Salt Farm
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Effects of salinity on the growth of different crops and the potential for saline farming

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SUMMARY

In 2018, 12 different varieties of 8 different crops were tested for salt tolerance at the open-air lab of the Saline Farming Group in the Netherlands. These crops were tested at a minimum of 6 different salinity levels (0.5, 4, 8, 12, 16 and 20 dS/m (irrigation water) with a minimum of 4 repetitions per salinity treatment. Results show that the pore water salinity in the soil is close to the target salinity levels of the irrigation water, especially when the seasonal mean of the pore water salinity level is considered. Crop yields were plotted against the seasonal mean pore water salinity per plot. A robust statistical analysis was used to evaluate the crop response to increasing salinity. In some cases the number of data points was limited due to the crop sensitivity (grasspea) and in other cases the variation in crop yield at comparable salinity levels was considerable. However, in general the crop response curves are robust and, under the described conditions and a single year of testing, the salt tolerance levels range from “sensitive” to “highly tolerant”. The results indicate that in the salinity range of 5-7 dS/m (based on the extract of a saturated paste: ECe) there are varieties of potato, carrot and cabbage that still show a 90% yield or a 10% yield reduction. This implies that these varieties are suitable for cultivation under moderate saline conditions.

Image 1. Impression of the open-air lab of Salt Farm Texel where the different crops were tested for salt tolerance.

Content

1. BACKGROUND

As part of the activities of the Knowledge Centre “Saline Agriculture Worldwide” the Salt Farm Foundation commissioned Salt Farm Texel (part of the Saline Farming Group) to determine the effect of salinity on the growth of various crops.

For this research, carrot (*Daucus carota*: varieties Danvers , Napoli, Nantes and St. Valery), onion (*Allium cepa*: Ishikura, bunching onion), potato (*Solanum tuberosum*: Desiree, Diamant), cauliflower (*Brassica oleracea*, subs. *botrytis*: Herfstreuzen), kohlrabi (*Brassica oleracea*, subs. *gongylodes*: Blaue Delikatess), white cabbage (*Brassica oleracea*, subs. Capitate: Langedijker Bewaar), grasspea (*Lathyrus sativus*, source: Vreeken Zaden), and Red orach or mountain spinach (*Atriplex hortensis*, source: Bolster) were tested for salt tolerance.

These crops were selected based on their global importance (crops like potato and onion are cultivated all over the world and have good market value (for smallholder farmers)), for their high nutritional value (crops like carrot, cauliflower, cabbage and kohlrabi contain many nutrients and vitamins often lacking in local diets). Red orach is a fast growing leavy vegetable that is reported to be highly salt tolerant. Grasspea produces protein rich seeds for human consumption and is commonly grown as a fodder. Also, this crop can act as a green manure species. All the crops together also form a good combination for crop rotation.

The crops were tested for salt tolerance at the open-air lab on Texel, The Netherlands, in the 2018 growing season.

The Knowledge Centre on Saline Agriculture is a one-stop resource centre for everything related to saline agriculture for farmers, NGO’s, scientists and students financed by the Dutch Ministry of Agriculture, Nature and Food Quality (LNV). The project supports the goals of the Ministry to increase global food security and more effective water management through the export of Dutch knowledge and technology.

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2. MATERIAL AND METHODS

2.1 Open-air lab Salt Farm Texel

The test facility of Salt Farm Texel consists of 56 plots, divided into 7 different salt concentrations and each salt concentration consisted of 8 repetitions, randomly divided in a 1 hectare plot. These 7 salinity levels were divided as follows: 0.5, 4, 8, 12, 16, 20 and 32 dS/m (salinity level of the irrigation water). In this report, only the first 6 salinity levels reported here. For all crops a minimum of 24 plots were used (6 different salinity levels, each with 4 repetitions). The soil type is sand (about 93% sand, 3% loam, 2% clay, 2% organic matter).

2.2 Fertilizer use

The different crops have received different concentrations of fertilizers. A base application in the form of compost (certified organic) and 2 types of organic fertilizer has been applied to all crops. Grasspea, Red orach and onion did not receive any additional fertilizers (see table 1 for calculated fertilizer use). All the other crops also received manure (certified organic). The amount of compost added was 20 tons per hectare, for manure, 12 tons/ha was added and of the two organic fertilizers 1 ton/ha of each was added (Orgevit and Monterra Malt). In table 2 an overview is given of the composition of the different organic fertilizers and the amounts of nutrients that became available from decomposition in year 1. Additionally, different beds or plots have received extra fertilizers to meet the crop demand.

Table 1. Overview of the fertilizer use for Grasspea, onion and Red orach in the form of added compost and organic fertilizers and the available fractions of the different nutrients (in kg/ha). The amount of the added sources is in tons per hectare.

Source	**amount**	**N**	**P_2O_5**	**K_2O**	**CaO**	**S**	**MgO**	**org. matter**
Compost	20	14	21	48			16	3840
Monterra	1	90	10	40	20	30	3	750
Orgevit	1	40	32	25	90	10	10	650
Total		**144**	**63**	**113**	110	40	29	5240

In this calculation it is assumed that (for compost), 10-15% of N is available for plant uptake in year 1, 50-60% of P_2O_5 is available and 75-100% of K_2O

Table 2. Overview of the added compost, manure and organic fertilizers and the available fractions of the different nutrients (in kg/ha). Amount is in tons per hectare.

Source	**amount**	**N**	**P_2O_5**	**K_2O**	**CaO**	**S**	**MgO**	**org. matter**
Compost	20	14	21	48			16	3840
Manure	12	44	17	72		2	26	1824
Monterra	1	90	10	40	20	30	3	750
Orgevit	1	40	32	25	90	10	10	650
Total		**188**	**80**	**185**	110	42	55	7064

In this calculation it is assumed that (for compost), 10-15% of N is available for plant uptake in year 1, 50-60% of P_2O_5 is available and 75-100% of K_2O

Table 3. Total added nutrients to the listed crops (in kg/ha). Part of the fertilizer use was in the form of organic fertilizer (based on table 2), the rest is in the form of mineral fertilizer, applied two times (22 June, 6 July). **Listed values represent the total fertilizer use per crop.**

Source	N	P_2O_5	K_2O	CaO	S	MgO	org. matter
Potato	285	106	281	213	128	55	7064
Carrot	208	132	281	110	128	55	7064
Cauliflower/cabbage	255	80	281	179	128	55	7064
Kohlrabi	235	80	281	144	128	55	7064

2.3 Irrigation

Frequent irrigation took place in order to make sure no water stress occurred and that the effect of rainfall and evapotranspiration on soil moisture content was minimal, so variation in salinity levels were as smal as possible. Before the salinity treatment started some fresh water irrigation took place to make sure that the moisture level was sufficient. On 07/06/2017 the salinity treatment started. The level of salinity was increased every day (in order to prevent potential osmotic shock) and on 09/06/2017 the highest level of 20 dS/m was reached. On average, a daily irrigation of 8.4 mm was given from the start of the salt treatments up until September 30th 2018. In total an average total of 964 mm of irrigation water was applied per salinity treatment in the period of June 7th-September 30th.

2.4 Salinity measurements

Salinity measurements were performed by sampling the pore water (with suction cups) and by taking soil samples. Pore water (EC_{pw}) was collected and analysed at two different depths in every plot (5-15 and 25-35 cm depth). Sampling took place every two to three weeks. The average of the two measurements (the two depths: = active root zone) per sampling date were used for further evaluation of the pore water salinity levels. Soil salinity was also determined by analysing soil samples. A soil sample consisted of 10 subsamples that were mixed into one sample per plot. Only the top 30 cm of soil was sampled. Soil samples were taken three times in the season. Soil samples were analysed according to the general 1:2 method (1 part (dry and sieved) soil mixed with 2 parts water (v:v) and the saturated paste method (ECe).

2.5 Planting and harvesting

The planting and harvesting has been performed as indicated in table 4. Potato has been planted in block of 8 plants per plot, with 4 plants on 2 separate ridges (space between plants is 30 cm, space between the two ridges was 75 cm). Carrot was planted as a single row per variety. Grasspea and Red orach were planted as a single row as well. Onion, cauliflower, cabbage and kohlrabi were planted as seedlings and later planted in blocks of 8 (for cabbage, cauliflower), 15 plants (kohlrabi) or 24 plants (onion). Seedlings were about 30 days old, with 3-4 true leaves. Onion was planted after the start of the salt treatment, the other crops were allowed to germinate and adjust after transplanting before the salt treatment started on June 7th.

For the biomass measurement at harvest, the focus was on the marketable part of the crop. This means for potato, only the tubers were harvested and weighed, for carrot the whole plant, for the cabbage the old leaves were removed before weighing, for cauliflower the majority of the leaves were removed (comparable to a “supermarket cauliflower”), for kohlrabi all leaves were removed, for red orach and grasspea, the total above ground biomass was used, and for onion the whole plant.

Table 4. Overview of the planting date, planting density, harvest date, and harvest "area" (number of plants or meters of row harvested per plot) of the different crops. All crops were planted on a minimum of 24 plots (6 different salt concentrations, each with 4 repetitions).

crop	type	planting date	planting density	harvest date	harvest "area"
potato	seed potato	May 14	30 x 75 cm	September 4	8 plants
carrot	seed	May 16	2.6 million seeds /ha	September 7	1 meter row
cauliflower	seedlings	May 23	40 x 40 cm	August 3	4 plants
cabbage	seedlings	May 23	40 x 40 cm	September 13	4 plants
kohlrabi	seedlings	May 24	30 x 30 cm	August 15	6 plants
red orach	seed	May 29	15 x 20 cm	August 2	8 plants
onion	seedlings	June 19	20 x 30 cm	September 18	17 plants (average)
grasspea	seed	May 29	3.6 grams/m2	August 14	1 meter row


Image 2. Impression of the open-air lab on June 11, 4 days after the salt treatment started.

2.6 Statistical analysis

Crop yields were determined per plot and, together with the seasonal mean pore water salinity per plot, crop response curves with increasing salinity were produced. So individual plot yields were plotted against the specific seasonal average pore water salinity level of the same plot, with a minimum of 24 plots (or data points). To analyse the results of the salinity tolerance of the crop varieties presented here, we use two different statistical models. The first one is the 'traditional' model originally developed by Maas and Hoffman (1977) which uses a threshold model and Ordinary Least Squares (OLS) to fit a curve to the data that allows the estimation of three parameters: the yield under control conditions (Y0), the threshold value ($EC_{threshold}$, the salinity level at which the yield becomes negatively affected) and the slope (the decline of the yield after the threshold value, either expressed in absolute yield (grams per tuber for example) or as a percentage. Other parameters, such as the EC_{90} (the salinity level at which the yield is 90% that of the Y0), can easily be derived from this model.

The second model is a smooth fit curve that also uses OLS and was originally developed by van Genuchten and Hoffman (1984). This model also allows the estimation of three parameters: the Y0, the EC_{90} and p, a description of the s-shape of the fitted curve.

All data was processed by both approaches as described in detail by van Straten *et al*. (2019). As was demonstrated in this paper, the EC_{90} allows for the most robust description of salt tolerance

of crops. This is why we focus mostly on this parameter to assess the salt tolerance of the crops described here. In addition, the levels of EC_{75} and EC_{50} are used to evaluate crop salt tolerance.
In case of *Lathyrus sativa*, we chose to present the data on the parameter estimates based on a third statistical model, originally developed by van Genuchten and Gupta (1993), in which the p-value (which determines the S-shape of the fitted curve) is fixed at 3. This model gives a much better fit to the data because when the model is free to minimize the sums of squares (as in the vG&H model), the p-value becomes lower than 1 and the S-shape of the model disappears. This is because there are so few data points that are actually on a straight line; the best mathematical way to describe this salinity response curve is with a linear model, such as generated by the M&H model.

3. RESULTS

3.1 Climatic conditions: precipitation and evapotranspiration

In figure 1, cumulative precipitation, evapotranspiration and the difference between the two (the water deficit or "water balance") are given. In figure 1 the results from 01/04/2018 onwards are given, just to indicate the water balance in the weeks before planting as well. In the period 01/04/2018 up to 30/09/2018 a total sum of 215 mm precipitation was recorded against a water loss of 622 mm due to evapotranspiration. So, the water deficit was 407 mm in this period. When the period between 07/06/2018 and 30/09/2018 is considered, a total amount of 117 mm of precipitation (rain) occurred, but the evapotranspiration was 407 mm, so a 290 mm water deficit occurred during the season during which saline irrigation took place. This, in combination with the 964 mm of irrigation, indicates that the effect of rainfall on the soil salinity levels was rather limited. This is further substantiated in figure 2 were the salinity levels of the soil pore water are presented.

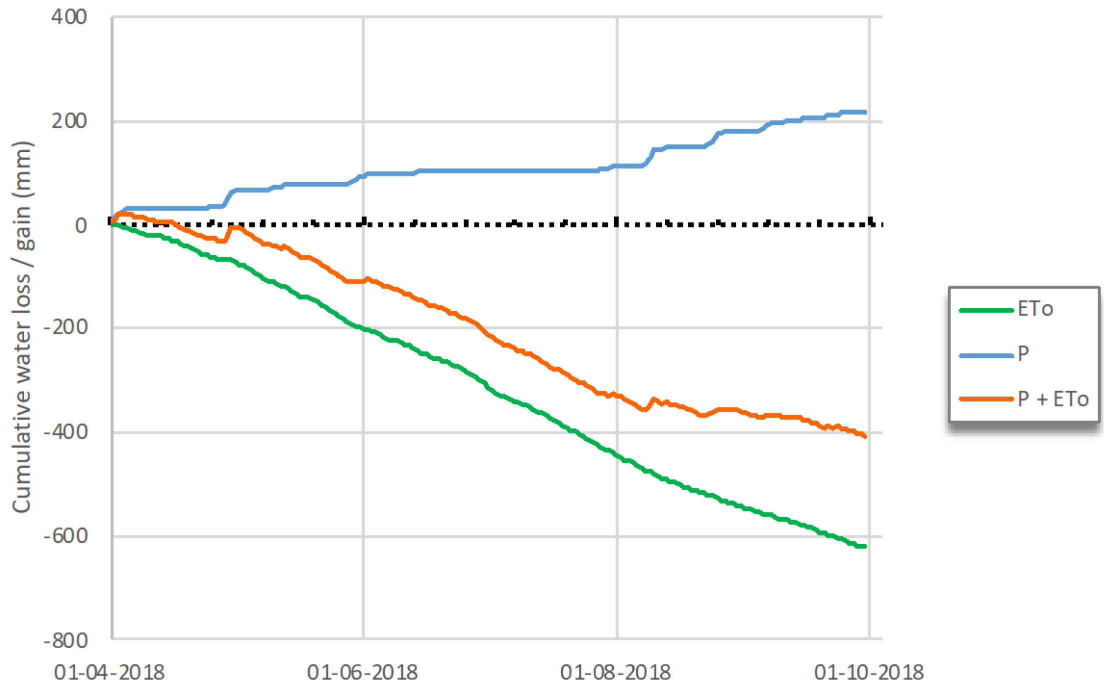


Figure 1. Water balance based on precipitation and evapotranspiration during the 2018 season, starting at 01/04/2018 up to 30/09/2018. The water balance consists of a total of 215 mm of precipitation ("P"), 622 mm evapotranspiration (ETo), so a 407 mm precipitation deficit (orange line in figure, "P+ETo") occurred during the season.

3.2 Pore water salinity

In figure 2 the results of the salinity measurements of the soil pore water are presented. The measurements that are presented start at 15/06, so 8 days after the salinity treatments started. On each sampling date, the average of the 8 plots per salinity treatment is presented in figure 2. In total, the pore water salinity was determined on 9 occasions during the season. The average pore water salinity, as displayed in figure 2, shows some variation within the season, but the seasonal average (see table 2) is very close to the target level (EC irrigation water). The increasing average salinity from the beginning of July up to the beginning of August appears to be consistent across the different salinity levels and is most likely linked to the dry summer with relative high evapotranspiration.

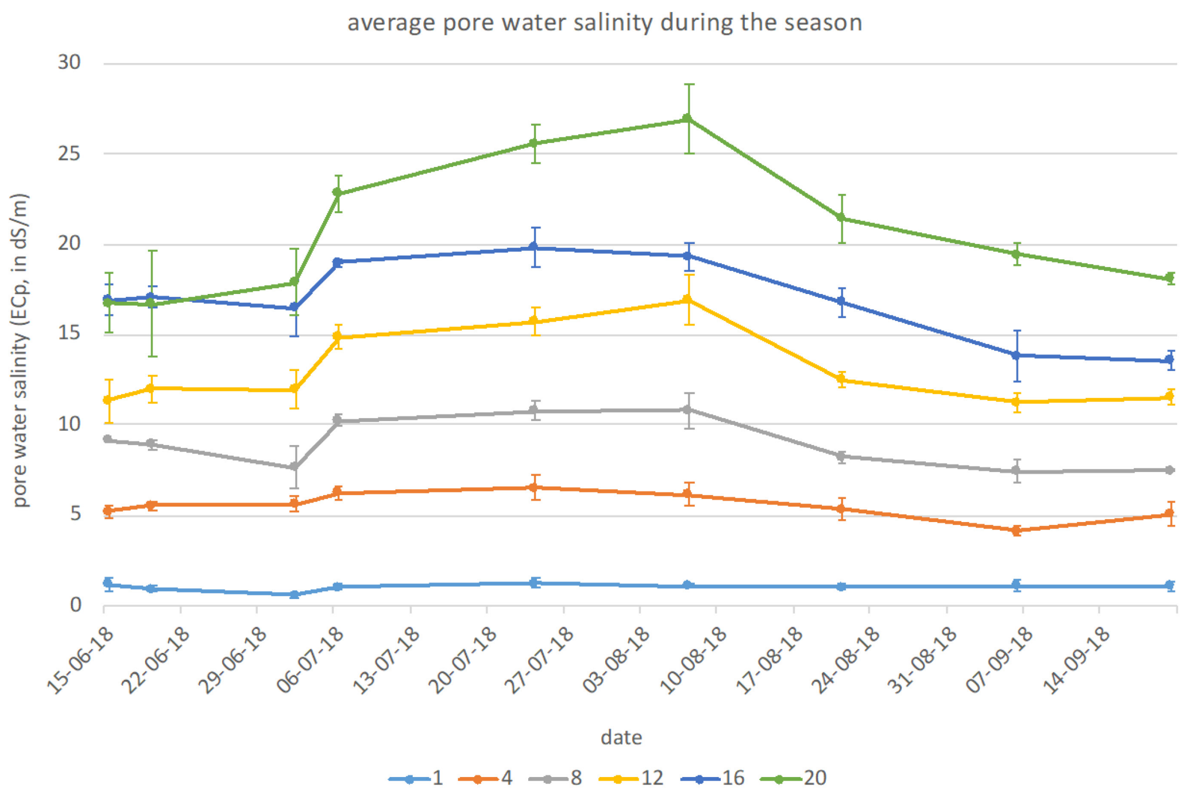


Figure 2. The average salinity level of the pore water of the different salinity treatments (listed as the target EC of the irrigation water: 1, 4, 8, 12, 16 and 20 dS/m (treatment 32 dS/m is excluded from this figure)) during the season. The data points represent the average EC of 8 plots per salinity treatment (with the error bars as standard error of the mean). Soil pore water was sampled on 9 occasions during the season.

In table 5 the seasonal mean pore water salinity per plot is presented. These values were used to express the crop performance, for which the yield per plot was plotted against the seasonal mean pore water salinity of the specific plot.

Table 5. Seasonal average pore water salinity per plot, expressed as ECp (in dS/m). The target EC level of the irrigation water (ECirr) is also provided.

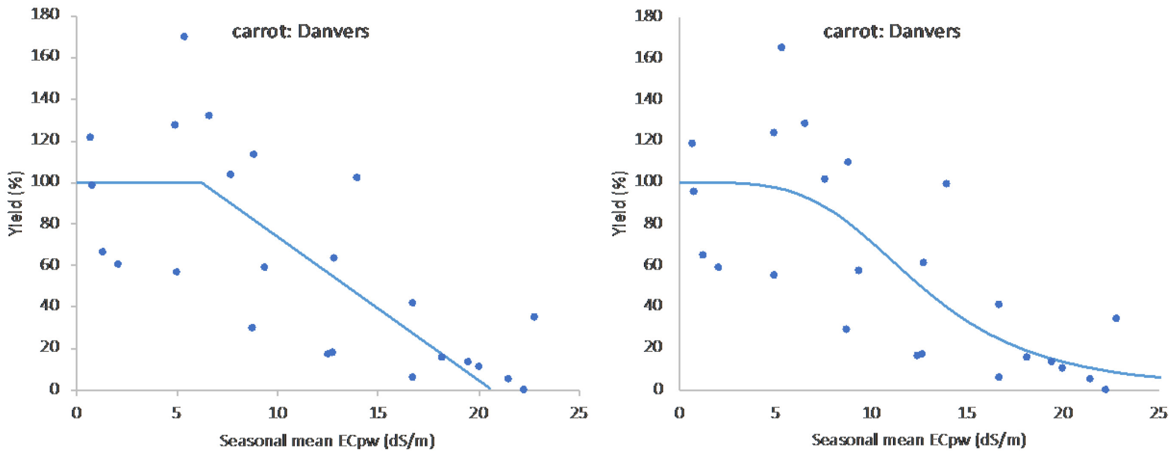
Plot	ECirr	ECp	Plot	ECirr	ECp	Plot	ECirr	ECp
4 Z	1	0.8	2 Z	8	8.8	1 Z	16	16.8
8 Z	1	0.7	14 Z	8	9.4	7 Z	16	16.8
15 Z	1	1.3	20 Z	8	7.7	16 Z	16	19.5
26 Z	1	2.1	22 Z	8	8.8	28 Z	16	18.2
4 N	1	0.8	5 N	8	9.1	3 N	16	15.8
6 N	1	0.7	9 N	8	9,9	11 N	16	16.4
10 N	1	0.7	20 N	8	7.1	14 N	16	17.5
13 N	1	1.2	24 N	8	9.7	21 N	16	17.2
9 Z	4	5.4	5 Z	12	12.5	3 Z	20	21.5
11 Z	4	6.6	10 Z	12	14.0	12 Z	20	22.3
19 Z	4	5.0	17 Z	12	12.7	21 Z	20	22.8
27 Z	4	5.0	24 Z	12	12.8	25 Z	20	20.0
7 N	4	5.3	2 N	12	13.8	1 N	20	19.9
15 N	4	7.3	12 N	12	12.6	16 N	20	22.4
19 N	4	4.9	17 N	12	15.2	18 N	20	18.6
27 N	4	5.5	26 N	12	12.3	25 N	20	20.9

3.3 Crop yields

3.3.1 Carrot (Daucus carota)

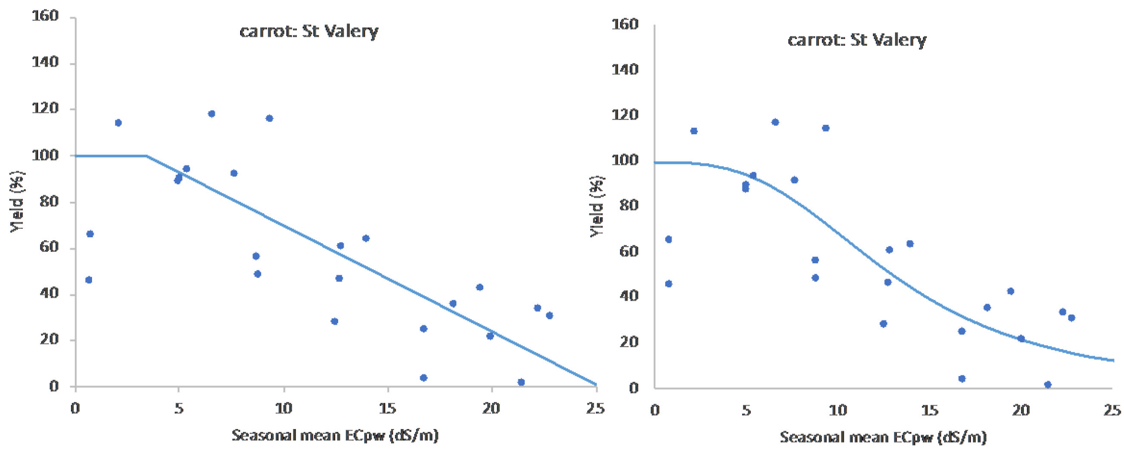
For carrot, four different varieties were evaluated for salt tolerance, namely the varieties Danvers, Napoli, Nantes and St. Valery. These varieties also represent different types of carrots. In image 3 you can see an impression of the crop development during the season. In figure 3, 4, 5 and 6 the results are presented.

Image 3. Carrot development on July 9 (54 days after planting) (left), and on July 30 (75 days after planting).



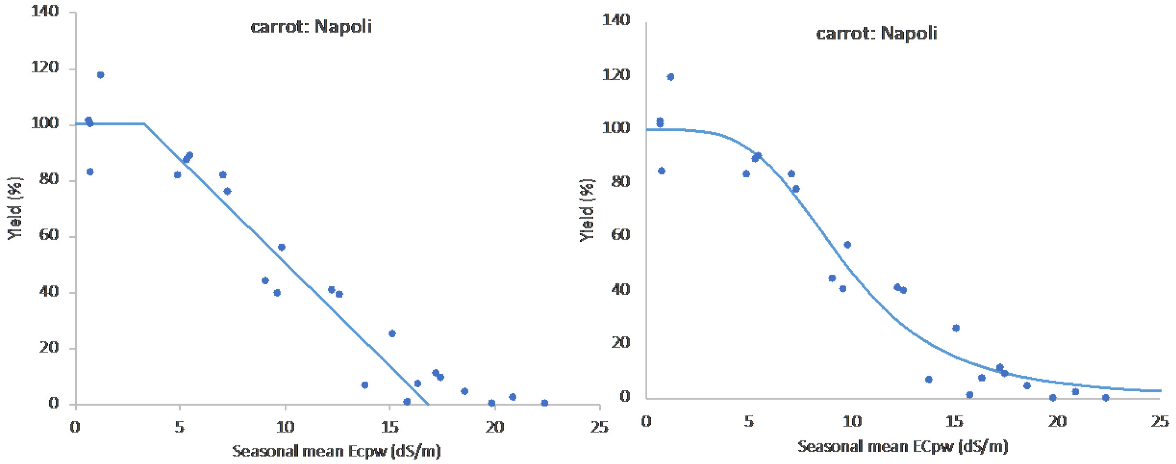
method	Yield (Y0)	ECpw90	ECpw75	ECpw50	ECpw threshold	Slope (%)	p
M&H	1292	7.4	9.8	13.4	6.2	-6.9	
vG&H	1320	7.2	9.5	12.5			3.98

Figure 3. Crop response curve to increasing salinity of **carrot, variety Danvers**. Each point represents the relative yield of carrot in a single plot as a function of its seasonal average pore water salinity (in dS/m, from table 2). Data was analyzed by the Maas and Hoffman method (M&H, image left) and the van Genuchten and Hoffman method (vG&H, (image right). The absolute yield (Y0) is expressed as yield of a 1 meter long row (in grams). ECp stands for the salinity level of the pore water, where "90" represent the salinity level at which 90% yield is till achieved, "ECp75" represent the pore water salinity levels at which 75% yield is still achieved, and "50" represents 50% yield. The threshold stands for the maximum salinity level with no yield reduction and the slope represent the yield reduction beyond the threshold value (in % yield decline per 1 dS/m).



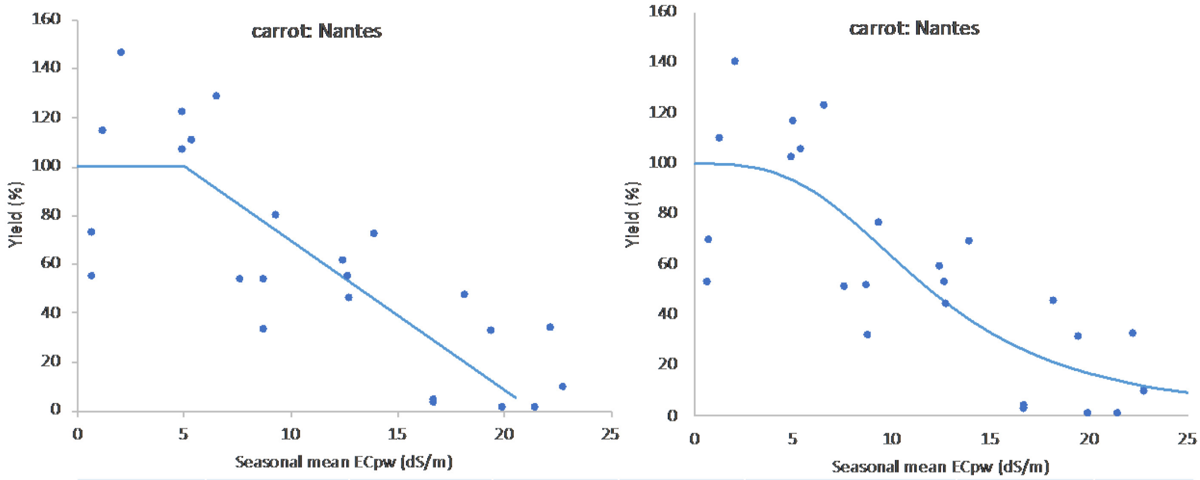
method	Yield (Y0)	ECpw90	ECpw75	ECpw50	ECpw threshold	Slope (%)	p
M&H	1995	4.6	8.9	14.3	3.5	-4.6	
vG&H	2010	6.2	9.0	13.0			2.97

Figure 4. Crop response curve to increasing salinity of **carrot, variety St. Valery**. For further description see figure 3.



method	Yield (Y0)	ECpw90	ECpw75	ECpw50	ECpw threshold	Slope (%)	p
M&H	1398	4.5	6.7	10.1	3.3	-7.4	
vG&H	1366	5.5	7.3	9.6			3.88

Figure 5. Crop response curve to increasing salinity of **carrot, variety Napoli**. For further description see figure 3.



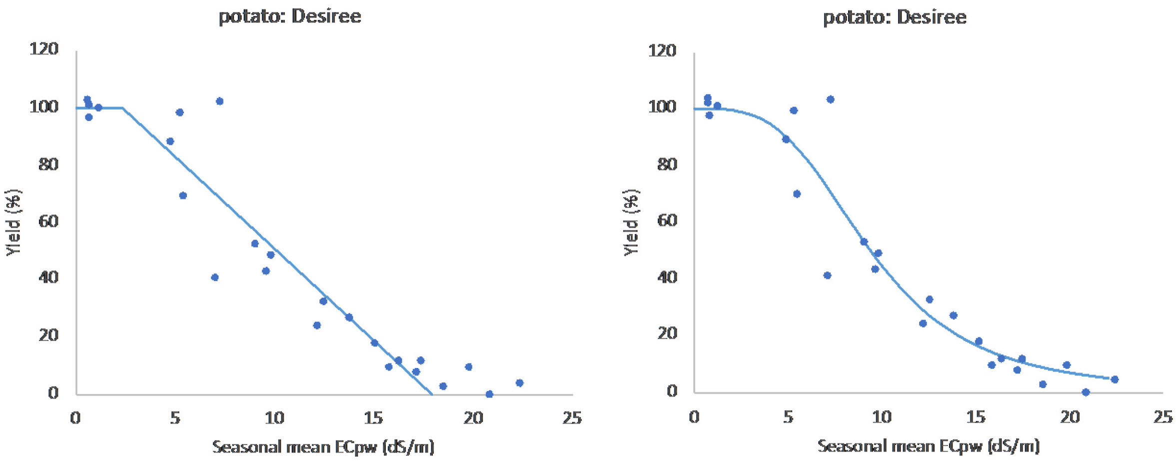
method	Yield (Y0)	ECpw90	ECpw75	ECpw50	ECpw threshold	Slope (%)	p
M&H	1988	6.6	9.1	13.2	5.0	-6.1	
vG&H	2074	5.8	8.3	11.9			3.07

Figure 6. Crop response curve to increasing salinity of **carrot, variety Nantes**. For further description see figure 3.

3.3.2 Potato (Solanum tuberosum)

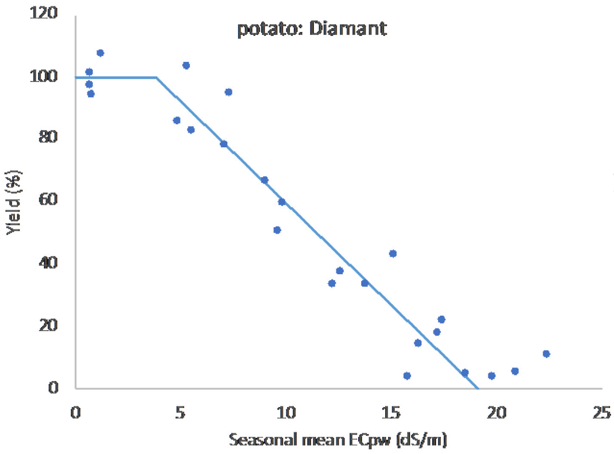
For potato, two varieties were evaluated for salt tolerance, Desiree and Diamant. These are both commonly cultivated varieties. For Diamant, seed potato of PB4 class was used, for Diamant the E class was used. Tuber size range was 35/45 mm. The results are given in figure 7 and 8.

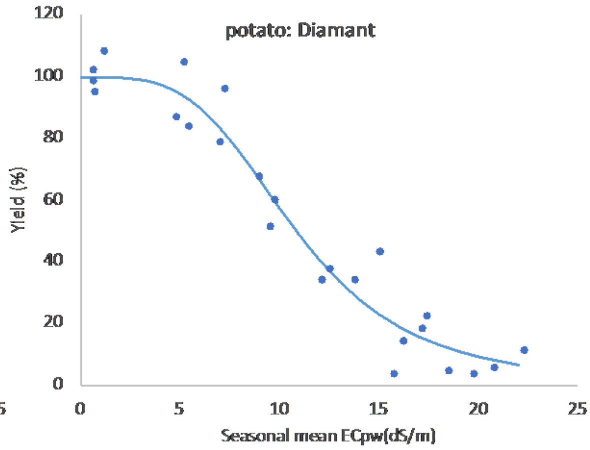
Image 4. Impression of the potato varieties on June 11 (image left: 28 days after planting and 4 days after the start of the salt treatment) and on July 2 (image right: 25 days after start salt treatment, with high salinity plot in the front and low salinity plot in the back).



method	Yield (Y0)	ECpw90	ECpw75	ECpw50	ECpw threshold	Slope (%)	p
M&H	38.3	3.9	6.2	10.1	2.3	-6.4	
vG&H	38.0	4.9	6.8	9.3			3.40

Figure 7. Crop response curve to increasing salinity of **potato, variety Desiree**. Yield (Y0) is given in tons/ha. For further description see figure 3.





method	Yield (Y0)	ECpw90	ECpw75	ECpw50	ECpw threshold	Slope (%)	p
M&H	32.3	5.3	7.6	11.5	3.8	-6.5	
vG&H	32.0	6.0	8.1	10.8			3.73

Figure 8. Crop response curve to increasing salinity of **potato, variety Diamant.** Yield (Y0) is given in tons/ha. For further description see figure 3.

3.3.3 Brassica crops: cauliflower, cabbage, kohlrabi

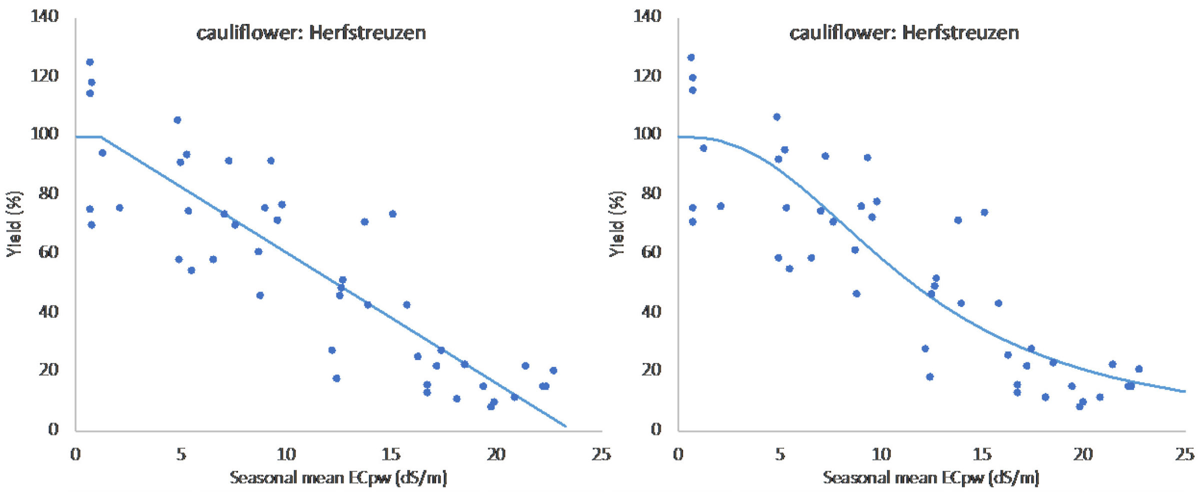
Cauliflower, cabbage and kohlrabi are closely related and are all part of the Brassica family. Image 5 gives an impression of these different Brassica crops on June 25.

Image 5. Impression of the different Brassica crops on June 25 (33 days after transplanting cauliflower and cabbage, 34 days for kohlrabi). The different Brassica's were planted on different beds, with cabbage on the right, kohlrabi in the middle, and cauliflower on the left bed.

Cauliflower (Brassica oleracea , subs. botrytis)

For cauliflower, the variety Herfstreuzen was used to evaluate the crop response to increasing salinity. In this case, a total of 48 plots were used (6 salinity levels with 8 repetitions each). The results are given in figure 9.

Image 5. Impression of the cauliflower crop on August 9.



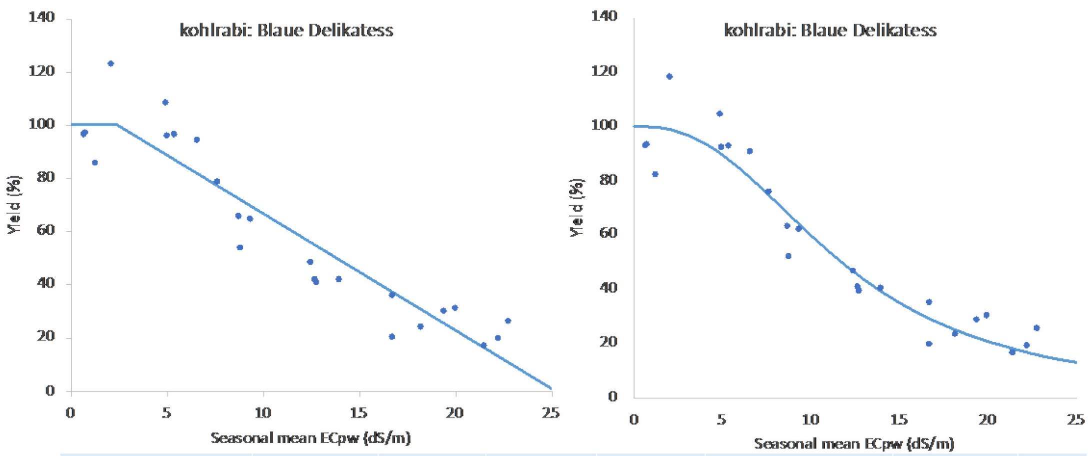
method	Yield (Y0)	ECpw90	ECpw75	ECpw50	ECpw threshold	Slope (%)	p
M&H	468	3.4	6.8	12.4	1.1	-4.4	
vG&H	462	4.7	7.3	11.5			2.42

Figure 9. Crop response curve to increasing salinity of **cauliflower, variety Herfstreuzen.** Yield (Y0) is given in grams per cauliflower. For further description see figure 3.

Kohlrabi (Brassica oleracea, subs. Gongylodes)

For kohlrabi the variety Blaue Delikatess was used. An impression of the crop is given in image 6 and the crop salt response is given in figure 10. In total, 24 plots were used.

Image 6. Impression of the kohlrabi crop on July 2 (image left, with Blaue Delikatess visible as the purple plants) and of the crop close to harvest time (image right, picture taken on July 26).



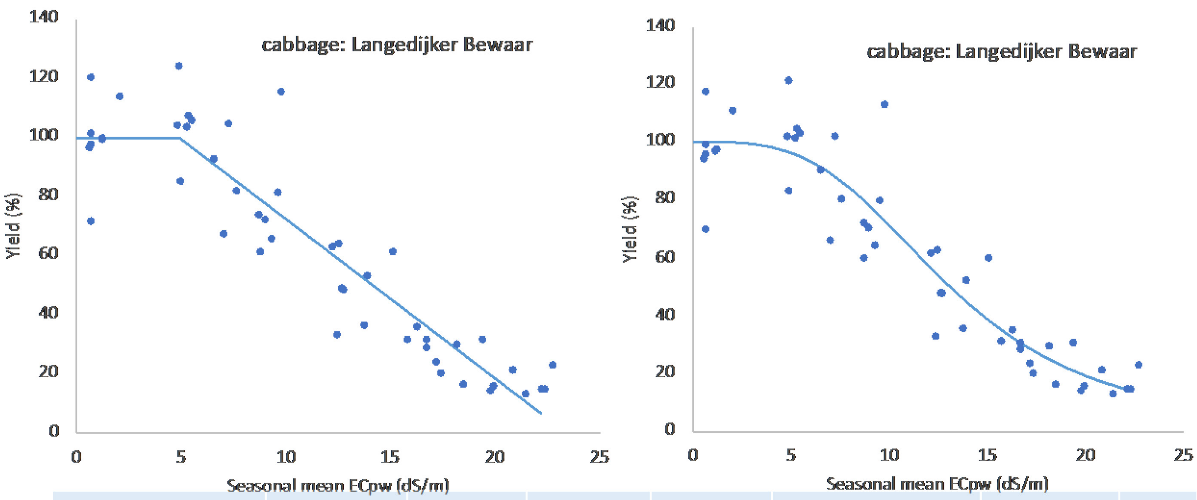
method	Yield (Y0)	ECpw90	ECpw75	ECpw50	ECpw threshold	Slope (%)	p
M&H	523	4.6	8.0	13.7	2.4	-4.4	
vG&H	544	4.7	7.7	11.7			2.50
2nd harvest M&H	970	3.7	7.9	14.9	0.9	-3.6	
2nd harvest vG&H	944	5.3	9.0	15.3			2.08

Figure 10. Crop response curve to increasing salinity of **kohlrabi variety Blaue Delikatess.** Yield (Y0) is given in grams per kohlrabi. Data of a second harvest, 15 days after the initial harvest, is also provided in the table (not plotted in the graphs). For further description see figure 3.

White cabbage (Brassica oleracea, subs. Capitate)

For cabbage, the variety Langedijker Bewaar was selected. In this case, a total of 48 plots were used (6 salinity levels with 8 repetitions each). An impression of the crop is given in image 7 and the results are presented in figure 11.

Image 7. Impression of cabbage bed on June 27 (left) and individual cabbage on August 17.



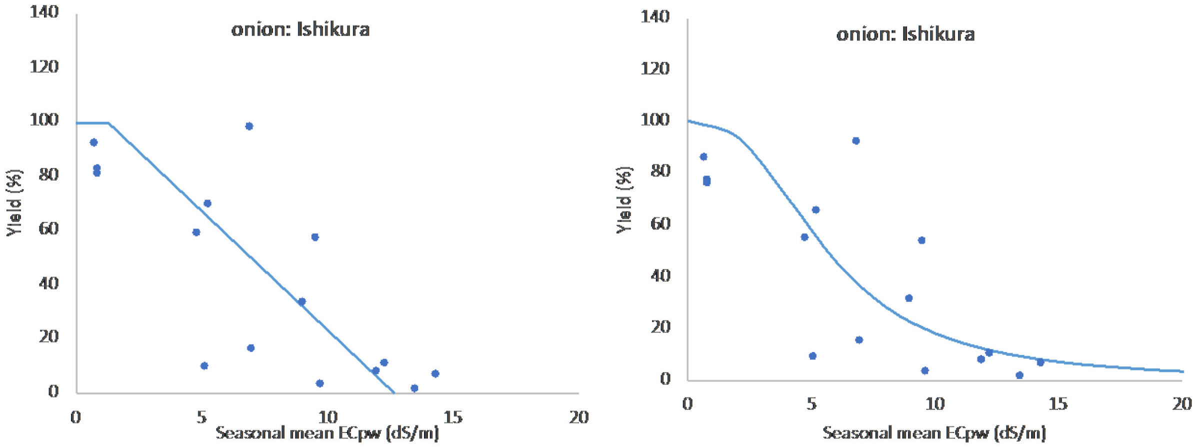
method	Yield (Y0)	ECpw90	ECpw75	ECpw50	ECpw threshold	Slope (%)	p
M&H	1282	6.7	9.5	14.2	4.9	-5.4	
vG&H	1310	6.8	9.4	13.1			3.36

Figure 11. Crop response curve to increasing salinity of **cabbage variety Langedijker Bewaar.** Yield (Y0) is given in grams per cabbage. Data of a second harvest, 15 days after the initial harvest, is also provided in the table. For further description see figure 3.

3.3.4 Onion (Allium cepa)

For onion, a bunching onion was evaluated, namely the variety Ishikura. First, seedlings were raised which were planted in the plots after the salt treatment started, so seedlings were planted directly in saline soil.

Image 8. Impression of the onion on August 1, 43 days after transplanting.

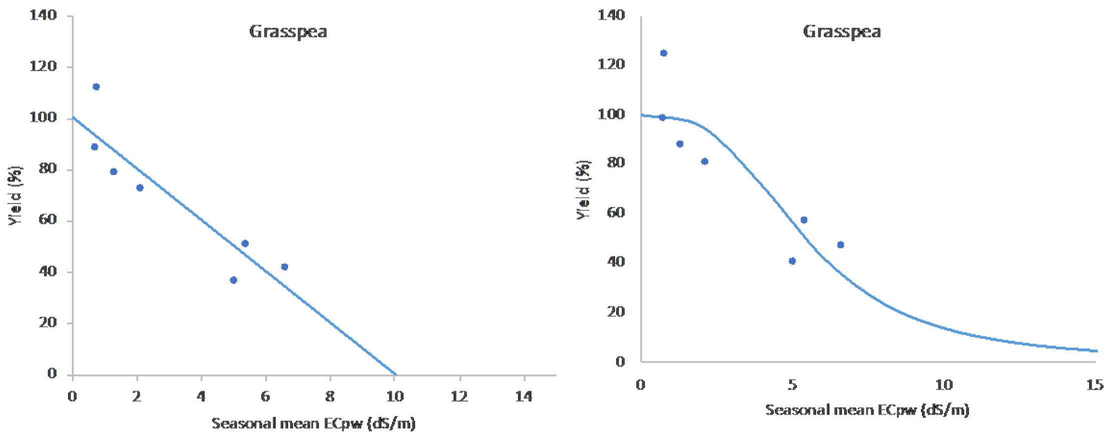


method	Yield (Y0)	ECpw90	ECpw75	ECpw50	ECpw threshold	Slope (%)	p
M&H	32	2.4	4.1	7.0	1.3	-8.8	
vG&H	34	2.4	3.7	5.6			2.60

Figure 12. Crop response curve to increasing salinity of the **bunching onion, variety Ishikura.** Yield (Y0) is given in grams per plant. For further description see figure 3.

3.3.5 Grasspea (Lathyrus sativus, source: Vreeken Zaden)

The results of the grasspea trial are given in figure 13. The limited number of data points is due to the fact that the plants only survived the first 2 salt levels (0.5 and 4 dS/m, EC irrigation water).

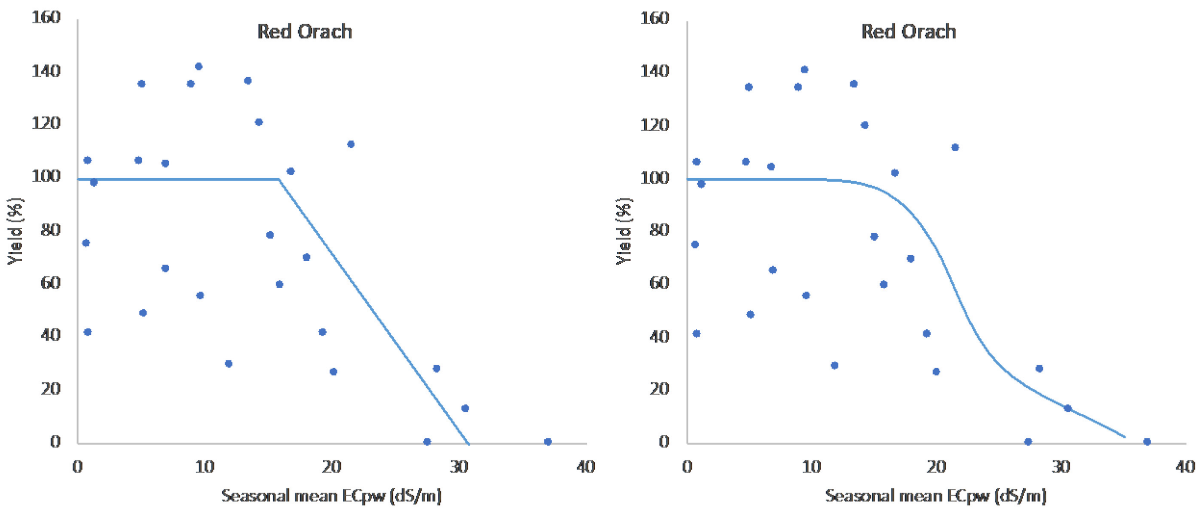


method	Yield (Y0)	ECpw90	ECpw75	ECpw50	ECpw threshold	Slope (%)	p
M&H	1103	1.0	2.5	5.0	0.0	-10.0	
vG&G (p=3)	988	2.6	3.7	5.4			3

Figure 13. Crop response curve to increasing salinity of the **Grasspea.** Yield (Y0) is given in grams for a 1 meter long row. For further description see figure 3.

3.3.6 Red orach or mountain spinach (Atriplex hortensis, source: Bolster)

The results of the Atriplex trials are given in figure 14. The data points show a large scatter, but on average the $EC_{pw}90$ is 17.3 dS/m.



method	Yield (Y0)	ECpw90	ECpw75	ECpw50	ECpw threshold	Slope (%)	p
M&H	44	17.3	19.5	23.2	15.8	-3.0	
vG&H	44	17.3	19.7	22.5			8.35

Figure 14. Crop response curve to increasing salinity of the **Red Orach (*Atriplex hortensis*).** Yield (Y0) is given in grams per plant. For further description see figure 3.

3.4 Classification of crop salt tolerance

A standard way of classifying crop salt tolerance is provided by FAO (table 6). This classification also indicates that at salinity levels above 10.5 dS/m (EC_e), yields for most crops are unacceptable. But as the results in this report show, there are crops with salinity tolerances in this range, and also halophytes (not evaluated in this report) can commonly withstand high salinity levels. So, it is suggested to revise this classification somewhat, and in table 7 a first suggestion for classifying crop salt tolerance is provided. Here, the salinity level of EC_{90} and EC_{75} are used. To evaluate the classification of the salt tolerance of the crops in this report, first a calibration of the salinity levels of extracted pore water (which have been used in this report up until this point) to ECe (salinity level of the extract of a saturated soil sample, which is commonly used as the international standard) has to be performed. For this, figure 15 can be used. In figure 15 the ECe is plotted as a function of the EC of the pore water (collected from the same plot).

Table 6. Standard classification of crop salt tolerance (FAO), based on EC_e threshold (EC_{100}) and EC_{50} (as calculated from the threshold and slope).

FAO classification	Level of salinity (EC_e100)	Level of salinity (EC_e50)
sensitive	0 - 2	0 – 5
moderately sensitive	2 - 3,5	5 – 9
moderately tolerant	3,5 – 6,5	9 – 15
tolerant	6,5 – 10,5	15 – 21
Yields unacceptable for most crops	> 10,5	> 21

Table 7. Suggested (by Saline Farming) revised classification of crop salt tolerance, based on EC_e90 and EC_e75

Updated classification	Level of salinity (EC_e90)	Level of salinity (EC_e75)
sensitive	0 - 2	2 - 4
moderately sensitive	2 - 4	4 - 8
moderately tolerant	4 - 8	8 - 12
tolerant	8 - 12	12 - 16
highly tolerant	> 12	> 16

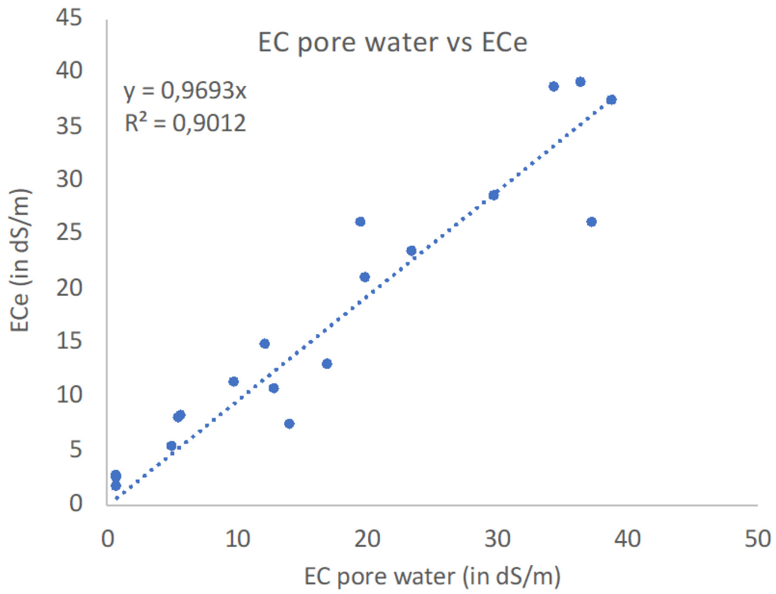


Figure 15. Salinity levels of the pore water plotted against the salinity levels of a soil saturated paste extract (ECe) of the same plot on the same day. Samples were taken on two separate dates during the 2018 season.

In table 8 an overview is given of the crop salt tolerance of the crops and varieties that were evaluated in this report. EC values have been calculated to ECe, based on the calibration of figure 15. The classification is based on the criteria of table 7.

Table 8. Overview of the crop salt tolerance of the different crops and varieties that were evaluated in this report. Salt tolerance is expressed as EC_e90, EC_e75 and EC_e50 (in dS/m), based on the Maas and Hoffman method. The calibration factor from figure 15 was used to calculate the EC_e values. Results are ordered from high to low salt tolerance.

crop	variety	Yield*	EC_e90	EC_e75	EC_e50	classification
red orach	-	44	16.8	18.9	22.5	highly tolerant
carrot	Danvers	1292	7.2	9.5	13.0	moderately tolerant
cabbage	Langedijker	1282	6.5	9.2	13.8	moderately tolerant
carrot	Nantes	1988	6.4	8.8	12.8	moderately tolerant
potato**	Diamant	32.3	5.1	7.4	11.1	mod. tolerant/mod. sensitive
carrot	St. Valery	1995	4.5	8.6	13.9	moderately tolerant
kohlrabi**	Blaue Deli.	523	4.5	7.8	13.3	mod. tolerant/mod. sensitive
carrot**	Napoli	1398	4.4	6.5	9.8	mod. tolerant/mod. sensitive
potato	Desiree	38.3	3.8	6.0	9.8	moderately sensitive
cauliflower	Herfstreuzen	468	3.3	6.6	12.0	moderately sensitive
onion	Ishikura	32	2.3	4.0	6.8	moderately sensitive
grasspea	-	1103	1.0	2.4	4.8	sensitive

* Yield potential (Y0) or maximum yield, is given for individual plants, except for potato where the yield is given in tons/hectare, and for carrot and grasspea the yield of a 1 meter long row is given.

** Based on the ECe90 this variety is moderately tolerant, but based on the ECe75 it is moderately sensitive

In table 9 a comparison has been made between the salt tolerance data described in this report and the commonly used classification of the FAO (2002). Although it can be tricky to compare different data sets, that have a different set up and most likely many other differences as well, it is still clear that the reported levels of salt tolerance can vary greatly. In the case of potato, carrot and cabbage, the salt tolerance levels of the varieties that were evaluated in this report, appear to be greater than the data reported by FAO.

Table 9. Comparison of the salt tolerance data of the different crops from table 5 with the commonly used data on crop salt tolerance from FAO (2002), calculated as EC_e90, EC_e75 and EC_e50. The classification is based on table 4.

crop	variety	EC_e90	EC_e75	EC_e50	classification
potato*	Diamant	5.1	7.4	11.1	mod. tolerant/mod. sensitive
potato	Desiree	3.8	6.0	9.8	moderately sensitive
potato	FAO, White Rose	2.5	3.8	5.9	sensitive / mod. sensitive
carrot	Danvers	7.2	9.5	13.0	moderately tolerant
carrot	Nantes	6.4	8.8	12.8	moderately tolerant
carrot	St. Valery	4.5	8.6	13.9	moderately tolerant
carrot*	Napoli	4.4	6.5	9.8	mod. tolerant/sensitive
carrot	FAO, variety unknown	1.7	2.8	4.6	sensitive
cabbage	Langedijker	6.5	9.2	13.8	moderately tolerant
cabbage	FAO, variety unknown	2.8	4.4	7.0	moderately sensitive
cauliflower	Herfstreuzen	3.3	6.6	12.0	moderately sensitive
cauliflower	FAO, variety unknown				moderately sensitive
kohlrabi*	Blaue Delikatesse	4.5	7.8	13.3	moderately tolerant
kohlrabi	FAO, variety unknown				moderately sensitive
onion	Ishikura	2.3	4.0	6.8	moderately sensitive
onion	"bulb"	1.8	2.8	4.3	sensitive
onion	FAO, "seed yield"	2.2	4.1	7.2	moderately sensitive

* Based on the ECe90 this variety is moderately tolerant, but based on the ECe75 it is moderately sensitive.

4. DISCUSSION

Based on the data of the different graphs it is clear that the variability of the crop yield at comparable salinity levels are often considerable, even when pore water salinity levels in the soil are relatively stable in time. This considerable variation in yield at comparable salinity levels is especially clear for carrot (all varieties except Napoli), cauliflower, onion, grasspea, and red orach. The white cabbage variety (Langedijker Bewaar) also shows some variation. Especially the two potato varieties, the carrot Napoli and kohlrabi seem to show little variation in the data. This can imply that the salt tolerance data of the crops with little variation are more reliable, but this should be validated by second year of testing. As was also indicated by the FAO (2002), absolute tolerances vary, depending upon climate, soil conditions and cultural practices. A second year of testing at the same location will provide more insight in the potential variation and the robustness of the current results.

In table 6 a comparison has been made between the salt tolerance data described in this report and the commonly used classification of the FAO (2002). This is a somewhat arbitrary comparison since both salt tolerance data sets can only serve as a guideline to relative tolerances among crops and all the different trials will often be difficult to compare. But still, according the FAO data set, both potato and carrot are sensitive crops (based on the EC_e90), whereas the results in this report indicate that 3 out of 4 carrot varieties are moderately tolerant and potato (Diamant) can almost be classified as moderately tolerant (EC_e75 is 7.4 and this should be at least 8.0 to be classified as moderately tolerant according to the chosen classification). When the soil salinity classes and the effect on crop plants of table 10 are considered (according to Abrol *et al*., 1988), the yield of many crops are restricted under moderate saline conditions (4-8 dS/m, ECe). When the EC_e90 of table 8 is considered, it appears that many of the tested crops still yield around 90% in this salinity range. The best performing varieties of potato, carrot and cabbage still show 90% yields in the 5-7 dS/m range. This implies that these varieties of these commonly cultivated crops are suitable for cultivation under moderate saline conditions. But it should be noted that the absolute or maximum yield of the cabbage" Langedijker Bewaar" was only in the range of 1.3 kg per cabbage. This appears to be low and it is not clear why this is the case. In comparison to other cabbage varieties that were tested in the same year, the growth seems to be somewhat slower than the other (early) varieties. Possibly this has an effect on the reported salt tolerance as well and it is advisable to test not only this cabbage variety again, but also other (early) varieties as well.

Table 10. Soil salinity classes and crop growth (Abrol *et al*., 1988). Soil salinity is based on the electrical conductivity of the extract of a soil saturated paste (EC_e, in dS/m)

Soil salinity class	**EC_e (in dS/m)**	**Effect on crop plants**
Non-saline	0-2	Salinity effects negligible
Slightly saline	2-4	Yields of sensitive crops may be restricted
Moderately saline	4-8	Yields of many crops are restricted
Strongly saline	8-16	Only tolerant crops yield satisfactorily
Very strongly saline	> 16	Only a few tolerant crops yield satisfactorily

5. CONCLUSIONS AND RECOMMENDATIONS

- The pore water salinity levels in the soil are very close to the target salinity levels of the irrigation water, especially when the seasonal mean of the pore water salinity level is considered
- In general, the crop response curves to increasing appear to be robust, although in some cases the variation in yield at comparable levels can be considerable
- The results of this single year of testing imply that there are varieties of potato, carrot and cabbage that still show a 90% yield in the salinity range of 5-7 dS/m (based on the extract of a saturated paste: ECe)
- This implies that these varieties of these commonly cultivated crops are suitable for cultivation under moderate saline conditions.
- A more robust data set will be generated by a second year of testing, which is highly advisable for field trials in general and more so for salt tolerance trials

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