rijksuniversiteit groningen

Salinization of Dutch Agriculture: How to Adapt?

Based on literature research

By

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Abstract

The extent of salinization in the Netherlands must not be underestimated. Even though the present situation is not very threatening, in the future salinization might have a lot of impact on Dutch agriculture. A change in climate and sea level rise will cause more pressure of salt water and less fresh water availability for cultivated areas. These global issues will not be solved in the near future so adaptation to an increase in salinization is required. To understand how to adapt, the way salinization affects crops needs to be explained. Salinized soil can decrease crop yield if the cultivated species/variety is not salt-tolerant, which is the case for many cultivated crops in the Netherlands. A toxic level of ion accumulation from the saline environment can cause enzyme inactivity that can damage a plant and restrict its yield. To achieve sustainable agriculture in a saline environment a plant has to possess salt-tolerance and a high yield, which is of importance to the farmer. Combining these two factors will be of importance and might be achieved. Genetically designing such a crop might be promising and realistic in the future, unfortunately, present knowledge is lacking. Breeding plants is another option, but for the same reasons as with genetic engineering it proves to be very hard to simultaneously breed salt-tolerant and high yielding crops. Using halophytes as alternative crops is the final option. High yielding halophytes are available and should be considered; only a lack of social acceptance might be a problem. Next to adapting our crops, our water management has to adapt as well. A method that takes into consideration local conditions must be implied to determine the amount of irrigation water needed to obtain an optimal crop yield. The Netherlands need to pay attention to these adaptations to achieve sustainable agriculture and to protect themselves from salinization.

Outline

This thesis is divided into four parts. In the first part, *"Manufacturing agriculture in the Netherlands against salinization",* the issue of salinization in the Netherlands is introduced together with an explanation what information is required to resolve this issue and how this will be documented. In the second part, "*What is causing the problem in the Netherlands?*", the causes of salinization in the Netherlands will be discussed alongside an overview of salinization threats per region. In the third part, "*How is salinization affecting crops?",* background about the specific way salinization affects crops is provided. The fourth and final part of this thesis, *"How can we adapt?",* will conclude and discuss how to adapt our agriculture to salinization. These adaptations will be in twofold and will both be accounted for.

Manufacturing agriculture in the Netherlands against salinization

Salinization is the process by which salts accumulate in the soil. When salt reaches toxic levels it has a negative influence on crop yield. The extent of this problem must not be underestimated; right now at least 8% of irrigated agricultural land worldwide is affected by salinization. (*Extent of land salinized by irrigation, 2011; the salt of the earth: hazardous for food production, 2002*)

Although efforts are being made to sustain crop yields on a worldwide scale, this paper will only focus on the situation in the Netherlands, where the source of salinization is the sea. Sea levels are rising and with already 26% of its area under sea level, the Netherlands is very susceptible to salinization. Right now, there already is some salt-water intrusion from the sea. To prevent damage to cultivated lands, this salt water is washed away with fresh water from the rivers. This is the current situation. In the future, this manner of protecting our agricultural land might not be possible. Climate change is causing a hotter and dryer environment whereby less fresh water is provided by the rivers (*ontstaan en gevolgen watertekort*). Climate change is also causing rising sea levels. These two events cause more pressure of salt water and a decrease in availability of fresh water, thereby making it increasingly difficult to protect our agriculture from salinization. At the moment salt water reaches 1,5 up to 6 kilometers inland and this increases with 5 to 30 meters per year. In addition, expected climate change will lead to a surplus of precipitation in the winter and a shortage of precipitation in the summer. This will lead to even more salinization pressure in the summer *(Verzilting in Nederland*, 2011). This shows that salinization is a very urgent issue in the Netherlands.

The various ways in which salinization affects Dutch agriculture can be divided into four causes:

1. Salt water intrusion through rivers and estuaries will lead to salinized irrigation water.
2. Salt water intrusion of agricultural land through capillary pressure.
3. A lack of water supply upriver that causes a deficit of fresh water.
4. Due to human activities.

The first three are caused by climate change and sea level rising. These are global issues that will not be solved in the near future, so adaptation is of major importance to protect our agriculture. To adapt ourselves to prevent further salinization an understanding about the way salt might affect crops is required. So why is a saline environment hostile to a plant? To answer this, the physiological background of a plant regarding salinization needs to be accounted for, with an emphasis on ion involvement. Next to this the two effector phases of growth limitation both need to be understood to give a broader sense how salinization affects a crop. Genetics of salinization are important as well to understand salinization, but in this context there is no need of including it.

There are species which are not affected by certain amounts of salt in the soil. These species are salt-tolerant, or halophytic, and share a number of features that result in a reduction of the toxic effects of salt. Through evolution halophytes have acquired adaptations, like salt-secreting glands, to prevent a too high internal accumulation of ions. An explanation concerning halophytes will be accounted for.

Understanding the mechanisms of salt-tolerance and causes of salinization in the Netherlands, it is possible to determine what adaptations are necessary to be made to make our agriculture sustainable. This is of rather importance to the Netherlands because a lot of inhabitants still depend on income from agriculture. And not only the Netherlands but the whole world suffers from salinization. If we come to a solution in the Netherlands it might aid to solve salinization in other places as well.

What is causing the problem in the Netherlands?

A wider perspective about the situation in the Netherlands has to be acquired. How does Dutch water management operate, how does salinization occur in the Netherlands and what are the biggest threats? These are a couple of questions that need to be answered before solutions can be found how to adapt to salinization of Dutch agriculture.

The source of salinization in the Netherlands is the sea and there are multiple ways the salt might enter Dutch agricultural land. One of them is through estuaries. Estuaries are the transition between the river and the sea in which the water is under influence of the tide. In the Netherlands we can distinguish four river catchments, the Eems, the Rijn, the Maas and the Schelde, that provide fresh water. At the other side the salt water comes from the sea, and with sea levels rising, the rivers endure a higher pressure from salt water (*oprukken zout water*).

There are a couple of ways in which agricultural areas in the Netherlands are affected by salinization. The areas that are close to salt water and are situated near or below sea level could endure salinization through the salt water reaching the root zone by capillary rise from salty subsurface water (*Actualisering van de Kennis, 2011*). With sea levels rising, the impact of this effect will increase in the future.
Sea level rise has another way of affecting salinization. Within the estuaries there is always a balance between salt and fresh water. With less fresh water flowing from the rivers and more salt water coming from the sea this balance can be disturbed. The influence of this change has already been shown when the salt water tide from the Lauwerszee (now the Lauwersmeer) reached till Groningen and Dokkum (*Zoet-zout overgangen*). This might have an effect on agriculture, because fresh water is taken from the rivers for irrigation. With high tide and less fresh water supply the water for irrigation taken downriver might be salt water affected.

The third way salinization might increase in the future is due to human activities. To recreate characteristic natural habitats, salt and fresh water passages might be reinstated. As an example, the Haringvliet sluices are already slightly opened. In the future the Haringvliet sluices might be opened completely, mainly to improve international fish migration (*Kabinet zet na druk EU en buurlanden,* 2011*)*. But by doing so, the Haringvliet will be consisting of salt water instead of sweet water, thereby decreasing the amount of available fresh water.

So there are a couple of ways salinization is affecting the Netherlands. But what can we do against these threats to our agriculture? Sea level rising and global warming are both global issues that might be solved, but probably not in the near future. And human influences like opening the Harlingvliet sluices might be forced upon us by the European Union (*Kabinet zet na druk EU en buurlanden*, 2011). Thus, we have no choice but to adapt ourselves to salinization.

An overview per region will now be outlined to conclude this explanation about salinization and water management in the Netherlands. The agricultural areas can be divided into three main regions, the north and north-west, Zuid-Holland and Zeeland.

In the north and north west of the Netherlands high concentrations of salts are found. Despite this, salt peaks are rare, fresh water to counter this is abundant and there are few fluctuations in fresh water supply and quality. This leads to a relatively predictable and controlled situation. Even more because most of the crops cultivated are relatively salt-tolerant. Only the potato and ornamental flower bulb farming are more susceptible to salinization and may be at risk in the future (*Verzilting in Nederland,* 2011*).*

In Zuid-Holland the concentrations of salts are less. Though, fresh water quality and supply is less certain, there is saltwater intrusion through the Nieuwe Waterweg and priorities might not always be on agriculture but, for instance, more on the maritime sector. Next to this, the crops cultivated are largely susceptible to salinization. So farmers in Zuid-Holland might need to adapt to sustain their yield (*Verzilting in Nederland*, 2011).

Zeeland suffers just as the north and north west of the Netherlands from high concentrations of salt. And just as in Zuid-Holland, supply and quality of fresh water can be limited and priorities might not be on agriculture. This implies that Zeeland suffers the most from salinization. Yet, salinization has always been present and farmers have mostly adapted to it. Mainly salt-tolerant crops are cultivated and the Deltawerken have led to more fresh water available. So Zeeland appears to be quite prepared for an increase in salinization (*Verzilting in Nederland,* 2011*)*.

How is salinization affecting crops?

To decide how Dutch agriculture has to adapt in order to sustain a high yield under saline conditions, it is important to understand the basic mechanisms of salt-tolerance. When a soil becomes saltier, crop yield will decrease if the plant species/variety that is being cultivated is not salt-tolerant. Salt-tolerant, or halophytic, plant species share a number of features that result in a reduction of the toxic effects of salt. Although the specific salt-tolerance genes are yet to be discovered, the physiological aspects of salt-tolerance will be covered. The following step would be, to develop methods by which salt-sensitive, or glycophytic, plants can be adapted to become more salt-tolerant. This information will also result in a better understanding how we can design alternative crops to maintain the crop yield.

The definition of a halophyte states that there has to be growth and survival under saline conditions. It must, however, be emphasized that the salt concentration with optimum growth greatly differs between halophyte species *(Flowers, 2004)*. So to implement a species within Dutch agriculture the saline environment needs to correspond with the specific plant species.

But how can a saline environment be hostile to a plant? The most common ions in a saline environment are K+, Na+ and Cl-. When Na+ and Cl- become too abundant in the cytosol of a plant they might become toxic and disable the activity of enzymes. Without enzyme activities a cell cannot function so it dies. The main protective manner against saline environments is to keep the ions out as much as possible *(Munns, 2005)*. Regulating this accumulation of ions might be a highly energy-demanding process, but the extent of the energy demand, however, remains unknown *(Flowers, 2008)*. Experiments with concentrations of ions inside halophytes indicate that mainly K+ and Na+ accumulate inside the plant. Cl- is also present but not in such levels as K+ and Na+. This implies that K+ and Na+ channels are more important with regard to salt-tolerance *(Flowers, 2008)*.

When a plant is exposed to a saline environment, there are two phases of effects on growth over time. During the first stage the ions won't be able to enter the plant. In this stage water-stress is caused in the plant because next to no water assimilation water is secreted in the roots to sustain osmotic pressure. Shoot growth and, to a lesser degree, root growth will reduce as a consequence. The second stage is when the ions enter the plant; this is the salt-specific phase. The ions are preferentially transported to older leaves, excluding salt from entering the young, still growing, leaves. When the amount of accumulated salt in a leaf becomes toxic it will die. In several plant species ions are secreted by accumulating them in an older leave, which subsequently senesces and dies.

With this method the plant can cast off the leave and will get rid of the ions simultaneously. At the same time there is still growth of new leaves. If such a plant wants to survive in a saline environment, the amount of growth of new leaves needs to exceed the amount of death of old ion-absorbing leaves *(Munns, 2005)*.

Salt-tolerant species have evolved over hundreds of million years. In all these years of evolution plants have acquired adaptations regarding salt-tolerance. One of the adaptations some plant species have acquired is the utilization of salt-secreting glands that eliminate excess salt from the leaves, thereby reducing the need of ion compartmentalization *(Flowers 2004*).

When experimenting in saline environments a limited effect of salt on vegetative growth might be an indication of salt-tolerance. However, it is known that crop yield in rice is more depressed than the vegetative growth in saline conditions *(Khatun and Flowers 1995; Flowers 2004*). In agriculture, yield is a better indicator of salt-tolerance than vegetative growth because for the farmer, yield is most important. In this way, in creating a salt-tolerant crop that sustains the same yield as its non-salt-tolerant sibling, a foundation might be lain down to achieve cultivating sustainable crops within a saline environment *(Flowers 2004)*.

This statement implies that to achieve sustainable agriculture in a saline environment, there are two features a plant has to possess, salt-tolerance and a high yield. Is it possible to combine those two features? Won't there be a trade-off between salt-tolerance and yield? The feature of salt-tolerance might be energy-demanding (see above), so being salt-tolerant might degrade the yield. Fortunately research suggests that salt-tolerance per se does not restrict yield *(Flowers, 2010; Rozema 2013)*. Although this seems to be promising, combining the two features remains to be very complex *(Flowers, 2010)*.

There are multiple ways of developing a sustainable agriculture in saline environments. The features and the advantages and disadvantages of each will be discussed in the last part of this thesis.

How can we adapt?

As explained before, there are multiple causes of salinization. Climate change and sea level rise are global issues that won't be solved within years. And salinization due to human activities might be forced upon us like at the Haringvliet sluices. This entails that salinization pressure in the Netherlands will grow in the near future. In this thesis, the way salinization is affecting crops has been explained. Combining this with the causes of salinization in the Netherlands solutions can be argued, how to adapt our agriculture to rising salinization. These adaptations are in twofold and will be discussed in detail.

1. Change the way we manage our water

Fresh water availability is going to decrease in the near future. This means that not all agricultural areas will have a sufficient amount of fresh water available to keep the soil from becoming salinized. To sustain the same crop yield a change has to be made in the way we manage our water.

Determining the amount of salinization an area can endure (comparable to the amount of fresh water an area needs), the salt-tolerance of a crop is an important factor. In the figure below the classification of crop tolerance to salinity is given. Salinization is measured in EC (electrical conductivity), units are given in dS/m (deciSiemens per meter) (*Zouttolerantie van landbouwgewassen, 2007*). Crops are divided in four classes: sensitive, moderately sensitive, moderately tolerant and tolerant. Each with its own relative crop yield related to the EC. Such a classification system might be of good use when deciding which crops to cultivate (*Actualisering van de kennis van de zouttolerantie van landbouwgewassen, 2011*).

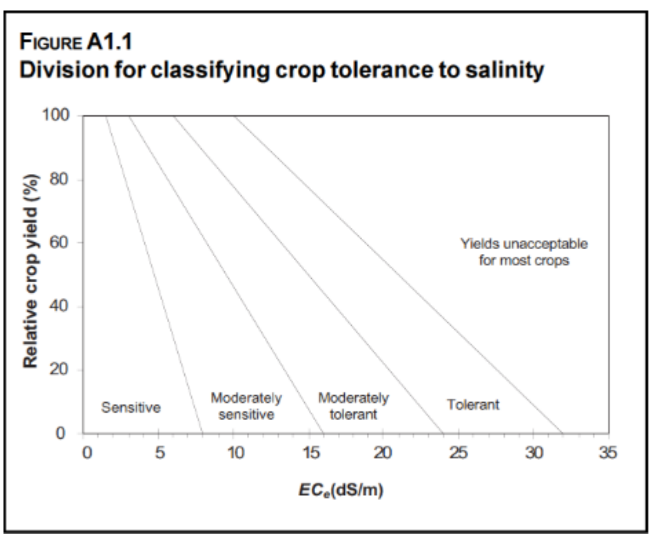

Figure 2: Salt-sensitivity classification of crops (Actualisering van de kennis van de zouttolerantie van landbouwgewassen, 2011)

The sensitivity for crops differs greatly between species, even within classifications (not every tolerant crop can endure same amount of salt). So how to determine which crop can grow in a certain salt environment? For this purpose a damage threshold and damage function can be determined for each crop. The damage threshold is the concentration chloride or the EC for which the crop loses yield. The damage function is the decrease of yield as a function of the concentration chloride or the EC. (*Zouttolerantie van landbouwgewassen, 2007*)

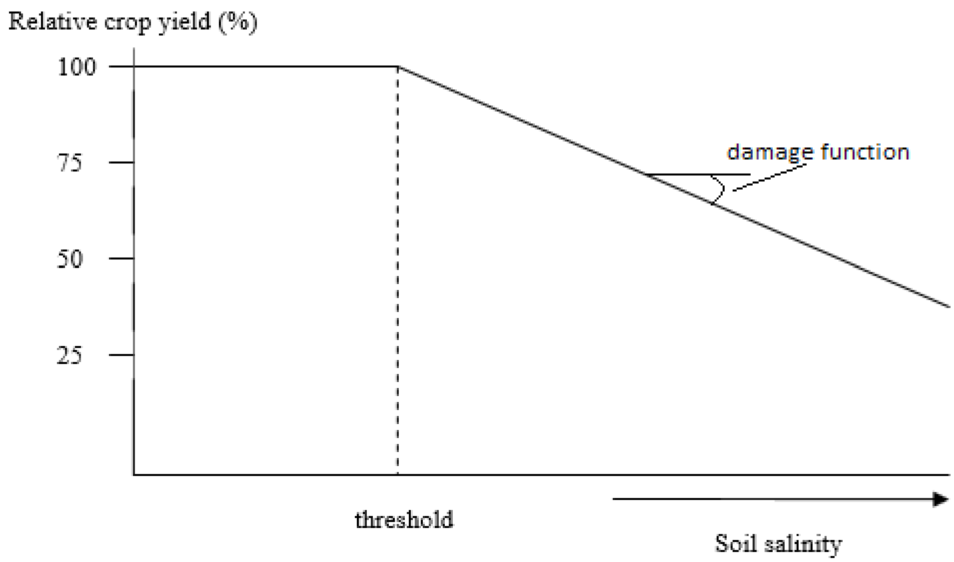

Figure 3: damage threshold and damage function

Generally, the determined damage threshold and function can be accepted, but to apply it in the Netherlands other factors will also have to be taken into consideration. These other factors determine the method that needs to be used to adapt to salinization. Firstly, the soil type has to be taken into account. Table 1 shows that in the south west delta, crops are cultivated on different soils (Loam, Clay, Sand and Peat). These soils all have different water holding capacities. It is important to take this into account, because for example sand has a much lower water holding capacity than loam. This influences the amount of irrigation water needed. Crops on sandy soils need a lot more irrigation water than crops on loamy soils. This means that crops on sandy soils will be under more salt pressure than crops on loamy soils, regarding that the irrigation water had been affected by salinization. So to determine crop yield for salinized areas, damage calculations should include soil type (*Review of crop salt tolerance in the Netherlands, 2009*). Taking into account that for instance not every loamy soil is of the same consistency, it might be clever to determine crop yield regionally.

Crop	Soil type (in % of agricultural area)				Total (in %)
	Loam	Clay	Sand	Peat	
Grass	9.6	5.1	1.7	0.7	17.2
Maize	2.4	1.1	0.4	0.1	4.0
Potato	10.0	3.6	0.2	0.0	13.8
Sugar beet	7.5	3.5	0.1	0.0	11.2
Grain crops	16.7	8.8	0.3	0.1	25.9
Other crops	16.8	6.4	0.7	0.1	23.9
Green houses	0.3	0.1	0.0	0.0	0.5
Fruit trees	2.3	0.7	0.0	0.0	3.1
Flower bulbs	0.3	0.1	0.0	0.0	0.4
Total	65.8	29.4	3.6	1.1	100.0

Table 1: Land-use in the south-west delta per soil type (Review of crop salt tolerance in the Netherlands, 2009)

There is another reason why determining crop yield regionally might be convenient. As explained before, for plants salt-stress and drought share some physiological similarities. Within salinized agriculture there is another relation between them: a trade-off between drought and salt stress. An excess of salt might be more damaging to a plant than some drought stress. So determining the optimal amount of irrigation water might lead to a higher yield. This has to be done regionally because it is very dependent on the water holding capacities of the soil (*Review of crop salt tolerance in the Netherlands, 2009).*

To adapt to salinization methods needs to be applied that take into consideration local conditions as soil type and the trade of between salt and drought stress. These methods should determine the amount of irrigation water needed to obtain an optimal crop yield.

2. Change plants we use as crops

Next to this methodical adaptation, a change in crop plants might be a smart adaptation for the future. If it is possible to sustain the same yield in a salinized area by cultivating another crop, that might be a good long-term solution. But is this possible?

In all those years the salt-tolerant species have developed different mechanisms enabling them to live in a saline environment. Nature did it so many times, but for us it still proves to be difficult to breed salt-tolerant crops. The battle between mankind and salinization is not a recent one. For millennia mankind has been adapting to salinization. In Iraq 3500 B.C. proportions of wheat and barley where nearly equal. 1000 years later only one sixth of the crops was consisting of the less salt-tolerant wheat. 800 years after that, the cultivation of wheat was abandoned in this region. This example shows that as long as thousands of years ago people were adapting to salinization *(Jacobsen, 1958)*. Today, with new technologies and more extensive knowledge, might there be a possibility to adapt our agriculture to salinization without losing crop yield? There are three ways in which crops might adapt; their qualities and potential are discussed below.

Molecular genetic engineering

One way of developing sustainable agriculture might be molecular genetic engineering. To genetically design a crop to be salt-tolerant and have a high yield seems to be very promising. Yet there are some disadvantages why it is still very hard to do this. These will be discussed together with the advantages and features of molecular genetic engineering.

One of the biggest disadvantages of genetic engineering is that it requires detailed knowledge of the mechanisms of salt-tolerance, which is presently lacking *(Rozema, 2013)*. Next to that, it is not just a matter of salt-tolerance, for a farmer high yield is most important. Combining these two factors with genetic engineering especially proves to be hard. Most studies find the differences between the degrees of plant mortality, growth inhibition and tolerance, to be just a little bit less than before. These findings have to become more impressive for farmers to notice them.

Although so far there aren't very promising results, there are some possibilities within genetic engineering. These experiments are done with single gene transformation and as said, could have a little positive effect. This could suggest that when more genes are used, a better result could be accomplished *(Rozema, 2013)*. Especially with interspecific hybridization, in which genes are introduced from wild salt-tolerance species, this may lead to salt-tolerant crops *(Flowers, 2004)*. Unfortunately, present knowledge is lacking. When knowledge is increased, molecular genetic engineering can be the feasible route to solving the salinization problem.

Conventional Breeding

Compared to genetic engineering, conventional breeding exists for a longer period of time. It does not incorporate genetic engineering; it is based on selection of desirable traits through breeding. One example is to select plants that have an ion content under saline conditions that is either higher or lower than that of their parental types. Doing this repetitively may lead to salt-tolerance in the species *(Flowers Yeo, 1995)*. This can only be done between two plants that are able to mate with each other (other than with interspecific hybridization).

One disadvantage is that when plants are crossed, not just the desirable traits are passed on; some undesirable traits might be passed on as well *(Conventional plant breeding, 2006)*. That's why it proves to be very difficult to breed a salt-tolerant plant which has a high yield as well. So despite all the effort put in, few productive salt-tolerant species have been bred *(Flowers, 2004).* There are some possibilities to for future generating of salt-tolerant crops. The realization that salt-tolerant plants have evolved multiple times might lead to the discovery of specific traits. These traits might then be selected by plant breeders to develop salt-tolerant crops *(Flowers, 2010).*

For both molecular genetic engineering and conventional breeding there is one thing that is holding them back: the lack of knowledge about salt-tolerance. Until more is discovered about the specific traits and the genetic information of salt-tolerance, there is a little chance of producing salt-tolerant species with a high yield.

Halophytes as alternative crops

Since it proves to be so difficult to produce salt-tolerant crops, another possibility might be to introduce wild halophytes in agriculture. Many halophytes show optimal grow curves in saline environments and might even grow at the same rate as glycophytes *(Flowers and Colmer, 2008).* For some species, the halophyte crops could even be irrigated with brackish water or seawater *(Rozema and Flowers, 2008).* Next to direct use as crops, these halophytes might be needed for remediation of salt-affected land. Due to industrialization a lot of toxic materials have been accumulating in the environment. Some seagrasses and salt-marsh plants show the ability of extracting these toxic materials from the soil and accumulating them in their tissue thereby remediating the environment *(Lewis and Devereux, 2009).* Other halophytes might improve other conditions like water conductance or soil fertility *(Qadir, 2008*). These applications of halophyte next to the direct use of crops imply that the domestication of halophytes should be considered.

So what concluding remarks can be made regarding this thesis? Through analysis from a scientific and social perspective, these two adaptations that have just been described are considered to be reasonable solutions to a growing problem. Dutch society has to pay more attention to the salinization of their agriculture, to prevent it from harming their crop yield. This is important, especially because it is becoming an urgent issue and a lot of research needs to be done before we can cultivate our crops in a sustainable way. Therefore, decisive action has to be taken to protect Dutch agriculture. And if the Netherlands succeed and a sustainable agriculture is established it might aid to solve salinization in other places as well.

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