention be given to international, collectively organized, irrigation research.

Résumé

Pédologie et Irrigation par Aspersion

L'agrologie pourra apporter un appui considérable à la bonne gestion des systèmes d'irrigation par aspersion.

Il est de haute importance de développer les recherches concernant les exigences des cultures pour ce qui est de l'humidité et d'approfondir l'étude relative à la mesure dans laquelle la plante est capable d'épuiser l'eau retenue dans le profil. Cette étude porte sur les constantes d'humidité permettant de représenter le mieux ou le plus simplement possible les réactions de la culture. Sont étudiés le pF (voir fig. 1 et 2) et l'évaporation (voir fig. 3 et 4). L'une et l'autre méthode permettent d'obtenir de bons résultats. Les connaissances à ce sujet pourront être considérablement approfondies par une étude concernant la soustraction d'eau par rapport à la profondeur de la couche et à la période de l'année (voir fig. 7). Vu la grande variété de

types de profils, de climats et de culture, une étude de ce genre aurait grand avantage à être exécutée en coopération internationale. Les résultats d'une telle étude permettront d'obtenir une vue d'ensemble sur le rendement en fonction du climat et de l'humidité du profil et sur l'effet produit par l'irrigation par aspersion.

Afin de donner à ces connaissances une utilité pratique, il faudra pouvoir déterminer par une méthode simple et rapide la teneur en humidité du profil. De plus, il faudra pouvoir déterminer la tension d'eau, le tracé du pF et la quantité d'eau pouvant être absorbée par la plante pour une teneur d'eau déterminée. Enfin, il faudra pouvoir prédire l'évaporation par l'intermédiaire des plantes pour être à même de calculer combien de jours le stock d'eau pourra encore suffire à la culture. Dans les grandes exploitations et les stations d'essais à grandes ressources scientifiques, ces problèmes pourront être résolus. Il faudra chercher des voies particulières pour l'instruction en masse des nombreuses petites exploitations. Malgré l'existence d'un grand nombre de méthodes, la teneur en humidité ne peut encore être mesurée aisément. A ce sujet, les meilleurs résultats semblent pouvoir être obtenus par la comparaison à des échantillons d'humidité artificiels ou par une évaluation visuelle directe. Lorsqu'il s'agit de quelques lots de terre, la détermination du tracé du pF ne présente pas de grandes difficultés. Mais si l'on veut fournir à partir de ce tracé du pF des conseils se rapportant à de grandes étendues, la détermination de ces tracés devra être liée au lever agrologique. La teneur en limon et en humus, ainsi que d'autres propriétés du sol permettent de prédire le tracé du pF (voir fig. 8).

Il faudra encore bien quelque étude pour déterminer à base de ces données la quantité d'eau accessible aux cultures, puisque l'étude de courants d'eau capillaire non-stationnaires a permis de constater que le sol peut retenir momentanément une quantité d'eau supérieure à sa capacité de rétention et que, par cette quantité d'eau supplémentaire, la plante peut disposer pendant un nombre de jours non négligeable d'une plus grande quantité d'eau qu'en présence de la quantité d'eau emmagasinée à l'état stationnaire. Les figures 5 et 6 en donnent une idée.

L'étude de l'état d'humidité du sol et de l'évaporation conclut la série d'exposés. On sait déjà que l'évaporation d'eau diminue à mesure qu'augmente la tension d'eau. Les figures 9 en 10 forment l'illustration de ce fait. Il doit cependant y avoir encore d'autres facteurs influençant l'évaporation et sous ce rapport, il serait important de procéder à une étude de tout l'équilibre hydrologique. La figure 11 montre une partie des résultats d'une telle étude de l'équilibre hydrologique. Une étude pareille semble tres importante pour l'obtention d'une vue d'ensemble des conditions hydrologiques et, vu la grande variété d'états du profil, de cultures, de climats et de systèmes hydrologiques, ne pourrait probablement donner des connaissances assez larges que si elle était entreprise en collaboration internationale. Comme centre de recherches, le „Working Party on Supplemental Irrigation" de la FAO semble être l'organisation indiquée.

ZUSAMMENFASSUNG

Bodenkunde und künstliche Beregnung

Die Bodenkunde wird einer guten Verwaltung der künstlichen Beregnung in erheblichem Masse Vorschub leisten können.

Es wird wichtig sein die Untersuchung der Anforderungen, die das Gewächs an den Feuchtigkeitszustand stellt, weiter aufzubauen und den Umfang, in welchem die Pflanze den Feuchtigkeitsvorrat des Profils erschöpfen kann, nach wie vor zu studieren. Dieses Studium umfasst eine Untersuchung der Feuchtigkeitskonstanten, die die Reaktion des Gewächses am besten oder am einfachsten darstellen können. Gegenstand der Untersuchung sind der pF (siehe Figur 1 und 2) und die Verdunstung (siehe Figur 3 und 4). Mit beiden Methoden lassen sich gute Resultate erzielen. Eine beträchtliche Vertiefung der Einsicht wird sich aus einer Untersuchung nach dem Feuchtigkeitsentzug im Zusammenhang mit der Schichttiefe und der Jahreszeit (siehe Figur 7) ergeben können. Dieser Untersuchungstypus wäre mit Rücksicht auf die grosse Variation in Profiltypus, Klima und Gewächs sehr geeignet für internationale Zusammenarbeit und kann zu einer besseren Übersicht der Abhängigkeit des Ertrags von Klima und Feuchtigkeitszustand des Profils, sowie des Einflusses von dessen künstlicher Beregnung führen.

Wenn man diese Kenntnisse praktisch verwerten will, so wird es notwendig sein den Feuchtigkeitsgehalt des Profils schnell und einfach zu bestimmen. Weiter wird es erforderlich sein die zu diesem Feuchtigkeitsgehalt gehörende Feuchtigkeitsspannung, die pF-Kurve und die für die Pflanze aufnehmbare Feuchtigkeitsmenge bestimmen zu können. Schliesslich sollte man die Verdunstung durch das Gewächs voraussagen können um daraus zu berechnen, wieviel Tage das Gewächs noch mit dem festgestellten zugänglichen Feuchtigkeitsvorrat wird auskommen können. Für grosse Betriebe und Versuchsfelder mit reichlicher wissenschaftlicher Unterstützung werden sich diese Probleme schon lösen lassen. Für die Aufklärung in grossem Umfange vieler kleinen Betriebe wird man besondere Wege suchen müssen.

Der Feuchtigkeitsgehalt kann trotz der vielen verschiedenen Methoden noch nicht auf einfache Weise bestimmt werden. Es scheint, dass durch Vergleichung mit künstlich zusammengesetzten Feuchtigkeitsmustern oder durch unmittelbare visuelle Schätzung vermutlich noch die besten Ergebnisse erzielt werden können.

Die Bestimmung der pF-Kurve weniger Parzellen ist keine schwierige Aufgabe. Will man aber auf Grund der pF-Kurve für grosse Gebiete Gutachten abgeben, so soll die Bestimmung dieser Kurven der bodenkundlichen Aufnahme angehängt werden müssen. Schlamm- und Humusgehalt sowie andere Bodeneigenschaften machen es möglich die pF-Kurve vorauszusagen (siehe Figur 8). Es wird aber noch viel Untersuchungsarbeit erforderlich sein aus diesen Daten den dem Gewächs zugänglichen Feuchtigkeitsvorrat zu bestimmen. Aus der Untersuchung nicht-stationärer kapillarer Feuchtigkeitsströmungen geht hervor, dass vorübergehend mehr Feuchtigkeit als die Feldkapazität festgehalten werden kann. Durch diese zusätzliche Feuchtigkeitsmenge während einer nicht zu vernachlässigenden Anzahl Tage steht der Pflanze eine grössere Feuchtigkeitsmenge zur Verfügung als dem Vorrat beim stationären Zustand entspricht. Die Figuren 5 und 6 geben davon einen Eindruck.

Die Untersuchung des Feuchtigkeitszustandes des Bodens und der Verdunstung schliesst die Reihe von Betrachtungen. Bekannt ist bereits, dass weniger Feuchtigkeit verdunstet, je nachdem die Feuchtigkeitsspannung höher ist. Die Figuren 9 und 10 machen das deutlich. Es wird aber noch mehr Faktoren geben, welche die Verdunstung beeinflussen und in diesem Zusammenhang wäre eine Untersuchung nach der ganzen Feuchtigkeitsbilanz von Bedeutung. Figur 11 gibt einen Teil der Resultate einer solchen Feuchtigkeitsbilanzuntersuchung. Ein solches Studium erscheint von sehr grosser Wichtigkeit zur Verschaffung einer zusammenfassenden Übersicht der Feuchtigkeitswirtschaft. Mit Rücksicht auf die grosse Variation der Zustände des Profils, des Gewächses, des Klimas und der Hydrologie würde ein Feuchtigkeitsbilanzstudium vermutlich erst eine ausreichende Einsicht gewähren, falls dieses Studium in internationaler Zusammenarbeit aufgenommen werden könnte. Als Zentrum dieser Untersuchung erscheint die „Working Party on Supplemental Irrigation" der FAO die geeignete Organisation.

DISCUSSION

CZERATZKI:

In Fig. 2 wird „field capacity" für den Sand- und den Tonboden einheitlich bei pF 2,4 angenommen. Eigene Untersuchungen haben gezeigt dass gewisse Unterschiede zwischen den Bodenarten zu bestehen scheinen und zwar tritt die „field capacity" bei Sand bei niedrigeren Werten ein als bei Ton und schluffhaltigen Böden.

Answer:

We found in literature the differences in field capacity mentioned but I do not quite remember in which direction they pointed. I wanted to stress with fig. 2 that the optimum for plant growth is found at a lower pF than that concurring with field capacity and this remains also true, according to our experience, for light soils if we stick to the definition that field capacity is the water content that remains in a deeply drained soil after free drainage.

ASLYNG:

Concerning fig. 3, I believe an other limiting factor is keeping the yield down. Fig. 9 to 10: I am inclined to think that the actual evapotranspiration is reduced more rapidly for lysimeters than for field crops.

We need more information about root depth and intensity as a function of soil aeration. It is important to have deep rootings to reduce the requirements for irrigation.

Answer:

The curve in the scatter diagram of fig. 3 depicts the law of the limiting factor. The horizontal part is the limitation due to an other factor.

The difference between evaporation in lysimeter tanks and the free soil depends on the water supply in both instances. In the lysimeters of MAKKINK the water was supplied to keep the groundwater constant. Here the reduction of the evaporation at higher soil water stresses, due to a higher soil watertable, might be less.

We see research of root depth and water relations, as given by Dr. SCHUURMANN, as a subject of utmost importance and should particularly appreciate international cooperation in this respect.

LYSHEDE:

Though the fig. 11 shows that discharge takes place before field capacity is reached it also shows that only a small part of the rain is drained-off when the soil moisture is below field capacity.

Answer:

The point I wanted to stress is, that we are simplifying the moisture relations in the soil too much, if we take that drainage only occurs if the moisture content in the profile agrees with the equilibrium content as given by the pF-curve. The errors, due to such simplification may amount to 50 to 100 mm. and must not be neglected.

HALLGREN:

The water capacity is no fixed value. It is greatly depending on the groundwater table. Especially on sandy soils there will be a great difference between the „field capacity" determined in the laboratory on short soil columns (10 to 20 cm.) and the field capacity determined in the field when the groundwater lies e.g. at 2 m. depth. In practical irrigation it is of course the conditions in field that are of primary interest.

Answer:

The point which I wanted to stress is that according to YOUNGS, even in deep profiles the field capacity is not a well defined quantity, due to hysteresis. The mentioned effect of the soil watertable is indeed an effect that is too often overlooked in practical application of the theory of the water in the soil.