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RECLAIMING LAND FLOODED WITH SALT WATER [1])

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INTRODUCTION

At least ¼ of the surface of the Netherlands lies below gale spring tide level and a considerable part of it even lower than the average sea level. This low country is safeguarded by dikes against inundations.

The dikes are sufficiently high to stem the flood, even during very heavy gales and dike bursts therefore happen rather rarely, especially during the last century. Exceptionally high tides may however occur, against which it is impossible to arm.

In many places there are inner dikes behind the outer dike, thus restricting the flooded area. During very heavy tides however one or more of these inner dikes collapse; the inundation then becomes widespread. Notorious gale spring tides of the 20th century were those of 1906, 1916, and especially of 1953, the latter being the most violent for many centuries: 135.000 ha of arable land, 6 % of the Netherlands agricultural area, was flooded.

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The areas flooded by the sea consist, as a rule, of well-drained clay and sandy clay soils, permeable to water (10–30 % of clay-particles smaller than 2 micron); the clay or sandy clay layer is ½ to 1 m deep and is separated by an intermediate layer from the underlying rather permeable sand. These soils have been reclaimed from the sea during recent centuries and they contain a considerable amount of calcium carbonate; they are employed for arable farming.

Sometimes also older soil is flooded. Its clay percentage is often higher (30 to 40 % of clay), its permeability is low and drainage bad. This soil does not contain calcium carbonate and it is usually covered with grass. The younger calcareous soils are flooded more frequently; for which reason they will be specially considered in this article. A final paragraph deals with the older grass-land.

To what extent an inundation with salt water influences the soil depends on many factors; on the degree of salinity of the invading water as well as on the duration of the inundation and the manner of flooding. The more common case will be considered here: the soil is flooded in winter, the dikes are then repaired comparatively quickly, after which the soil gets dry again in spring. It is further surmised that duration of the inundation and the salt content of the water are such that the soil has become practically impregnated with salt to a depth of 1 m.

The salt which has impregnated the soil impedes the growth of the crops, but also the sodium displaces a great part of the exchangeable calcium in the clay as a result of which soil structure may suffer badly.

First the problems will be considered connected with the high salt content of flooded soils and with the removal of the salt. Next follows the influence of the salt on the exchangeable cations. The third subject will then be the influence of these two factors on agriculture.

I Salt

Ways of expressing the salt content. The solved matter in sea-water consists of 85 % of common salt. It is therefore customary to confine most researches to this common salt and even exclusively to the chlorine ion. The chlorine ion content, calculated as NaCl is briefly called "the" salt content of the soil; this practice has been followed also in this paper.

With respect to the salt content of the flooded soil, two magnitudes are of importance: the quantity of salt the soil contains (expressed in g salt per 100 g dry matter: symbol B), and the concentration of the salt in the soil moisture (expressed in g salt per l soil moisture: symbol C). Both magnitudes are related via the water content of the soil (expressed in g water per 100 g dry matter: symbol A). $C = \frac{1000\ B}{A}$. A and B are determined analytically; C is calculated from A and B.

Elsewhere the characterisation of saline soils is almost exclusively based on the salt content calculated on dry matter (B); however, in the Netherlands attention is also given to the concentration of salt (C). The knowledge of the concentration of the salt in the soil moisture is of importance in certain respects: in the first place there is a relation between the salt content of the inundation water and the salt content of the soil moisture of the flooded soil. Besides, the salt acts in the soil as a solution; for an insight into the displacement of the salt it is therefore necessary to know the strength of this solution.

Finally, it is very important that plant life is concerned with the concentration of the salt in the soil moisture and not with the salt content calculated on dry matter. This becomes particularly evident when peat soils flooded with salt water, which retain a very large water content, are considered. Even at a low concentration of the salt in the soil solution (harmless for the plants) the salt content determined on dry matter is very high; at the same salt content in dry matter, crops on sandy clay soils are seriously damaged because this salt is dissolved in a much smaller quantity of water, the concentration consequently being higher.

For this reason in the Netherlands the concentration of the salt is always determined in the soil moisture, for which purpose the samples are analyzed both for the salt content and for the amount of water.

The salt content immediately after drainage and during the first summer. It has already been remarked that during a long inundation the soil becomes thoroughly impregnated with a salt solution, the salt content of which is nearly ⅔ of the salt water which has flooded the soil; in the case of soil flooded with very saline water one will frequently have to deal with a salt concentration of 20–25 g per l. As long as the water is on the land the soil is saturated with this salt solution.

After the dikes have been repaired and the normal drainage has started, the excess of water seeps down; the resulting water content of the top soil is about as high as the water content normal soils have during the spring in the upper layer, provided the uppermost 5 cm be left out of consideration. This "spring" runs from the end of February till the end of March, when vegetation is still of minor significance. The water content in spring defined in this way amounts for sandy clay soils to about 25 g per 100 g dry matter; for clay soils it is higher, 30 to 35 g; for clay soils rich in humus, 40 to 45 g. Thus the initial salt content of the dry matter of well drained soils will be about $\frac{30 \times 23}{1000} = 0.7\,\%$ for soils flooded with very saline water.

In the Netherlands precipitation ($\pm$ 700 mm) exceeds evaporation ($\pm$ 500 mm); therefore an annual surplus of about 200 mm is carried away through the soil and leaches the salt from the soil in the long run. This rain surplus occurs mostly in the winter months; in summer by far the most moisture evaporates. When therefore the flooded soil is drained in spring, which is the rule, the salt content first drops only a little.

This small decrease of the salt content during the first summer, is observed only in the subsoil. In the upper layer the salt content calculated on dry matter even increases owing to the salt rising from the subsoil by capillary ascent. This process also causes the concentration of the salt in the soil moisture to increase; the concentration increases even more than the salt content calculated on dry matter because the water content of the upper layer is reduced by evaporation.

During the first year the soil is so saline that it remains practically without vegetation. As a result evaporation is only limited, even in a dry summer; also the capillary ascent is, as a rule, small, though exceptions occur. Table 1 gives a picture of the average salt contents of saline soils without vegetation; this table also shows the salt content of the soil, which has been flooded for a long period of time, directly after drainage [8]).

8) The table refers to a few high fields in the Zuidwatering on the island Walcheren. which were sampled after drainage in 1946; the soil consists of sandy clay.

Table 1. Salt content of very saline soils without vegetation at the beginning and the end of the first summer after drainage.

Layer (in cm)	Water content in g per 100 g dry matter (A)		Salt content in g per 100 g dry matter (B)		Salt content in g per 1 soil-moisture (C)	
	End of March	End of July	End of March	End of July	End of March	End of July
0– 5	22	13	0.36	0.62	16	46
5–20	23	20	0.36	0.42	16	21
20–40	24	22	0.49	0.45	21	20
40–60	25	24	0.53	0.44	21	19
60–80	26	26	0.48	0.42	18	16

These figures show that though the contents of water and of salt in the subsoil decrease a little during this first summer, they remain of the same order; on the other hand in the layer of 5–20 cm, and especially in that of 0–5 cm, a noticeable salinization and an increase of the concentration are observed. August is often wet in the Netherlands. Owing to frequent rains the salinity of the upper layer may then be greatly reduced.

Desalinization in winter. In winter there is a rain surplus in the Netherlands. The rain water initially takes up so much salt from the upper layer that the percolating water soon contains as much salt as the subsoil moisture, and does not remove any salt from the subsoil. Disappearance of salt from the subsoil, therefore, only starts when the topsoil has already lost a great part of salt. Table 2 gives an example of the way in which the desalinization takes place [9]).

Table 2. Course of the desalinization of a sandy clay soil.

Layer (in cm)	Stage of desalinization					
	I	II	III	IV	V	VI
	Salt content in g per 100 g dry matter					
0– 5	0.55	0.02	0.02	0.01	0.01	0.00
5–20	0.42	0.07	0.02	0.01	0.01	0.01
20–40	0.43	0.32	0.11	0.04	0.01	0.01
40–60	0.51	0.40	0.35	0.17	0.06	0.02
60–80	0.63	0.43	0.47	0.41	0.11	0.05
	Salt concentration in g per 1 soil-moisture					
0– 5	23	1	1	1	1	0
5–20	17	3	1	1	½	½
20–40	18	15	5	1	½	1
40–60	22	17	15	7	3	1
60–80	24	18	19	15	4	2

When a rain surplus of 200 mm percolates through the soil, the latter is, after one winter, sufficiently free from salt to be planted with moderately

[9]) The table refers to a sandy clay soil in the polder Oost Beveland on the island Zuid-Beveland. This flooded polder was drained in 1946; samples were taken several times in the period 1946–1948.

salt-resisting crops; even a water flow of 150 mm through the soil is amply sufficient. Before the inundation, the rain surplus percolated almost completely through the soil towards the drains and ditches because these soils are well drained and satisfactorily permeable to water. After the inundation however, the upper layer is inclined to lose its structure and so becomes impervious and sticky when wet, as a result of which the rain surplus partly runs away along the surface without leaching any salt. Nevertheless, in most of the well drained soils the water seepage in winter is at least 150 mm, so that after one winter they are sufficiently free from salt as to be taken successfully into cultivation.

In badly drained soils of low permeability, however, the water seepage is less; it can then take 2 or, in exceptional cases, even 3 years before the soil is sufficiently free from salt. Table 3 gives a picture of the course of the desalinization after the first year [10]).

Table 3. Course of the desalinization of very saline soils.

Layer (in cm)	Soil type: Well drained sandy clay; arable land, formerly grass-land		Moderately drained sandy clay; arable land, formerly grass-land		Badly drained sandy clay; grassland	
	Before winter	After winter	Before winter	After winter	Before winter	After winter
	Salt content in g per 100 g dry matter					
0– 5	0.77	0.02	1.03	0.04	1.09	0.10
5–20	0.81	0.02	0.58	0.15	0.58	0.27
20–40	0.36	0.05	0.42	0.28	0.40	0.34
40–60	0.33	0.12	0.44	0.34	0.46	0.39
60–80	0.51	0.38	0.59	0.51	0.64	0.54
	Salt concentration in g per 1 soil-moisture					
0– 5	18	1	32	1	26	2
5–20	19	1	18	4	20	10
20–40	14	2	17	10	16	13
40–60	13	5	17	11	17	15
60–80	15	10	17	14	18	16

The further course of the salt content. When the salt has sufficiently disappeared from the soil, sowing may be started. In cropbearing soils the evaporation is, however, considerably greater than in soils without vegetation. It now depends on the rainfall during the period of growth how the course of the salt content will be in summer. In dry years the water loss from the soil is greater than in the previous stage when it was bare; the same applies to the capillary ascent, if water supply from the subsoil is possible to a considerable extent. In wet years, however, the rain is capable of meeting the water requirements of the plants for the greater part, so that the course of the water content and the salt content is about equal to that in bare soil. In table 4 some data are given referring to a dry and a wet year [11]).

[10]) The table refers to a number of fields situated on the island Schouwen–Duiveland. They were drained in the spring of 1945. Between the sampling in the autumn of 1945 and the spring 1946 it rained 290 mm.

[11]) Table 4 refers, in respect of the wet year (1946), to a plot situated on the island Schouwen–Duiveland; in respect of the very dry year (1947), a field on the island Walcheren has been chosen. Both fields consisted of sandy clay. In the wet year 355 mm rain fell between the first and second sampling; in the very dry year 136 mm.

Table 4. Salt content at the beginning and the end of summer in cultivated soil already partly free from salt.

Layer (in cm)	Water content in g per 100 g dry matter (A)		Salt content in g per 100 g dry matter (B)		Salt concentration in g per 1 soil moisture (C)	
	Spring	Summer	Spring	Summer	Spring	Summer
			Wet year			
0– 5	26	22	0.03	0.08	1	4
5–20	27	23	0.07	0.12	3	6
20–40	26	23	0.17	0.18	7	8
40–60	28	27	0.21	0.24	8	9
60–80	31	28	0.21	0.23	7	8
			Dry year			
0– 5	30	8	0.03	0.09	1	11
5–20	25	10	0.06	0.11	2	11
20–40	24	12	0.12	0.15	5	13
40–60	24	14	0.19	0.21	8	15
60–80	25	19	0.25	0.26	10	14

This table shows that in a wet year the concentration of the salt in the soil moisture (in which figure the combined influences of drying out and capillary ascent is expressed) rises relatively little. In still wetter years it even happens that the concentration in the upper layer does not change. In a dry summer, however, the concentration in the upper layer increases much more, due to drying and capillary ascent. Thus, in dry summers the plants have to grow at much higher salt concentrations than at the time of sowing.

In spite of even strong capillary ascent, the quantity of salt in the upper layer at the end of the second summer after drainage is much lower than at the end of the first one; in the case under review the salt content in dry matter amounted in the layer of 0–20 cm to 0.4% at the end of the first summer against 0.1% at the end of the second. This means, therefore, that in the third year the salt content will be still lower than in the second, when sowing was already possible. After the second year the salt content in well drained soil does not further interfere with crop growth.

Criteria for judging the possibility of sowing in spring. An investigation into the salt content of the soil is of importance because the crops can only bear a limited quantity of salt; in soils saturated with pure seawater, for instance, no crop can be grown. The question arises therefore, how far should the salt content drop before the soil can be cultivated ? As will become evident later this question is of the utmost importance for sowing summer crops; these will therefore be considered first.

A prognostication like this is not easy. In the first place the salt content in the soil differs from layer to layer ; it is not known in advance which layer or layers are the most important for the crop. Besides, the salt content during the period of growth need not be the same as in spring. Finally the composition of the soil moisture is not always the same ; for this composition the chlorine ion content calculated as NaCl is only a rough standard. This point is of importance because the composition of the salt solution influences the salt sensitiveness of the crops.

Because the problem is so complicated one can give only an approximate answer. But if we are content with an approximation there are a few bright spots. In the first place the soil moisture contains always considerable amounts of Ca, Mg, K and Na: so the solution is rather well balanced. The strength of this rather well balanced solution can therefore be measured roughly from the concentration of the Cl in the soil moisture.

As regards the difficulty that the salt content is different in each layer, it should be borne in mind that the entire process of desalinization, as was shown before, proceeds in accordance to certain rules. In spring, after a period of leaching and before drying out and capillary ascent blur the picture, the salt content in the different layers of the soil correlates rather narrowly, as is shown in table 5, referring to the spring salt content of a number of experimental plots in Zeeland in 1946.

Table 5. Salt content of the soil moisture in g per l in different stages of leaching.

Experimental plot	Layer (in cm)			
	0–5	5–20	20–40	40–60
GW 32	0.0	0.0	0.1	0.9
GW 15	1.0	0.5	1.8	2.7
GW 6	1.2	1.4	3.6	6.9
GW 8	1.6	1.8	3.8	5.3
GW 12	2.0	2.7	5.5	7.7
GW 27	2.4	3.4	6.6	8.2
GW 11	3.8	4.9	7.5	8.4
GW 40	4.5	5.7	10.2	9.0
GW 38	4.5	7.3	12.5	13.4
GW 39	4.5	8.4	14.4	15.1
GW 43	18.9	15.0	20.1	19.4

These figures show that, for instance, the salt content of the soil moisture in the layer of 5–20 cm is a good measure for the salt content of the entire soil profile; the layer of 5–20 cm is at the same time the one which is of the greatest importance for the vegetation because it contains most of the roots.

It is therefore customary in research on the connection between the salt content and the vegetation to take the salt content of the layer of 5–20 cm as a measure for "the" salt content of the soil.

The determination of the connection between the salt content of the layer of 5–20 cm in spring and the growth of the crops is a matter of field experiments and observation. For the indication of the salt content the choice is between the salt content in dry matter and the concentration of the salt in the soil moisture. In the Netherlands it is customary to base the indications for sowing on the concentration of the salt in the soil moisture.

Elsewhere the objection has been raised that the salt concentration in the soil varies considerably during the season and that it would therefore be a bad measure for "the" salt content of the soil. It is necessary to pay some attention to this point. As has been remarked before, the water content of Dutch soils, provided the uppermost 5 cm be left out of consideration, is practically constant from the end of February till the end of March (i.e. the period when the possibility of sowing is taken into consideration).

It has been argued before that there is a relation between the concentration of the salt in the soil moisture (C), the salt content in dry matter (B), and the water content (A); viz. $C = \frac{1000\ B}{A}$. As A – for samples taken in spring – is a constant for one certain soil type, there is for this soil a fixed relation between B and C; as long as one soil type is considered it does therefore make no difference whether the possibility of sowing is judged from the concentration or from the salt content in dry matter. Also when similar soil types, all having about the same spring water content, are considered, it is of little importance whether the sowing limits are based on the B or C figure.

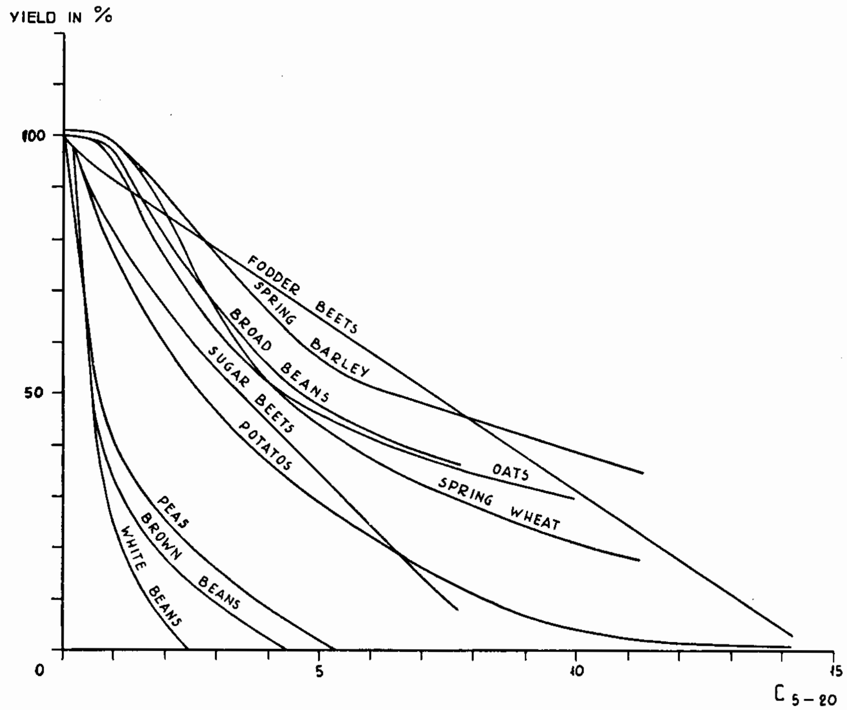

FIG. 1. RELATION BETWEEN SALT CONTENT IN SPRING (C_{5-20}) 1) AND RELATIVE YIELDS 2) OF VARIOUS CROPS IN THE DRY AND WARM YEAR 1947.
1) C_{5-20} = g of common salt per l soil moisture in the layer 5—20 cm.
2) Yield on comparable not inundated soils put at 100.

However, the spring water content is different for the various soil types — and, parallel with this, also the summer water content; for sandy clay it is lower than for clay and here again lower than for clay containing humus and much lower than for peat. When the spring water content of the soils to be sown varies considerably, difficulties arise when trying to estimate the possibilities of sowing from the salt content in dry matter. In peat soil with a high water content (in spring and in summer) a higher salt content in dry matter is admissible than in a sandy clay soil because the plant reacts in the first instance on the concentration of the salt in the soil moisture. The application of the spring concentration of salt may overcome this difficulty. With this figure one should not think of a real concentration but of a figure for the salt content in dry matter, that is multiplied by a constant (the spring water content) typical for each soil species, by which the error inherent to the use of the figure for the salt content in dry matter is corrected.

Possibility of sowing in spring. The concentration of the salt in the soil moisture in the layer of 5—20 cm in spring (shortly C_{5-20}) is, consequently, a useful measure to decide on the salt condition of a profile in view of the vegetation at that moment. This spring salt condition would obviously be a very good relative measure for the entire period of growth if the salt concentration remained the same during the period of growth or if it invariably changed to the same extent.

However, as we did already explain, the concentration of the salt in a dry year increases much more than in a wet one. The same spring salt content leads to a much higher summer value in a dry year than in a wet one. In this respect it makes no difference whether the salt content has been based on dry matter or on the concentration.

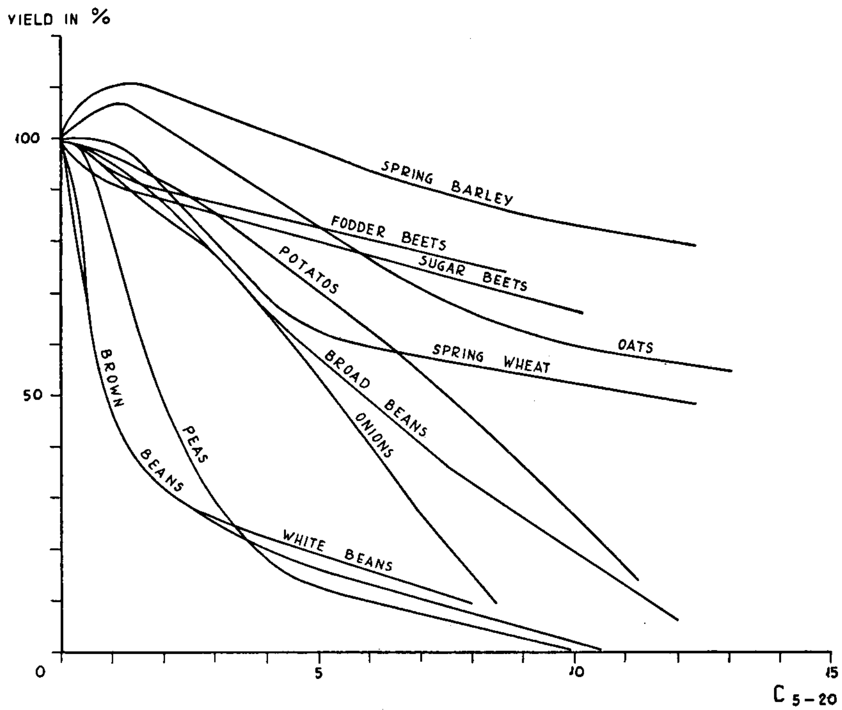

FIG. 2. RELATION BETWEEN SALT CONTENT IN SPRING (C_{5-20})[1]) AND RELATIVE YIELDS[2]) OF VARIOUS CROPS IN THE MORE WET AND COOL YEAR 1948.
[1]) C_{5-20} = g of common salt per l soil moisture in the layer 5–20 cm.
[2]) Yield on comparable not inundated soils put at 100.

As the plants primarily react on the concentration of the salt, this means that with the same spring salt content a crop stands a better chance in a wet summer than in a dry one. Besides, the plants appear to be more sensitive to a high salt content at high temperatures, as is the case in a dry year; in particular this is important for the summer cereals. A hot and dry summer is therefore disadvantageous for more than one reason.

How the value of C_{5-20} in spring and the response of the crop are related is shown in the diagrams 1 and 2. These diagrams show in the first place that with the increasing salt content the yields of the crops decrease perceptibly and that at a high salt content a crop failure results. It is remarkable that a small quantity of salt seems to stimulate the growth of different crops. The diagrams further emphasize the well known fact that the salt tolerance of field crops varies considerably. The figures show that the influence of the type of summer is very great and that the limiting salt content in spring was much higher in the wet year 1948 than in the dry year 1947 [12]); with a salt content in spring of 10 g per l summer barley gave 40% of the normal yield in 1947, as compared to 85% in 1948.

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[12]) 1947 had for the Netherlands an extremely dry summer (from April till July, incl. it rained 164 mm against 216 normally), the average day temperature in this period of time being 15.4° against 13.9° normally. 1948 had a wet summer; during the same period of time it rained 256 mm and the temperature was 14.5°.

These data clearly show that it is never possible to give a reliable forecast at which salt content a crop will succeed and sowing may be advised. If the limit is taken too high there is the risk of a poor crop in a dry year; if the limit taken is too low, fields which could have given a crop in a wet year, are not sown. Since a decision between sowing or not sowing has to be taken anyway and an advice must be given, there is no other way than to base the decision on the average conditions for the Netherlands. The relation between these average conditions and the salt content has been determined from a considerable amount of figures (table 6).

A further question in formulating a recommendation is what yield level makes sowing on flooded soil justified. A normal yield is not necessary because part of the cost (the rent) have to be paid anyhow and another part (the wages of the farmer who otherwise would be without employment) need not be taken into account; the point at issue is whether the yield will be greater than the extra cost invested in sowing and tending the crop. The percentage of the normal yield at which the costs are covered will vary with the type of crop; for potatoes, for instance, it is greater than for cereals. Moreover, it depends on the price of the commodities. For specified directions we therefore refer to diagrams 1 and 2 which have to be considered in the light of the economic situation. Table 6 furnishes a rough criterion when it is assumed that with 75% of the normal yield sowing is still justified.

Table 6. Spring concentration of the salt (in g per l soil moisture) in the layer of 5–20 cm, whereby for average Dutch conditions a reasonable yield (75% of normal) can be expected.

Crop	C 5–20
Spring barley	10
Beetroots	7
Oats	7
Lucerne	6
Spinach for seed	5
Spring wheat	4
Red clover	3
Flax	3
Potatoes, for yield	3
Onions	2
Broad beans	2
Potatoes, for consumption	1½
Peas	½
Brown and white beans	½

To this table a few notes may be added. With spring barley the variety Kenia is distinguished from the Saxonia variety by a greater salt tolerance. In general both the quality and the quantity of the planted crops (flax, peas and beetroots) but also the keeping quality (beetroots and onions) are less on saline soils. With high salt contents potatoes suffer in particular as regards mealiness and taste. Of the cereals, especially spring wheat may have a low volume weight.

Possibility of sowing in autumn. In the Netherlands only colza and winter cereals are known as winter crops. Their vegetative period lies in the next summer and they are then reasonably salt-resistant, about as resistant as the comparable summer crops. Even strongly saline soils, if well or even moderately drained, lose so much salt in one winter period that the next year salt-resistant crops may be grown successfully. If therefore the winter crops pass the winter uninjured they will next year not suffer much from the salt in well drained soils. In judging the possibilities of sowing winter crops the only point is therefore whether they are able to develop in autumn.

As has been remarked before, crops can bear a much higher salt content at a low temperature than at a high one; in autumn, i.e. in cool weather, cereals are able to germinate with a salt concentration in the upper layer of 20 g per l. Even in a very saline soil, the salt concentration soon drops below this value in the uppermost centimeters, owing to the autumn rains. Germination is then possible and soon after, owing to the progressive leaching, also in the deeper layers the salt is no longer a deterrent for the further growth in the cool autumn and winter months.

These observations indicate that with proper drainage germination as well as first growth in autumn is possible on very saline soils, while in the next spring the salt need not be a deterrent for further growth. The general opinion is, therefore, that winter crops can be sown in autumn even on very saline soils, provided they are well drained.

If a dry summer is followed by little rain, circumstances will not be very favourable for sowing; instances of poor winter crops are known after dry autumns, especially of colza. The risk of a dry autumn, however, is small in the Netherlands, and need therefore be no deterrent for sowing winter crops on very saline soils, other conditions being favourable.

To be continued.