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The influence of the unevenness of the landsurface on the possibilities of subsoil irrigation as a method for watersupply in delta areas

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1. Introduction

In areas in which the soils have an insufficient moisture holding capacity in periods of drought of some appreciable length the available water stored in the soil will be consumed by the plants, before replenishment takes place. The effect will be that yield depressions in plant production will occur. The measure of these depends on the deficiency of natural precipitation and the moisture holding cacacity of the soil profile.

If these yield depressions are to be prohibited it will be necessairy to bridge the period of shortage by supplying water by way of some artificial method. There are several of these, but one of them is subsoil irrigation, to which in the Netherlands there has been payed some attention in the near past.

By way of subsoil irrigation it is being attempted to maintain the groundwater tabel at a level which is most expedient for plant production. To this end water is being admitted to penetrate into the soil by way of a system of ditches and/or tilelines to compensate the water losses which are caused by the natural drainage process and by the water use for evapotranspiration. The capacity of the system should be as large as to be able to cope with these losses, which occur in occordance with the waterlevel that is being aimed at. The technical demands and the methods by way of which such a subirragation system is deviod is not the aim of this article. In consequence of this in the following it will be assumed that the required system of subirrigation is at hand and that it is functioning in an appropriate way.

2. The configuration of the landsurface

When studying the occurrence of yield depressions in a certain area, it can be remarked that these depressions tend to become larger as the mean groundwater table level becomes lower. This tendency as a rule is being accentuated as the soils on the high grounds mostly are having a smaller waterholding capacity.

It is a well known fact that subsoil irrigation can only be a success, when the watertable is being held in the optimal position, although a smallfluctuation is permissable. Fot the sandy soils of the south eastern part of the Netherlands this fluctuation may not be larger than approximately 20 to 30 cm. which is constituting a rather high demand to the irrigation system.

Subsoil irrigation has in common with some of the other systems of articicial water supply, that the landsurface has te be plane to a high degree as to be able to attain the best possible effect of the measure. Farmland of some appreciable acreage on which level differences smaller than the above mentioned tolerance of 20 - 30 cm. do occur is rarely being found in the areas with sandy soils. In the polder area's the soil surface is usually more level, although here also differences in level may occur of the same magnitude. On the other hand these differences of the land surface are less important as the waterholding capacity of these mainly claysoils is larger as a rule. Further more in these areas the drainage of these soils contitutes a more serious problem than that of watersuppley. Basically the unevenness of the soil surface constitues a similar problem. although yield depressions in these polder areas are more often being caused by waterlogging, soilstructure deterioration etc.

In the high and sandy soils an other problem presents itself with regards to subsoil irrigation. These soils as a rule have not a horizontal position, but show a certain inclination. Furthermore the area has been remoulded by the rivers and rivulets, to the effect that the landsurface has also a certain mount rectangular to the direction first mentioned. Both forms of inclination could be named the macrorelief of the area.

The groundwater table in the strip of land between two rivers shows a certain vaulting in the same manner, although on a much larger scale, as is the case with tile drainage. In addition to this the vaulting of the watertable between two rivers or rivulets is being remoulded by the local drainage ditches located in or near the river valleys.

In the polder areas occurring level differences of the soil surface are being overcome by the formation of poldersections with each its own polder waterlevel in the ditches, which is adapted to the requirements in the best possible way. In the sandy soil areas however, the existing level differences can not be bridged in a satisfactory way by the formation of polder sections with each its own watertable level and corresponding water level in the ditches. In these areas in the first place the groundwater table that is being aimed at as the most suitable has to be adapted to the natural shape that presents itself under the prevailing hydrological conditions. Small deviations from this natural shape are possible, but when these are being permitted to become to large, the subsoil water losses that will present themselves, will become disproportionally high. To compensate these the demands that have to be made to the irrigation system will become correspondingly higher and in relation to these the system will be more expensive.

From the preceding it will be clear that the prevailing natural hydrological conditions in the area and the topography of the landsurface constitute important factors, which impose certain limitations to the possibilities of subsoil irrigation as a method of artificial watersupply to farmland. It can be said that the shape of the groundwater table in summer- and in wintertime is to a high extend governing the possibilities for subirrigation. A raising of the groundwater table up to winter level constitutes a possibility that can be reasonably be put into effect, whilst the amount of water needed for this, i.e. the subsoil water losses by drainage to rivers and rivulets, the water consumption by the plants and evaporation directly from the ditches, remains within reasonable limits.

It has been pointed out before, that raising the water table to a higher level than is usually occurring in wintertime, will cause the subsoil water losses to increase substantially, whilst this process is being accentuated because of the measures that have to be taken to prevent waterlogging of the soils situated on a lower level near in the river valleys. In addition to subirrigation the construction of weirs in the rivers, to prevent high flowvelocities and as a measure of waterconservation and with the aim of lowering the drainage of the bordering lands is being propagated. As with regards to limiting the drainage influence of the river on the high soils it can be said that the effect of a weir is usually small, because the hight over which the river level can be raised often does not exceed 0,5 - 1 meter. Upstream from the weir the rise of the water level decreases with in creasing distance and proportionnally with it, its influence on the surrounding.

3. <u>The expiriment</u>

It seemed important to make some further inquirings with regard to the relations between the facet of the soil surface configuration and sub surface irrigation. Taken as a starting point the extend of adaptation of the natural shape of the groundwater table to the soil surface in a certain area, it was assumed that the realisable watertable does not deviate very much from its natural shape under winter conditions.

The possibilities of such an inquiry presented themselves in an area situated in the southeastern part of the Netherlands near the little town of Deurne. In the area which has an acreage of about 6 000 ha. and which exclusively consists of sandy soils, an extensive hydrological researchprogram had been carried out DE RIDDER (   ), ERNST (   ), from which the necessary data could be obtained. In connection with this hydrological research BON (1961) constructed two maps showing the depth of groundwater table beneath soil surface, both for the winter- and the summerseason. As an intermediary step a number of crosssections through the area in the directions north-south and west-east were made into which the position of the groundwater table in both seasons were plotted. Derived from these crosssections frequency diagrams of the depths of water table (figures 1-4) and of the differences of the same, measured over selected distances (figures 9-12), were constructed.

The yield depressions of the area could be calculated by means of the yield-depth of water table relation curves of the report by the Committee on Agro-hydrological Research (C.O.L.N.) VISSER (1958) and the afore mentioned maps of depths of groundwater table. These yield curves were converted by adding to them the influence of the unevenness between the soil surface and the water table, which is expressed by the frequency diagrams for the depths of groundwater level (figures 5 A-C).

From these converted curves the mean most desirable depth of water table and the necessary rise of it could be determined.

Finally, by way of the diagrams showing the frequency of differences of depths of water table over certain distances, an appreciation could be arrived at about the need of land levelling within the area under survey.

4. A short description of the area

As had been mentioned before the area under discussion is situated near the country town of Deurne in the eastern part of the province of North Brabant. It borders directly to the provincial border between North Brabant and Limburg, which is being formed here by the Peelkanaal and the Kanaal van Deurne. By way of the Kanaal van Wessen-Nederweert and the Noordervaart water from the river Maas can be pumped to the afore mentioned Peelkanaal and from this directly into the area under survey.

The area can be divided in an eastern part, which is rather level and a western part which is much less so. The former part consists of reclaimed peatsoils of which most of the peat has been removed and which has a rather high water table, whilst the latter part consists exclusively of sandy soils with a lower water table position.

The soil surface shows an inclination in the direction west. The rivulets take their source in the eastern part of the area, which is situated near the divide of the catchment area of the river Aa, into which the rivulets merge. These rivulets have formed rather deep valleys in the western part of the area. The groundwater table also shows an inclination in westernly direction; its drop being about 1 $^{o}/oo$. Perpendicular to this main direction of flow the water table shows a vaulting caused by the draining effect of the rivulets and the ditches in the low lying soils in valleys.

The agricultural situation is being characterized by the following data concerning the yield depressions caused by unsufficient water management, BON (   ).

a yield depression more than 10% by waterlogging on:	4,5% of the area
a yield depression less than 10% on	: 10,2% of the area
a yield depression by drought of more than 10% on	: 80,2% of the area
a yield depression alternately by drought and by waterlogging on	: 5,1% of the area

The mean yield depression for the whole area amounts to 19%.

The farm found within the area is of the mixed type, consisting partly of livestock and partly of arable farming. The livestock part of it forms the most prominent one, because an important part of the arable crops is being feeded to the livestock.

About 40% of the area consists of grassland and 60% of arable land, of which in its turn 78% is taken by cereals (rye, oats and barley) and 20% by beets and potatoes.

5. The depths of groundwater table

The maps indicating the depth of groundwaterlevel by BON (1961) only show some seven classes. However more detailed data were desirable. Therefore from the available cross sections of the area made by BON some five were selected suitable for the purpose. In these cross sections every 50 m. the depth of groundwater level below soil surface was measured and grouped into classes of 10 cm each. The number of data per class were calculated into percentages of the total amount of data and further summated cumulatively. Next these summated data were plotted against the cumulative distribution scale. When this was done while using a metric scale for the depth of water table classes, curving lines were the outcome. Because of the limitation of the material the obtained cumulative distribution curves are imperfect owing to the fact that in the classes of the extremes data are scanty or even lacking.

With the aim of being able to adjust the data by way of curve fitting a logarithmic scale for the water table classes was tried out. It was found that when using the scale log. (x + 20) for the whole of the area and for the western part and log.(x + 10) for the eastern part of it, a straight line relation was reasonably approximated. Figure 1 depicts the cumulative distribution curves for the winter- and figure 2 for the summer level of the groundwater table, converted into straight lines.

If the depths of groundwater level classes are read back when using these straight lines and when plotted the readings on a metric scale against there percentual presence, the frequency distribution curves of the figures 3 and 4 are the result. These curves appear to be skew. They depict quite clearly in what way the curve for the summer groundwater table merges into that for the winterseason. The former curve is shifted along the horizontal axis to the left hand side of the diagram, whilst becoming increasingly steeper and higher.

From the diagrams the following data can be derived, respectively calculated:

		depth of water table in cm.	
		in winter	in summer
depth with highest frequency	east	40	120
	west	50	140
depth with a 50% probability of being greater or smaller	east	45	130
	west	70	160
mean depth	east	55	140
	west	90	175

Table 1. Some representative depths of water table of the area near Deurne

6. The influence of the unevenness between the soil surface and the ground-water table on the yields of crops

The frequency distribution curves of the figures 3 and 4 show clearly that there exists a substantial difference between the shape of the soil surface and of the water table. If these two were quite parallel there would have been only a difference in altitude, but otherwise the shape of both surfaces had been quite similar and there should have been no question of a frequency distribution curve,

The question arises in what way these differences in shape and level will influence the crop yields in the area. To the end of attaining some appreciation of these matters the yield curves mentioned in the C.O.L.N-report VISSER (1958) were used. As representative curves for the area in question were chosen the curve marked 3 for arable land and curve 4 for grassland. These curves are depicted in figure 5 A with the lines drawn in full. However these curves were only valid when using the mean depth of water table during cropping season. Therefore the latter were converted into depths of watertable during summertime by multiplying the former by the factor 1,18. This is possible because of the fact that the way according to which the winter depth of water table changes into that for the summertime (June/July) is approximitely the same every year. KOUWE (1958) STOL(1960).

When reading the yield corresponding with a certain depth of water-table, only that single depth is in question. This would be the situation for a piece of land of uniform soiltype and perfectly level. In this case every square yard of soil has the same depth of water table and produces the same crop yield. However in most cases there exists, as has been explained before, a deviation in depth of water table caused by the soil surface not being perfectly level and parallel to the water table. Now these deviations can be summarized as constituting frequency distribution curves like those of the diagrams 3 and 4.

In consequence of this the single depth of water table used in reading the yield curve can be imagined as being the depth corresponding with the one with highest frequency in the curves of figure 4. Next to this ruling depth on same piece of land larger and smaller depthsof the water table do exist in the way the frequency distribution curve is indicating. Together they produce the total yield of the piece of land. Because of these deviations from the optimal depth of water table the yield will show a certain depression when compared to that acquired, if the piece of land would have had an optimal depth of water table for every single square foot. The yield acquired is expressed in percents of the maximum possible under favourable conditions.

By using the depth of water table with the highest frequency as a ruling depth and assuming that the frequency distribution curve of figure 4 is valid either for the high or for the low laying soils - which needs not necessarily be so - by adding to them the unevenness of the soil surface and water table, the yield curves of figure 5 A and B can be converted into the curves drawn in dotted lines.

These converted curves show that for a depth of water table equal to zero, still a certain yield remains. This is due to the fact that although a certain part of the land is waterlogged and does not yield anything, there are the higher parts which do still have some crop yield. The shape of the frequency distribution curve is to a large extend responsible for this phenomenon.

With increasing depths of the water table the converted curves finally merge into the original ones. Byond this point of mergeance the depth of water table is too great as to have any influence on plant production.

The separate curves for arable- and grassland can be put together to one curve, as has been done in figure 5 C. To do this the ratio between the acreages in use as arable- and grassland for areas having a different depths of water table is needed. These data could be obtained from

SNIJDERS (1961) and are being shown in figure 6.

From figure 5 C can be read that the maximum possible combined yield of arable- and grassland in the eastern part of the area amounts to 93% and in the western part to 89%. The consequence of this is that there remains a yield depression of 7% and 11% respectively, which cannot be overcome by practising subirrigation.

From the curves of the figure 5 C and from figures 1 - 4 the following data can be derived and brought together:

	area :	west	east
1. Yield for mean summer depth of water table	%	80	84
2. Yield for optimal depth	%	89	93
3. Possible yield increase	%	9	9
4. Mean depth of water table in summer	cm	175	140
5. Mean optimal depth	cm	84	86
6. Mean rise of water table necessary	cm	91	54
7. Mean summer depth equal to winter level	cm	90	55
8. Mean yield for this situation	%	88	85

Table 2. Calculation of the possible yield increase and the necessary rise in watertable

In the first place it appears that only an increase of the yield with 9% is possible when the groundwater table is raised by 91 cm. in the western and 54 cm. in the eastern part of the area. Then it may be noted that this improved situation is approximately attained, i.e. up to a level of 88% of the maximum possible yield, when it would be possible, to realize a water table level equal to winter level. However in the eastern part of the area the optimum water table level has been surpassed already when realising winter level and the gain by eliminating depression by drought has been lost again in change of yield depression by waterlogging. In this part of the area the aim should be a water table level of about 30 cm. below winter level, corresponding with which a yield depression of about 7% will still remain.

The effect of raising the water table up to winter level during the cropping season was also studied by BON. It appeared that the mean yield depression for this situation remains practically the same as in the present situation i.e. about 20%. The causes however will show a shifting from yield depression by drought to one by waterlogging of the soils. It was found that the area suffering from drought would decrease from 86% to 64% and that the area suffering from waterlogging would increase from 4,5% to 24%, and that the area with depressions in yield less than 10% would remain practically unchanged at about 12%.

The raising of the water table by way of subirrigation without further adaptation of it to the shape of the soil surface will cause the soils near or in the river valleys to be suffering by waterlogging. The same will be probable for a number of soils on the high grounds which are relatively low to their surroundings. An increase of the area suffering from waterlogging from 4,5% to 24% will be quite unacceptable for the farmers in question. Thereforea better adaptation of the shape of the water table to that of the soil surface will be nacessary in the case one does not agree with a lower depth of water table and corresponding by higher lasting yield depression.

For the case in the eastern part of the area a groundwater table level of 30 cm. less than winter level is realised, in figures 1 and 3 is also shown the cumulative distribution curve as a dotted line and the frequency distribution curve respectively. These curves represent a transitory stage between the winter- and the summer situation of the water table.

The phenomenon of the lasting yield depression within an area, regardless of subirrigation is put into practice, was mentioned before by VISSER (1958). Based on the C.O.L.N.-research figure 7 was constructed. In this triangular diagram for a number of large areas, consisting of sandy soils, the percentages of acreage suffering from drought and water logging and with no important yield depression were plotted. In the diagram also the lines of equal yield depression have been drawn. The marks show clearly that two lines can be drawn through them. These lines are originating from the angle of 100% dry and are curving when extrapolated to the point of 100% waterlogging. The area near Deurne belongs to the curve marked I.
Somewhere the line must have an optimum. It appears that in the most favourable situation that can be arrived at, about 40% of the soils may be regarded as having a sufficiently good water management, whilst 35% is too dry and 25% is too wet. The mean yield depression, which cannot

be overcome, amounts to 12-13%, which agrees reasonably well with the expected lasting yield depression for the Deurne areas of 7-9%, say 10%.

7. The need for land levelling in the area

Subirrigation as a method of watersupply to crops claims a depth of water table, which only may fluctuate between narrow limitations. This is overall the case for the soils which in the first place are in need of additional watersupply. Only a few areas are sufficiently level to answer the demands. Land levelling will therefore be necessary for most of the soils.

The requirement of maintaining a certain depth of water table does not assume that the soil surface has to be perfectly horizontal and parallel with it. the groundwater table. In sandy soil areas a horizontal position of the soil surface is rarely at hand, whilst the water table usually shows a certain mount owing to the prevailing hydrological conditions. In most cases it will be far more practical to perform the land levelling parallel to the existing or expected position of the groundwater table. This implies that it is not necessary to deviate too much from the natural shape of the water table. In addition in doing so, one does not run the risk of levelling a piece of land in such a way that the one end may receive a depth of water table which is too small whilst that on the other end is still to deep.

A measure for the unevenness of a piece of land may be found by determining for a large number of points of it the defferences in hight above a certain ordinance datum. From these data frequency distribution curves may be constructed for differences between points situated apart at a certain member of fixed distances. For a piece of land, which is level to a high degree, the frequency distribution curves for different distances will be steep and narrow. The same curves for a piece of land that is very uneven will be broad and flat, having a very large dispersion of difference classes.

As the parallelness of soil surface and water table for sub irrigation is a ruling demand, in this case the water table itself may be taken as an ordinance datum for the differences of depth of water table over a certain distance.

Again by using the cross sections of the area, which have been used to construct the figures 1 and 2, the differences in depth of water table between points laying apart at distances varying from 50 to 300 m. were measured and grouped into classes of 5 cm. each. From these data cumulative distribution curves were constructed. From these curves can be read the probability that a certain difference in depth over a certain distance will not be exceeded. In figure 8 a metric scale for the difference classes was used. It is clear and reasonable that the lines have their asymptote at x = 0. However the right hand asymptote does not hold a fixed position for all the lines. With increasing distances over which the depths of water table were measured the asymptote is shifting to the right, i.e. that increasingly large differences occur. It seems clear that the right hand asymptote will not exceed a certain ultimate value, which may be regarded as a special property of the area in question. From the diagram of figure 8 this ultimate value appears to be approximately 280 cm. In fact in the cross sections used the largest difference in depth of water table between two points has been 270 cm. at a distance of 300 m. A difference of 275 cm. was present only once at distances of 400 and 550 m.

To be able to adjust the data by linear curve fitting the data concerning the depth of water table difference classes were also plotted to the probability scale by using a logarithmic scale. It appeared that when plotting log. (x + 10) to the corresponding cumulative distributions of the classes an approximately straight line was the result, of which the data of the extremes are deviating (figures 9, 10 and 11). These deviations in the 0-5 cm. difference class may be ascribed to the kind of the material used, i.e. the cross sections. Differences less than 20 cm. could not be measured with sufficient accuracy. On the other hand the data in the classes of large differences were scanty.

An appreciable approximation of the relation between the cumulative distribution of the depth of water table classes seems to be.

$$y = \log.\ 6\ (x+10)^{a} = a \log.\ (x+10) + \log.\ 6$$

in which x is the difference in depth and y the cumulative distribution according to the probability scale;

a. being a constant for the slope of the lines and

b. a constant which means a shifting of the line over a distance log. b along the probability scale.

The diagrams of the figures 9 and 10 show that the probability of occurrence of certain differences of depth of water table over distances larger than 200 m does not change substantially any more, in fact not more than a few percents. This means that, for the Deurne area as a whole (figure 9), it has to be taken into consideration that, for instance on a circular piece of land with a radius of 200 m., the probability for a difference in depth of water table of 32 cm. or less, between the central point and the circumference of the circle, is about 50%. The probability of a smaller difference than 32 cm. between the central point and any point within the circle is larger than 50% and for a distance of 50 m. even 80%.

From the diagram of figure 9 - and as a matter of fact also from those of figures 10 and 11 - it is possible to deduct diagrams showing the probability of a certain difference in depth of water table over a varying distance, as has been done in figure 12. This diagram may be used to determine in what manner the probability of a certain difference of depth of water table in connection with the distance is changing, and vice versa.

Figure 12, in connection with the yield curve of figure 5 C (line in full), may also be used in determining the acreage on which certain differences of depth of water table will not be exceeded with a certain probability. If yield depressions of 10% are permissable, deviations from the optimal depth of water table (80 cm.) of 32 cm. to the wet side and 52 cm. to the dry side are permissable. According to figure 12 the largest distance between two points may not exceed 200 m. if a probability of 50% for deviations of 32 cm. or less are desired.
It is possible to show by calculation from figure 12 that by taking the radius of the area larger, that the <u>mean probability</u> of a smaller difference then 32 cm. will not be substantially smaller than 50%, because the lines are in an ever increasing way approximating a position parallel to the horizontal axis as the distances between points increase.

In this way it is possible to arrive at a certain appreciation of the need for land levelling in a certain area. However it will not be possible to get at a more concrete conception about the amount of soil transportation that is needed for the levelling desired.

Summary

In an area situated in the eastern part of the province of North Brabant a hydrological research has been carried out in connection with a study on the possibilities of subirrigation as a method of watersupply to farming crops.

Investigations were made of the possible influence of the soil surface unevennesses on the yield of farmingcrops. It was found that in the area, because of the unevenness of the soil surface, a lasting mean yielddepression of about 7-9% could not be overcome by way of subirrigation, without carrying out intensive land levelling.

The need of land levelling was studied by way of cumulative distribution curves for differences of depth of water table over distances varying from 50 to 300 m. A deviation of 32 cm. from the optimal depth of water table of 80 cm. causes a yield depression of 10%. The mean probability for an area with a radius of 150 m. or more on which a difference of 32 cm. will not be exceeded is slightly less than 50%.

The method discribed supplies merely an appreciation and gives no opportunity for more concrete planning with regard to realising a certain subirrigation project.

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