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## RECLAIMING LAND FLOODED WITH SALT WATER

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## II EXCHANGEABLE CATIONS

Some general remarks on exchangeable cations. One of the disadvantages of flooding with seawater is the replacement of a great proportion of the exchangeable calcium ions in the clay substance by sodium ions from the salt; this phenomenon causes difficulties with soil structure.

As an introduction to the treatment of this problem it is desirable to make some general remarks on exchangeable cations. In Dutch clay soils the clay fraction (particles smaller then 2 micron) has practically always the same mineralogical composition. For this reason its adsorption capacity is always the same, i.e. (at pH 7½) about 60 m.e. per 100 g. The humus which is present in the soil has an adsorption capacity about 3 times as great as the clay. In the Netherlands it is usual to express the adsorption capacity of the soil besides per 100 g dry matter, also per 100 g adsorbing material; the adsorbing material is understood to be the sum of the clay content and 3 times the humus content.

The exchangeable cations may consist of Ca, Mg, K, or Na. Ca and Mg, and to a certain extent also K, are firmly bound to the clay substance, Na only feebly. When therefore Ca salts are added to a soil which contains much exchangeable Na, this exchangeable Na is easily removed from the adsorption complex. Another consequence of this difference in binding force between Na and Ca is, that there is a difference in physical characteristics and therefore also in agricultural behaviour between soils where the adsorption complex is occupied almost exclusively by Ca, and soils where a considerable part of the exchangeable cations consist of Na.

In the first mentioned soil type a granular structure once formed is stable. Soils with much exchangeable Na in their adsorption complex, on the contrary, easily lose their granular structure; the soil particles soon become disengaged when there is an excess of water. This structure is very unfavourable for agriculture, as will be discussed later in detail.

This harmful influence is already caused by small amounts of exchangeable Na. Of course it is important to know the lowest Na level at which breakdown of structure occurs. This level however can only be roughly estimated, as no sharp line can be drawn and as several secundary circumstances can also be of influence.

The critical Na level may be expressed in two ways, viz. as a percentage of Na ions among the ions adsorbed or as a certain amount of Na per 100 g dry matter. Probably the breakdown of structure is primarily governed by the percentage of Na ions at the adsorption complex. According to this point of view the critical Na level may be expressed as the percentage of Na among the adsorbed cations; it may be roughly stated that soil structure may be unfavourably influenced as soon as more than 5% of the exchangeable cations consist of Na.

However, on heavy soils a breakdown of structure is far more harmful to agriculture than on light soils; so a given percentage of Na is the more dangerous as the soil in question is heavier. As a consequence the percentage of Na among the adsorbed cations at which agricultural troubles appear is lower for light soils than for heavy ones. This difficulty may be avoided by expressing the critical Na level in m.e. per 100 g dry matter. In heavy soils this figure corresponds to a relatively low percentage of Na among the exchangeable bases, whereas in light soils the reverse is true.

Troubles with soil structure may be expected if the exchangeable Na exceeds 1 m.e. per 100 g dry matter; these troubles increase at increasing Na content.

But a high amount of exchangeable Na has only an unfavourable effect on the structure when the soil contains only a small amount of dissolved salts. In soils, which have been flooded by seawater the structure remains practically normal as long as the salinity is still high. During the first summer after inundation only slight troubles with soil structure may be expected.

In this stage the structure may deteriorate when heavy rains remove the soluble salts from the surface of the soil crumbs. In that case these crumbs may stick together, forming a crust, which will not disappear at once, after the salinity has risen again. This crust-formation however is not the rule; moreover it is only limited to the surface and substantially less serious than in following years.

The typical heavy decline of structure begins in the first winter after drainage, when the soluble salts are largely removed from the topsoil. Its first signs occur as soon as the concentration of common salt in the soil moisture drops below 5 g per l. There is some evidence that even small amounts of soluble salts have a beneficial effect on the structure. The above mentioned limit of 1 m.e. exchangeable Na per 100 g dry matter is only valid after some years, when nearly all soluble salts have been leached out.

Furthermore, the crumb structure is only lost if the soil is stirred; therefore, this only occurs in the layer that is ploughed and especially at the surface which is exposed to the devastating influence of falling raindrops. Finally it must be mentioned that a high humus content makes the soil less sensitive to the unfavourable influence of the Na. Arable soils converted from grassland for instance, are therefore little affected by a high content of exchangeable Na.

Exchangeable cation relationships in inundated soils. In normal soils the exchangeable cations consist for the greater part of Ca. Seawater is relatively poor in Ca and very rich in Mg and Na. In inundation by seawater, therefore, a considerable part of Ca is exchanged against Mg and Na. The affinity of Mg for the soil is much stronger than that of Na. In this way, though the Na content of the seawater is much higher than the Mg content, about as much Ca is replaced by Mg as by Na.

A flooded soil obtains the highest Na content when the adsorption complex is in equilibrium with the seawater. Usually this Na content is not attained even if the soil moisture is entirely saline, because the exchanged Ca remains in the soil and therefore counteracts the adsorption of other ions. In table 7 a number of data are included; for the soil flooded with seawater a soil is chosen which has been under salt water for a long period of time; the salt content of the soil moisture at the moment of drainage amounted to about 20 g per l.

Table 7. Composition of the cation saturation of the adsorption complex expressed in percentages.

	Normal soil	Soil in equilibrium with seawater	Soil flooded with seawater
Ca Mg K Na	88 8 3 1	21 36 10 33	48 25 6 21
Total	100	100	100

As may be derived from these figures, a light soil (e.g. with 10% clay and 2% organic matter), flooded with seawater, will contain about 2 m.e. of exchangeable Na per 100 g dry matter, whereas in a heavier soil (e.g. with 30% clay and 3% organic matter) this figure will be about 5 m.e.

As has been remarked before the excess of salt quickly leaches from the soil. During this leaching the saturation of the adsorption complex changes little so that also after the leaching of the salt it has a high Na content. The consequences of the inundation are therefore much longer noticeable in the Na content of the adsorption complex then in the salt content of the soil moisture.

As exchange of Na against H is only possible on a very limited scale the Na percentage of the adsorption complex can only drop when this Na is exchanged for other cations. In calcareous soils such cations mainly have to be produced by the calcium carbonate. In laboratory experiments under adequately favourable conditions calcium carbonate noticeably affects an adsorption complex rich in Na. It is, however, questionable whether this reaction is also of much importance in the field where circumstances are less favourable. The calcium carbonate being practically insoluble the action is probably slow as there is little contact between calcium carbonate and soil particles.

However, there is still another way in which the calcium carbonate acts on the regeneration of the adsorption complex. Through the carbonic acid from the rainwater and from biological processes a certain quantity of calcium carbonate dissolves yearly. This dissolved quantity of calcium acts very quickly on the adsorption complex. As the Ca has a much greater affinity to the adsorption complex than the Na, the Ca ions of the Ca(HCO<sub>3</sub>)<sub>2</sub>, which was formed in the course of a certain period, expel almost completely an equivalent amount of Na ions. In the well drained Dutch soils the Na HCO<sub>3</sub> so formed is drained away in the next winter, which makes a further exchange possible.

The rate of regeneration of the adsorption complex, therefore, depends on the quantity of Ca ions which are mobilized; table 8 gives an example which is representative for a very salty soil <sup>13</sup>).

Table 8.	Content of exchangeable Na in milli-equivalents per 100 g dry matter in a so	oil
	having become very salty by seawater.	

Lover		Yes	ars after drain	age	
Layer (in cm)	1	2½	3½	4½	5½
0-10	6.2	5.3	4.1	2.8	2.4
10-20	7.1	6.4	6.2	5.9	4.7

From this table it appears that the decrease of the Na content in the uppermost 10 cm is quicker than in the next 10 cm. One of the reasons for this difference is, that the Na HCO<sub>3</sub> exchanged from the uppermost layer, in

<sup>&</sup>lt;sup>13</sup>) Table 8 refers to a soil, situated on the island of Walcheren. This soil which was drained in late autumn 1945 contains in the upper layer 33% of adsorbing material. After drainage the soil moisture of the upper layer contained  $\pm$  30 g salt per l, after 1 year  $\pm$  5 g and after 2½ years  $\pm$  1 g.

leaching down, impedes the regeneration of the subsoil. In the layer of 20–40 cm the regeneration proceeds still slower than in that of 10–20 cm.

The table further shows that the regeneration has proceeded at a practically constant ratio, which is independent of the content of exchangeable Na. From a considerable number of figures it was concluded that the ratio of regeneration is always about the same in soils, either rich or poor in clay or in Na; with respect to the uppermost 10 cm of the soil the drop of the Na content amounts to an annual average of 0.7 m.e. per 100 g dry matter.

This means, consequently, that the Na content of the adsorption complex and with that the physical behaviour of the soil, become normal at a quicker rate when less exchangeable Na is present at the moment of drainage i.e., when the clay content and the percentual saturation of Na in the adsorption complex are lower. This conclusion is also corroborated by observations in practice.

The above mentioned facts apply to soils containing calcium carbonate. Few data are available on the regeneration of soils lacking calcium carbonate. It is to be expected that in these soils the natural regeneration proceeds slower. Sometimes this is experienced indeed. In other cases the Na content of these soils drops with about equal rapidity as is the case with calcareous soils. Evidently the quantity of Ca which is mobilized from the fertilizers and vegetable residues cannot be neglected provided the pH is not too low. Perhaps this drop of the Na content in soils without calcium carbonate which are often acid soils is partly attributable to an exchange by H; further data in this respect are, however, not available as in this type of soils so far only Na is determined.

Application of gypsum for the regeneration. The preceding paragraph shows that the natural regeneration in the uppermost 10 cm of the soil results in an annual drop of 0.7 m.e. Na per 100 g dry soil.

For very light soils with, for instance, 15% adsorbing material and 15% exchangeable Na in their adsorption complex, which consequently contain about 1.4 m.e. Na per 100 g dry matter, this means that the Na content here has dropped below the dangerous limit of 1 m.e. in one year. In heavy clay soils, however, the regeneration takes 5 to 10 years.

Such a long period of poor structure, however, causes serious disadvantages for the highly developed crop production in the Netherlands. For this reason a quicker regeneration of the structure is attempted by application of soluble Ca salts, for which purpose in the Netherlands gypsum is used generally. This gypsum treatment of flooded soils was already practised in 1918 bij Hissink in field experiments; its use on a large scale in agriculture dates from 1940, gypsum as a remedial agent for saline soils being generally used after the inundations during the second world war. For the effect of a gypsum application on the Na content of the adsorption complex may be referred to table 10, the discussion of which will follow later on.

An important question in this gypsum treatment is, how much gypsum should be given in order to restore the structure of the soil. This point could only be solved by field experiments with different dressings of gypsum. These experiments have been carried out in large numbers after the inundations of 1944—'45.

The trial fields were observed for several years; for each field the amount of gypsum needed was derived from crop production and from general observations of the structure.

It was not easy to draw conclusions from these data as in different years greatly varying results were obtained. It stands to reason that the disadvantage from a bad structure largely depends upon the tolerance of the crop and upon meteorological circumstances. Therefore the amounts of gypsum derived from these observations are somewhat arbitrary.

It appeared from the experiments that sufficient crop production was possible at gypsum dressings too low to secure a good soil structure. Obviously a moderate structure was generally good enough to secure satisfactory crop growth. As however the farmer's risks are largely reduced by a good structure the latter was also taken into account in evaluating the results.

In diagram 3 the dressings of gypsum thought necessary on different trial fields are mentioned. These dressings were plotted against the original Na content of the upper 10 cm in m.e. per 100 g dry matter. The upper 10 cm were chosen as a reference as breakdown of structure is generally limited to this layer. After an inundation the soil is only tilled very shallowly (about 10 cm) and the untilled soil beneath does not lose its structure. So the amount of gypsum only has to regenerate the upper 10 cm; regeneration of deeper layers may be left to nature or to an excess of gypsum percolating from the topsoil.

Furthermore, it seems reasonable to express the original Na content of the soil in m.e. per 100 g dry matter as the gypsum dressings are intended to remove the exchangeable Na. This line of thought was confirmed by a study of the results from different trial fields; very saline light soils possessing about the same amounts of exchangeable Na per 100 g dry matter as heavy, but less saline soils, needed about the same dressings of gypsum.

The results shown in fig. 3 may be expressed by the equation:

$$a = 2.2 (b-1)$$
 in which

- a= amount of gypsum (CaSO $_4$  . 2 aq) in tons/ha needed to reach agriculturally satisfying conditions,
- b = amount of exchangeable Na, just after draining, in the upper 10 cm of the soil, expressed as m.e. per 100 g dry matter.

As follows from fig. 3 no gypsum is needed in soils containing less than 1 m.e. Na per 100 g dry matter. This agrees with an earlier statement that in such soils either no breakdown of structure occurs or that agriculture is not seriously affected by it.

Moreover in such cases the excess of Na is soon removed by natural recovery (c.f. table 8). Therefore on very light soils gypsum dressings are not advised. The amounts of gypsum which are thought desirable are mentioned in table 15; to avoid risks they are slightly higher than would follow from fig. 3.

The relation between Na-content of the topsoil and the amount of gypsum may also be determined in quite another way, viz. by investigating the amounts of Na which must be replaced by Ca. If in addition to that, we know the efficiency of gypsum dressings we can calculate the amounts of gypsum needed. This efficiency of gypsum dressings can be derived from soil analyses carried out on the experimental fields. In this calculation natural recovery must be taken into account (c.f. table 8); therefore the amounts of gypsum will be lower than might be expected from the initial Na content of the soil and from their efficiency.

According to this method of calculation the gypsum dressings should begin at a Na content being somewhat higher than 1 m.e. per 100 g dry matter. At medium Na contents the amounts of gypsum calculated with this method are nearly the same as those derived from fig. 3. At high Na contents however a discrepancy occurs, the new method giving higher values than those from fig. 3. Comparing the results of this method with the data

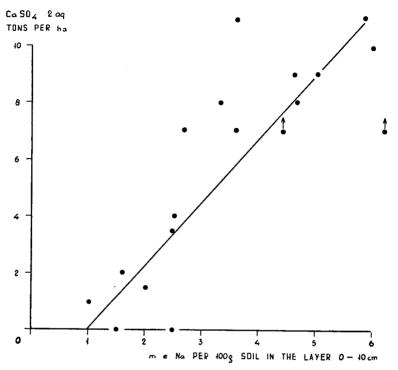


FIG. 3. RELATION BETWEEN CONTENT OF EXCHANGEABLE NA AND THE AMOUNT OF GYPSUM NEEDED TO REACH AGRICULTURALLY SATISFYING CONDITIONS.

Maximal gypsum dressing applied on experimental field not sufficient for reaching agriculturally satisfying conditions.

from fig. 3 it may be stated that they do not come into statistical conflict with those data, but that they are not the most probable solution.

Gypsum treatment and crop production. As has already been stated, soils which contain much exchangeable Na are inclined to desintegrate into separate particles under wet conditions. In consequence thereof they turn to a structureless slush. Nevertheless the structure present from before the inundation is still so stable that, for the greater part, it persists, provided the soil is left untouched. In the subsoil, therefore, little structural breakdown occurs; the breakdown is mainly limited to the cultivated layer. Cultivation more or less destroys the original structural elements and it seems that the newly formed ones are considerably less stable. Even more than the cultivated layer the surface which is exposed to the destructive action of the falling raindrops suffers from structural breakdown. This surface layer very soon becomes sticky and impermeable.

Another peculiarity of Na clay is, that in case of drought the silted layer dries into a homogenous mass, with only a few large cracks here and there.

The loss of crumb structure due to Na has disagreeable consequences for agriculture. When ploughed in autumn the soil gradually collapses so that the losse condition is lost; in serious cases a tough paste with very little permeability is formed.

The surface is also eroded by rain. Here the sand and clay particles become



Photo 1. Effect of Gypsum on the structure of an inundated soil. On the untreated plots the soil has lost its coherence; the clay particles were transported downward, the sand particles were left behind. Therefore the untreated plots show a white colour, whereas the plots treated with gypsum are grey.



Photo 2. Structure of an inundated light soil in spring. The surface has become entirely flat. The soil particles are packed so densely that even in this light soil cracks were formed.



Photo 3. Structure of an inundated heavy soil in spring. The small elevations are already dry; much clay has been transported to the small depresions, which are still wet. The soil is heavily cracked.

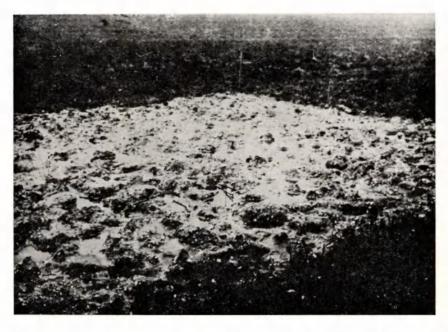


Photo 4. Breakdown of structure caused by a large amount of exchangeable Na. The plot in the centre was treated with 60.000 kg/ha of common salt some years before. It is entirely covered with poors.



Photo 5. Bad structure of a heavy soil caused by a large amount of exchangeable Na.

Two lumps of soil with the same clay content were crumbled by hand for the same time. The left one is from a normal soil, the right one had been inundated.

separated; many of the clay particles are washed to the ditch so that the latter becomes partly filled with thin mud. The remaining sand-grains yield to the soil a whitish appearance (photo 1). The erosion reduces the relief of the ploughed soil considerably. Light soils become absolutely level (photo 2); in heavier soils the relief only decreases (photo 3); the soil is washed away from the higher parts into the depressions, if not into the ditch. Already early in autumn there are pools on the land and it becomes unmanageable (photo 4). This situation often causes great troubles as to autumn cultivation and harvesting of late crops such as potatoes and beetroots.

Owing to the many pools and the compact structure the soil remains wet for a long time in spring so that it can only be cultivated late. It is remarkable that on the surface the transition from a wet, tough mass into a stone-hard crust takes place very quickly. One may find that in the morning the soil is still too wet to cultivate, and too hard already in the afternoon. Under the hard surface-crust, however, the soil remains tough and wet for a long time so that when the horses break through the crust they make holes in the soft subsoil. The decrease of the permeability and the difficulties as to structure are greater as the clay content of the soil is higher. In all inundations it appeared that even small differences in texture are clearly reflected in the tilth of the soil.

Under these conditions it is difficult to make a proper seedbed. The available time is very short. It is hardly possible to turn a heavy soil into a fine seed bed (photo 5); it is easier with lighter soils but here the seed bed tends to become impermeable after rain. A dressing with gypsum under such circumstances causes a remarkable improvement. The soils get much more crumbly and no separation of the soil particles takes place any longer. In gypsum

experimental fields the plots treated with gypsum are recognizable from a distance by their dark colour against the greyish-white of the untreated plots (photo 1). The soil becomes more permeable, dries sooner and is less hard and cindery.

This improved physical condition makes it possible to cultivate the soil with better results and for a longer period of time. For this reason alone, a gypsum treatment is already very valuable. The better seed bed allows the crops to germinate better and less resowing is necessary (photo 6).

It stands to reason that the better physical condition of the soil is also manifest from a higher yield of better quality, especially with structure-sensitive and fine crops. Table 9 gives a few examples <sup>14</sup>).

Table 9. Influence of gypsum on the yield of different crops.

Experimental field	Clay content in % of dry soil	Crop	Yield of plots treated with gyp- sum in % of un- treated plots
GT 17	13	winter wheat	108
GT 30	12	winter wheat	100
AG 15	11	winter wheat	100
AG 12	21	oats	112
GT 11	25	winter wheat	109
AG 2	21	winter wheat	105
GT 34	34	summer barley	202
AG 17	33	summer barley	161
GT 22	32	summer barley	100
GT 8	17	sugar beets	115
AG 13	17	sugar beets	100
AG 13	20	sugar beets	115
GT 1	24	sugar beets	115
AG 3	15	lucerne	130
GT 33	13	brown beans	125
AG 14	12	onions	108

These details show that in many cases the gypsum treatment has clearly increased the yield. The examples given in the table were chosen in such a way that the general trend met with in the research on the influence of gypsum treatment is reproduced as closely as possible. On light soils the influence of gypsum treatment on cereals and sugarbeets is generally small, even though sometimes under circumstances unfavourable to the crop a considerable increase of the yield may be obtained. On heavier soils the crop suffers more, and as a rule the effect of gypsum treatment is greater. But even on heavy soil one may be lucky as regards the sowing and the growth of the crops so that a higher yield is not always secured.

The second tendency apparent in the results of the field experiments is that

<sup>14)</sup> The experimental fields were laid out after the inundations of the second world war and were situated on differend islands in Zeeland. The results given in the table were obtained in 1946, i.e. 1 to 2 years after the soil got dry.

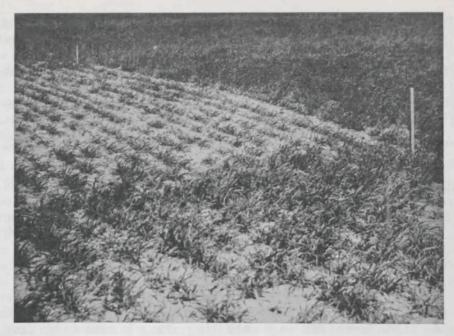


Photo 6. Effect of GYPSUM ON A WHEAT CROP. The wheat crop on the background has suffered badly from the impermeability and the bad structure of the Na clay. The plot in the foreground was treated with gypsum.

the reaction of the crop on the gypsum is stronger in structure-sensitive and fine crops than in cereals and sugarbeets. Also on light soils gypsum treatment often results in a better yield of the former crops. Hence the effect of a gypsum treatment differs from case to case. In 50 out of 53 experimental fields with more than 18% clay an increase in yield through a gypsum treatment was observed. On soils containing less than 18% clay a higher yield was obtained with gypsum treatment in 10 out of 14 cases. Moreover, from experimental fields on medium to heavy soils, usually observed during six years, it appeared that an average increase of about 25% is to be expected; this figure in itself is sufficient to demonstrate the importance of the gypsum treatment in agriculture.

Application of gypsum on soils not yet free from salt. An important question is, at what time the gypsum must be, or rather may be, applied. As long as the soil is still saline no serious breakdown of the soil structure occurs. Consequently, there is no reason to apply the gypsum comparatively shortly after the soil is drained. It might even be supposed that the effectiveness of the gypsum will be smaller when it is applied on very saline soils: the gypsum must then compete with the common salt as regards adsorption on the adsorption complex and consequently may be partly washed out and wasted. In view of some formulas on the adsorption there is also reason to suppose that in the leaching of the salt, part of the exchangeable Na is automatically replaced by Ca.

However, for agricultural purposes it is easier to apply gypsum before the soil is being cultivated, i.e. when it is still very saline. Besides, the experimental fields demonstrated that an early application of gypsum (before the first winter,

therefore in a saline condition) sometimes has a better effect on the crop than the application during next spring when the soil is desalted for the greater part and the structural breakdown has started already.

In many experimental fields it could be demonstrated that the theoretical objections are of little importance and that, for the replacement of the Na, it matters little at what stage gypsum is applied. Table 10 gives an example thereto <sup>15</sup>).

Table 10. Influence of different times of application of gypsum on the regeneration of the adsorption complex.

Quantity of gypsum in	Time of ap-	Na content of the adsorption complex in m.e. per 100 g adsorbing material					
tons/ha	plication	Autumn 1945	Spring 1947	Spring 1948	Spring 1949		
None		12.4	9.5	9.2	6.9		
3	Autumn 1945	12.4	9.1	6.8	5.3		
3	Spring 1946	12.4	9.1	7.0	5.0		
6	Autumn 1945	12.4	6.7	6.5	4.0		
	Spring 1946	12.4	7.2	6.0	4.7		
12	Autumn 1945	12.4	4.8	5.9	4.3		
12	Spring 1946	12.4	6.3	5.3	4.5		

Apart from the fact that an early application of gypsum has advantages, both from the standpoint of farm management and crop growth, in various cases it is of importance for the leaching of salt, viz. when the soil is naturally less permeable to water or when the loss of the salt causes the upper layer to get impervious. Then part of the rainwater flows away uselessly along the surface. Some examples have been included in table 11 <sup>16</sup>).

Table 11. Influence of a gypsum treatment on the leaching of salt.

_	Salt concentration of the soil moisture in g per l in the layer of 0-20 cm					
Experimental field	Before winter	After winter; plots without gypsum	After winter; plots with gypsum			
AG 12	11.0	2.4	0.6			
AG 8	14.4	4.0	0.5			
GT 41	5.2	1.6	0.4			

<sup>15)</sup> The table refers to the experimental field AG 13 on the island of Goeree-Overflakkee. The soil contains about 30% adsorbing material in the upper layer. The experimental field was drained during the summer of 1945; the concentration in the soil moisture was about 10 g per l in the upper layer at that time. The autumn dressing of the gypsum was given before the leaching of salt made much progress.

<sup>&</sup>lt;sup>16</sup>) The table refers to a number of experimental fields situated on the islands of Zeeland, the upper layer of which contains 20 to 30% clay. The gypsum was applied in the autumn of 1945; the experimental fields were sampled during the autumn 1945 and the spring of 1946.

In view of the advantages it is therefore advisable to apply at least a part of the gypsum at an early moment. In practice on very saline soils half of the gypsum needed is given in the first autumn after draining and the remainder in the second autumn. If in the second spring a crop is to be grown which is sensitive to bad structure or which requires a good seedbed (e.g. sugarbeets) 1–1½ tons are reserved for spring application to avoid crust formation on the seedbed. The same is done, when a crop is sown in the first spring.

## III AGRICULTURE

The cultivation during the first year. During the first year the agricultural possibilities are determined by the moment upon which the soil is drained and by the salt content of the inundation water; as in the preceding paragraphs, it is assumed that the soils were flooded with very saline water and that they are drained in spring. The soils are then too saline as to produce a reasonable crop in the first summer. As even with a very high salt content, spring barley can give some yield under exceptionally favourable weather conditions — much rain in spring and a cool, damp summer — farmers are often inclined to speculate on these exceptionally favourable circumstances. Although there is but a small chance even of a poor yield, there is no reason to dissuade unconditionally those who have such an intention. Most probably part may germinate, giving cover to the soil, a fact which is favourable for many reasons (amongst others it checks the blowing away of dust and the soil becoming impermeable).

The little work that can be done in the first year consists of draining the pools which may have remained in the depressions. Besides this the ditches and drain-ends are often more or less silted up; these must be seen to as quickly as possible.

Farmers are often inclined to harrow and plough the soil thoroughly in order to break it up and enable the air to act upon it. Though during this first summer the soil is still very saline and therefore no breakdown of the soil structure is to be expected, experience has taught that also under these conditions it is undesirable to disturb the soil much. Therefore, any deep cultivating should be dissuaded, though sometimes it is advisable to hoe the soil a few times in summer to check the capillary ascent.

Though the soil structure has not yet deteriorated during the first year, for technical reasons it is desirable to apply part of the gypsum, for instance half of the total quantity.

It has been discussed previously that winter cereals may be grown successfully even on very saline soils. It is desirable to lay part of the land in winter cereals, both for restricting the labour peak in spring and for spreading the risk. Operations for sowing winter cereals should be restricted to very shallow ploughing or harrowing. The gypsum for these plots should be applied after sowing, which is also of importance from the viewpoint of spreading of labour.

The cultivation in the second year. Next spring the soil, if not treated with gypsum, already clearly shows signs of a very bad tilth. As the soil dries out late, but then very rapidly, and quickly becomes hard and cindery, the time for preparing the seedbed is very short; in this respect high demands are made on the skill of the farmer.

For spring crops cultivation also should be very shallow; if possible a seed-

bed is only made with the harrow, even if parts remain untouched. If the greater part of the seed is covered, there is every reason to be content.

However, on the heavier soils the upper layer may be so crusty and hard that the harrow is of no avail. Then a disc-harrow should be used; the discs are then placed at a small angle so that the crust is slightly cut and the ordinary harrow can afterwards break the remaining strips.

In preparing the soil a very fine seedbed should not be aimed at; on heavier soils this is impracticable and on lighter soils a fine seedbed silts during rain, the resulting crust killing the seed. For the same reason one has to be careful with dragging and rolling. It is further advisable to sow without delay after cultivating the soil in order to avoid its silting up during rain or becoming cindery during drought.

Though the above mentioned difficulties are smaller when the soil has been treated with gypsum, they are not altogether absent; also in this latter case cultivation during spring should be done in the way as indicated before. Moreover, the active penetration depth of the gypsum after the first winter is still so small that deeper soil rich in Na would be brought up in cultivating.

A great difficulty is the planning of a rotation scheme, especially when the soil has not been treated with gypsum. As a rule, for leguminous plants the soil is still too saline in the second year after drainage. In addition to this, the structure does not allow fine seed crops to be grown; often the soil is also too saline for this purpose. Beets and potatoes cannot be grown because they require a deep cultivation and the land will soon become wet and unworkable in autumn, which will cause troubles as to the harvesting of these crops. Thus cereals are the most suitable crops, they also have the advantage that they are very salt-resistant.

However, a high proportion of cereals has some distinct disadvantages, such as a very uneven labour consumption. Furthermore, cereals are financially unprofitable crops. Finally, a large area of cereals involves the necessity to grow corn for two, sometimes three years in succession on a number of fields, which may lead to Take all (Ophiobolus graminis) and Eyespot (Cercosporella herpotrichoides).

Therefore, the aim must be to plant also a limited area with other crops; the risk unavoidably involved must be taken. Of course, the most suitable fields should be chosen; as a rule these are the lightest fields. Plots which before the inundation were under grass are suitable too, provided they are properly leached and not low-lying. On such fields one can risk growing beetroots and flax; at a low salt content also potatoes, though this crop is risky because the tubers easily rot away in a wet summer. If one sows fine seed crops an extra ton of gypsum may be given over the seedbed to avoid crust formation.

During the first year heavy soils are less suitable for other crops than light soils; the most suitable other crop on heavy soils is beetroots. On heavy soils a moderate quantity of lucerne growing may be tried. This crop gives rest to the soil and because lucerne requires no cultivation it restricts, so to say, the extent of the farm; this is greatly desirable as the period of time during which the soil can be cultivated is very short in the case of soils after inundation. Probably even better for the heavy soils would be a temporary grass cover, but the arable farms in the Netherlands are not adapted to grassland farming.

Most probably all these hazards are less when sufficient gypsum is applied

at the right moment. In this respect, however, there exists little experience in the Netherlands because after the inundations of the second world war gypsum was used only in a later stage owing to the restricted possibilities of supply.

The phosphate situation has not changed through the inundation; the phosphate dressings can therefore be the same as previously. As sea-water contains a considerable quantity of potassium, the potassium content increases by inundation with salt water. This increase depends on the original potassium content; for the soils in Zeeland, flooded in 1944, the increase of the readily assimilable (the exchangeable) potassium amounted to about 50 %.

When the inundation has been of short duration the nitrogen dressings can be normal; if a crop shows retarded growth its development can be promoted with extra nitrogen. Inundations of long duration, for instance during a year, may cause an accumulation of nitrogen in the soil; in that case nitrogen dressing may largely be omitted. About the cause of this so-called "Tholen" effect little is known.

The yields of the crops depend entirely on the weather. The weather after sowing and during germination is of primary importance. If the soil forms a surface cap because of rain it is a tough job for the crop to pull through; serious drought also causes difficulties during germination in the somewhat rough sowing bed. If the soil still contains a moderate amount of salt, an extremely dry year may lead to low yields. On the other hand, wet weather in summer and autumn may cause great difficulties in harvesting beetroots and potatoes. Potatoes also rot easily in a wet summer and autumn; it is therefore advisable to lay the seed-potatoes high in the ridge and to earth up frequently.

The cultivation in later years. After the first harvest (the first, if the possible sowing of barley in the year of drainage is left out of consideration) ploughing will be necessary. All experiences point in the same direction, viz. that this must be done as shallow as possible. After the ploughing (and never before) the second part of the gypsum can be applied. If one is afraid to drive the carts over the ploughed soil, the gypsum may be applied simultaneously with ploughing by running the cart on the unploughed soil and scattering the gypsum sideways. Preferably, however, the gypsum is to be applied with the fertilizer distributor.

If no gypsum is used at all, the difficulties in the next spring will be very considerable. The salt has then been leached almost entirely, the soil still contains much exchangeable Na, so that deterioration of soil structure is then complete. The rules prescribed before for cultivation of saline soils are then of preponderant importance.

If gypsum has been used in sufficient quantity the soil is noticeably better than in the previous year. The tilth of light soils (up to 15% clay) may already be the same as before the inundation so that the traditional rotation scheme can be followed. With heavy soils some restrictions will have to be observed, meaning that the area of cereals will be greater than normally.

During the next year of cultivation also heavy soils treated with gypsum will allow a normal management. However, shallow ploughing remains necessary for the first years on all types of soil.

Influence of short inundations and of inundations by brackish water. When the soil is flooded with very saline water only for a short time no complete salinization to any great depth takes place. The length of the inundation period, the drainage condition of the soil and the soil profile then determine the extent of salinization. Soils not ploughed before the inundation, absorb much less salt water than ploughed land; grassland, again, absorbs less salt than unploughed arable land. It is plausible that also the water content of the soil is of importance for the extent of salt penetration. If a flooded field emerges at low tide and if it is well drained, at each low tide water is drained to the subsoil and is replaced by new sea-water at high tide; salinization then goes very quickly.

The extent of salinization following a short time of inundation, is influenced by so many factors that it can be very different from one case to another. The examples given in table 12 <sup>17</sup>), classified according to the *length* of the inundation period, do not, therefore, constitute a series and an explanation of this discontinuity is lacking; therefore, the only object of the figures is to give an approximate idea on the order of magnitude of this process.

Table 12. Salt content of the soil moisture (g per l) in some ploughed soils, after having been flooded for a longer or shorter time.

Polder	Onrust	Willems	Zuiderland	Nieuw Neuzen	Hoogland	Schouwen	Walcheren
Duration of inundation in days	6	10	15	19	36	± 100	± 500
Salt content of inundation water	± 25	± 25	± 25	± 20		± 25	± 30
Layer (in cm) 5-20	11 8 7	8 6 5	14 14 14	10 7 4	13 7 6	18 17 17	23 25 26

After each inundation of short duration it appears again that the condition of the soil at the moment of inundation is of considerable importance for the degree of salinization of the upper layer; when the inundation is of long duration this difference, of course, tends to disappear. Table 13 gives an example of the influence of the condition of the soil <sup>18</sup>).

<sup>17)</sup> The data given in table 12 refer to polders in Zeeland, the five first mentioned flooded in spring 1953, the latter 2 in 1944. The salinization of the Onrust and the Zuiderland is probably excessively high. The explanation may be sought in the presence of a sandy subsoil and the good drainage of these polders.

 $<sup>^{18}</sup>$ ) The table refers to some polders in Zeeland, inundated in spring 1953. Both polders were flooded with water containing  $\pm$  25 g salt per l; the polder Oosterland during 16 days, the polder Oud Sabbinge during 20 days. The figures in the table are averages of many observations.

Table 13. Salt content of the soil moisture (g per l) in some polders with diversified conditions of the upper layer which were flooded for a short time. Layer 5-20 cm.

	Condition of the upper layer						
Polder	ploughed	in winter wheat	in lucerne	grassland			
Oosterland	18	14	9	8			
Oud Sabbinge	24	22	13	11			

The influence of brackish water is easier to describe; the depth of salinization is about equal to that of an inundation with very saline water, but the salt content itself decreases proportionally to the salt content of the inundation water.

Where the soil is less saline and the salt water has penetrated less deep into the soil, the content in exchangeable Na is lower. In the top layer there is a fairly close relation between the salt content of the soil moisture and the content of exchangeable Na; table 14 gives a few examples <sup>19</sup>).

Table 14. Relative amounts of the cations adsorbed by the adsorption complex in some flooded soils at various salt contents of the inundation water.

Salt content of the inundation water in g per l								
30	20	15	8	5	0			
21	48	50	68	74	88			
36	25	35	18	15	8			
10	6	2	. 4	2	3			
33	21	13	10	9	1			
100	100	100	100	100	100			
	21 36 10 33	30 20 21 48 36 25 10 6 33 21	30     20     15       21     48     50       36     25     35       10     6     2       33     21     13	30     20     15     8       21     48     50     68       36     25     35     18       10     6     2     4       33     21     13     10	30     20     15     8     5       21     48     50     68     74       36     25     35     18     15       10     6     2     4     2       33     21     13     10     9			

After the inundation of February 1953 the soils flooded with brackish water contained relatively more exchangeable Na. Up to a salinity of 15 g per l the number of m.e. exchangeable Na per 100 g of adsorbing material nearly equalled the salinity in g per l (e.g. when the layer 5–20 cm had a salt concentration of 10 g per l, the amount of exchangeable Na proved to be about 10 m.e. per 100 g adsorbing material).

Owing to the lower contents both of salt and exchangeable Na, the difficulties with these soils, flooded only shortly or by brackish water, are less than with completely saline soils; the land can be sown earlier, the choice of crops is larger, the difficulties in cultivation are less, the gypsum dressings can be smaller or may be dispensed with altogether.

For the soils, inundated in the spring of 1953, the amounts of gypsum, listed in table 15 have been recommended. These amounts have been based

<sup>&</sup>lt;sup>19</sup>) The table refers to a number of experimental plots on the islands of Zeeland, laid out after the inundations during the second world war. The experimental fields were sampled shortly after drainage.

upon the texture of the soil and the concentration of the salt just after drainage. To avoid risks these amounts are for the heavier soils about 1 ton/ha in excess of the values given by fig. 3.

Table 15. Amounts of gypsum (CaSO<sub>4</sub>. 2aq 90% purity) in tons/ha recommended for soils with varying clay content and salt concentration.

Clay content in g per 100 g dry matter	Salt concentration of the soil moisture (g per l) in the layer 5-20 cm just after draining							
(particles smaller than 2 micron)	< 3	3–6	6–10	10–15	> 15			
0- 7	0	0	0	0	0			
7-14	0	1	1	2	4			
14-21	0	2	3	6	8			
21–28	0	3	5	8	12			
28-35	0	3	6	10	14			
35–42	0	3	7	12	18			

If in the year of drainage the farmers are inclined to sow spring barley in very saline soils, this cannot be unconditionally rejected. When the salt concentration is somewhat lower (say 15 to 20 g per l in spring) sowing barley can even be recommended, though it still involves considerable risks. But the costs of this operation are low and if the weather will remain cool and moist there is a fair chance for a small harvest. In view of the low costs this chance is preferred to the certainty of no harvest at all. Moreover secondary motives are also in favour of sowing: it will be better for the soil and give more satisfaction to the farmer.

The lower the salt content, the wider is the range of possibilities, so that other crops than spring-barley may be considered. Crops requiring a good seedbed (e.g. flax and beets) receive 1 to 2 tons of gypsum per ha to prevent the seedbed from becoming crusty.

If the salt content is very low nearly all crops may be grown, except for some very sensitive crops as haricot beans and peas.

Restoration of inundated grass-land. The damage done by flooding to grass-land is dependent on the salt content of the water, the duration and the time of inundation, the botanical composition of the turf, the draining possibilities, and the weather conditions after drainage.

At a salt content of the inundation water of more than 20 g per l, even at rather low temperatures as occur in winter, the turf may be heavily damaged after  $\pm$  4 weeks of inundation. At lower salt contents the damage is less and then sometimes the difference in salt resistance of various plants clearly manifests itself. Especially Lolium perenne, Agropyron repens, Agrostis stolonifera, Alopecurus geniculatus and A. bulbosus sprout immediately after draining; even the old leaves remain alive. The Poa species and Trifolium repens do not sprout so well or even get burnt later.

In spring, when the temperature goes up and if the grass-land is still flooded, the plants start becoming active after which a rapid decay sets in owing to lack of oxygen, no matter what is the salt content of the water. If this situation lasts for a long time most plants die. Only in those grass-lands which were

always badly drained such species, that have characteristics similar to marshplants, will remain alive. Especially *Lolium perenne* is sensitive to this submergence at high temperatures where lack of oxygen sets in.

The very best grasslands, where this grass is abundant, suffer the greatest damage. Agriculturally less valued species then occupy the area made vacant if nothing is done in the way of reseeding open patches and good treatment of the turf.

It is well known that after inundations with salt as well as with brackish water which have lasted for such a long time that the turf is absolutely dead, a new vegetation appears. The character of this vegetation varies according to the salt content of the soil moisture and the botanical composition of the turf before the inundation. On soils which were inundated with moderately salt or brackish water and which have a good drainage after emerging from the flood water, usually in the first year a vegetation appears in which Chenopodiaceae prevail, such as Atriplex hastatum and Chenopodium rubrum. If the land is grazed or mown the proportion of the grasses increases in the next year; in the beginning especially Triticum repens and Agrostis stolonifera occur. When the water is more saline and the leaching proceeds slowly owing to poor drainage, Salicornia herbacea or Spergularia marginata and Suaeda maritima are the principal species.

After inundations of long duration with salt or brackish water the primary vegetation on the good grass-lands preponderantly is *Poa annua* and *Plantago major*. On hayland or more extensively used grass-lands, *Agrostis stolonifera*, *Holcus lanatus*, *Triticum repens* (especially in the case of brackish water), *Alopecurus geniculatus* or *Glyceria* spec. and *Phalaris arundinacea* may occur in masses.

The point at issue is to act before this natural vegetation develops, as in many cases the making of a favourable seed bed for re-sowing is then much more difficult. After many years a reasonable good turf can be obtained by mowing and grazing without re-sowing, but the quality and production lag behind resown fields for a long time. An exception is to be made only for the fields which were already saline before the inundation or which were in a bad cultural condition and are apt to remain so afterwards. In the long run, here the sown species would not be able to compete with the spontaneous grass species of inferior quality.

In all other cases, i.e. with severely damaged or dead turf re-sowing with a suitable seed mixture is the best method of repair. Both for the benefit of a rapid desalinization and of an aeration of the soil, proper drainage comes first. Furthermore, cultivation of the old turf is necessary to obtain a suitable seed bed. However this has to be as light as possible, as otherwise soil poor in humus would be turned up; the latter is less resistant against getting impervious and losing its structure and is poorer in plant nutrients. This shallow cultivation is best done by repeated harrowing thereby using a harrow with many short teeth. Application of gypsum is not necessary as the upper layer is protected against loss of tilth by its high humus content and the great quantity of dead organic matter. After sowing, rolling is very useful to promote quicker germination.

The experience has been gained that when the weather is normal in the Netherlands, sowing of a normal seed mixture for permanent grassland is possible up to a spring salt content of 8 to 10 g per l soil moisture in the

layer of 5–20 cm. However if the salt content is near to this upper limit, the production is small and the Poa species and Trifolium repens often look poor in summer. This being so, Lolium perenne becomes predominant in the first years, but the establishment of high-valued grasses and the formation of turf is successful all the same.

If the spring salt content per l soil moisture in the layer of 5–20 cm is between 8 to 10 and 15, it is better to sow a mixture without *Poa* species and clover because for these species the chance to germinate and grow up will be rather small. Later, after the disappearance of the salt, a few kilograms of these species can always be sown, if necessary. For the first sowing on these more saline fields a mixture is used consisting of different types of Lolium perenne, Festuca pratensis and Phleum pratense.

If the spring salt content per l soil moisture in the layer of 5–20 cm is higher than 15, it is better to delay sowing, and to keep the weeds in check by mowing or grazing. In general in such a case the natural vegetation does not develop so quickly.

For the rest, in dry summers, it has become clear that, if the salt content in the upper layer rises temporarily (and not permanently) to 25 g per l and higher, *Lolium perenne*, *Festuca pratensis* and *Phleum pratense* do not yet die. The *Poa* species and *Trifolium repens* still keep alive at a temporary rise of salt figures of 15 to 18.

With such salt contents the production is very small and even stops, the plants having a poor appearance. But the turf remains, so that, when the salt content drops, the grass develops immediately.

Up to now only grass-lands have been considered which were killed completely or for the greater part by the inundations. If the damage to the turf is small or if only special species such as *Lolium perenne* have suffered, a suitable seed mixture or seed of some of the damaged species are sown. By this practice the quality of the grassland is sooner up to standard than if the natural repair had been awaited.

