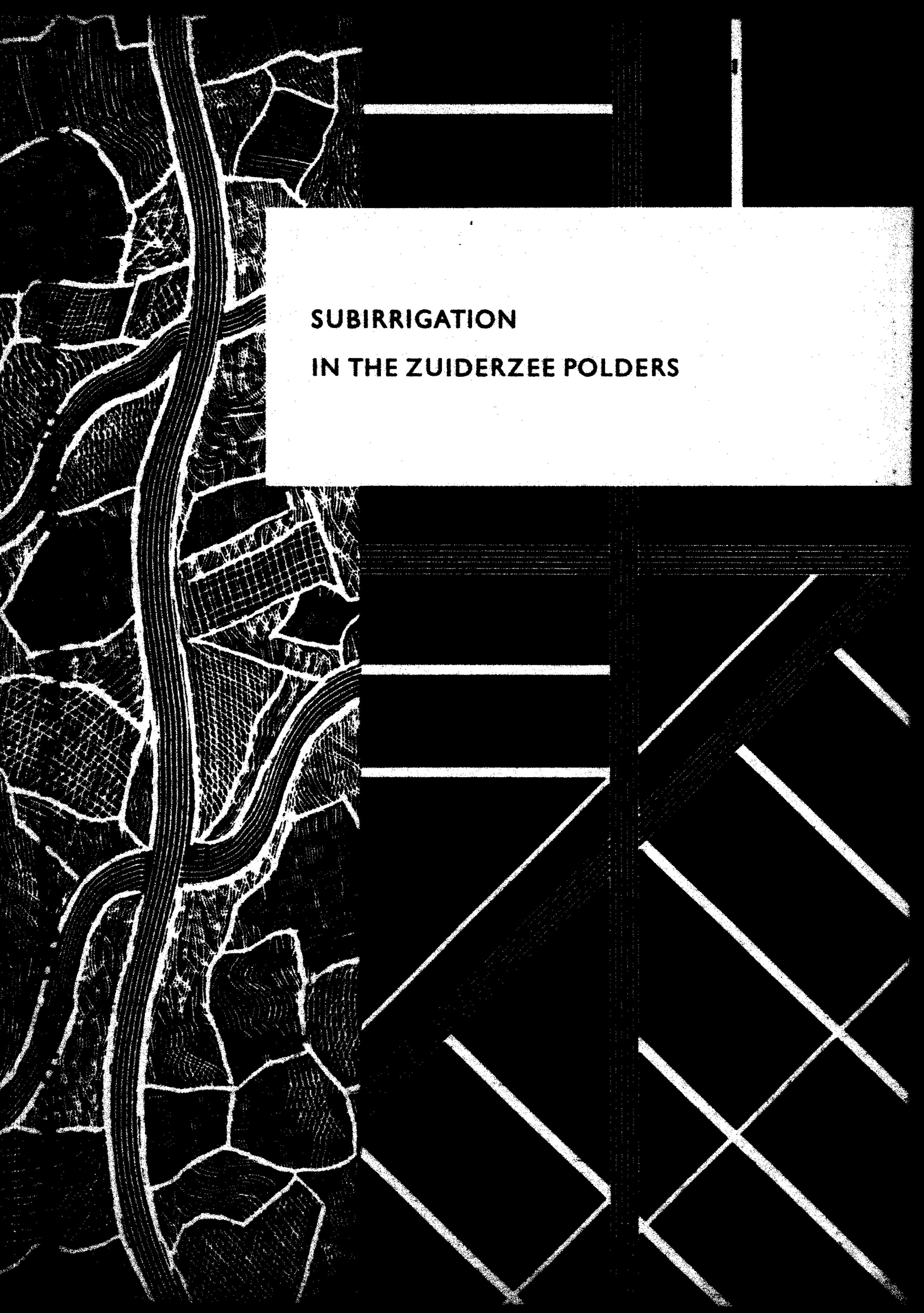

SUBIRRIGATION IN THE ZUIDERZEE POLDERS

INTERNATIONAL INSTITUTE for LAND RECLAMATION and IMPROVEMENT

Wageningen, July 1958

The International Institute for Land Reclamation and Improvement, which started its activities in 1956, was established with the object of forming a centre where knowledge concerning the subjects mentioned in its name can be exchanged on an international level.

Dissemination of knowledge and experience will a.o. be assumed by editing a series of publications. In these publications various subjects will be dealt with such as drainage, irrigation, desalinization, reclamation methods, crops on new soils, problems of soil science, layout and settlement of new areas, land consolidation, and other objects of importance to moderate, subtropical and tropical regions.

In the series not only papers of the Institute's specialists will appear, but also publications by other authors or institutions, which can be considered of such importance that compilation and/or translation is desirable.

Generally the publications will be printed in English, French, German or Spanish with a fairly extensive summary in one or more of the other languages mentioned.

It is a pleasure to me to offer you herewith the second publication in this series dealing with subirrigation in the Zuiderzeepolders. In preparation are publications on desalinization of saline soils, land consolidation in Europe (in cooperation with FAO), the role of water in rice cultivation, on settlement problems, and others.

Although the Institute is non-commercial the costs involved will prevent us from sending future publications free, unless a publication series, a periodical, single publications, reports or any other papers in the sphere of the Institute's activities can be offered in exchange. If exchanging of information is desired we shall be pleased to hear so.

In case you cannot obtain the publications by way of exchange you may order them from Messrs. H. Veenman and Sons, Printers and Publishers, P.O. Box 7, Wageningen, the Netherlands, which firm takes care of selling our publications.

I may request you to confirm on the enclosed card receipt of this publication, to state if necessary your latest address and – if possible – inform us whether you should like to receive future publications. This does not apply to those persons and institutions that already responded to our first publication.

If desired I shall be glad to supply you with any further information on the aims of the Institute.

INTERNATIONAL INSTITUTE FOR
LAND RECLAMATION AND IMPROVEMENT
J. M. van Staveren, *Director*

INSTITUT INTERNATIONAL pour L'AMELIORATION et LA MISE EN VALEUR DES TERRES

Wageningen, juillet 1958

L'Institut International pour l'Amélioration et la Mise en Valeur des Terres commença ses activités en 1956. Le but de l'Institut est de former un centre pour l'échange de données scientifiques relatives aux sujets indiqués par le nom de l'Institut.

Un des moyens dont on s'y prendra pour propager les connaissances et les expériences faites sur ces terrains sera l'édition d'une série de publications. L'intention est de publier dans cette série des articles traîtant des sujets différents, comme le drainage, l'irrigation, le dessalement, le défrichement, les cultures sur de nouvelles terres, les problèmes pédologiques, l'aménagement et la colonisation de nouvelles régions, le remembrement, etc., tous sujets importants pour les régions tempérées, sub-tropicales et tropicales.

Dans la série ne paraîtront non seulement des articles rédigés par les experts rattachés à l'Institut, mais encore des publications d'autres auteurs, qu'il est désirable de traduire et de modifier afin de les rendre accessibles pour un plus grand groupe d'intéressés.

En général les publications seront imprimées en Anglais, Français, Allemand ou Espagnol, tandis qu'elles contiendront un résumé assez détaillé en une ou plusieurs des autres langues nommées.

Par la présente j'ai l'honneur de vous offrir le second numéro de cette série de publications traitant l'irrigation souterraine dans les polders du Zuyderzée. En outre on prépare des publications traitant le dessalement de terres salées, le remembrement en Europe (en coopération avec la FAO), le rôle de l'eau dans la riziculture, les problèmes de colonisation, et autres.

Quoique l'Institut ne poursuive point un but commercial, il sera impossible, vu les frais élevés, d'envoyer encore dans le futur à titre gratuit les publications de l'Institut à moins que l'on possède des objets d'échange sous la forme d'une série de publications, de revues ou de publications détachées, de rapports ou d'autres qui soient intéressants pour notre Institut.

Si vous tenez à recevoir nos publications et que vous disposiez d'un tel objet d'échange, nous vous prions de nous en mettre au courant. Si toutefois il vous est impossible de faire échange vous pourrez commander nos publications chez Messieurs H. Veenman et fils; imprimeurs et éditeurs, Boîte Postale 7 à Wageningen (Pays-Bas) qui prennent soin de la vente de nos publications.

Nous vous saurions gré de bien vouloir nous accuser réception de la publication no. 2 en renvoyant la carte ci-joint, de rectifier les inexactitudes éventuelles dans l'adresse et de nous communiquer si vous tenez à un envoi ultérieur. Ceci n'est pas appliquable pour tous ceux (institutions e.a.) avec qui l'on a déjà établi des relations d'échange.

C'est avec plaisir que nous vous fournirons, si désirable, de plus amples renseignements sur les buts de l'Institut.

INSTITUT INTERNATIONAL POUR
L'AMÉLIORATION ET LA MISE EN VALEUR DES TERRES
J. M. van Staveren, *ing. agr. Le directeur.*

INTERNATIONALES INSTITUT für
LANDGEWINNUNG und KULTURTECHNIK

Wageningen, Juli 1958

Das „Internationale Institut für Landgewinnung und Kulturtechnik", welches im Jahre 1956 seine Tätigkeit aufnahm, wurde zu dem Zwecke gegründet, ein Zentrum zu bilden für den Austausch von Kenntnissen auf dem im Namen genannten Gebiete.

Eines der Mittel, womit die Verbreitung von Kenntnis und Erfahrung angestrebt werden soll, ist die Herausgabe einer Reihe von Schriften. Es liegt in der Absicht darin Abhandlungen aufzunehmen über Themen verschiedener Art, wie z.B. Dränierung, Bewässerung, Entsalzung, Urbarmachung, Kulturen auf Neuland, bodenkundliche Probleme, Einrichtung und Besiedlung von neuen Gebieten, Neuparzellierung, usw., und zwar alles, was von Bedeutung ist für Länder mit gemässigtem, subtropischem oder tropischem Klima.

In der Schriftenreihe werden nicht nur Veröffentlichungen von den am Institut tätigen Spezialisten erscheinen, sondern auch von anderen Autoren oder Instanzen verfasste Veröffentlichungen, die als so wichtig angesehen werden, dass es erwünscht ist, sie durch Bearbeitung und/oder Übersetzung mehr allgemein zugänglich zu machen.

Im allgemeinen werden die Schriften in einer der Sprachen Englisch, Französisch, Deutsch oder Spanisch gedruckt werden, unter Hinzufügung einer ziemlich ausgedehnten Zusammenfassung in einer oder mehreren der erwähnten anderen Sprachen.

Es ist mir ein Vergnügen Ihnen einliegend das zweite Heft dieser Serie anbieten zu können; es handelt über die Untergrundbewässerung in den neugewonnen Zuiderzeepoldern in Holland.

In Vorbereitung sind ferner Veröffentlichungen über die Entsalzung von salzigen Böden, über Flurbereinigung in Europa (in Zusammenarbeit mit F.A.O.), über die Rolle des Wassers in der Reiskultur, über Siedlungsprobleme, usw.

Obgleich das Institut keine kommerziellen Ziele verfolgt, wird es wegen der damit verknüpften Kosten nicht möglich sein, die Schriften des Instituts auch in Zukunft unentgeltlich zuzusenden, es sei denn, dass man über ein Tauschobjekt verfügt in der Form einer Schriftenreihe, einer Zeitschrift, einigen losen Veröffentlichungen, Arbeitsberichten, Gutachten oder dergl., die für die Tätigkeit des Instituts von Bedeutung sein können.

Wenn Sie auf weitere Zusendung unserer Veröffentlichungen Wert legen und wenn Ihnen ein derartiges Tauschobjekt zur Verfügung steht, dann möchten wir das gern von Ihnen vernehmen. Sollten Sie jedoch nicht in der Gelegenheit sein unsere Veröffentlichungen auf der Grundlage des Austausches zu beziehen, dann wollen Sie gefl. davon Kenntnis nehmen, dass sie bestellt werden können bei der Firma H. Veenman & Zonen, Druckerei und Verlagsanstalt, Postfach 7 in Wageningen (Holland). Diese Firma befasst sich mit dem Verkauf unserer Veröffentlichungen.

Ich möchte Sie bitten, mir den Empfang des Heftes no. 2 zu bestätigen durch Ausfüllung und Zusendung der beigefügten Karte. Ferner belieben Sie eine möglicherweise unrichtige Adressierung zu berichtigen und mir möglichst auch Bescheid darüber zu geben ob Sie auf die weitere Zusendung unserer Druckschriften Wert legen. Dies gilt nicht für diejenigen Instituten, usw., mit welchen schon Kontakte gefesselt worden sind.

Wir erklären uns gern bereit, etwa gewünschte weitere Auskunft zu erteilen anlässlich der Zielsetzung des Instituts.

INTERNATIONALES INSTITUT FÜR
LANDGEWINNUNG UND KULTURTECHNIK
Ir. J. M. van Staveren, *Direktor.*

INSTITUTO INTERNACIONAL de RESCATE y MEJORAMIENTO TÉCNICO DE TIERRAS

Wageningen, Julio 1958

El Instituto Internacional de Rescate y Mejoramiento Técnico de Tierras, que inició sus trabajos en el año 1956, fué fundado con el objeto de constituir un centro para el intercambio de conocimientos y experiencias relacionados con el rescate de tierras laborables y su mejoramiento técnico, al servicio de todo el mundo.

Uno de los medios que se aprovechará para la divulgación de conocimientos y experiencias en este terreno, consiste en la edición de una serie de publicaciones. El Instituto se propone incluir en esta serie informes sobre asuntos diversificados tales como el drenaje, la irrigación, la desalación, los procedimientos y métodos de cultivo, los cultivos en tierras nuevas, los problemas edafológicos, la disposición y la colonización de tierras nuevas, la reparcelación y otros que se consideren de importancia para las zonas templadas, subtropicales y tropicales.

En esta serie no sólo aparecerán monografías de los especialistas colaboradores del Instituto, sino que se incluirán tales publicaciones editadas por otros autores u otras instancias que se consideren de importancia suficiente para justificar su divulgación en el plano internacional por medio de adaptaciones y traducciones.

Por regla general estas publicaciones se editarán en una de las lenguas siguientes: español, inglés, francés o alemán, con un resumen detallado en una o más de las otras lenguas mencionadas.

Me es muy grato presentarle, incluida en la presente, la segunda publicación en esta serie, que trata del riego subterráneo de los pólderes más recientes en el Zuiderzee, en Holanda.

Además se hallan en vías de preparación informes sobre la desalinización de suelos salinos, sobre la concentración parcelaria en Europa (en cooperación con FAO), sobre la función del agua en el cultivo arrocero, y sobre los problemas de colonización.

Aunque el Instituto no persigue objeto comercial, los gastos inherentes a la publicación de sus monografías no permitirán su distribución gratuita. En el futuro las publicaciónes se remitirán gratis tan sólo a quienes ofrezcan un objeto de canje consistente en un boletín, una revista, una serie de monografías u otras publicaciones que sean importantes para los trabajos del Instituto.

En el caso de que Vd. aprecia la recepción regular de los números futuros a base de canje, nos será muy grato aprenderlo. Al interesarse por nuestras publicaciones sin posibilidad de intercambio, podrá Vd. pedirlas de la casa editora, H. Veenman & Zonen, Drukkerij en Uitgeverij, Wageningen (Holanda), Apartado No. 7, que se encarga de la distribución y venta de nuestras publicaciones.

Le quedaré muy agradecido de una confirmación de la publicación No. 2, a cuyo fin podrá emplear la tarjeta anexa, y de la corrección de los errores eventuales en su dirección postal. Sírvase comunicarme a la vez si está interesado por la recepción de las demás publicaciones.

Esto no tiene aplicación para los institutos o personas que ya respondieron a la remesa de nuestra primera publicación.

INSTITUTO INTERNACIONAL DE RESCATE
Y MEJORAMIENTO TÉCNICO DE TIERRAS
J. M. van Staveren, *ing. agr. Director.*

SUBIRRIGATION IN THE ZUIDERZEE POLDERS

Issued by

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in collaboration with:

ZUIDERZEEPOLDERS DEVELOPMENT AND COLONIZATION AUTHORITY

publication 2

SUBIRRIGATION IN THE ZUIDERZEE POLDERS

IRRIGATION SOUTERRAINE DANS LES POLDERS DU ZUYDERZÉE

UNTERGRUNDBEWÄSSERUNG IN DEN ZUIDERSEEPOLDERN

SUBIRRIGACION EN LOS POLDERES DEL ZUIDERZEE

BY

Ir. C. KALISVAART

Senior Scientific Officer of the Zuiderzeepolders Development and Colonization Authority

H. VEENMAN & ZONEN / WAGENINGEN / THE NETHERLANDS / 1958

International Institute for Land Reclamation and Improvement
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Internationales Institut für Landgewinnung und Kulturtechnik
Instituto Internacional de Rescate y Mejoramiento técnico de Tierras

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1. INTRODUCTION

The climate and topography in the Netherlands are such that drainage has traditionally formed the main element in the water control of agricultural land, particularly in the winter season when rainfall almost always exceeds evaporation (see Fig. 1). In the summer season this is only the case during unusually wet periods, but on the whole evaporation then greatly exceeds rainfall. This does not mean, however, that an artificial supply of water is always required during the growing season, because besides the rainfall also moisture stored in the soil at the commencement of this season is available to the crops. As a rule, only agricultural land with a low moisture storing capacity needs an artificial supply of water. This is a matter which is receiving an increasing amount of attention in the Netherlands.

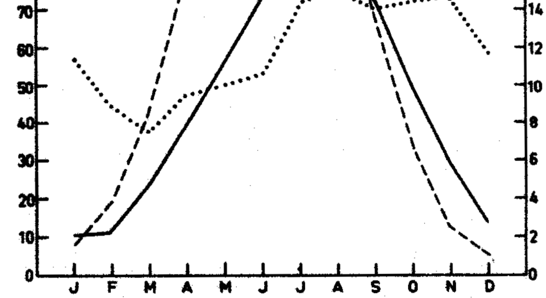


Fig. 1. Mean monthly rainfall, evaporation (from open water surface) and temperature in the Netherlands according to observations made by the Royal Netherlands Meteorological Institute, De Bilt.

In the new Zuiderzee polders which are situated down to 5 m (16 ft) below sea-level, drainage is a prime necessity, but it is also necessary to deliver water to drought-sensitive soils, *viz.* in the form of subirrigation. The drainage is efected by means of pumping stations, which discharge the water on the surrounding Yssel Lake, the pumping lift being maximal 7 m (22 ft). As the enclosure dam keeps out the North Sea water, the Yssel Lake has become a fresh-water lake and its water can be used

very well for irrigation purposes; it does not contain more than 180 milligrams Cl per liter in summertime. Information on this irrigation method will be given in the present paper, the Northeast Polder being taken as our example. This is the second of the five polders being made in the former Zuiderzee (see map). It covers an area of 48,000 ha (120,000 acres), 8,000 ha (20,000 acres) of which are irrigated. The irrigated areas are shown in outline on the map.
Irrigation conditions are favourable inasmuch as it is merely a question of letting in the necessary water from the Yssel Lake surrounding the polder. Moreover the areas are favourably situated with regard to this external water, and their topography lends itself well to gravity irrigation.

Subirrigation might be termed drainage in reverse. In drainage the excess water flows from the soil towards the drains. This drainage lowers the water table so that the development of the root system and the growth of crops is not limited.
What happens in subirrigation is exactly the opposite. By supplying water and maintaining a given ditch water level, the water is made to enter the drains and thence to infiltrate into the soil. In this case, therefore, the water table is kept at a sufficient height

Ramspol subirrigation area with main supply ditch (area 9).

for the crops to derive their moisture supply from it, while drainage requirements are kept in mind at the same time.
Just as the type of drainage system will be adapted according to 'natural' conditions, so also will the system of subirrigation. A dune does not require artificial drainage, as the surplus water freely percolates through the subsoil to the land adjoining. A depression in the dunes has often a favourable water supply because precipitation falling on the high dunes sinks towards the depression and there is, so to speak, a kind of natural subirrigation.

Examples of such deviations from the general situation may also be found in the Northeast Polder. Thus, in a number of fields bordering the Lemstercanal (area 4 on the map), of which the subsoil consists of deep and very permeable low terrace sand, the bordering strips of 300 metres (1000 ft) in width at both sides of the canal have not been provided with trenches or tile drains because they drain off sufficiently through the subsoil of the Lemstercanal, the water level of which is more than two metres below the land. On the other hand, there is so much seepage in the plots on either side of the Gemaalroad (part of area 2) that in the growing season practically all that is needed to maintain the requisite water table is to dam up the discharge. In this case there is natural subirrigation through the deep, sandy subsoil from the side of the Yssel Lake. The lake level is about 4 metres (13 ft) above the land at this point.
Here it should be stated at once that where there is such a natural (underground) drainage, any subirrigation that may be required is beset with difficulties. Owing to this subterranean flow the water table cannot be controlled. Vice versa, land in which there is seepage requires more intensive drainage.

In the Northeast Polder, however, it is only exceptionally, or to a minor degree, that the level of the polder or the external water determines the need and intensity of the drainage or subirrigation system. Usually it are only local soil conditions, both of the topsoil and subsoil, wich determine the method of drainage or subirrigation to achieve an adequate water control.
In the case of drainage, which will not be further discussed in this paper the sole determining factor for the intensity of the system is the permeability of the various soil layers. Whether subirrigation is possible and how it has to be executed also depends chiefly on this permeability although the sensitiveness of the soil to drought is a further factor determining the desirability or need of subirrigation.

2. CHOICE OF THE IRRIGATION SYSTEM

2.1. SOIL TYPES AND SUBIRRIGATION

As the map shows, the greater part of the Northeast Polder consists of loamy soils. These soils do not require subirrigation since even when the water table is at a low level they store a great deal of the surplus winter precipitation. On such soils this stored water, together with the precipitation during the growing season, is generally sufficient to ensure the development of the crops. This water is available to the plant down to the root-zone depth, and owing to the low water table maintained in these soils the roots can extend to a considerable depth. These loamy soils are also difficult to subirrigate, being too impervious for this purpose. The water does not infiltrate into the ground rapidly enough. On the other hand, the coarse sandy soils low in silt and humus (areas 5, 6, 8, 9 and 11 totally or part of them) retain only a small amount of water. What retained water occurs in spring in the zone penetrated by roots is rapidly exhausted, while the rainfall during the growing season is insufficient or too intermittent to constitute a regular means of overcoming moisture deficiencies. The result is wilting of the crop, or at any rate reduced production.

In addition to these two extreme soil types there are also soils in the Northeast Polder of which the profile partly consists of loamy soil and partly of sand. Soils having a thin layer of loam overlying coarse sand (parts of areas 3 and 5) are also subirrigated, although this is clearly not so necessary as in the case of the purely sandy soils. Where sand overlies loam the impermeability of the loamy subsoil is a hindrance to subirrigation, as will be mentioned later.

The fine sandy soils (in areas 1, 2 and 7) have less need of subirrigation than the coarse ones; they are, however, subirrigated, and this is also beneficial in dry and even in normal years.

A special condition is presented by soils which have peat in their profile, as in areas 1, 2, 3, 10 and 11. In the case of these soils it is primarily the fear of irreversible drying up of the peat (turning into peat-turf) which has led to the adoption of the subirrigation.[1]) Where this peat overlies permeable sand at a comparatively slight depth (not more than

[1]) When peat soils have been dried out irreversibly, they can no longer be wetted and they become less productive. By maintaining the water table at a sufficient height (about two feet below the soil surface) irriversible drying out may be prevented.

about 1 metre), as is generally the case in the Northeast Polder, subirrigation is not a particularly difficult matter; but when there are dense layers of peat its comparative lack of permeability may be a drawback.

2.2. SUBIRRIGATION VERSUS SPRINKLING AND SURFACE IRRIGATION

Under the conditions prevailing in the Northeast Polder subirrigation is the most suitable form of water supply. We will discuss briefly the chief arguments in favour of subirrigation and against sprinkling irrigation and surface irrigation.

Thanks to the situation of drought-sensitive soils in large units in the polder along the border, with the surface of the ground always below the level of the Yssel Lake, it is comparatively simple and inexpensive to convey irrigation water from the Lake or the tracts of water communicating with it. In addition the fields are generally level, with in most cases only a very slight slope from the margin of the polder, but just sufficient to make it fairly easy to distribute the water over the area under irrigation. Practically no deep excavations or conduits above the surface are needed for the subirrigation system and only in exceptional cases leveling or smoothing operations are required. There is generally a uniform type of soil over large areas, which makes easier also the installment of the work. Moreover the water-carrying ditches are a good source of drinking water supplies for cattle and serve as cattle fences (see Photograph 1 and 2). The most important advantage, however, in favour of subirrigation is the fact that the system needed for the distribution of water in the soil is present already for drainage purposes. In using the drainage system also for subirrigation only small modifications are needed and therefore additional costs will be low.

As a result of these various factors the average cost of interest (4 %), depreciation, upkeep and attendance chargeable to the subirrigation system is barely f 20 per hectare per annum ($ 5,5). Put in another way, the total outlay capitalised on the date of installation is about f 500 ($ 130) per hectare. To this figure should be added the additional upkeep to be executed by the farmer required by ditches and tile drains when used for subirrigation, and which may be roughly put at f 5 ($ 1,3) per hectare (upkeep is always required in behalf of the drainage function, also when there is no subirrigation). Subirrigation only affects the farm management in so far there is an increase in the potentialities and intensity of cultivation. It takes little time to operate and most of the maintenance work can be carried out during slack periods.

Let us now consider sprinkler irrigation. Bearing in mind the drinking water needed by the cattle, and also the cost, the best method of supplying this water would probably be via the ditches, as in the case of subirrigation. The level in these ditches would have to be kept lower and rather fewer and simpler structures would be required than for subirrigation. Nevertheless, the cost of supplying this water would not be appreciably less than with the use of subirrigation. In view of the drainage required in wet periods it will be just as necessary to provide underground tiles as in the case of subirrigation.

Photograph 1.: Drinking water supply for young cattle at pasture before the land had been subirrigated. At this period drinking water was still supplied from tank trucks.

Photograph 2.: Drinking place in a subirrigation-ditch.

Provided it is fresh, the water required for sprinkling could also be pumped out of the polder canals or the subsoil *in situ*. Water drawn from canals has a low salt content which generally makes it not unsuitable for the purpose, but subsoil water will usually be too brackish. Apart from this, however, the cost of such methods of supplying water is substantial. To obtain the water from the subsoil a well has to be made and when either well or canal water is used long pipe lines are required to deliver water from the pumping site to all parts of the fields. When water is supplied in ditches, a pump which can be moved along the ditch can be used for sprinkler irrigation. It is, of course, possible to pump the water first into the ditches from a well or canal, but in this case pumping in two stages is required.

When water is supplied in the ditches, as in the case of subirrigation, it generally has to be a community project, whereas the use of a well or canal-water is a matter for the individual, each person providing his own water supply.

But whatever method is used to obtain the water used for sprinkler irrigation, it is certain that it will not cost much less to acquire than by the subirrigation method. Once a subirrigation system has been installed there is practically no further outlay, whereas with sprinkling there is also the cost of interest, depreciation and upkeep of the equipment (pump, engine, pipe lines, spray apparatus) as well as the cost of operating. The latter is not only more expensive than in the case of subirrigation, but as it is usually required during the peak season it has a far more serious effect on farm management.

In the Northeast Polder there are, however, a number of factors which make the provision of sprinkling for irrigation a somewhat more economic proposition than in the southeast of Holland where sprinkler irrigation is already applied to a considerable extent owing to the unsuitability of other irrigation systems in this region. In particular, the size of the holdings (area sprayed per farm) and the situation and shape of the fields in the Northeast Polder are better adapted to the practice of sprinkler irrigation than in the south of the country. Thus whereas the cost of sprinkler irrigation in the south is estimated at about f 200 ($ 55) per hectare per annum, there is no reason why this figure should be strictly adhered to in the case of the Northeast Polder. It is, however, certain that at current prices sprinkler irrigation in the Northeast Polder would cost well over f 100 ($ 25) per hectare more than subirrigation.

This does not mean to say that in cases where subirrigation is unfeasible, or is unsatisfactory for any reason, sprinkler irrigation would be out of place in the Northeast Polder, but before deciding to purchase a sprinkler irrigation installation it will be necessary to draw up a good plan and make a detailed estimate of the cost.

With regard to surface irrigation it should first be pointed out that owing to the climate irrigation is a supplementary expedient in the Netherlands, even in the case of soils highly sensitive to drought. For this reason surface irrigation is usually less suitable. Compared to subirrigation as applicable in the Northeast Polder, a surface irrigation project may also involve much more labour and expense. The supply of water over the

surface and the great amount of excavation work required to give the necessary gradients to the fields, as well as the attention required every year, may make this form of irrigation more expensive and a greater burden to the farmer than subirrigation.
We would not, however, deny that in certain exceptional cases the method of delivering water over the surface, especially in the form of basin irrigation, might not also be preferable in the Northeast Polder.
But as a rule subirrigation will be the most suitable method, and in the following we shall confine ourselves to this method of providing water.
We should also mention at this point that one drawback of subirrigation in fairly arid regions, namely the great danger of salinization of the soil, does not occur under climatic and drainage conditions in the Netherlands. Any tendency to salinization resulting from the upward movement of the water during the growing season is entirely overcome by the downward movement of the water during the winter season.

3. PRINCIPLES OF SUBIRRIGATION

3.1. WHAT HAPPENS IN SUBIRRIGATION?

We will take as our example the area near Vollenhove (area 8). The inlet sluice (near the Repelweg) admits enough water for the water level in the ditches to be kept at about 35 cm (14 inches) below the surface by means of dams[1]). Via tile lines which discharge into the ditches and are here 70 cm (2.3 ft) below the surface, this ditch water level influences the water table in the soil.

The following cases may then arise (see Fig. 2):

a. If no moisture is absorbed and transpired by the plant or removed by evaporation of the soil or ground water discharge, and nothing is added by rain or seepage, the ground-water will also reach a level of 35 cm below the surface in the soil above the tile lines and in the fields between these lines. This will also be the case when equilibrium is reached owing to evapotranspiration being equal to the rain and/or seepage, or the rain being equal to the evapotranspiration and/or ground-water discharge.

b. If more water is supplied by rain or seepage than evaporates, the watertable in the fields will be higher than it is above the tile lines, and above these lines it will be

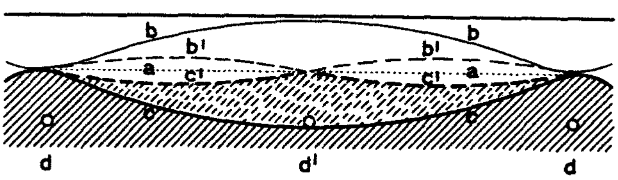


Fig. 2. Cross-section of a subirrigated field showing the height of the water tables when the distance apart of the tile lines is d-d (a, b, c) and when it is half this distance d-d^1-d (a, b^1, c^1).

a: height of water table when there is no rain or seepage and no evapotranspiration or groundwater discharge or there is equilibrium between these supplying and draining elements.

b: and b^1: height of water table when the rainfall and/or seepage exceeds the evapotranspiration (drainage).

c: and c^1: height of water table when evapotranspiration and/or ground water discharge exceeds the rainfall (infiltration).

[1]) In the next sections small dimensions, such as depth of water table, will be expressed in centimeters (cm), 1 cm = 0,4 inch.

somewhat higher than in the ditch. In such a case the tiles will function as drain and water will flow towards the ditch.

c. If the amount of water lost by evapotranspiration and/or ground-water discharge exceeds the rainfall, the water table in the middle of the field will be lower than above the tiles and above the tiles it will again be slightly lower than in the ditch. In this case water will enter the land by infiltration from the ditch.

In the last case, i.e. infiltration, the difference in the height of the water table above the tiles and in the middle of the fields depends on:

the degree of evapotranspiration (in this case rain and ground-water discharge are ignored):

the permeability of the soil,

the distance apart of the tile lines.

A high rate of evapotranspiration means that more water is used; poorer permeability implies that the water is unable to flow so freely towards the fields and a greater distance apart of the tile lines has the effect of increasing the distance the water has to flow. The result is a lower level of the water table in the middle of the field. Evapotranspiration and soil permeability cannot be controlled, so that the difference in the height of the water table can only be regulated by varying the interval between the tile lines. Fig. 2 shows how halving this interval affects the water table (b becomes b′, c becomes c′).
In deciding the distance apart of the tile lines the aim is to prevent the difference between the height of the water table above the tiles and that in the middle of the field from exceeding 10 cm under normal evaporation conditions of a grass crop in dry periods (4 to 5 mm per 24 hours, or 0.5 litres per second per hectare during June and July). Hence the tile lines will be nearer to each other on poorly permeable fine sand than on highly porous coarse sand, *e.g.* 8 metres (27 ft) apart on the Blokzijl sand (areas 1,2 and 7) and up to 30 metres (100 ft) apart on the Urk sand (areas 8 and 11). Actually the tile lines on the finest Blokzijl sand had to be spaced even more closely in order to fulfil requirements. In Table I the distances apart of the tile lines for different sandy soils and other characteristics are presented.

The difference between the water table in the ditch and that above the tile line increases very gradually from the intake to the end of the line. In this case also the extent of the difference depends on the water consumption as well as the diameter and length of the lines. If there is a considerable distance between lines, water sufficient for a large area, *i.e.* a great deal of water, has to be delivered through one line. In such a case the tile diameter will be greater in the first section of the line, according to requirements[1]). The object is to prevent the difference between the height of the water table in the ditch and that above the end of the line from ever exceeding 10 cm, and preferably to make it less. If the two said requirements are met, this means that over the entire parcel of land which is subirrigated the average ground-water level will not fall more than 10 cm below the ditch water level.

[1]) If, *e.g.*, the distance apart of the tile lines is 30 m and the length of the lines 200 m, then the inside diameter of the tiles has to be 8 cm over a length of 75 m and 5 cm for the remaining 125 m.

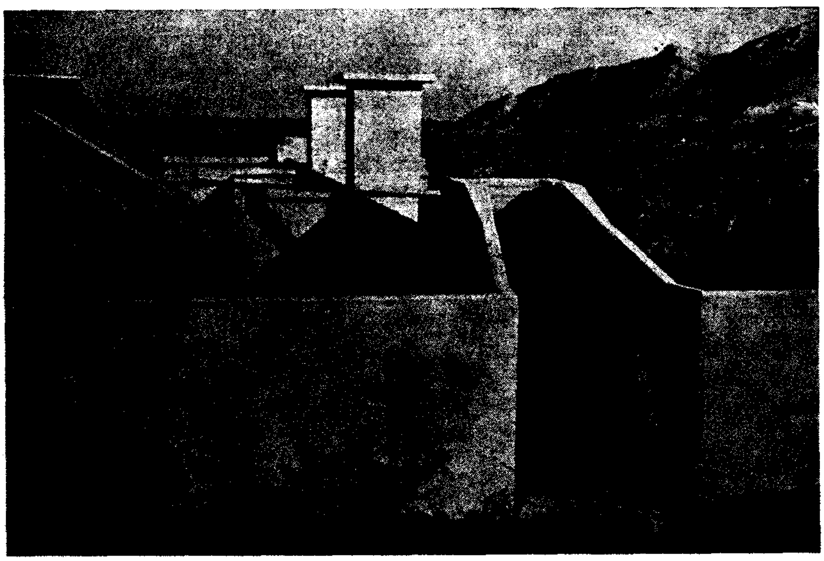
TABLE I. Typical characteristics (average data) of three sandy soils in the Northeast Polder

	Blokzijl sand	Ramspol sand	Urk sand
Clay content (%)	6	6	2
Humus (%)	0,8	0,6	0,3
Calcium carbonate ($CaCO_3$; %)	7	7	0,2
Texture of the sand fraction, expressed in U-figure[1])	275	75	55
Capillary rise (cm)	120	50	40
Hydraulic conductivity (Permeability) (m per 24 hours)	0,3	3	4
Desirable depth of ground-water table below surface in dry periods (cm)	60	40	35
Maximal distance of the tile lines (m) [2])	8	25	30

[1]) The specific surface, expressed by the U-figure represents the proportion between the total surface of all the sand grains contained in one cubic centimeter of the soil *in situ* and the surface of a ball with a diameter of one centimeter. The finer the sand the higher the U-figure is.
[2]) For practical reasons (costs) the distance of 8 m in the Blokzijl sand area is also a minimum.

3.2. THE CAPILLARY RISE ABOVE THE GROUND-WATER TABLE

What we now have to consider is how crops benefit by this ground-water. It is known that there is little or no penetration of the roots into the ground-water, nor is it true to say that the roots extend to the surface of the ground-water and absorb water at this point. The great mass of the roots (and this is particularly true of grassland) are in the shallow soil layers, and for a good production these roots should be able to absorb



Photograph 3. Subirrigation inlet flume in the polder bank near Ramspol; concrete structure ready to be embanked with earth.

sufficient moisture. The ground-water is able to assist in this as a result of the upward capillary flow of the water.

If a glass tube filled with sand (its bottom sealed off by wire gauze) is placed upright in a basin of water, there will be an upward movement of capillary moisture in the pores between the sand. The height reached and the rate of flow depend on the coarseness of the sand and the corresponding size of the pores. The same thing happens in the fields which when subirrigated are so to speak placed in the ground-water. Here, however, we should mention that the actual upward capillary movement in the fields cannot be determined in a simple way by introducing the soil into tubes which are placed in water, as in this case there will be differences from what actually happens in the field. The best idea of the height to which the moisture rises is obtained by measuring the moisture content of samples taken from different depths of a soil profile in which the water table should be some distance lower than the height of capillary rise. In this case it is the capillary moisture plus the suspended[1]) water that is measured. The contents found are plotted on a graph and a line drawn through it as was done in Fig. 3 for three types of soil. The heights above the ground-water table, at which the moisture contents found (shown by the broken lines) assume a constant value, correspond to the heights of capillary rise. The shape of the curves which in the figure denote the capillary moisture contents (the full lines) could not be entirely based on moisture measurements because a state in which the moisture above the water table is only due to upward capillary flow hardly ever occurs under climatic conditions in the Netherlands. Hence although the shape of these curves may be subject to some correction, it is a fairly good representation of the actual conditions.

According to Fig 3, in the coarse Urk sand the capillary moisture rises to 40 cm above the water table, in the somewhat finer Ramspol sand to 50 cm, and in the very fine Blokzijl sand 120 cm (in reality further varieties will exist within these types of soil). In Table I some specific figures are given about the different types of sand in the Northeast Polder.

The moisture rises rapidly in the coarse sand and slowly in the fine sand. It will be immediately clear that the most desirable water table in a specific type of soil is first of all determined by the height and rate of the upward capillary movement.

Figure 3 also indicates that just above the ground-water practically all pores in the soil (of which the percentage also differs greatly in the three types of soil) are entirely filled with water,

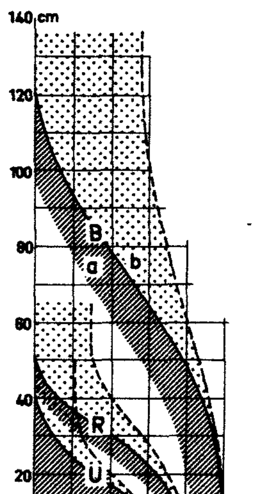
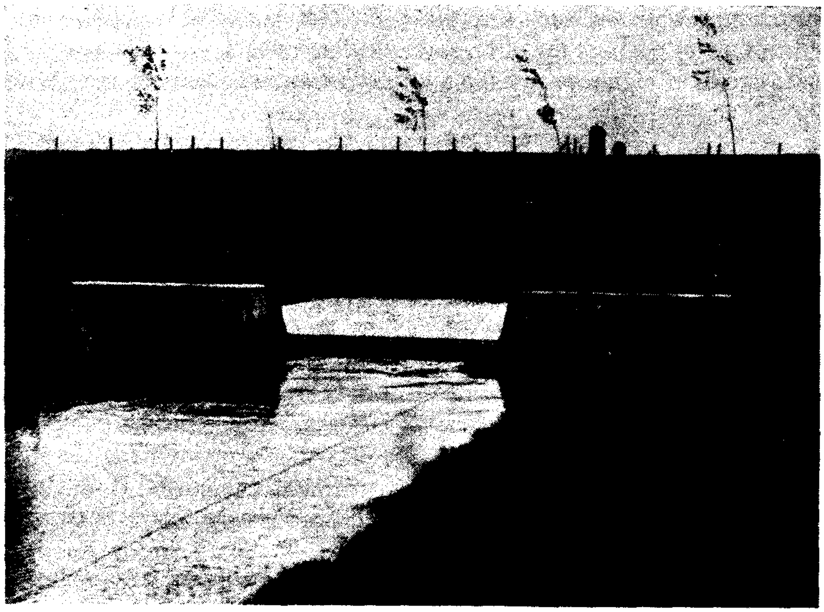


Fig. 3. Moisture content (in volume percentages of the soil above the ground-water table) in three different types of sandy soil in the Northeast Polder (schematically).
B = Blokzijl sand. R = Ramspol sand. U = Urk sand.
a = capillary rising water. b = suspended water.

[1]) See note page 19.

Photograph 4. The flume at Ramspol in operation. On the dyke are two adjustable valves; in the foreground is a Cipoletti weir for measuring the amount of water admitted. Its maximum capacity is 1,000 litres/second.



but that the amount decreases the greater the distance above the groundwater. This is important since both air and water are now present in the soil in this "capillary layer" which can therefore be penetrated by roots.

In the case of the Ramspol sand, the situation is again shown separately in Fig. 4. Here the following values are given in percentages by volume for the various layers below and above the water table: the solid particles content (including unavailable moisture), the content of readily available moisture, and the air content. It can be seen from this figure that 40 % of pores occur in this soil. Below the water table all pores are filled with moisture. At 10 cm above the water table about 38 % is occupied by rising capillary moisture, at 20 cm about 32 %, at 30 cm about 23 %, at 40 cm about 8 %, and at 50 cm 0 %. In this case the water does not rise to more than about 50 cm above the water table.

The figure also shows that suspended water may occur in addition to moisture resulting from the capillary ascent; this suspended water is that which is retained in the soil (above and next to the capillary rising moisture) after rain or a fall in the water table.[1]) In this particular case no more than 15 of the 40 % of pores may retain suspended water. The state of affairs shown in the figure may be imagined as having arisen after excess precipitation when the water table was 70 cm below the surface, or after a very high water table had fallen to 70 cm below the surface.

An ideal supply of water and air in the soil would be achieved by an irrigation system where the soil periodically fastly and fully could be wetted by means of a high water level, followed by a free drainage of the water.

[1]) The term *suspended* water indicates the water held by the soil against gravitational forces; it may be present because of rainfall and/or floods. It is particularly important as a source of moisture for the plant in the soil layers above the zone of capillary rise. In these layers it is thus essentially the same as the moisture content known as field capacity which is, according to definition: the moisture content of the soil after gravitational water has drained away and capillary water movement has become very slow. In the lower layers of the soil (the zone of capillary rise) the moisture present comprises both suspended water and capillary rising water.

In practice, however, such a system is difficult to realise because of the slowness of the flow of water through the ditches, the tile lines and through the soil. This system should need canals of high capacity and a very short distance between the tile lines.

3.3. THE WATER TABLE AND WEATHER CONDITIONS

We will first ignore the suspended water by assuming that during a continuous dry period all suspended water has already been used up. In order to supply the plant with moisture it is then necessary for the rising capillary moisture to extend to the root zone and preferably even to the surface. In the case shown in the figure the water table should accordingly be 50 cm below the surface (in the figure the surface will then be situated at S 1). This applies to grassland in particular where most roots are found in the upper part of the soil. In continuous dry periods it will even be desirable to have the water table somewhat higher, since, as the figure shows, there is only a low moisture content at the top of the capillary zone (from 0 to 8 % in the top 10 cm). By maintaining the water table at, say, 40 cm instead of 50 cm below the surface (surface situated at S 2) we obtain a considerable improvement in the supply of capillary moisture in the top layer (from 8 to 23 % in the 0–10 cm layer).

But Figure 4 also shows that the water table should not be raised too far, as in this case too little air remains in the soil, and it is also necessary to remember that even in intensively drying periods a continuously high water table, *e.g.* one of 30 cm below the surface (surface situated at S 3) a shortage of air harms the roots and consequently the plant.

In the Netherlands, however, it is seldom necessary to cope with very prolonged drying periods. Rainfall often intervenes, and moreover the situation changes as a result of reduced evaporation caused by cloud, lower temperatures, increased humidity of the air and changes in the plant.

Figure 4 also shows what happens in the soil concerned when there is substantial rainfall and the water table is kept at the same level. Above the capillary zone there is a maximum quantity of suspended water (15 % by volume). In the top 10 cm of the capillary zone the moisture content becomes 15 to 20 % instead of 0 to 8 %, and in the next 10 cm it becomes 20 to 30 % instead of 8 to 23 %. As a result less air remains.

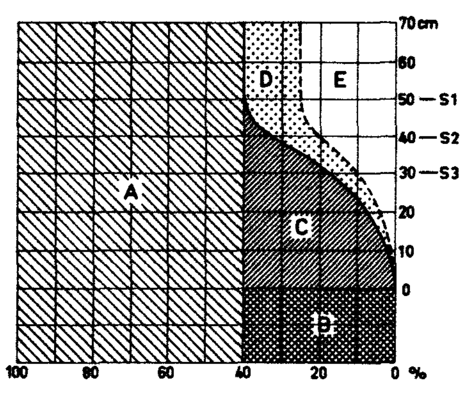


Fig. 4. Schematic representation of the contents in percentages by volume of: (A) solid particles (including unavailable moisture), (B) groundwater, (C) capillary rising water, *i.e.* soil moisture content after a dry period, (D) suspended water, *i.e.* the water wich is added by rainfall or floods and (E) air in Ramspol sand when the groundwater level is 70 cm below soil surface.

But when there is more rain than is held by field capacity, the water table will also (temporarily) rise, sometimes even as far as the surface, thereby forming pools. In this case the water/air ratio is still more unfavourable.

3.4. THE DITCH WATER LEVEL

In the case of Figure 4, what should now be done with the ditch water level under varying weather conditions in order to ensure optimum ground-water level and moisture conditions?

When there is a continuous period of dry weather and the only water available to the plant is that provided by rising capillary moisture, it was assumed above that the supply of water and air is good at a ground-water level of 40 cm (surface situated at S 2). As we saw above, when evaporation is of the order of 4 to 5 mm per 24 hours, in order to maintain such a water table a ditch water level is required which is about 10 cm higher, viz. 30 cm below the surface. But should evaporation be reduced as a result of cloud, lower temperature, etc., (*i.e.* without any actual rainfall) and possibly even decrease to practically zero, the ditch and ground-water level will be the same; in this case it will be necessary to lower the ditch water level from 30 to 40 cm, as otherwise the ground-water level would also rise to 30 cm.

When so much rain falls that it infiltrates into the soil, the roots are provided with suspended water as well as rising capillary water. When the rainfall is slight, *e.g.* just sufficient to provide for evaporation, the result will be approximately the same as though there were no evaporation. But should the rain fill up the entire field capacity, as illustrated in the figure, assuming the ground-water level to be at 50 cm (surface situated at S 1) the supply of water and air will be approximately equal to that supplied by capillary moisture alone when the ground-water level is 40 cm. We assumed that this supply of water and air was a good one, so that when there is such a high supply of suspended water the ditch water level should be reduced to 50 cm. If more rain falls than is required to fill this suspended water capacity, the ditch water should be even lower than 50 cm to ensure rapid evacuation of surplus water.

If after the rain a drying period sets in, the ditch water level will again have to be raised. It is possible to make a rough calculation from the stored water and assumed evaporation data how rapidly this should be done in the case illustrated in Figure 4.

The relationship between ground-water level, ditch water level, weather conditions and moisture supply of the plant can also be determined in a corresponding manner for other sandy soils having greater or lesser heights of capillary moisture. We shall not do this here, but rather examine to what extent the above principles can actually be applied in subirrigation practice.

3.5. THE REGULATION OF THE IMPOUNDED WATER LEVEL IN PRACTICE

The principle outlined above is, in fact, followed in practice, but practical potentialities and difficulties limit its application. We will briefly mention the chief of these.

In the first place, we do not know what exactly is the optimum ground-water level in a given soil during periods of continuous dry weather. Since the climate in the Netherlands fluctuates so often between rain and drought, high and low temperatures, high and low humidity of the air, slight and strong winds, sunshine and cloud, it is practically impossible to determine this optimum ground-water level accurately by means of experiments. The same is actually true of the maximum ground-water levels that can be tolerated in temporary or prolonged periods of rain without doing harm.

Secondly, we should point out that although optima no doubt exist in theory, the reductions in yield caused by a slightly higher or lower water table will be of no practical significance, or at any rate difficult to demonstrate. This is a phenomenon which is of fairly general occurrence in agriculture. We might instance the amount of nitrogenous fertilizer applied to crops, when there is practically always some margin between a dressing which is obviously too small and one which is obviously too large.

Thirdly, a fact probably deserving consideration is that the excessively high water tables temporarily occurring during the subirrigation periods are caused by rain. This rain is rich in oxygen, so that an excess thereof can be tolerated by the roots of the plant for some while. The water in itself does no harm, injury only being caused by the lack of air, or rather oxygen.

Fourthly, and this is very important in practice, the slow rate of flow of water supplied and drawn off through the lines (from inlet weirs to tile lines) and of the movement of water in the soil, makes it impossible to adjust the ground-water level strictly in accordance with theoretical requirements. To do this would require such a line capacity and dense spacing of tile lines as would be economically impossible to provide, and in addition a great deal of water and labour would be needed. The result of this slow movement is that the ideal for the actual situation (*e.g.* a storm rainfall which floods the land and would need very low water levels in the ditches to ensure rapid drainage) is not attained until the new situation (drought) which has begun makes it necessary to reverse the procedure once more if one is not to be too late again.

For these reasons the practice adopted in the Northeast Polder is to make as little deliberate change as possible in the level in the ditches during the subirrigation season.

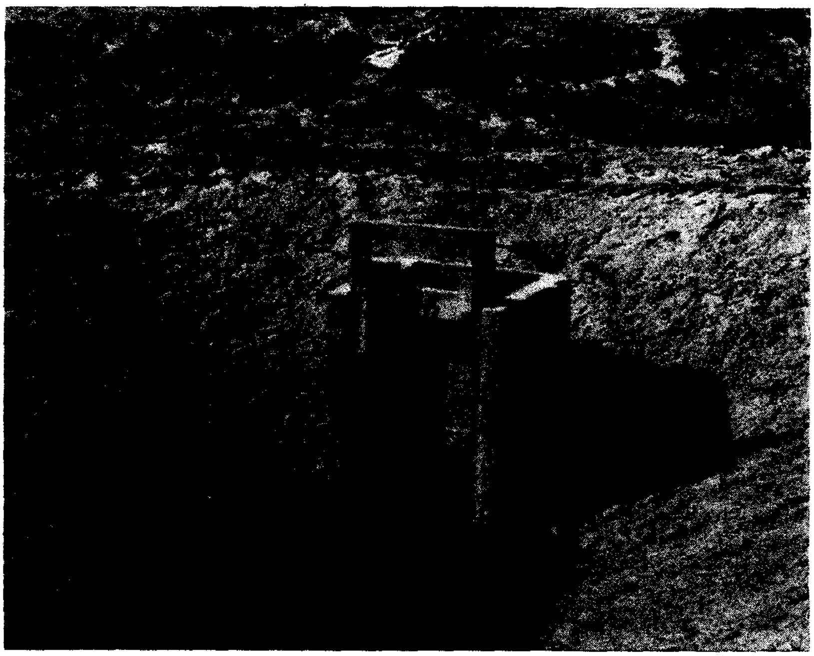
The simplest method would be to set permanent weirs in canals and ditches throughout the year in locations susceptible to drought so as to maintain a moderately high water level; to this end water would have to be let in during summer droughts. It may be imagined that this in itself would have a good effect on the susceptibility to drought.

From this it is a comparatively small step to the maintenance of separate winter and summer levels, and it is one which is particularly easy to take in a deeply drained polder. In the Northeast Polder ditches that run dry could be taken as the winter level. The permanent summer level could be obtained by arranging permanent weirs with a wide overflow and a closable opening to enable the ditches to drain off in winter (the overflow should be wide in order to ensure a minimum rise during wet periods with discharge). The permanent irrigation head should be adjusted as well as possible to the average requirements of the soil type(s) and cultivated crops in question. During the summer water should, of course, be supplied whenever needed. In the spring and autumn and during wet periods in summer such a permanent summer level might occasionally be too high, or sometimes too low in periods of severe drought, but despite this it may well be imagined that even such a simple method as this will result in an improvement on drought-sensitive soils which is even greater than that obtained by means of the first-mentioned solution, and it would also be easy to put into practice.

From this it is but a short step to the method used in the Northeast Polder where different winter and summer levels are maintained together with a transition level in the spring and autumn, the summer level being modified during extreme weather conditions.

In winter the water level in the ditches is maintained by pumping at about 100 cm (40 inches) below the surface. The increase to the spring level is generally begun when the cattle are put to pasture; this has the additional advantage of providing drinking water at this period (see Photograph 2). Later on an adjustment is made of the actual water level determined for the various soils, depending on the trend of the weather and the drought-sensitivity of the soil type concerned. This level is then maintained until the autumn, except during the extreme weather conditions mentioned above.

On coarse sandy soils such as the Urk sand (areas 8 and 11) and the Kuinre sand (area 7) in which the water table is directly controlled via the tile lines by the impounded water



Photograph 5.
A field weir which has just been constructed in a field ditch; the banks and bottom of the ditch are lined with boulder clay over a distance of several yards.

level in the lateral ditches, and which moreover are almost entirely put down to grass, the 'summer level' is not usually begun until the first half of May. On soils less sensitive to drought the time is usually somewhat later.

On land which is subirrigated by the 'combined method' (see below) the water table is not directly determined by the ditch water level. Hence in this case the ditches could be raised to their summer level as early as spring, but in view of the strips of land alongside the ditch this is not done, but also postponed in this instance until such time as the land may require the summer level.

The level is usually lowered again in September. Annual variations in the weather are probably even greater in autumn than in spring, and accordingly there are greater differences in the time at which the level is lowered. The change-over to and from the summer level may also be effected in stages.

4. TECHNICAL ASPECTS OF SUBIRRIGATION

4.1. THE TECHNIQUE OF CONTROLLING THE LEVEL

It will be obvious that in this method a permanent water level is inadequate.
For this purpose, therefore, adjustable fieldweirs have been constructed to regulate the water level and the flow of water in the ditches (see Fig. 5 and Photographs 5 and 6).

These 'prefabricated' fieldweirs consist of a concrete box, which has no wall at the upstream side. In the opposite wall of the concrete box there is an opening (orifice) which is connected with a pipe going through an earth dam in front of which the fieldweir is installed. Depending on the available loss of head and the amount of water, which has to flow in or the desirable discharge the inside diameter of this pipe measures 30 or 40 cm.

To prevent leakage through the dam, which usually is built up of local soil the upstream side of the dam and also the banks and bottom of the ditch on that side of the dam have to be lined with a layer of clay or glacier-clay as the soils in subirrigated areas generally consist of permeable and erodible sandy material. It is assumed that leakage is prevented when this lining with clay is done to the maximum impounding height and over a distance from the dam in upstream direction which is equal to 10 times the maximum loss of head.

The outside dimensions of the box are in all directions 70 cm. The thickness of the downstream wall and of the bottom is 6 cm and that of both sidewalls 8 cm. The depth of the box is 90 cm, which allows damming up of water in the ditch to a height of 65 cm. If water levels of a height more than 85 or 105 cm are wanted the depth of the boxes can be increased accordingly to 110 and 130 cm, respectively. The depth of the fieldweir, therefore, will depend upon the desirable ditch water level and the depth of the ditch.

During the winter and also in abnormally wet periods during the growing season the front of the weir is left open to allow a complete discharge of water from the ditch.

To dam up the water a concrete frame is let into the shallow grooves running in the sides of the box. To prevent leakage sometimes a loosely woven cord is inserted around the edges of the frame. The crest of the rectangular opening in this frame is held 45 cm (with deeper fieldweir boxes 65 and 85 cm, respectively) above the bottom of the box and 30 cm below the normal (usual) impounded level.

In spring impounding is started at that level. To make impounding at a higher level possible an adjustable wooden shutter is placed against the concrete frame. In this shutter a Cipoletti-notch is made and a gage from which the discharge can be read in litres per second is attached to it. The crest of this Cipoletti-notch can be placed in a level line with the crest of the rectangular opening in the concrete frame and up to 30 cm above it; the latter height corresponds with the normal impounded level. For discharging purposes, however, this 30 cm height cannot be used completely, as may be seen from the following:

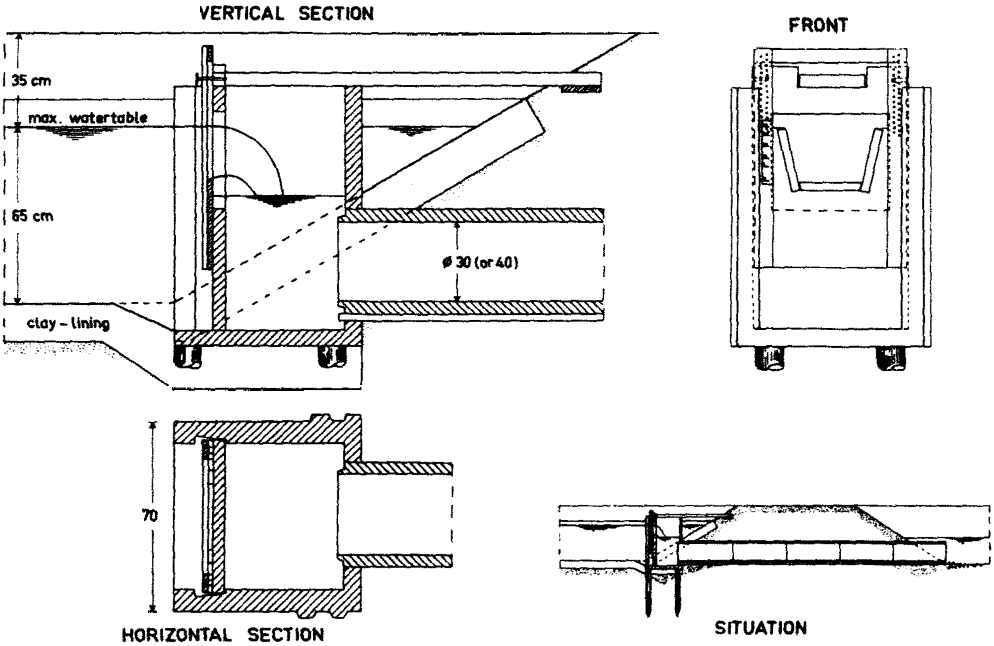


Fig. 5. Prefabricated concrete fieldweir for regulating the watertable and the rate of water flow in the ditches as used for subirrigating a coarse sandy soil with the normal water level in dry periods at 35 cm, the drainlines at a depth of 70 à 80 cm and the bottom of the ditch at 1 meter below soil surface.

For maximum discharge of 40 litres per second the height of the water above the crest has to be 20 cm and only 10 cm are left for further possibilities. For accurate functioning of the Cipoletti-weir the loss of head between the upstream and downstream side of the weir has to be then at least 20 cm. On the other hand maximum discharge only happens to be necessary in the case of inlet of water from the main supply ditches and only in exceptional cases as the moisture requirement of the land behind such a weir is generally less than 40 litres. To supplement the losses of evaporation (maximum 4 mm or 0.5 litre/sec/ha) a quantity of 40 litres suffices for an area of 80 ha, whereas in the Northeast Polder the maximum area behind a fieldweir is only about 50 ha (two plots). A discharge capacity of 25 litres would, therefore, be sufficient, A higher capacity, however, is wanted because of the possibility of water losses through the subsoil. inadequate upkeep of the system and also to enable a rapid 'filling' of the area.
Furthermore a maximum head will not be required, because as soon as weather conditions change a desirable lower water level in the ditches will be obtained by decreasing or stopping the inlet of water. Excessive rainfall may, however, even in this case increase the discharge of water over the weir. If it is assumed, for instance, that the inlet weir of an irrigation ditch is adjusted to such a height that the discharge over its crest is 40 litres and if in the ditch behind it two other weirs are placed halfway and at the end of it, through which 20 and 0 litres are discharged, respectively, then with excessive rainfall the weir in the main ditch will have to be closed (*i.e.* with the crest at a height of 20 cm) and the height of the crest of the other two weirs will have to be changed to allow a discharge of *a* and 2*a* litres, respectively. When *a* exceeds 20 it will not be possible (temporarily) to maintain the desirable low water level unless the wooden structure, or even the concrete frame, will be removed.

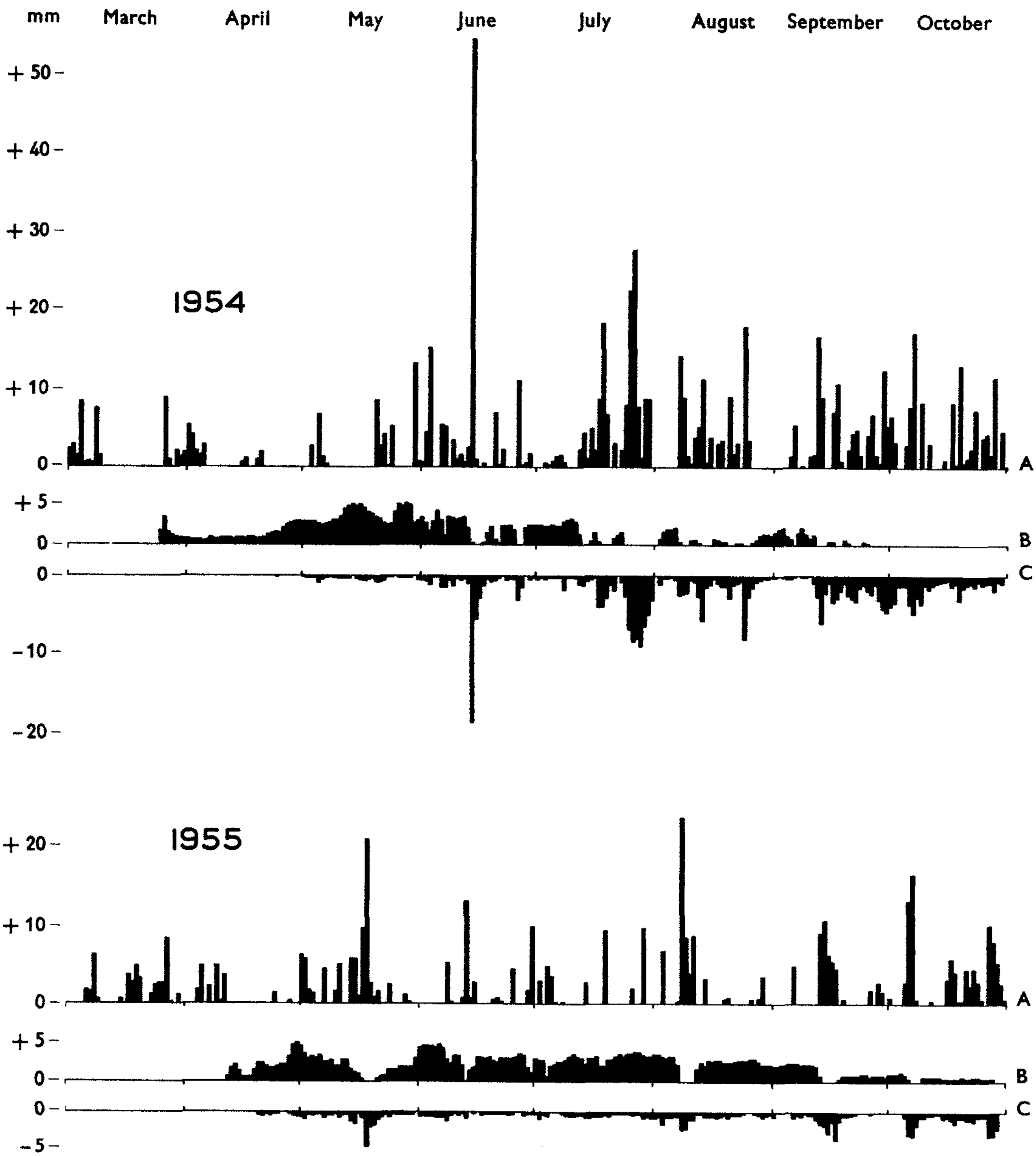
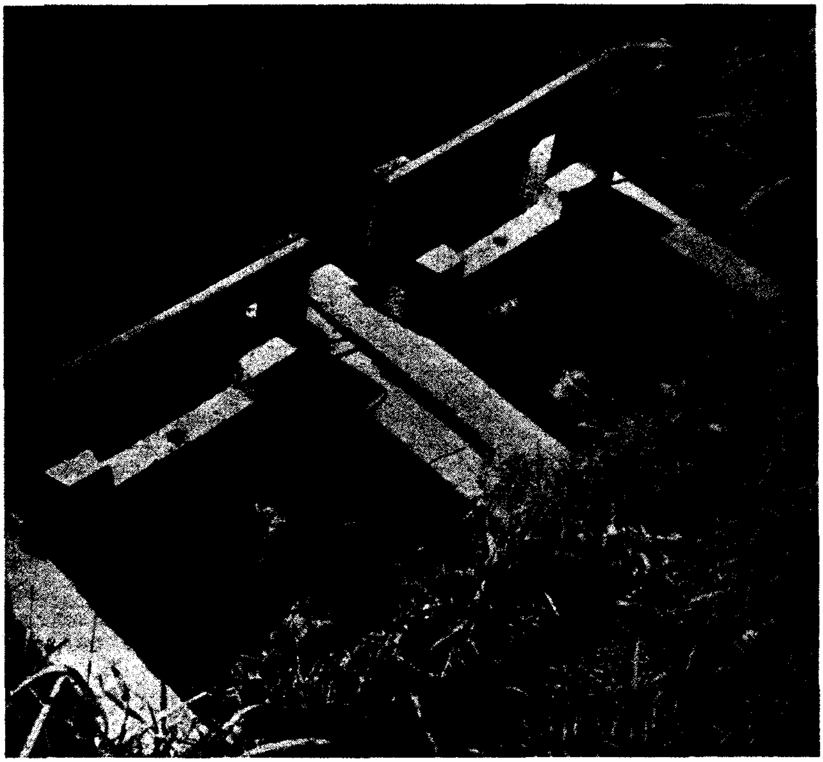


Fig. 6. Course of daily rainfall (A), water supply (B) and water discharge (C) in the subirrigation area Vollenhove during the growing season 1954 (wet) and 1955 (rather dry). Coarse sandy area, pastures.

If more variation is wanted the length of the crest has to be increased in order to obtain a larger discharge with the same or even smaller heads. The structure of the box described allows a variation in this way as there is space to increase the usual length of the crest of 24 cm to 34 cm. It is – of course – also possible to enlarge the dimensions of the box and weir but in such a case the advantage of uniform structures will be lost. Another possibility is to install two boxes side by side (see photograph 6). This is always done at those places in the Northeast Polder where the maximum discharges have to be larger than 40 litres. For this purpose the sidewalls of the boxes have a special structure. Larger discharges are in practice mainly needed in the main supply ditches. When the discharge will be more than 120 litres (for which discharge 3 boxes should have to be installed) other devices with a higher capacity are constructed which can be regulated either by increasing or decreasing the height of the crest or making the opening through which the water is discharged narrower or wider, by inserting or removing movable shutters.
The weight of the standard concrete box is 375 kilograms, and it can be transported and installed with simple means. There are no iron parts protruding from this concrete structure as climatological conditions and the place of installment are highly promotive for rusting of iron.
The wooden shutters are removed at the end of the irrigation season, assembled, painted with carbolineum and put in storage. For the irrigated area in the Northeast Polder the total number of fieldweirs is 1200, which means: 1 fieldweir per 7 ha irrigated land.

During a drying period the inlet sluice will be opened sufficiently and the crests of the weirs so adjusted that the impounded water level is reached at all points without water running to waste over the last weirs (at the end-dams). The supply and consumption of water are then in equilibrium.
If water consumption falls because of lower evaporation, *viz.* without rainfall, the supply should be reduced accordingly. If this is not done water will run to waste over the end-dams, and the extent to which this happens indicates what reduction is required in the water supply. Since the amount of water passing through can be read at both the inlet and the end-dams, the amount of water admitted can be adjusted fairly accurately according to need. The impounded water level in the ditch will not be reduced as soon as there is a decrease in evaporation, although, as we saw above, this would be theoretically desirable. It should, however, be done whenever there is a prolonged period of low evaporation. This will always be the case later on in the season, even though the weather is dry, and the level is accordingly reduced. But the level should also be reduced 5 to 10 cm during long periods of cloudy weather in summer (a greater reduction is required on fine sandy soils).
Should there be occasional slight rainfall during a dry period, *e.g.* less than 5 mm, this will scarcely have any noticeable effect on water consumption and no steps will be taken. Should more rain fall, the supply will have to be reduced, since the rainwater causes a reduction in the amount of irrigation water (rising capillary moisture) consumed. Even then the level will not be reduced immediately; this will only be done if the rain continues or there is a sudden heavy rainfall. The need to reduce the level becomes urgent when the rainfall is so heavy that the supply has to be stopped entirely and surplus water has to be drained off. Even in this case, however, one should be cautious of lowering the level immediately, and take into consideration the past, present and anticipated weather conditions. When pools begin to form this is a fairly clear indication that the level

Photograph 6.
A double weir
in a supply ditch.



should be reduced, at least insofar as this means that the water table is above the surface (pools may also occur on the land for a short time when the surface of the soil is too compact, but without the water table being excessively high).

In case of doubt it is also important for the land-user to check the water table and the moisture available in the root-zone, and it is even better to do this at regular intervals; a check should first be made midway between the tile lines, and also above them. Should reduction phenomena begin to appear in the soil (lack of oxygen) steps should certainly be taken to lower the water table, but even without this the humidity of the soil may indicate whether the moisture and air delivered to the crop is good, particularly when such an indicator is combined with observations of the water table and the behaviour of the crop.

When there is a certain amount of seepage and the subirrigation applied in dry periods is to be regarded as supplementary thereto, in all the above-mentioned cases in which lowering of the level is envisaged it will have to be carried out earlier. It is possible to stop the supply of water, but not seepage.

Fig. 7. Subirrigation plan of the two systems as applied in the Northeast Polder (dimensions lots 300 × 800 metres/1000 × 2700 feet).

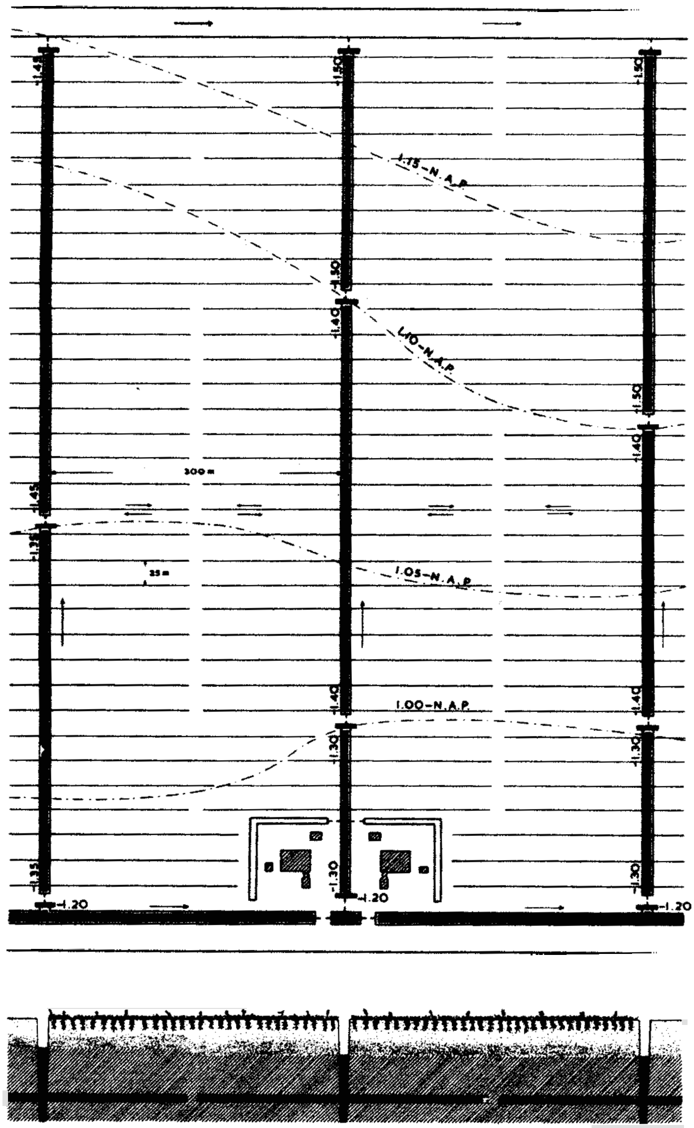
-1.20

main supply ditch.

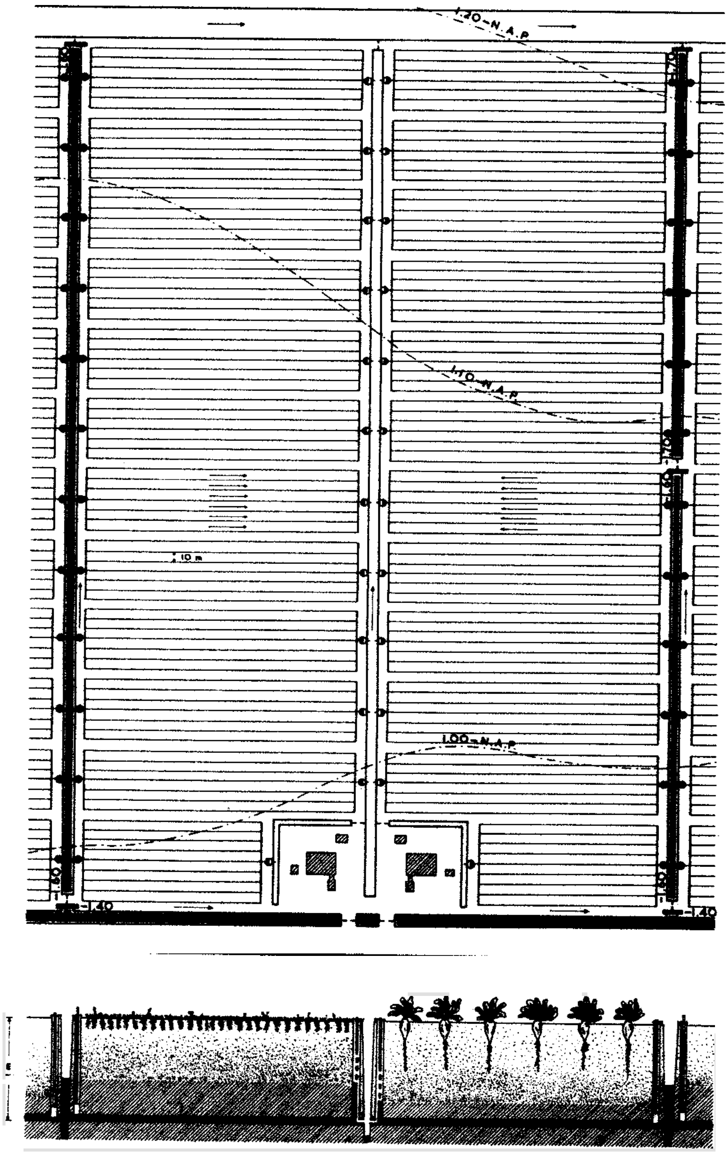
-1.40 -1.50

supply or supply and discharge ditch with maximum impounded water levels upstream and downstream of the dam, in metres below mean seawater level.

discharge ditch.



Left: The simple system in a coarse sandy soil; all tile lines 25 m/83 feet apart. The ditches function both for supply and for drainage of water. The tile lines end directly in the ditches. Control of the groundwater level is only accomplished by weirs in the ditches.



main discharge ditch.

inlet and outlet of a block.

100-N.A.P.

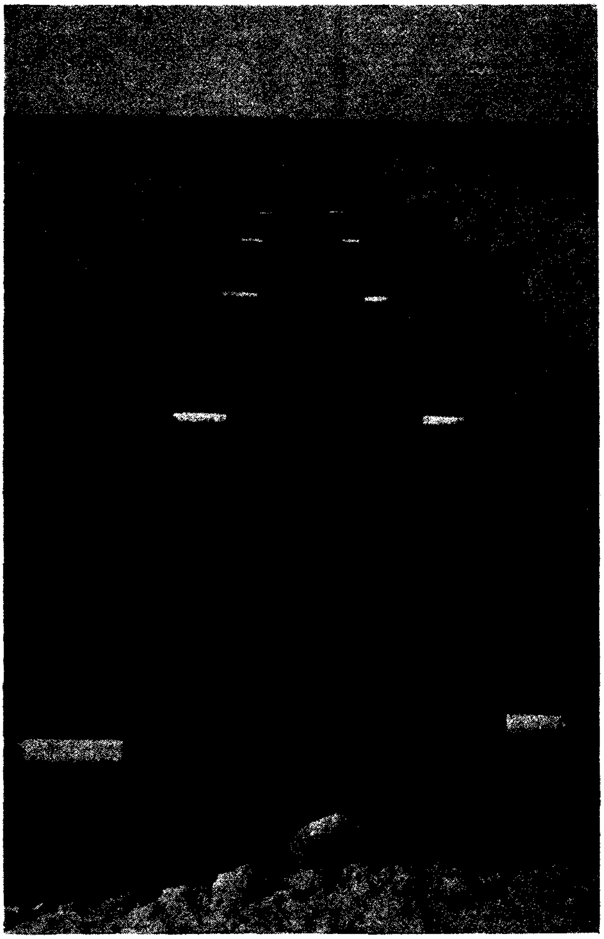
contour lines.

direction of flow.

Right: The compound system in a fine sandy soil; tile lines 10 m/33 feet apart. The ditches function alternately for supply and for discharge of water. The tile lines of each block end through a common collecting pipe in the ditches. The groundwater level can be regulated separately for each block by means of block inlets and block outlets.

4.2. DIFFERENT LAY-OUTS IN USE

Some of the matters discussed above are seen in a somewhat different light when the combined subirrigation system is employed in stead of the simple one we have hitherto had in mind in our descriptions. In both cases water is delivered to the lots in the same way. (In the Northeast Polder a lot is usually measuring 300 by 800 metres (1000 × 2700 ft), the shorter sides being adjacent to a road and a secondary canal, and the longer sides being bordered by ditches.)[1]) The water is drawn from the Yssel Lake by means of an adjustable inlet sluice constructed as far as possible at the highest point of the area which is to be subirrigated. The main supply ditches leading from this sluice follow the highest parts of the land, approximately parallel to the contour lines. From these main ditches the water is led into the border ditches which are sited as far as possible at right angles to the contour lines (see Figure 7).



Photograph 7. Subirrigation ditch of the Vollenhove method, each tile line ends freely in the ditch.

In the *simple method* (also known as the *Vollenhove method* from its original use in area 8 near Vollenhove) each separate tile line ends freely into the field ditches (see photograph 7).

All field ditches are utilized both for supplying and drawing off water, and also for controlling the height of the water table. For the latter purpose fieldweirs are arranged in the ditch, and are usually spaced at such intervals that the difference in height between any two fieldweirs on the same land is not more than 10 cm. This means that in order to maintain a mean optimum water table the highest part of the land has a water table which is 5 cm too low, and the lowest part a water table which is 5 cm too

[1]) See Takes, Physical Planning, Publication No. 1, International Institute for Landreclamation and Improvement 1958. (Editor's Note).

high. On steeper slopes more dams will have to be installed in the same length of ditch. Should this mean installing too many dams, a greater difference in height is often tole rated in practice. In areas 8 and 11 the land is locally divided up into horizontal terraces on account of excessive differences in height and surface irregularities.
In the simple system the tile lines do not run from one ditch to the next, but are interrupted, usually in the centre of the field. Hence a ditch is used to subirrigate adjacent halves of a field. (When contour lines run diagonally across the field the number of dams can be reduced by adjusting the interruption to the contour, as is done in the right of Fig. 7 left, instead of always siting it in the centre of the field).
In the *combined system* (also termed the *Ramspol method*) during the subirrigation season alternate border ditches are used for the delivery and removal of water (Fig. 7 right). Tile lines serving a maximum of 2 to 3 hectares are combined in a block and have joint outfalls into both ditches. An adjustable inlet is arranged in these outfalls on the side of the "wet" ditch, and an outlet on the side of the "dry" ditch; by this means it is possible to regulate the inlet and overflow level in the block (see Fig. 8). The difference in height between the dams in the field ditch may be somewhat greater than is possible in the simple method as they are not used for regulating the water table in the land, but having regard to the strip of land alongside the ditch carrying water the difference should not usually exceed 20 cm.

4.3. ADVANTAGES AND DISADVANTAGES OF THE TWO METHODS

A comparison of the two methods shows that the advantage of the simple one is in the first place its very simplicity. The height of the water table in ditches and on the land is regulated by means of a number of weirs, and it is easier to see what one is doing than in the combined method and also easier to prevent waste of water. A further advantage is that for the same field-width of 300 metres, the distance over which water has to be delivered through a tile line in the simple method is on an average half that required in the combined method. (In both methods, but particularly in the combined method, it would be an advantage if the tile lines were shorter. Hence a field-width of 200 metres has been planned for land to be subirrigated in the East Flevoland Polder.)
Moreover, maintenance is much easier in the simple method, particularly when blockages occur, as the tile can be cleaned from the ditch. On the other hand, in the combined method the lines have to be excavated *in situ* and a number of tiles removed in order to clean them; at any rate, this was the case in the method of laying tile lines which was practiced until recently, *viz.* with T-joints connected to the mains. If cross-pieces are used instead, as shown in Fig. 8, and one or more tiles which can be closed with a plug are laid on the fourth arm of these cross-pieces, there is no need to remove any tiles from the line for the purpose of cleaning, as the tile can be dug up and opened at this point.
The biggest drawback of the simple method is that the water table of a field cannot be regulated independently of the other fields supplied with water from the same ditch, although a different level may nevertheless be required, since apart from any differences

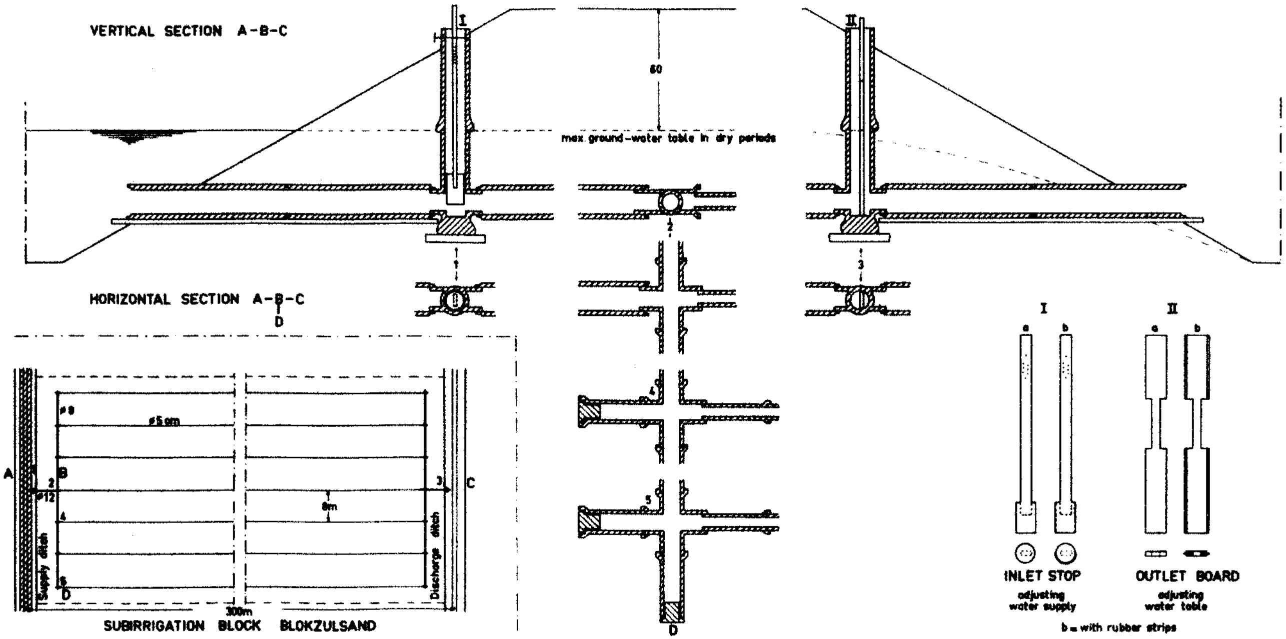


Fig. 8. Plan and some details of an irrigation block on fine Blokzijl sand. The inlet stop and the outlet board are presented with (b) and without (a) rubber strips. Rubber strips are fitted to prevent leakage. The outlet board represented here can also be used in reversed direction for a 10 cm lower height of the impounded water level.

of opinion which two neighbours may have regarding the most desirabel height of water table, irrigation requirements will vary from one crop to another.
A field of beet will need a different water control than a field of pasture. Pasture will need water already earlier in the season, and will also require a higher water table than beet. Differences may also be anticipated as between one meadow and another. A meadow which has been mown and is ready for haymaking needs less water than one in a state of vigorous growth. If the simple method is used it will be necessary to estimate the most suitable average water table by weighing up the requirements of the fields used for various purposes. Fortunately this is not very difficult to do in practice. A water table which in dry weather is the optimum for a given crop (*e.g.* grass) will certainly do little or no dämage to another crop. Vice versa, a water table which in wet weather will cause considerable harm to one crop will not usually benefit another. It is practically always the case that one crop is particularly sensitive to a water table which is too low, while another is most affected by one which is too high, although there is not a great deal of difference between the optima for either crop. In this case we have to choose as our common water table one half-way between the optima. This will be easier to do if we are able to control the water properly according to fluctuations in the weather, but we have already seen that there is a limit to what can be done in this respect. What this amounts to in practice is that pasture is kept rather on the dry side, and beet rather on the wet.
In any case, the simple method is admirably suited to coarse sandy soils which do not require any great differences in water table in dry and wet periods, and which, moreover, are wholly or almost wholly laid down to grass in the Northeast Polder. But with a little allowance either way, this simple method will generally produce reasonably good results in other cases as well. This allowance also consists in taking time to observe the behaviour of the soil, the water and the crop.
This does not imply that the combined method is not without its advantages for the mixed dairy and arable farm, or at any rate does not afford more opportunities of attending to the requirements of the various crops in their various stages of development and use. On soils where the water table has to be precisely adapted to weather conditions, *e.g.* on the fine Blokzijl sand, this can also be done more easily by means of the block system.
In order to derive the full benefit from the possibility of giving each crop its own water table, the fields growing the various crops should coincide with the subirrigation blocks. In case of need several crops of the same type may actually be grown on the same block, but in general the number of blocks per farm will have to be adjusted to a proper scheme of cultivation for the farm concerned. On the subirrigated sandy soils in the Northeast Polder there are many farms with 24-hectare plots growing crops in rotation, two-thirds of the area being grassland. The minimum number of blocks required on such farms will be 9 or 12 in order to provide 6 or 8 fields of grassland and 3 or 4 fields of arable.
Another reason why the water table can be more easily modified in the Ramspol method is that the ditch water level can be left unchanged. On the other hand, after the water table has been lowered in a wet season it frequently happens that one waits too long before

raising again when a drought sets in. This particularly applies to the spring when there is still little evaporation, the temperature is comparatively low, and the need for supplying water still seems far-off. Nevertheless there is a gradual fall in the water table, and a few warm days may suddenly create an urgent call for water. But it is then impossible to raise the water table rapidly to a sufficient height; the water-carrying capacity of weirs and supply ditches, and the tile system which is spaced according to the permeability of the soil, would be inadequate for such a demand. At this time a preferable situation is provided by the simple method in which the spring level of impounded water also keeps the water table at a reasonable height, so that the desired level can be easily reached when the dry period begins. Hence in the Ramspol method in particular, the variation of the water table should be controlled as well as possible, and the water-inlet in the blocks regulated accordingly.

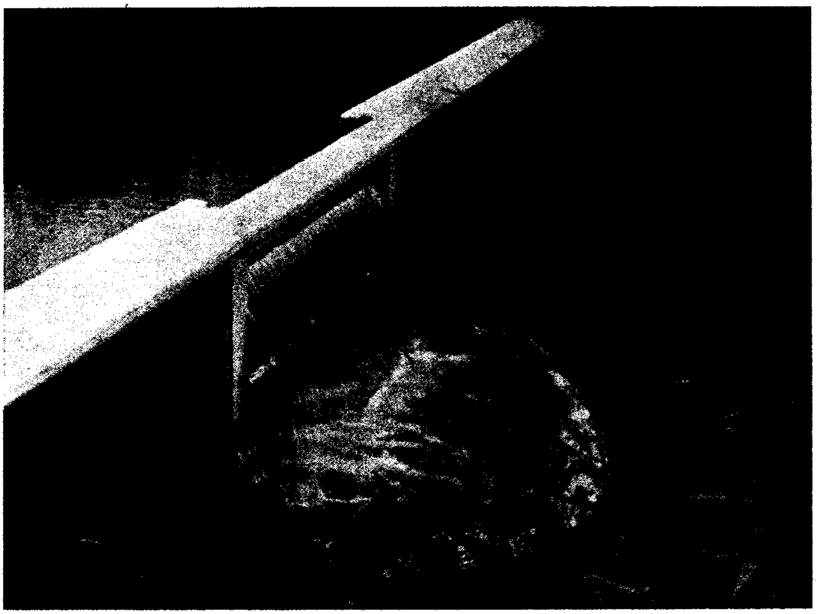
5. DROUGHT PHENOMENA OCCURRING DESPITE SUBIRRIGATION

In the above it was assumed that the ditch water level determined in periods of continuous dry weather is a guarantee of a good supply of water, but subirrigation practice has taught us that this is not always the case. Some of the causes of this will now be discussed.

In the first place, the impounded water level may actually be rather too low. In the case of the Kuinre sand, for example, (area 6) the impounded water level originally fixed had to be increased a few years afterwards.

Secondly, it should be borne in mind that on extremely dry and warm days evaporation is somewhat in excess of the assumed 4 to 5 mm, or at least it will be if water supplies are increased. This is also bound up with the problem as to whether on such days the damage should be regarded as being caused by heat rather than by drought. In any case, we must assume that after a fairly long period of dry and warm weather (when the available suspended water will have been all absorbed and the plant will be entirely dependent on rising capillary water) an increase in the impounded water level beyond the normal one will be beneficial, or in any case do no harm. When the adjustable weirs as described before (page 25) are used it is in many cases possible to go another 10 cm above the normal level. But under climatic conditions in the Netherlands it is frequently found in practice that a dry period suddenly ends in a thunderstorm, and in this case it is all to the good if the level has not been increased.

Thirdly, we should mention the local draining effect of the existing canals as a result of which it is impossible to maintain a sufficiently high water table in a strip alongside these canals, despite a high impounded water level in the ditches delivering water. In exceptional cases local draining may be noted even at a fairly great distance from a canal when the subsoil is very permeable. This draining is kept in check as far as possible by constructing dams in the secondary canals (see photograph 8). This cannot be done in the main canals as they are in general use for conveying the water to the pumping stations and for shipping. (Only these main canals are shown on the map. The three pumping stations are located at the outlets of these canals into the Yssel Lake, etc., where, of course, there



Photograph 8. Structure of a dam in a secondary canal, serving to dam up the water locally to 1.40 metres below the surface in winter, and to 0.9 metres below in summer.

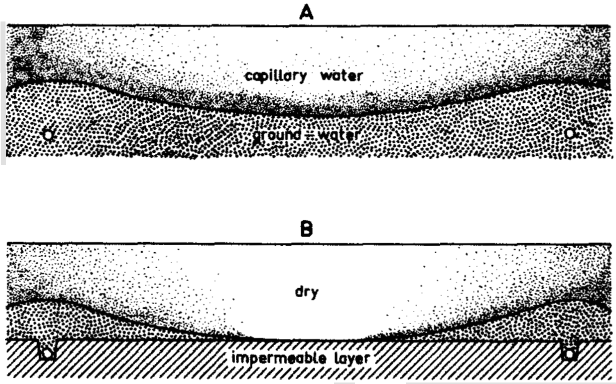
are locks also. The secondary canals are usually situated half-way between the roads, the latter being shown on the map).

Fourthly, anomalies in the soil may cause local drying out.

Occasionally, as in some places in the Blokzijl sand areas 1 and 7, patches or strips occur in which the composition of the soil differs from that in the vicinity, being coarser or poorer in silt, so that there is a reduced upward capillary flow. If the impounded water level is suitable for the surrounding land it will be too low for such patches which consequently dry out to a greater or lesser extent. If the level is suitable for the patches it will be too wet for the surrounding land. Sometimes, as in area 11, patches of loam or peat may occur in parcels of land which otherwise consist of coarse sand.

In other cases there may be disturbing soil layers which prevent an easy delivery or rise of the water. When the sand which is to be subirrigated overlies an impermeable or almost impermeable clay or peat layer, for proper subirrigation the impounded water level should be higher than this formation, as otherwise the water is unable to infiltrate into the fields. If the impounded water level is only a slight distance above the impermeable layer, infiltration will be a slow process, and in periods of drought it will even be too slow, as a result of which the soil dries out, starting from the middle of the fields (see Figure 9). Some help may be afforded by making the distance between the tile lines narrower (see also Figure 2) or raising the impounded water level. Raising the impounded water level is dangerous, however, as in periods of drought it causes the land in the neigh-

Fig. 9. Diagram showing how an impermeable subsoil affects subirrigation in drying periods.
A. A profile which is permeable to a great depth.
B. An impermeable layer high up in the profile (in this case extending above the tile lines but below the impounded water level).



bourhood of the tile lines to become sodden, while in rainy periods it is chiefly the middle of the fields that is thus affected because the impermeable layer also reduces the rate of drainage.

If the impermeable layer is of good quality (calcareous clay or loam) it is better to surface-plough it; this has in fact been done on a large scale, particularly on the border of areas 7, 8 and 9. If the layer of good soil which has been surface-ploughed is sufficiently thick there is no need for any subsequent subirrigation. If it is only a thin layer subirrigation is still just as much needed as on soil profiles naturally consisting of a thin layer of loam on sand, *e.g.* in parts of areas 3 and 5. In this case the impounded water level should be set sufficiently high for the capillary moisture to reach the heavier upper layer.

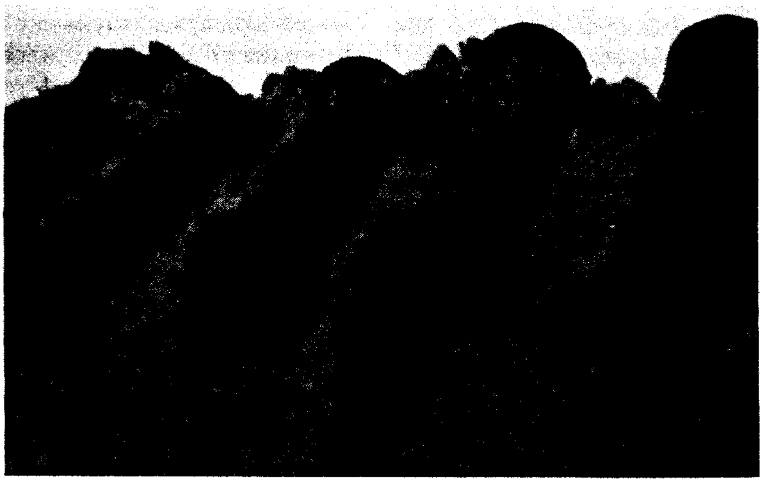
If the impermeable layer is of variable quality, as in area 6 in a narrow strip facing the former coastline, where it consists of acid, highly humous clay, or acid peat, should the soil dry out the merits of the various methods of improvement (narrowing the distance apart of the lines, raising the impounded water level, deep ploughing accompanied by deacidification) should be compared with each other and with the existing state in each separate case. Since in this area the impermeable subsoil is sometimes found at varying depths within a short distance, the drying patches occasionally form a very irregular pattern. Disturbing formations may also occur above the impounded water level and thus hinder the upward capillary movement. This is a local phenomenon in the Northeast Polder in the drought-sensitive profile having a thin stratum of loam overlying pleistocene sand, as is the case in areas 3 and 5. Between the loam and the pleistocene sand are occasionally found thin strata of peat, peat detritus or alluvial sand which are a hindrance to the upward capillary movement or cause it to vary. It is also important to know whether the pleistocene sand still has the complete ABC profile, or whether the A or the A and B horizons are missing, particularly when this profile is irregularly distributed over the area. It is not easy to make adequate provision for the irregularities in moisture supplies resulting from these various factors. Only a very complex soil improvement scheme might answer the case, but this will not be gone into at this place.

Fifthly, defects in the tile system should be regarded as a possible cause of drying out in subirrigated land. In fact, we might have mentioned such defects in the first instance, seeing that an uninterrupted supply of water via the tile lines is an essential condition of the proper functioning of a subirrigation system. It is quite possible for the tile system to be out of order. As the chief cause of failure we should mention blockages of various kinds, of which three groups may be distinguished, *viz.* obstructions in the tiles, in the joints, and in the vicinity of the tiles.

The principle causes of blockages in tile lines are silting, deposits of iron compounds, and roots which penetrate the lines (see photograph 9). These obstructions may be serious as regards the effect they have on subirrigation and drainage, but they can usually be overcome sufficiently by cleaning (opening and flushing) the tile lines. We shall not discuss such cleaning methods here, but only stress the fact that cleaning is necessary and should be done by a skilled practitioner.

Regarding blockages in the joints we know far less than about obstructions in the tiles, but it is a fact that blocked joints may occur and that iron compounds are often a potent cause of trouble. The clogged joints may sometimes be improved by cleaning the inside of the tile lines, but in many cases the only final solution is to excavate the tiles and re-lay them. In doing this one should bear in mind the possibility of history repeating itself sooner or later, even though some deposits of material in the joints may sometimes be of a temporary kind. But in any case it is useful to enquire whether preventive measures are also possible in this case. One might, for instance, suggest keeping the joints somewhat wider apart, and provided the tiles are carefully laid there is no real reason why this should increase the risk of silting. In any case, the problem of choking of the joints will call for an investigation into its incidence, remedy and prevention.

Regarding the question as to whether the vicinity of the tile lines becomes impermeable,



Photograph 9. Excavated pipes, clogged by penetrating roots.

we have even less information than about the joints, although there are some indications that this occurs as well. Such a state of affairs might be imagined to arise, particularly in the form of a reduction in permeability after the tiles have been laid. The peat fibre placed on the joints in laying the lines and the earth which is loosely shovelled in over the tiles will begin to settle. If subirrigation is applied it is fairly certain that this settling will proceed more rapidly and possibly also result in a compacter final state than if the tile lines were only used for drainage. But it is not to be expected that this will result in the soil becoming appreciably less permeable than it is in natural condition, and we must assume that the reason for this phenomenon is deposits of material, *e.g.* precipitated iron in the pores of the turf fibre and the sand. At any rate, attention should also be given to the vicinity of the tiles even while they are being laid. For instance, care should be taken to use the coarsest material from the profile for the immediate covering of the tiles. For the time being there does not seem to be any need to supply very coarse material such as gravel for the specific purpose of subirrigating sandy soils, an idea which is now and then put forward.

In view of the drawbacks attaching to subirrigation by means of tiles, it is sometimes queried whether subirrigation by means of open trenches would not after all be preferable. Regarding this we would only say here that the great advantages which tiles have over open ditches are even more evident in the case of subirrigation than in the use of drainage (one has only to consider the loss of land and the upkeep of the trenches). Instead of avoiding the admitted difficulties by employing such a less rational method, it is better to try and overcome them as far as possible.

6. SUBIRRIGATION ADMINISTRATION

It will be obvious that if subirrigation is applied to a drought-sensitive area it will be a joint undertaking for the entire area requiring a central administration and control. The mere fact that an inlet sluice and a system of supply ditches and structures have to be built for such an area, and that these also require regular attendance and servicing, makes it necessary to have a central authority. But even distribution of water to the field ditches cannot just be left to the cultivators concerned, because any alteration to one part always affects the efficient working of the whole system. When more or less water is led into the ditches, more or less water has to be admitted through the sluice; otherwise, if one or two farmers were to let in more or less water, this would be accompanied by a reduction or increase in the amount supplied to others.

Nor is it possible to lower or raise the impounded water level without more ado; in practically every case the supply has to be increased or reduced at the same time. Even the block inlets in the Ramspol method have to be opened and closed in consultation with the persons appointed by the central authority to carry out the work of regulation, as in this case also it may be necessary to alter the supply.

In the Northeast Polder the central control and management of subirrigation rests with a body known as the State Property Department, since the land belongs to the State. To carry out the daily work a number of sub-inspectors are appointed, each serving an area of approximately 500 hectares. They work according to fixed rules, although the necessary allowance is made for complying with the reasonable requests of the cultivators who lease their farms from the State.

The management also sees that subirrigation functions properly, inasmuch as rules are laid down for cleaning the farm ditches (there are two inspection dates in the summer) and the upkeep of the tile system is supervised. The main supply ditches are kept up by the controlling body.

These regulations are by no means intended to relieve the farmers of their responsibility for this part of their husbandry, nor does it have such a result. In practice the reverse is true. Persons in particular who originally are entirely ignorant of subirrigation practice

(and this applies to most farmers on the subirrigated farms in the Northeast Polder) are becoming increasingly aware that water is not a factor to be passively accepted, but one which can be controlled and put to some useful purpose on the farm.
As a result of good co-operation and an exchange of experiences among farmers, management, agricultural extension and research workers, subirrigation will be in an increasingly better position to answer its purpose of improving production in soils sensitive to drought.

RÉSUMÉ

IRRIGATION SOUTERRAINE DANS LES POLDERS DU ZUYDERZÉE

Quoique les Pays-Bas aient un climat nettement humide, la saison de croissance y connaît des périodes où le manque d'eau se fait sentir dans l'agriculture. Il en résulte que des sols retenant mal l'humidité nécessitent un apport d'eau artificiel. Dans les nouveaux polders du Zuyderzée, la distribution des eaux sur les terres sensibles à la sécheresse a été entreprise par irrigation souterraine ou „infiltration". Dans le présent article, l'irrigation au polder Nord-Est – le deuxième des cinq polders dans l'ancien Zuyderzée – a été prise pour exemple. La superficie irriguée atteint ici plus de 8.000 hectares (voir la carte).

Par infiltration, on entend le maintien du plan d'eau à une hauteur telle que les végétaux puissent entièrement en profiter pour leur alimentation en eau. L'infiltration est obtenue en maintenant l'eau dans les fossés à un certain niveau élevé qui lui permet d'entrer dans des rigoles ou des systèmes de tuyaux et, de là, d'imbiber le sol.

Si la sensibilité du sol à la sécheresse est déterminante de l'opportunité ou de la nécessité de l'infiltration, la possibilité d'infiltration et le procédé à appliquer, eux, dépendent de la perméabilité et de la composition du sol en ses différentes couches. Dans le polder Nord-Est, ce sont surtout les sols pauvres en argile et en humus qui conservent mal l'eau et demandent donc l'infiltration. Les terres composées d'une mince couche sablo-argileuse sur du gros sable et les sables fins sont également irrigués par infiltration. Les sols dont le profil présente du sable sur une couche sablo-argileuse sont d'infiltration difficile, parce qu'ils manquent de perméabilité; on les améliore par défonçage profonde. L'infiltration des sols tourbeux est particulièrement importante pour prévenir un dessèchement irréversible. Comme la tourbe repose le plus souvent à faible profondeur sur du sable perméable, l'infiltration ne présente pas de difficultés. Celles-ci n'apparaissent qu'en présence d'épais bancs de tourbe.

Au cas du polder Nord-Est l'infiltration est à préférer aux autres modes de distribution d'eau ou d'irrigation. Les conditions du terrain, telles que sa situation basse par rapport aux eaux extérieures, la faible pente à partir du bord, la surface plane du sol, sont favorables à l'application de l'infiltration. Il en est de même de la nature du sol, qui est uniforme sur de grandes étendues. L'alimentation en eau d'abreuvage et l'arrêt du bétail se trouvent facilités. La commande du système prend peu de temps, l'entretien peut avoir lieu en dehors de la saison de croissance et à la différence par exemple de l'irrigation par aspersion l'organisation de l'entreprise n'est guère modifié.

Eu égard à la nécessité de drainage durant

la période humide, un système de conduits ouverts et de drains souterraines est indispensable, même si l'on n'infiltre pas. A relativement peu de frais et par des interventions assez simples, ce système de drainage peut être adapté à l'infiltration. Les frais ne sont que de 20 florins (5 dollars) par an environ, y compris les intérêts, l'amortissement, l'entretien et la commande du système, c'est-à-dire, exprimés en capital au moment de l'installation, fl. 500,— (130 dollars) par hectare.
L'irrigation par aspersion coûterait au moins fl. 1000,— par ha de plus; même un projet d'irrigation par submersion ou par ruissellement demanderait des mesures plus importantes et serait plus coûteux que l'infiltration.
La figure 2 montre un exemple de la nappe phréatique dans un profil infiltré, où sont démontrées l'influence de l'espacement des séries de tuyaux, les conséquences d'un apport de pluie ou d'eaux d'infiltration supérieur à l'évaporation, qui nécessite le fonctionnement du système pour le drainage, et les conséquences d'une évaporation ou d'un écoulement souterrain dépassant la précipitation - où il doit être question d'infiltration dans tout le sens du mot. Dans ce dernier cas, la différence du niveau des eaux souterraines au-dessus des tuyaux et au milieu des champs dépend de la mesure dans laquelle l'évaporation a lieu, de la perméabilité du sol et de l'espacement des séries de tuyaux. Pour déterminer cet espacement on accepte comme critère qu'en cas d'évaporation normale d'une végétation herbeuse dans les périodes sèches (4 à 5 mm par 24 heures aux mois de juin et de juillet), le plan d'eau n'est pas permis de présenter de différences de plus de 10 cm. Il en est de même de la différence du niveau de l'eau dans le fossé et au dessus du bout des séries de tuyaux. Selon la perméabilité du sable, les séries de tuyaux sont espacées de 8 à 30 mètres.
Le niveau optimum des eaux souterraines pour un sol de nature donnée est tout d'abord déterminé par la hauteur et la rapidité de la montée capillaire à partir de la nappe phréatique. La figure 3 montre pour trois types de sols sablonneux l'humidité en pourcentage du volume à différentes hauteurs au-dessus du niveau phréatique. Pour un de ces types les pourcentages en volume de terre, d'eau dans les pores, d'eau capillaire et d'air sont indiqués séparément pour les différentes couches à la fig. 4. Ces données permettent de conclure que ce sol comporte 40 % de pores, qui contiennent de l'eau capillaire en quantité décroissante jusqu'à 50 cm au-dessus du niveau phréatique. De plus, après une pluie, 15 % des pores peuvent rester pleines d'eau au moment que le sol atteint son point de ressuyage. En déterminant le niveau optimum de la nappe phréatique il faut avoir soin que l'apport d'eau capillaire dans la zone des racines soit suffisant et, en même temps, que l'aération de cette zone ne soit pas compromise. Pour les patures, le niveau phréatique dans un sol du type de la fig. 4 pendant une période sèche devrait se trouver à 50 cm de la surface du terrain afin que l'eau montant par capillarité atteigne suffisamment la zone de racines peu profonde. Le niveau de l'eau dans les fossés doit alors être de 10 cm plus élevé afin d'assurer une alimentation suffisante en eau. En cas de grande sécheresse prolongée, le niveau phréatique devrait encore être un peu plus élevé, pourvu que l'aération reste suffisante. Aux Pays Bas, cette nécessité ne se présente que rarement. En cas de pluie, le rapport eau/air est modifié par le fait que d'abord, les pores s'emplissent au-dessus du niveau phréatique, et que ce dernier monte ainsi que la zone de capillarité. Si la pluie remplissait les pores jusqu'au point de rétention, il faudrait baisser le niveau phréatique de 10 cm par exemple pour assurer l'aération. Si la pluie dépassait la quantité nécessaire pour ce remplissage, il faudrait diminuer le niveau de l'eau dans les fossés pour permettre une évacuation rapide des eaux d'exces. Le rapport existant entre la hauteur de montée capillaire, le niveau phréa-

tique, le niveau dans les fossés, les circonstances météorologiques et l'apport d'eau a été étudié également pour d'autres sols sablonneux.
Dans la pratique, ces conditions idéales ne peuvent être réalisées, vu les variations assez fréquentes des circonstances météorologiques. La lenteur de l'amenée et de l'évacuation d'eau par les conduits et celle des mouvements des eaux dans la terre rendent impossible une adaptation exacte. Il n'est pas probable, cependant, qu'un niveau un peu trop bas ou trop élevé soit d'un grand effet sur le rendement de la culture. Il faut donc se contenter de réaliser dans les fossés un niveau devant subir le moins possible de changements durant la saison d'infiltration. Dans le polder Nord-Est, on maintient un niveau d'été et un niveau d'hiver distincts, avec un niveau de transition au printemps et en automne, tandis que le niveau d'été n'est modifié qu'en présence de circonstances météorologiques extrêmes. Le niveau d'hiver s'obtient par l'assèchement des fossés. La montée jusqu'au niveau de printemps commence lorsque le bétail est mis à l'herbe. Le niveau d'infiltration proprement dit est établi, selon l'évolution météorologique et la sensibilité du sol à la sécheresse, le plus souvent au mois de mai. Il en est de même de l'établissement du niveau d'automne, le plus souvent au mois de septembre.
Afin de pouvoir établir différents niveaux de l'eau, on a construit des vannes puits régulateurs (fig. 5). En hiver, ces vannes sont entièrement ouverts. Au moyen d'une planche à coulisse en bois devant un cadre de béton, on règle la hauteur désirée, du niveau d'infiltration et l'apport d'eau vers les terrains à irriguer. Il y a une marge de 40 cm pour le réglage de la vanne. En cas d'augmentation de la consommation d'eau (évaporation) ou de diminution (précipitation), l'amenée de l'eau vers les différentes parcelles doit être modifiée en conséquence à l'aide des prises d'entrée et des vannes régulateures. Le débit pouvant être lu, une adaptation assez exacte est possible. Il faut tenir compte d'une action tampon et d'un certain retard. En cas de doute, il est recommandable de procéder au contrôle du niveau phréatique et de l'humidité du sol.
La régulation de l'eau s'effectue selon deux systèmes différents: le système d'infiltration simple (*système Vollenhove*) et le système d'infiltration composé (*système Ramspol*).
Le système d'infiltration simple comprend la poussée de l'eau des fossés laterales dans des séries de conduits de chaque côté, longues chacune de la moitié de la largeur du lot (fig. 7). Les séries de tuyaux aboutissent séparément dans ces fossés. Ceux-ci servent autant à l'amenée et à l'évacuation des eaux qu'à la régulation du niveau de l'eau à l'aide des vannes régulateurs (pas plus de 10 cm de différence d'altitude entre deux régulateurs).
Dans le système composé, durant la période d'infiltration, les fossés servent l'un à l'amenée, l'autre à l'évacuation de l'eau (fig. 7). Les séries de tuyaux irriguant 2 ou 3 ha au maximum sont réunies en un bloc, avec un déversement commun dans l'un et l'autre fossé: du côté du fossé de distribution, il y a une entrée réglable, de celui du fossé d'écoulement une sortie permettant de régler la hauteur d'élévation de l'eau. Ici, la différence d'altitude entre deux régulateurs ne dépasse pas 20 cm (voir également fig. 8).
Le système simple a pour avantages le caractère simple du réglage et de la construction, la longueur relativement faible des séries de tuyaux et le facilité d'entretien. Son inconvénient est que le niveau de l'eau dans un lot donné ne peut être réglé indépendamment de celui des autres lots lorsqu'on le désire (que l'on compare par exemple le besoin en eau des paturages et des cultures de betteraves). Dans la pratique, cet inconvénient n'est pas très considérable, les circonstances optimum pour une culture ne causant guère de dommage à une autre, dans la plupart des cas. Le système simple se trouve être le plus approprié à l'irri-

gation de sols de gros sable avec peu de différences de niveau d'eau et destinés aux paturages.

Pour l'exploitation mixte d'agriculture et d'élevage, le système composé offre plus de possibilités, surtout sur des sols de sable fin qui nécessitent l'adaptation du niveau phréatique à chaque culture. Un autre avantage important est que le niveau phréatique peut être modifié sans manipulations du niveau de l'eau dans les fossés. Un inconvénient pratique, cependant, est que les exploitants attendent trop longtemps avant de faire remonter le niveau au début d'une période de sécheresse.

L'infiltration d'une région sensible à la sécheresse se fait en commun pour la région entière et doit être gérée centralement. La distribution de l'eau doit être réglée dans tous les détails, car les modifications partielles ne manquent jamais d'exercer leur influence sur le fonctionnement de l'ensemble. Cela vaut autant pour la détermination de la hauteur d'infiltration que pour l'entrée de l'eau dans les fossés et les blocs de tuyaux.

Malgré l'infiltration, il peut se manifester des symptômes de sécheresse, par exemple si le niveau d'infiltration est trop bas, par des journées extrêmement sèches et chaudes, par l'action asséchante de profonds canaux dans le voisinage, par des irrégularités locales de la nature du sol ou par des couches du sol faisant obstacle. Pour améliorer la situation, on peut alors augmenter le niveau d'infiltration, faire un apport d'eau supplémentaire diminuer la distance entre les séries de tuyaux ou opérer un défonçage profonde. Quand le profil du sol est irrégulier, il est le plus souvent impossible de régulariser la distribution de l'eau sans procéder à des travaux compliqués d'amélioration du sol.

Des défauts du système de tuyaux peuvent également être cause d'une insuffisance de l'apport d'eau, par exemple à cause d'obstructions des tuyaux, des joints ou du sol dans le voisinage immédiat des tuyaux, obstructions dans lesquelles les composés de fer jouent un rôle important. Aussi faut-il signaler l'importance d'un contrôle et d'un entretien réguliers. S'il le faut, les séries de tuyaux sont déterrées et reposées. L'infiltration au moyen de canalisations à ciel ouvert est peu recommandable ici, vu entre autres les pertes de terrain, entretien etc.

Dans le polder Nord-Est, la direction et l'administration centrale sont exercées par le Service des Domaines de l'Etat, qui a nommé des sous-inspecteurs en charge chacun d'un territoire de 500 ha environ. Dans la question de détermination des niveaux, on s'efforce à laisser aux fermiers la responsabilité définitive.

ZUSAMMENFASSUNG

UNTERGRUNDBEWÄSSERUNG IN DEN ZUIDERSEEPOLDERN

Obgleich Holland ein ausgesprochen nasses Klima hat, kommen während der Wachstumszeit trotzdem wohl Perioden vor, in denen ein Mangel an Wasser für die Landwirtschaft auftritt. Dies ist der Grund, weshalb Böden mit geringer Wasserkapazität einer künstlichen Wasserversorgung bedürfen. In den neuen Zuiderseepoldern wird die unterirdische Bewässerung der dürre empfindlichen Böden zur Hand genommen. In dieser Abhandlung ist die Untergrundbewässerung im Nordostpolder – dem zweiten der fünf Polder in der ehemaligen Zuidersee – als Beispiel gewählt worden. Die bewässerte Fläche beträgt hier gut 8000 Hektar (siehe Karte).

Unter Untergrundbewässerung oder Infiltrierung wird verstanden: das auf so hoher Stufe halten des Grundwasserspiegels, dass die Gewächse für ihren Wasserbedarf vollen Nutzen daraus ziehen können. Die Infiltrierung wird bewerkstelligt, indem man ständig für einen bestimmten Hochwasserstand in den Gräben sorgt, wodurch das Wasser in die offenen Feldrinnen oder in die unterirdisch liegenden Röhren (Dränrohre) treten kann und von dort aus in den Boden sickert.

Ist die Dürreempfindlichkeit des Bodens entscheidend dafür, ob Untergrundbewässerung wünschenswert oder gar notwendig ist, für die Möglichkeit, sowie die Art und Weise, wie infiltriert werden muss, sind die Durchlässigkeit und der Aufbau der verschiedenen Bodenschichten ausschlaggebend. Im Nordostpolder sind es vor allem die ton- und humusarmen Sandböden, die wenig Wasser festhalten und deshalb für Infiltrierung in Betracht kommen. Auch Böden mit einer dünnen Tonsandschicht auf Grobsand, ferner auch die Feinsandböden werden bewässert. Böden mit einem Profil von Sand auf Tonsand verursachen bei der Bewässerung Schwierigkeiten in Bezug auf die Durchlässigkeit; diese Böden werden durch Tiefpflügen verbessert. Die Infiltrierung von Moorböden ist ganz besonders wichtig, um irreversibele Eintrocknung zu verhüten. Da dieses Moor gewöhnlich in geringer Tiefe auf durchlässigem Sand ruht, stellen sich der Bewässerung keine Schwierigkeiten entgegen. Diese treten nur dort auf, wo dicke Moorpakete liegen.

Untergrundbewasserung hat im Nordostpolder den Vorzug vor anderen Formen von Wasserbeschaffung oder Bewässerung. Die Geländeverhältnisse, wie z.B. die Höhenlage im Vergleich zum Aussenwasser, das geringe Gefälle vom Rande ab, die flache Lage der Erdoberfläche, dies alles ist günstig für die Anwendung der Infiltrierungsmethode. Dasselbe gilt für die Bodenart, die über grosse

Flächen gleichmässig ist. Auch die Trinkwasserversorgung und die Trennung bzw. Abwehr des Viehes werden erleichtert. Die Bedienung erfordert wenig Zeit, während die Unterhaltungsarbeiten ausserhalb der Vegetationsperiode verrichtet werden können. Der Eingriff in die Wirtschaftsführung ist demnach – im Gegensatz zur Beregnung – nur sehr geringfügig.

Im Hinblick auf die Notwendigkeit der Entwässerung während der nassen Periode ist das System der offenen Abfuhrgräben und der Reihen Dränrohre an sich schon ein unbedingtes Erfordernis, auch wenn nicht infiltriert wird. Mit verhältnismässig geringen Kosten und Eingriffen kann dieses Entwässerungssystem für Infiltrierung geeignet gemacht werden. Die extra Kosten betragen nur etwa 20 Gulden ($ 5.5) je Hektar je Jahr, einschl. Zinsen, Abschreibung, Unterhaltung und Bedienung, d.h. kapitalisiert am Datum der Anlegung 500 Gulden ($ 130) je Hektar.

Beregnung würde mindestens 1000 Gulden ($ 260) je Hektar mehr kosten. Auch ein Berieselungsplan würde im Vergleich zur Untergrundbewässerung viel eingreifender und kostspieliger sein.

Figur 2 gibt ein Beispiel des Grundwasserstandes in einem unterirdischen bewässerten Boden; der Einfluss des Abstandes der Dränrohrreihen, die Folgen, wenn Regen oder Quellwasser grösser als die Verdampfung sind – wobei dann das Entwässerungssystem in Tätigkeit ist – und die Folgen, wenn Verdampfung oder unterirdische Abfuhr grösser als der Regenfall sind – wobei also von der eigentlichen Untergrundbewässerung die Rede sein kann – werden hier aufgezeigt. In letzterwähntem Falle ist der Unterschied im Grundwasserstand über den Röhren und mitten da zwischen abhängig vom Mass der Verdampfung, der Durchlässigkeit des Bodens und der Abstände zwischen den Rohrreihen. Bei der Festsetzung des Abstandes wird danach gestrebt, dass bei einer normalen Verdampfung in einem Grasbestande in trockenen Perioden (4 bis 5 mm Niederschläge je Tag im Juni und Juli) der Unterschied im Grundwasserstand nicht grösser ist als 10 cm. Dasselbe gilt für den Unterschied im Wasserstand der Gräben und über dem Ende der Dränrohrreihen. Je nach Stärke der Durchlässigkeit des Sandes schwankt die Entfernung zwischen den Rohren zwischen 8 und 30 m.

Der wünschenswerteste Grundwasserstand in einer bestimmten Bodenart wird in erster Linie von der Höhe und der Schnelligkeit der kapillaren Steigung (vom freien Grundwasser aus) bestimmt. In Figur 3 ist von drei Typen Sandboden der Wassergehalt in Volumenprozenten über dem Grundwasserspiegel angegeben. Von einem der Typen sind in Figur 4 die Volumenprozente Boden, penduläres Wasser, Kapillarwasser und Luft für die einzelnen Schichten getrennt dargestellt. Hieraus wird der Schluss gezogen dass in diesem Boden 40 % Poren vorkommen, die in abnehmendem Masse bis auf 50 cm über dem phreatischen Niveau Kapillarwasser enthalten. Obendrein können nach Regenfall 15 % der Poren mit pendulären Filmwasser gefüllt bleiben. Beim Festsetzen des vorzugsweise gewünschtem Grundwasserstandes muss darauf geachtet werden, dass die kapillare Wasserzufuhr in der Wurzelzone ausreichend ist und dass ferner der Lufthaushalt in dieser Zone nicht in Gefahr gebracht wird. Im Grünland würde der Wasserspiegel in einem Boden vom Typ der Figur 4 in einer Trockenperiode 50 cm unter der Erdoberfläche liegen müssen, damit das kapillar aufsteigende Wasser die meist sehr untiefe Wurzelzone in genügender Weise erreicht. Der Grabenwasserstand muss dann 10 cm höher sein, um das Wasser in ausreichender Menge zuführen zu können. Bei anhaltender grosser Trockenheit würde der Grundwasserspiegel noch etwas höher liegen müssen, unter Beding, dass die Luftzufuhr dabei nicht unzureichend wird. In Holland kommt diese Notwendigkeit nur selten vor. Bei Regenfall wird das Wasser/Luft-Verhältnis geändert, da erst die Poren gefüllt werden mit pendulären Filmwasser wonach der Grundwasserstand und auch die Kapillarzone steigen. Wenn alle Poren mit diesem Wasser gefüllt sind, würde der Grundwasserstand beispielsweise um 10 cm gesenkt werden müssen, damit die Durchlüftung gewährleistet ist. Bei mehr Regen, als nötig ist für diese Porenfüllung, würde der Grabenwasserstand gesenkt werden müssen, damit das überschüssige Wasser schnell abgeleitet wird. Der Zusammenhang zwischen kapillarer Steighöhe, Grundwasserstand, Grabenwasserstand, Witterung und Wasserversorgung kann auch bei den anderen Sandböden festgestellt werden.

In der Praxis kann kein „Idealzustand" geschaffen werden wegen der verhältnismässig häufigen Änderung der Wetterverhältnisse. Die Trägheit der Wasserzufuhr und -abfuhr durch die Leitungen und die Wasserbewegung im Boden machen eine genaue Anpassung unmöglich. Es ist aber nicht wahrscheinlich, dass ein etwas zu hoher oder zu niedriger Wasserstand in der Praxis die Erträge beeinflussen wird. Man muss sich also begnügen mit einer Wasserhöhe in den Gräben, die während der Infiltrierungszeit so wenig wie möglich geändert wird. Im Nordostpolder hat man einen getrennten „Sommerpegel" und „Winterpegel" des Grundwasserstandes, mit einer Übergangsform im Frühjahr und Herbst. Der Sommerpegel wird nur bei extremen Witterungsumständen geändert. Den Winterpegel erhält man durch das Leerlaufen der Gräben. Mit dem Steigenlassen bis auf Frühjahrshöhe fängt man an, sobald das Vieh auf die Weide kommt. Die eigentliche Stauhöhe wird geregelt unter Berücksichtigung des Witterungsverlaufs und der Empfindlichkeit des Bodens für Trockenheit, gewöhnlich im Mai. Dasselbe gilt auch für die Festsetzung des Herbstpegelstandes, was meistens im September geschieht.

Um verschiedene Wasserhöhen schaffen zu können, sind regulierbare Wehre konstruiert worden (Figur 5). Im Winter ist die Vorderseite dieser Stauwerke ganz offen. Mit Hilfe eines Holzschiebers, vor einem Rahmen aus Beton sitzend, wird die gewünschte Höhe eingestellt, die abhängig ist von der erforderlichen Stauhöhe und der notwendigen Wasserzufuhr nach tieferliegendem Gelände. Man hat dabei einen Spielraum von 40 cm. Bei Steigung des Wasserverbrauchs (infolge Verdampfung) oder Verminderung (durch Niederschläge) muss die Zufuhr nach den einzelnen Parzellen dementsprechend geändert werden mit Hilfe der Einlassvorrichtung und der Schieber in den Wehranlagen. Da der Wasserverbrauch abgelesen werden kann, ist eine ziemlich genaue Anpassung an den Bedarf möglich. Natürlich muss auch der Pufferwirkung des Bodens, sowie der „Verlangsamung" Rechnung getragen werden. In Zweifelsfällen ist die Nachprüfung des Grundwasserstandes und der Bodenfeuchtigkeit zu empfehlen.

Zum Zwecke der Wasserbeherrschung wendet man zwei Systeme an: das einfache Infiltrierungssystem oder „*Vollenhove-System*" und das zusammengesetzte System oder „*Ramspol-System*".

Bei dem einfachen Infiltrierungssystem wird Wasser aus den Grenzgräben der Parzellen beiderseitig in Rohrreihen eingelassen, die jede eine Länge haben, welche mit der halben Parzellenbreite übereinstimmt (Figur 7). Die Rohrreihen münden einzeln in die Grenzgräben. Diese Gräben dienen sowohl zur An- und Abfuhr des Wassers, als auch zur Regulierung des Wasserstandes mit Hilfe von Wehren (nicht mehr als 10 cm Unterschied in Geländehöhe zwischen zwei Wehren).

Bei dem zusammengesetzten System dienen die Grenzgräben in der Infiltrierungszeit einer um den andern für die Bewässerung und die zwischenliegenden für die Entwässerung (Figur 7). Rohrreihen von höchstens 2 bis 3 Hektar sind zu einem Block vereinigt und haben gemeinsame Ausmündungen in beide Gräben, und zwar an der Seite des sog. „nassen" Grabens mit einem regulierbaren Einlass und

an der Seite des „trockenen" Grabens mit einem Auslass mit Stauhöheregelung. Der Unterschied in Geländehöhe beträgt hier nicht mehr als 20 cm (siehe auch Figur 8).
Das einfache System hat als Vorteile: die Einfachheit der Regulierung und Konstruktion, die verhältnismässig geringe Länge der Rohrreihen, die bequeme Pflege der Anlage. Der Nachteil ist, dass der Wasserstand in einer Parzelle nicht unabhängig von anderen Parzellen geregelt werden kann, wenn dies erwünscht sein sollte (vgl. z.B. Wasserbedarf Grünland und Rübenfeld). In der Praxis ist dies meistens wohl nicht so schlimm, weil ein optimal günstiger Umstand für die eine Kultur gewöhnlich wenig oder keinen Schaden anrichtet bei der anderen Kultur. Das einfache System erweist sich am geeignetsten für die grobsandigen Böden mit nur geringen Unterschieden im Wasserstand und mit der Bestimmung Grünland.
Für den gemischten Betrieb bietet das zusammengesetzte System mehr Möglichkeiten, besonders auf den Feinsandböden, die für jede Kulturart die Anpassung des Grundwasserstandes erfordern. Ein wichtiger Vorteil ist ferner, dass der Grundwasserstand geändert werden kann ohne Zuhilfenahme des Grabenwasserstandes. Dagegen ist es in der Praxis ein Nachteil, dass die Bodengebraucher beim Eintritt der Trockenheit zu lange warten mit der Erhöhung des Wasserstandes.
Anwendung der Infiltrierung in einem für Trockenheit empfindlichen Gebiet geschieht gemeinschaftlich für das ganze Gebiet und mit zentraler Verwaltung. Die Wasserverteilung muss bis in Einzelheiten geregelt sein, da Änderungen in einem Teilstück das gute Funktionieren des Ganzen beeinflussen. Dies gilt sowohl für die Regulierung der Stauhöhe, als auch für den Einlass von Wasser in die Gräben und Röhrensysteme.
Trotz Infiltrierung können Austrocknungssymptome auftreten, z.B. bei zu niedriger Stauhöhe, ferner an aussergewöhnlich trockenen und warmen Tagen, durch die dränierende Wirkung von tiefen Kanälen in der Umgebung, durch örtliche Abweichungen in der Bodenart oder durch störende Bodenschichten. Zwecks Verbesserung der Sachlage können dann in Erwägung gezogen werden: Erhöhung der Stauhöhe, zusätzliche Wasserzufuhr, Verschmälerung des Abstandes zwischen den Dränrohrreihen, eventuell auch Tiefpflügen. Bei unregelmässigem Bodenprofil ist es vielfach nicht möglich, um ohne komplizierte Bodenverbesserungen eine gleichmässige Wasserversorgung zu erreichen.
Auch Mängel im Rohrsystem können die Ursache ungenügender Wasserzufuhr sein, z.B. Verstopfungen in den Röhren, in den Stossfugen oder in nächster Umgebung der Röhren, wobei Eisenverbindungen eine bedeutsame Rolle spielen. Auf das fachkundige und regelmässige Kontrollieren und Reinigen der Dränrohre wird mit Nachdruck hingewiesen. Nötigenfalls werden die Reihen ausgegraben und neu gelegt.
Infiltrierung mittels offener Rinnen verdient keineswegs den Vorzug, unter anderm wegen des Landverlustes und der Unterhaltungsarbeiten.
Im Nordostpolder beruhen die zentrale Leitung und die Verwaltung beim Domänenamt, welches Unteraufseher angestellt hat, jeder für ein Gebiet von rund 500 Hektar. Bei der Regelung liegt das Bestreben vor, die Verantwortlichkeit für diesen Teil der Bewirtschaftung nicht von den Bauern abzuwälzen.

COMPENDIO

SUBIRRIGACION EN LOS POLDERES DEL ZUIDERZEE

Si bien Holanda tiene un clima marcadamente húmedo, no por eso dejan de presentarse en la época de crecimiento vegetal períodos de escasez de humedad para la agricultura, motivo por el cual es necesario adicionar agua artificialmente a los suelos de reducida capacidad de retención.

En los nuevos pólderes del Zuiderzee la adición de agua a los suelos sensibles a la sequía tiene lugar mediante la subirrigación. En el presente artículo hemos tomado el pólder Nordoriental – el segundo de los cinco que surgirán en el que fué Zuiderzee – como ejemplo. La superficie subirrigada asciende a más de 8.000 hectáreas (véase plano).

Por subirrigación se entiende el elevar el nivel del agua freática a una altura tal que los cultivos puedan sacar pleno provecho de ella a los efectos de su provisión de humedad. La subirrigación se consigue manteniendo el agua de los canales a un nivel determinado, de forma que pueda penetrar en las zanjas e hileras de tubos, desde donde es absorbida por la tierra.

Si la sensibilidad a la sequía del suelo sirve para determinar la conveniencia o la necesidad de proceder a la subirrigación, por lo que respecta a la posibilidad y sistema más adecuado de subirrigación, la permeabilidad y la constitución de las diferentes capas del suelo, constituyen factores decisivos. En el pólder Nordoriental son sobre todo los suelos arenosos pobres en arcilla y mantillo los que entran en cuenta al efecto. Tambien son subirrigadas las tierras con una capa areno-arcillosa delgada sobre arena gruesa, y las tierras arenosas finas. Los suelos con un perfil de capa arenosa sobre areno-arcillosa ofrecen dificultades para la subirrigación por consecuencia de la permeabilidad; estos suelos son mejorados mediante el laboreo profundo. La subirrigación de los suelos turbosos es importante sobre todo para evitar la desecación irreversible. Como la capa turbosa descansa por lo común y a poco profundidad, sobre arena permeable, la subirrigación no presenta dificultades. Estas sólo surgen en aquellos lugares en que se encuentran gruesos depósitos turbosos.

Por lo que al pólder Nordoriental se refiere, la subirrigación resulta preferible a cualquier otra forma de adición artificial de humedad.

Son circunstancias favorables al empleo del método de subirrigación: el nivel más bajo del terreno con respecto a las aguas circundantes, escaso declive desde el borde, superficie de cultivo llana, y no menos la uniformidad del tipo de suelo sobre grandes superficies. Tales circunstancias, por lo demás, favorecen igualmente a la provisión de agua potable y limita la libertad del ganado. El servicio requiere poco tiempo, las labores de conservación pueden ser realizadas fuera de la temporada de crecimiento vegetal, su trascendencia en cuanto al sistema de explotación es de escasa monta, a diferencia del riego por aspersión. En efecto, dada la necesidad de evacuar las aguas sobrantes durante el período húmedo, es preciso disponer de un sistema de zanjas e hileras de tubos de drenaje aunque no se aplique el método de subirrigación. En estas condiciones el habilitar el sistema de desagüe para la subirrigación no supone sino un gasto muy reducido y escasas previsiones. Los gastos, incluyendo intereses, amortización, conservación y servicio, no sobrepasan los 20 florines ($ 5.5) por año y hectárea, es decir, florines 500 ($ 130) capitalizado en la fecha de construcción.

El riego por aspersión costaría 1000,- florines más por hectárea como mínimo. Un plan de irrigación superficial sería, tambien, mucho más costoso y difícil.

El diseño No. 2 constituye un ejemplo de la situación de nivel del agua freática en una tierra subirrigada; en él queda demostrada la influencia de la distancia entre las hileras de tubos, las consecuencias resultantes de una precipitación pluvial o una infiltración de aguas circundantes superiores a la evaporación, las consecuencias derivadas de una evaporación o escape de aguas del subsuelo superiores a la precipitación pluvial, todos los aspectos, en fin, de la subirrigación. En el último de los casos enunciados, la diferencia de nivel de aguas freaticas encima de las hileras de tubos y en el centro de la parcela guarda dependencia con el grado de evaporación, permeabilidad del suelo y distancia entre las hileras de tubos. Para determinar esta distancia se procura que en caso de evaporación normal de pastizales en períodos secos (4 a 5 mm por día en junio y julio), la diferencia de nivel del agua freática no exceda de 10 cm. Lo mismo cabe decir del nivel del agua en la zanja y por encima del terminal de las hileras de tubos. La distancia entre hileras oscila entre 8 y 30 metros, con dependencia de la permeabilidad del suelo.

El óptimo nivel freático en un tipo de suelo dado es determinado en primer lugar por la altura y la rapidez de absorción capilar desde las aguas del subsuelo. En el diseño No. 3 se consigna el grado de humedad en porcentaje/volumen de tres tipos de suelos arenosos. De uno de estos tipos se indica en el diseño No. 4 el porcentaje/volumen de tierra, agua suspendida, agua capilar y aire, para cada una de las capas por separado. De ello cabe deducir que en este tipo de suelo el porcentaje de poros es de 40, que contienen agua capilar, en grado decreciente, hasta una altura de 50 cm. por encima del nivel freático. Además, después de una precipitación pluvial, el 15 por ciento de los poros puede quedar lleno de agua suspendida. Para la determinación del nivel freático óptimo ha de tenerse buen cuidado de que la adición de agua capilar en la zona de la raíz sea suficiente, sin que quede alterado el proceso de aereación. Para praderas, el nivel de agua del subsuelo en el tipo de suelo del diseño No. 4 habrá de encontrarse en períodos secos a 50 cm. de la superficie, con el fin de que el agua de infiltración capilar llegue en cantidad suficiente a las poco profundas raíces de la planta. El nivel del agua de la zanja habrá de tener 10 cm. más de altura para asegurar la necesaria afluencia. En caso de sequía pertinaz el nivel del agua freática podría ser algo más elevado aun, siempre que no se perturbe el proceso de aereación. Esta necesidad no se presenta en Holanda sino muy raras veces. En caso de lluvia la proporción agua/aire es alterada ya que primero se llenan los poros de agua en suspensión, después de lo cual ascienden tanto el nivel del agua freática como la zona capilar. Si la lluvia hubiera colmado todos los poros del agua suspendida, habrá de hacerse descender el nivel del agua freática en 10 cm. para asegurar la aereación. Y si la precipitación pluvial es más intensa de lo necesario para colmar estos poros, habrá de hacerse descender el nivel del agua de los canales para permitir la rápida evacuación de las aguas sobrantes. Del mismo modo podrá estudiarse la relación entre altura capilar, nivel del agua freática, nivel de agua de la zanja, condiciones climatológicas y provisión de humedad, en los demás tipos de suelos arenosos.

En la práctica resulta imposible alcanzar la situación ideal por causa de los frecuentes cambios que experimentan las condiciones atmosféricas. La lentitud de afluencia o reflujo del agua por los conductos y los movimientos de las aguas en el suelo imposibilitan la rigurosa adaptación. Ahora bien, no es probable que un nivel algo más alto o más bajo de lo debido influya en la producción. Bastará, pues, con llegar a un nivel del agua en las zanjas que durante la época de subirrigación apenas sea necesario modificar. En el pólder Nordoriental se mantiene un nivel de invierno y un nivel de verano diferentes, con un nivel de transición en primavera y otoño; el nivel de verano sólo es modificado en caso de condiciones atmosféricas excepcionales. El nivel de invierno se consigue vaciando el agua de las zanjas. Con el nivel de primavera se empieza cuando el ganado se saca a las praderas. El nivel de embalse propiamente dicho se regula generalmente en mayo, si bien el momento exacto depende de las condiciones atmosféricas y de la sensibilidad a la sequía del suelo. Lo mismo cabe decir del nivel de otoño, que por lo común es regulado en el mes de septiembre.

Para poder establecer diferentes niveles se han construido vertedores de embalse regulables (diseño No. 5). En el invierno la cortina está abierta por completo. Con una compuerta de madera que se desliza en un bastidor de cemento se establece la altura deseada, con dependencia del nivel de embalse deseado y de la necesaria afluencia de agua a las zonas más bajas de terreno. Se dispone de un margen de 40 cm. En caso de aumento de consumo de agua (evaporación) o disminución (precipitaciones), ha de ser regulada la afluencia a las diferentes parcelas por medio de las compuertas de los vertedores de embalse. Como es fácil comprobar la descarga en la escala, resulta posible una regulación bastante exacta. Ha de ser tenida en cuenta la permeabilidad de suelo y el tiempo de concentración. En casos de duda, es recomendable el control del nivel freático y del grado de humedad del suelo.

Para la regulación de las aguas se aplican dos sistemas: el sistema simple de subirrigación o *sistema Vollenhove*, y el sistema compuesto o *sistema Ramspol.*

En el primero el agua es impulsada desde las zanjas de parcelación en las hileras de tubos, cada una de las cuales tiene una longitud igual a la mitad del ancho de la parcela (diseño No. 7). Las hileras de tubos desembocan una por una en la zanja de parcelación. Todas las zanjas de parcelación sirven tanto para la afluencia y evacuación del agua como para regular su nivel con ayuda de vertedores de embalse (no más de 10 cm. de diferencia en altura de terreno entre dos vertedores).

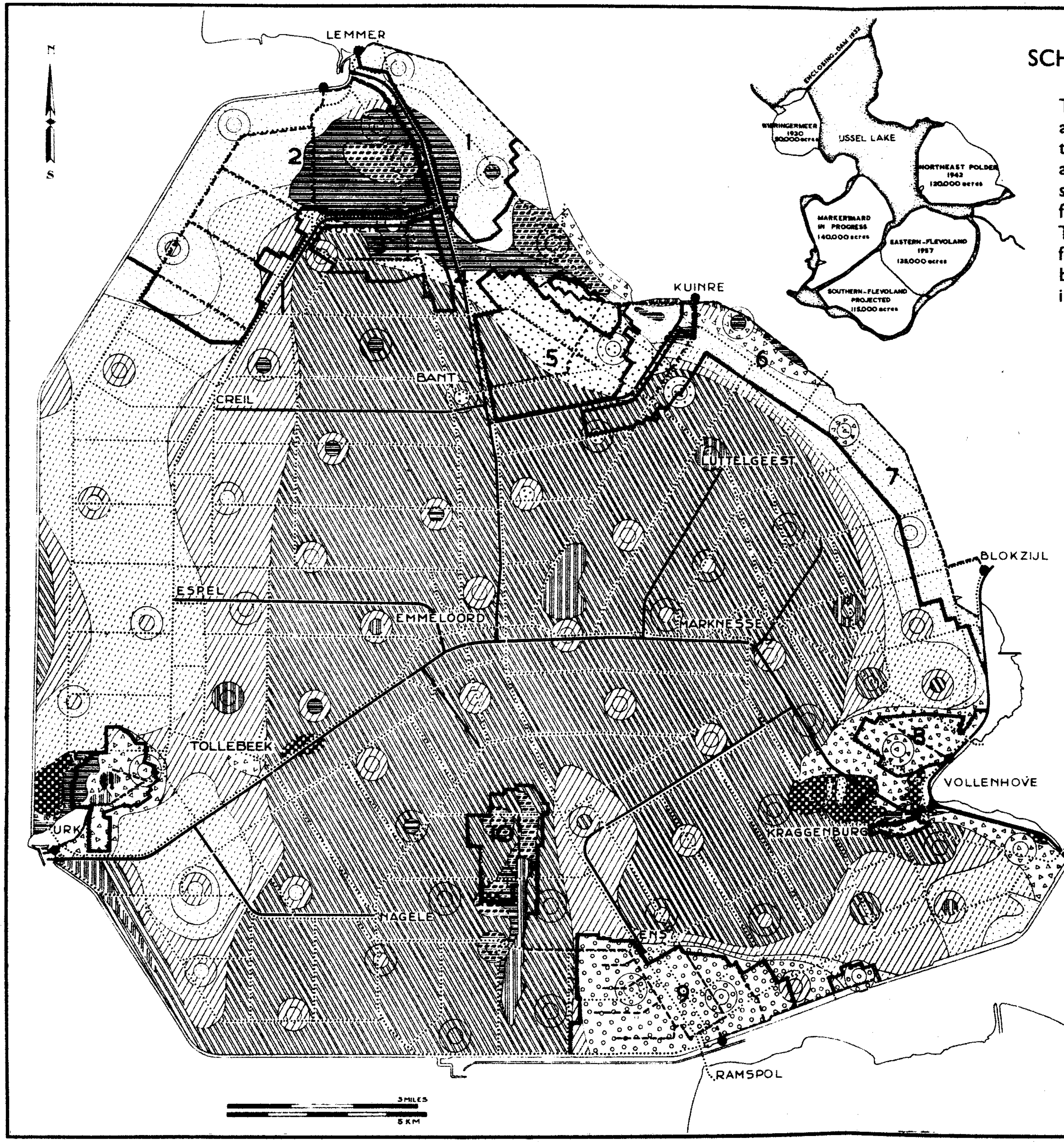
En el sistema compuesto las zanjas de parcelación sirven una para la afluencia y otra para la evacuación de aguas alternativamente (diseño No. 7). Las hileras de tubos de 2 a 3 hectáreas como máximo están unidas en un solo bloque con desembocaduras comunes en ambas zanjas, y ello con una compuerta regulable de admisión en el lado de la zanja «húmeda» y una compuerta de descarga provisto de regulación de altura en el lado de la zanja «seca». La diferencia en altura de terreno no sobrepasa en este sistema los 20 cm. (véase también diseño No. 8).

El sistema simple ofrece como ventajas: sencillez de regulación y de construcción; longitud relativamente corta de las hileras de tubos; facilidad de entretenimiento. Y presenta el inconveniente de que no es posible la regulación de aguas en una parcela con independencia de las demás, lo cual puede resultar nece-

sario (compárese las necesidades de humedad de pastizales y remolacha por ejemplo). En la práctica, sin embargo, el problema no es tan grave como parece pues en general las condiciones óptimas de humedad para un cultivo no serán perjudiciales, o bien sólo en grado reducido, para los demás cultivos. El sistema simple resulta el más adecuado para los suelos de arena gruesa con pequeños diferencias en nivel de agua y destinadas a cultivos pratenses.
En las explotaciones mixtas el sistema compuesto ofrece más amplias posibilidades, sobre todo en los suelos arenosos finos que requieren una adaptación del nivel de las aguas a cada uno de los diferentes cultivos. Ventaja importante además que es posible regular el nivel freático sin alterar el nivel de las zanjas. Como inconveniente práctico puede mencionarse que al presentarse un período de sequía los agricultores suelen demorar excesivamente la elevación del nivel.
La aplicación de la subirrigación en zonas sensibles a la sequía tiene lugar en común para toda la zona y ha de ser administrada centralmente. La distribución de aguas ha de ser estudiada con todo detalle porque las modificaciones en las partes son siempre de influencia en el buen funcionamiento del todo. Esto es de aplicación tanto a la regulación del nivel de embalse como al llenado de las zanjas de parcelación y de las hileras de tubos.

A pesar de la subirrigación pueden producirse fenómenos de sequía, v.gr. en caso de un nivel de embalse demasiado bajo, en días extraordinariamente secos y cálidos, por la acción desecadora de canales profundos en las cercanías, por diferencias locales en la composición del suelo, o por la presencia de capas que constituyen factor perturbador. Como soluciones posibles pueden ser consideradas: la elevación del nivel de embalse, adición posterior de agua, estrechamiento de las parcelas entre las hileras de tubos o el laboreo profundo. Si las anomalías proceden de un perfil irregular del suelo, resulta, en general, difícil llegar a una distribución uniforme de humedad sin complejas labores de mejora del suelo.
La adición insuficiente de humedad puede ser originada tambien por deficiencias en el sistema de tubos, v.gr. por atascamiento de éstos, en las juntas de acoplamiento o en la directa proximidad de los tubos. En los atascamientos suelen desempeñar importante papel las precipitaciones de hierro. Así pues, con énfasis se recomienda un control y limpieza regulares de los tubos por personas expertas. En caso necesario se procederá a extraer los tubos y volverlos a colocar. La subirrigación por medio de zanjas abiertas no es recomendable, entre otras razones por la pérdida de superficie de cultivo, entretenimiento de las zanjas, etc.

En el pólder Nordoriental la administración central está encomendada al *Dienst der Domeinen* (Servicio del Patrimonio Real), que tiene subinspectores con un campo de operaciones de alrededor de 800 hectáreas. En la regulación se tiende a no cargar al agricultor con la responsabilidad de esta operación.



SCHEMATIC SOILMAP OF THE NORTHEAST POLDER

The map shows the types of soil in the upper layer of 25 cm, as mentioned in the legends. On representative spots the types of subsoil are shown within two concentric circles according to the same legends (outermost circle for the subsoil from 25 cm-50 cm, innermost one for underlying layer from 50 cm-75 cm beneath the soil surface).
The types of soil are recorded in their natural location before the water was removed. Consequently soil transposed before or afterwards by human action has not been taken into consideration.

Mineral Zuiderzee – sediments	% < 2 Micron
1. Fine and very fine sand	0-5
2. Light loam A	5-8
3. Light loam B	8-12
4. Heavy loam A and B	12-25
5. Clay-loam	25-35

Other mineral soils

6. Boulder clay
7. Pleistocene sand
8. IJssel sand
9. Coarse sands of older origin shifted by the influence of the Zuiderzee

Peat-Soils

10. Peat and peat-detritus
11. Complex of peat-decay

Roads
canals
Main water supply ditch with inlet subirrigated areas
7 Subirrigated areas

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THE INTERNATIONAL INSTITUTE FOR LAND RECLAMATION AND IMPROVEMENT

No. 1: TAKES, Dr. Ch. A. P., Physical planning in connection with land reclamation and improvement
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In preparation:

Soil survey for drainage reclamation and landclassification of the Zuiderzee
Reclamation of soils flooded by salt water
Role of water in rice cultivation
Water deficiencies in Europe
Land consolidation in Europe