THE EFFECT OF SOIL MOISTURE ON THE GROWTH AND YIELD OF VEGETABLE CROPS

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1. INTRODUCTION

Although the total precipitation in humid climates of the temperate zone is sufficient for the growing of vegetable crops, it is known that considerable damage can be caused by short spells of drought. Therefore, Dutch vegetable growers often use sprinkler irrigation to supply additional water. Generally speaking the expenditure necessary in that case is rather low in comparison with overhead production costs.

Fundamental research on the relation between plant growth and soil moisture content is necessary as a basis for advice on sprinkler irrigation. Previous moisture regime experiments do not correspond, however, since the results obtained by various investigators largely depend on the procedure followed, the climatic conditions, the soil type and the crop with which the experiment was carried out, c.f. STANHILL, 1957.

In the next paragraphs some results are given concerning the relations between soil moisture and various aspects of plant growth. The influence of some external factors on this relation will also be discussed.

At our Institute investigations concerning the effect of soil moisture on plant growth were performed with vegetable crops, in containers placed in a glass house or on field plots, that could be sheltered against natural precipitation by movable glass covers. In the experiments the moisture content of the soil varied between field capacity and fixed tension limits. As soon as the latter were reached the soil was again irrigated to field capacity. The irrigation frequency and the amount of water supplied depended on the tension limits, the transpiration conditions during the experiment and the plant development. In the containers the whole root-zone (20 to 60 cm.) was brought to field capacity, in the field only a depth of 30 to 40 cm. In the latter case, the majority of the roots was found in this layer. The different treatments started some time after planting or sowing, to obtain a favourable initial development.

For the characterization of the soil moisture content, pF curves were used. In fig. 1 they are given for the soils used in the experiments: a coarse sand (A), a clay loam (B) and a loess loam soil (C), respectively. The moisture content was determined at certain intervals, either by oven drying of samples or by resistance measurements with nylon blocks. The mean tension was calculated from the moisture content data. Field capacity corresponded with a pF 2.0 or pF 2.1.

2. THE RELATION BETWEEN SOIL MOISTURE AND PLANT GROWTH

The conclusions drawn from experiments on soil moisture and plant growth,

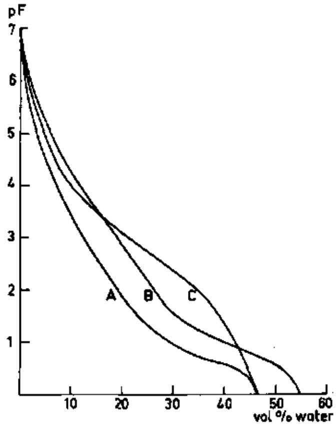


FIG. 1. pF-curves of the soils used in the experiments
A. Sand
B. Clay loam
C. Loess loam

depend for a great deal on the properties studied. Differentiation ought to be made according to a.o. vegetative growth, production of fresh material or dry matter, yield of reproductive organs, root development, quality, etc.

In the following paragraph various aspects of growth will be discussed.

2.1. Influence on stem elongation and leaf area

Generally, soil moisture depletion had a large effect on the development of vegetative parts of the plant, in a great number of crops.

In broad beans the stem elongation, for example, was measured under various moisture treatments starting three weeks after planting from the 15th of June till the 6th of July. This period represents nearly one irrigation cycle of the dryest plot (tension limit: pF 3.4). The results are shown in fig. 2, in which the increase in height of the main stem is plotted against the mean moisture tension in the top 40 cm. of the soil. It can be seen that the maximum stem elongation of 40 cm. occurred with a mean tension between pF 2.1 and 2.4. At the highest tension (pF 2.9), the length of the stem increased only 25 cm.

In other crops a maximum in stem elongation between pF 2.1 and pF 2.4 was observed as well. A similar effect was found for the increase in leaf size,

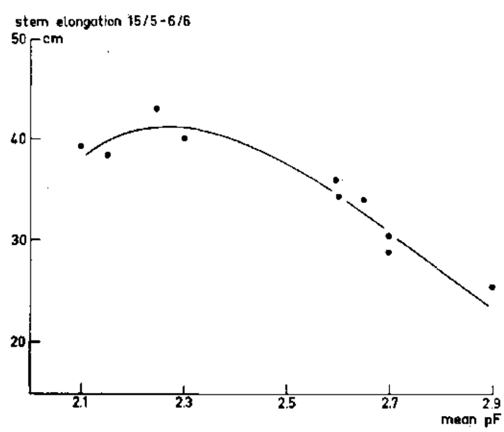


FIG. 2.
The effect of mean moisture tension on stem elongation of broad beans (field experiment)

while the number of leaves and the number of internodes was nearly the same for all treatments. No marked differences were found in the number of cells. The reduction in leaf size under clay soil moisture conditions can be mainly attributed to a corresponding reduction in cell size. This may imply, that the development of primordia is not very drought-sensitive.

2.2. Influence on fresh weight and dry matter production

In the glass house experiments with various vegetables, large containers were used. The latter were filled with 5 cm. gravel, 5 cm. coarse and 50 to 60 cm. of a sandy or clay loam soil (fig. 1, curves A and B). The total weight of the containers varied between 180 and 230 kg. depending on soil type and moisture content. The surface area was 0.2 sq.m. The experiments were carried out for four moisture levels with four replicates, unless indicated otherwise.

All the crops investigated showed a large decrease in fresh weight yield of the vegetative parts, with an increase of the mean moisture tension. The yield varied according to the crop used: those with the highest fresh weight production displayed the largest decrease. It is obvious that this decrease is nearly the same for various crops, such as lettuce, spinach and radish (fig. 3), when represented as a percentage. The yield decreases regularly from 100 % to 20–30 % in spring, with an increase in mean pF from 2.3 to 3.4. In autumn this decrease is less pronounced, however, than in spring and amounts to only 50 to 60 % under comparable soil moisture conditions. On clay loam and on sandy soil nearly the same trend was found in our experiments. The seasonal influence and the effect of the soil type on the yield of vegetable crops will be discussed in paragraph 3.

The experimental procedure may give rise to deviations in the decrease of the observed yield. It is possible, for example, that on soils irrigated to field capacity immediately before harvest, higher yields in fresh weight will be observed than on plots treated in the same manner and harvested at the end of a drying cycle. The higher yield may be due to a rapid passive water absorption, through which the water content of the plant in gms. of water per gm. dry matter increases. On the other hand, the mean moisture tension may show a small change whether or not water is supplied immediately before harvest. These assumptions have been verified in an experiment with lettuce, in which some low (L) and some high (H) tension replicates were irrigated immediately before harvest time (table 1).

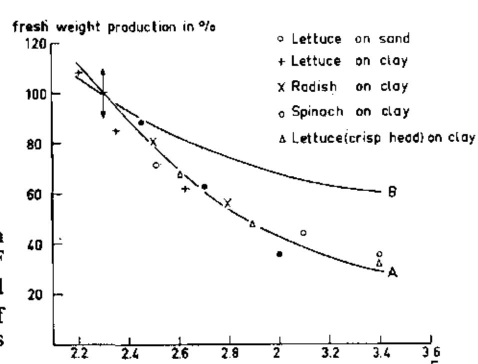


FIG. 3.
The effect of mean moisture tension on fresh weight production (% of that at pF 2.3 ↕) of various crops in the spring (A) and in the autumn (B). The individual points of curve B were omitted, as the variation was nearly equal to that of A

TABLE 1. The effect of irrigation before harvest on: fresh weight, dry matter production and water content of lettuce

Harvested	Mean moisture tension (pF)		Fresh weight (gms/container)	Dry matter production (gms/container)	Water content (gms. of water/ gm. dry matter)
Before	L	2.1	656	29.5	21.2
Irrigation	H	3.2	366	20.1	17.1
After	L	2.1	687	31.5	20.8
Irrigation	H	2.9	546	24.5	21.2

It can be seen that the fresh weight of the dry plot (H) increased from 366 to 546 gms., after irrigation, whereas the change in mean moisture tension was relatively small. The increase in fresh weight is mainly due to the rise of water content from 17.1 to 21.2, the latter value being nearly equal to the water content of the wet plot. Dry matter production is, therefore, less affected than fresh weight production by water supplied before harvest. In practice, vegetable growers usually irrigate some vegetable crops shortly before harvest in order to obtain higher yields in fresh weight.

Beside the above mentioned four moisture treatments, two groundwater tables (30 and 50 cm.) were used with lettuce to obtain, together with the above experiment, a wide range in mean pF. The effect of moisture stress on fresh and dry weight production is given in fig. 4. It is evident that a sharp maximum in fresh weight production occurs at approximately pF 1.9. The decrease at lower tensions may be due to restricted aeration. The water content of the heads was 12.7, 16.6 and 6.6. gms. of water per gm. dry matter with a pF of 1.5, 1.9 and 3.3, respectively. Dry matter production, therefore, shows a relatively smaller decrease than fresh weight production, resulting in a broad maximum. The same trend was observed in experiments with other vegetables.

In the field a large decrease in fresh weight with an increase in the mean moisture tension was observed as well (STOLP, 1956).

Thus far, no exception to this was found when testing a large number of crops, both in field- and in pot experiments.

2.3. Effect of soil moisture content on some other plant aspects

A period of high moisture stress during certain growth stadia may have a detrimental effect on various plant aspects of certain vegetable crops, which cannot be compensated for by a low moisture stress later on. With pulses, for

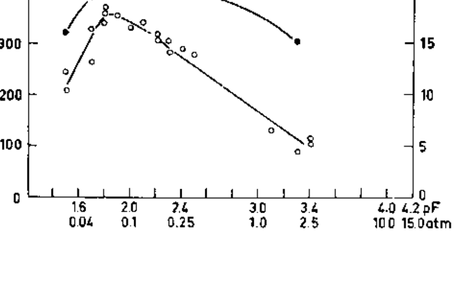
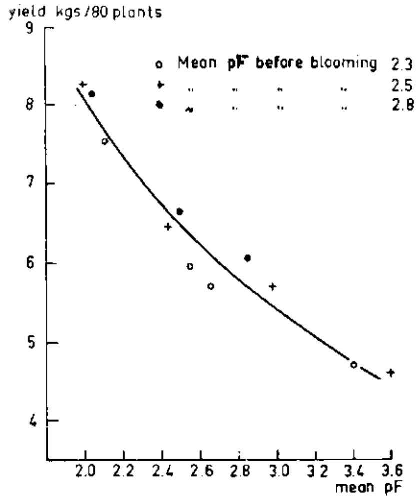


FIG. 4.
The effect of mean moisture tension on fresh weight (o—o) and dry matter production (●—●) of lettuce in the spring of 1957

FIG. 5.
The effect of mean moisture tension during blooming till first picking date of dwarf French beans



example, a large influence of soil moisture tension on vegetative growth was observed. The final yield of pods, however, is determined to a great extent by the moisture regime during blooming and podset. In fig. 5 the pod-yield of dwarf french beans is plotted against the mean pF over the period from blooming till the first picking date. A rather stunted growth appeared if before blooming the moisture stress in the top foot of soil increased to pF 3.6. No decrease in yield was found in this case, provided a low tension was maintained during blooming. A large decrease was observed with a high tension during blooming. This fact may be attributed to abscission of flowers or young fruits.

Losses due to a decrease in quality are at least as important as the height of yield itself, especially for vegetable crops. Often, at higher stress regimes, a lower percentage of marketable products is harvested. Although irrigation before harvest increases to a great extent fresh weight of some crops under a dry regime – lettuce for example – (table 1), no compensation in quality was obtained. This has been demonstrated in fig. 6, in which are pictured some lettuce heads grown at different moisture regimes. The numbers 1 to 4 relate to objects irrigated when tension limits of 2.5, 3.0, 3.5 and 4.0 respectively, were reached. It is evident that no marketable heads were obtained with a tension limit of 3.0 or higher, due to their unfavourable appearance, tipburn and bolting.

With other crops also, e.g. strawberry and cauliflower, yield response to a high stress at certain periods is not compensated for by a low stress later on.

The growth of roots is strongly affected by increasing moisture stress. BIERHUIZEN and PLOEGMAN (1958) found a marked decrease in root elongation at high moisture stresses using various vegetable crops. A tension rise to pF 3.0, corresponding with 50 % of the available water used, resulted in a growth rate that was 40 to 90 % lower than the one at field capacity. Drying out of the topsoil will result in a more intensive root development in the subsoil, provided the tension in this layer is low (fig. 7). However, this cannot always prevent a decrease of vegetative growth, as was found for example for dwarf french beans. This effect may be partly attributed to the unavailability of nutrients.

FIG. 6. The effect of irrigation regime on quality of lettuce in sand (1 to 4 represent tension limits of 2.5, 3.0, 3.5, and 4.0 respectively)

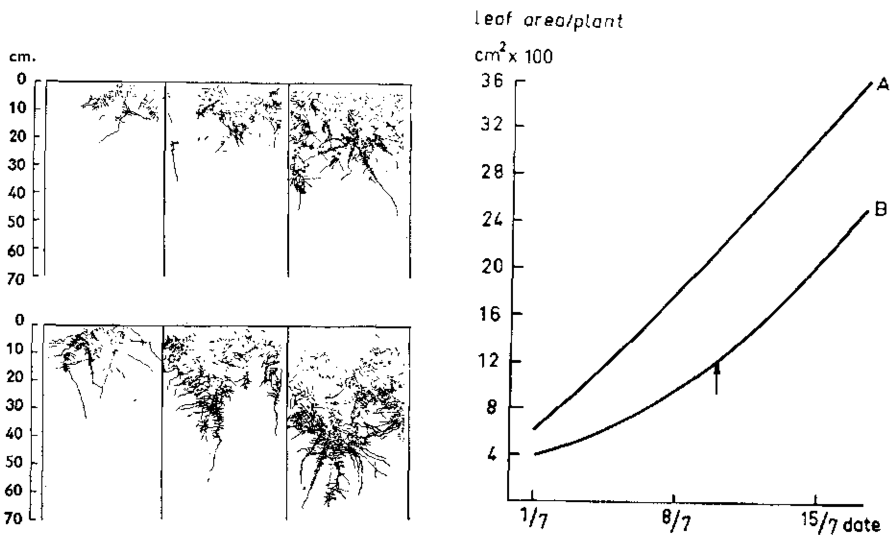
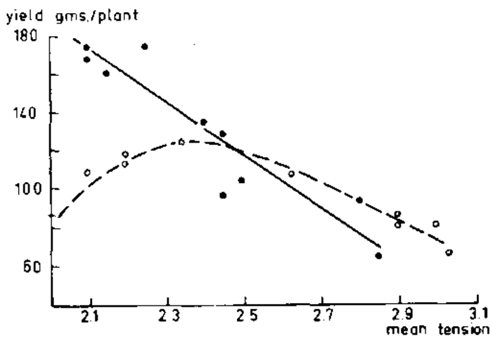


FIG. 7. *a*. Root development in successive periods of one week drawn from root chambers with glass panels and *b*. increase of leaf area for wet (A) and dry (B) plots. Arrow indicates irrigation of dry plot

FIG. 8.
The effect of mean moisture tension on yield of broad beans in sand (•—•) and loess (o—o) soil



3. Effect of some external factors on the relation between soil moisture and plant growth

Soil characteristics and climatic conditions can affect the relation between soil moisture and plant growth. When advising on irrigation one cannot exclude those factors.

3.1. Influence of soil type

The pF curve of the clay soil (fig. 1B) is quite normal above field capacity. The air content, however, is higher than in most clay soils. The curve for the sandy soil (fig. 1A) deviates from the normal type in this sense, that a smoother slope in the range between pF 2.0 to pF 2.5 or pF 3.0 is more characteristic for sandy soils. No difference in yield reaction was found on the above mentioned soils, as was shown in figure 3. Certainly a different reaction may occur on other soils. On soils with a low air capacity, for example, the highest yield will not be found at or near field capacity, but at a higher mean stress. This is shown in fig. 8, where the yield of broad beans both on sandy and loess soils are given. The curve found for the loess soil indicates that the potential productivity of such a soil is lower than that of soils with sufficient aeration (see figure 1A and 1C). At a low stress the air content is the limiting factor in the loess soil, whereas under conditions of sufficient aeration in this soil moisture tension will be too high for an optimal productivity.

Most sandy soils show a smoother slope of the curve in the range between pF 2.0 to pF 2.5 or 3.0, than the sandy soil used in our experiments. In those cases more available water is present in this pF range. It may be possible, therefore, that a less pronounced reaction will be found on such soils.

3.2. Seasonal influences

The significance of the season is shown in fig. 3. For various crops the relation between soil moisture tension and yield is represented for crops grown in spring and in autumn. At high stress, the higher transpiration conditions from March to May cause a sharper depression in fresh weight than is found for the same crops grown in the period from September till November (container experiments in the glass house). An identical effect can be expected to occur for early grown crops and for crops with the greatest part of their vegetation period in the summer months. In the Netherlands the probability of periods with high rainfall deficits and high potential evapotranspiration is the highest in June

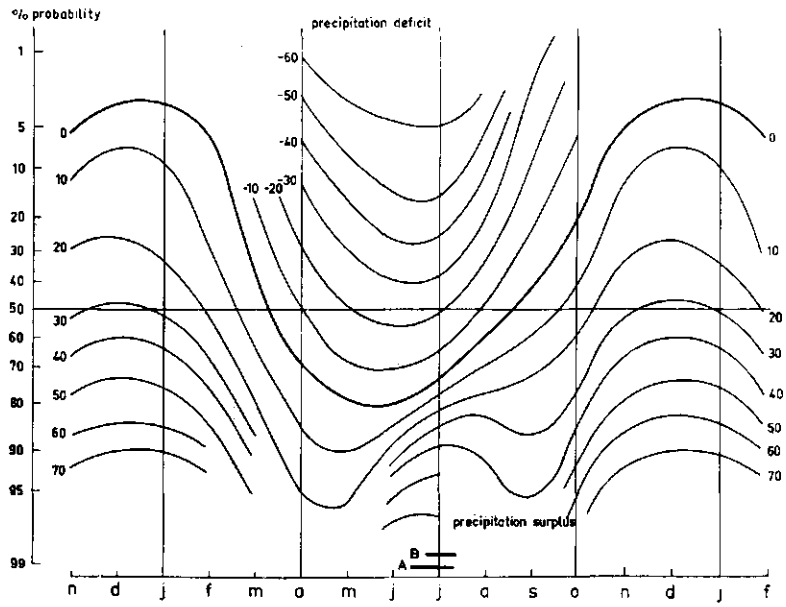


FIG. 9. Probability of differences between rainfall (R) and evapotranspiration (E) during the year. Calculated for twenty-day periods and a reduction factor 0.7 for E (after STOL, this report). E was calculated from meteorological data by PENMAN's formula over a twenty-year period (first approximation)

and July (STOL, 1958). It is obvious that critical periods of crop response generally coincide with the above mentioned period, as is shown in fig. 9. The lines A and B indicate periods in which strawberry (var. *Jucunda*) resp. dwarf french beans are more susceptible to drought than in other periods of their growing cycle.

4. DISCUSSION AND CONCLUSIONS

The relation between plant growth and soil moisture has been studied as a basis for advice on sprinkler irrigation. Various aspects affecting this relationship were investigated.

It was observed that a moderate soil moisture stress already causes a considerable decrease in vegetative growth and fresh weight production, as is shown in figs. 2, 3 and 4. This reduction in growth was mainly due to a decrease in cell size and water content, and in general not a result of a reduction in the number of leaves or internodes nor in the number of cells per leaf. The dry matter production is influenced to a much lesser extent by increasing soil moisture tension, indicating that the assimilation is not decreased at a moderate stress. The decrease in fresh weight, due to a high moisture stress, can be partly neutralized to some degree by irrigation later on (table 1), increasing the water content of the plant due to passive absorption.

In certain horticultural crops, however, a detrimental effect on quality was observed, which cannot be compensated for by later irrigation. Moreover, also a reduction in yield due to a high soil moisture stress in certain stages of growth, e.g. during blooming and podset (for pulses) or growth of receptacles (for strawberries), cannot be influenced by irrigations later on, whereas a high stress during other periods does not, or only to a lesser extent, influence the yield.

At low evapotranspiration conditions, limitation of water availability is less important. So the fresh weight differences between plants grown under low and high moisture tensions will be less pronounced (fig. 3). WITTE (1956) stresses this fact from a practical point of view, stating that the irrigation response of crops grown early in the season is less than half of that found for summer grown crops. This effect may be partly attributed to the higher moisture content of the soil at the date of planting or sowing and to a higher frequency of excess of rain over evapotranspiration early in the season.

It can be concluded from a large series of experiments, both in the glass house and in the field, that maintaining a low stress during the whole growth period generally results in the highest yield and quality. This leads to important consequences as regards the irrigation frequency for vegetable crops. In most soils in the low tension range (say between pF 2.0 and pF 2.5) no more than 20 to 25 mm. water can be consumed in a soil layer with a depth of 40 cm. Under conditions of high evaporation and low rainfall, the period between sprinklings must therefore not exceed 7 to 10 days, provided irrigation water is not scarce. This frequency also determines the capacity of the installation, taking into account of course the acreage planted with crops of high marketing value, since for those the above statements only hold true. On soils with a low air content at field capacity the above mentioned frequency of sprinklings could result in restricted aeration and in that case may cause detrimental effects in crop response.

RÉSUMÉ

L'influence de l'humidité du sol sur la croissance et le rendement de certains végétaux

On a exposé quelques résultats d'essais traitant les réactions de légumes sous l'influence de différences dans l'approvisionnement d'eau. L'expertise a eu lieu en partie en serre et en partie en pleine terre. L'approvisionnement d'eau a eu lieu après la constatation d'une certain degré de desséchement. Pour la caractérisation de l'humidité du sol on s'est servi de courbes-pF.

Pour nombre de végétaux on a constaté que la croissance et le rendement de matériaux frais décroîent à mesure que la tension de l'humidité augmente. La plus grande croissance et le plus grand rendement de légumes frais furent obtenus après une application d'un pF 2,0 à 2,4 en moyenne. Pour certains végétaux on peut réduire les conséquences défavorables de la haute tension d'humidité durant une partie de la saison de croissance en appliquant une adduction d'eau. Certains végétaux subissent par suite d'une tension d'humidité élevée dans le sol, des dégâts irréparables pendant certaines périodes de la croissance. Ceci vaut pour le rendement aussi bien que pour la qualité. En automne la diminution du rendement est moins grande par suite du desséchement du sol, qu'au printemps. Sur une terre ayant un petit volume d'air, une irrigation fréquente provoqua un baissement du rendement.

Les résultats nous montrent en outre que c'est surtout pendant des périodes de grande évaporation et de peu de pluie qu'on doit augmenter la fréquence de l'irrigation.

ZUSAMMENFASSUNG

Der Einfluss der Bodenfeuchtigkeit auf Wachstum und Ertrag einiger Gewächse

Der Einfluss wechselnder Wasserversorgung auf einige Gemüsegewächse wurde untersucht und die Ergebnisse dieser Experimente wurden dargestellt. Die Untersuchungen sind teilweise in einem Gewächshaus, teilweise im freien Felde durchgeführt worden. Man gab

Wasser wenn der Boden in einem bestimmten Mass ausgetrocknet war. Zur Charakterisierung der Wassergehaltes des Bodens wurden pF Kurven benutzt.

Die Experimente haben ergeben, dass bei vielen Gewächsen das Wachstum und der Ertrag frisches Pflanzenmaterial nachlässt im Verhältniss zu einer Zunahme der Bodenfeuchtigkeitsspannung. Das Wachstum war am starksten und der Ertrag frisches Pflanzenmaterials am höchsten bei einem durchschnittlichen pF von 2,0 bis 2,4.

Die schädliche Wirkung einer hohen Feuchtigkeitsspannung während eines Teils der Wachstumsperiode können bei einigen Gewächsen teilweise aufgehoben werden durch späteren zusätzlichen Wassergaben.

Es gibt Gewächse die in bestimmten Wachstumsperioden unwiderbringlich beschädigt werden durch eine hohe Bodenfeuchtigkeitsspannung. Dies kann sowohl den Ertrag wie auch die Qualität angehen.

Im Herbst hat eine starke Austrocknung des Bodens ein geringeres Effekt auf dem Ertrag frisches Pflanzenmaterials wie im Frühling.

Wenn der Boden nur ein kleines Luftgehalt hat gibt eine häufige künstliche Beregnung bedeutende Ertragssenkungen.

Die experimentellen Erfolge zeigen an dass in Perioden höherer Verdünstung und geringerer natürlichen Niederschläge eine häufige künstliche Beregnung notwendig ist.

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