Detecting the effect of sodic soils on alfalfa crop performance in Saratov, Russia

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Student registration number:
830805 165060

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Supervisor(s):
Dr. Eli Argaman
Dr. Simone Verzandvoort
Dr. Koos Groen

Examinator:
Prof.dr.ir. L. Stroosnijder

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Wageningen University, Land Degradation and Development Group

Moscow State University of Environmental Engineering

Vrije Universiteit Amsterdam, Faculty of Earth and Life Sciences

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Abstract

According to the Millennium Ecosystem Assessment (MEA, 2005) the percent of drylands affected by degradation lies between 10% to 20% MEA (2005). This process, if based on the total number of people threatened by it, ranks among one of the greatest contemporary environmental problems (MEA, 2005). In the semi-arid climate of Saratov, Russia, land degradation, especially in the form of alkaline salinity, plays an active role in the region where agriculture is very important to the regions population. It is therefore of essence to be able to understand the effects of salinized land on crop performance. This research project is a joint effort, which focuses on the performance of alfalfa, when the effects of soil salinity and the crop water stress are taken into account. This thesis focuses on the former, while the latter is discussed in Beets (2009). The experimental design comprised of measuring: the EC, pH and soil moisture at different depths in the soil. The measured characteristics of crop performance consisted of: above ground biomass, root biomass to 40 cm depth in 20 cm partitions, maximum plant height, plant density, leaf area index (LAI) and plant water content (plant H_2O). The statistical techniques performed on these variables were kept simple due to a small sample pool and included pair wise correlations and partial correlations to discover the strongest relationships between the variables. The results of the different analyses indicated that the root biomass, in general, was significantly correlated with EC as well as pH. Plant water content was in turn negatively correlated with EC. Plant H_2O, fresh biomass and LAI were all positively correlated with soil moisture, as expected. The other plant characteristics did not produce any significant correlations. These results indicated that both EC and pH had a positive effect on the alfalfa root biomass, which is normally unlikely in salinized soils. For EC, this was due to saline levels not being high enough. The positive correlation between pH and root biomass at such high pH (basic) levels, however, is a relationship that has not been observed before and more research is required to be able to explain this occurrence. The negative correlation between plant H_2O and EC is explained by an increase in soil water potential and osmotic stress.

1.Introduction

Land degradation, as defined by the UNEP (2007), is “a long-term loss of ecosystem functions and services, caused by disturbances from which the system cannot recover unaided”. When this process occurs on arable land, it can result in low crop yields and can pose a serious threat to livelihoods, welfare, and ultimately on global food supplies and future agricultural practices in various arid to semi-arid areas around the world. This degradation can take shape in different forms, including soil erosion, water scarcity, salinity and disruption of biological cycles (GEO4, UNEP 2007). According to the Millennium Ecosystem Assessment (2003) around 10-20% of earths dry lands are affected by land degrading processes. Less rainfall due to climate change and inadequate land management (Metternicht et al. 2008), as well as increasing demands for food production (Dorjee, 2008) form the major contributors to this degradation.

The Russian Federation has also had to cope with its share of degradation, as an estimated 14,4% of the Russian territory is being threatened by degradation (Stolbovoi et al. 1999). This degradation is predominantly found in cultivated lands, which mostly lie in Central and Southern European Russia (Ladonina et al. 2001). In the South of European Russia the type of degradation is mainly in the form of salinity, more specifically alkaline salinity (Pankova, 1998). This type of salinization receives a special place among saline lands because it sets limits on fertility not only by the amount of salts in the soil solution, but also by physico-chemical and physical properties of the soil water (Pankova, 1998). The main cause of alkaline soils lies is their high content of sodium carbonates and bicarbonates, especially when found in clayey soils (Vorobeva et al. 2006). These types of alkaline soils are associated with a bad soil structure and a low infiltration capacity, making them difficult to use for agriculture purposes.

One factor that has contributed for a large part to salinization in this region of the Russian Federation is the agricultural practice during Soviet times (Zonn, 1995). In Southern European Russia, this was achieved by applying intense irrigation schemes on land once covered by the Caspian Sea (Plit et al. 1995). This resulted in the phenomenon known as secondary salinization. This process is defined as salt accumulation in the upper part of the soil profile resulting from evaporation of irrigation groundwater in the capillary fringe (Stolbovoi et al., 1990). Furthermore, following the collapse of the USSR, many old systems of land management had been left in a new geographical context (Ladonina et al. 2001). This resulted in impractical situations with borders dividing lands that were previously connected, rivers no longer feeding arable land beyond new borders and vast territories of cultivated lands being abandoned. This has resulted in the remnant infrastructure becoming either too expensive to upkeep or too excessive compared to the demand required. Since the fall of the USSR intensive irrigation has ceased, but has also still left the area susceptible to land degradation (Pankova, 1998).

All these different problems have caused the region to become a hotspot of degradation and desertification. In the EU-co-funded DESIRE project, promising alternative strategies for sustainable land management are developed and tested to reduce land degradation. In the context of the DESIRE project, it was decided to study the effects of soil salinity and vegetation water stress on the performance of Alfalfa crops in the province of Saratov, located in Southern European Russia. This oblast is part of the Volga-Ural River Interstream region, of which 41% of the land is used for agriculture and 44% is used for pasture (Blagoveshchenskii et al. 2002). Saratov oblast (province) is the largest supplier of grain in the Volga region (Visible Earth, NASA, 2002). Besides grains, forage crops like Alfalfa are also very important. This is because collective farms in the region are subsidized if they produce forage crops, which is part of a plan to introduce the region as a main supplier of meat in Russia. Alfalfa, however, is sensitive to soil salinity (Lixandru et al. 2007), but in contrast relatively well adapted to soils with high pH (Norton, 2009). A study aggregating and accumulating a large amount of data on salt tolerance for vegetable crops carried out by Shannon et al. (1999) revealed that many species had not been studied sufficiently and useful information was lacking or even absent. This emphasizes the need for further research into the effect of soil salinity on alfalfa crops.

Thus, the aim of this study is to monitor the effects of soil salinity on the performance of Alfalfa. The soil variables measured to do this, included soil moisture content, pH and EC. Their interaction with several characteristics of the performance of Alfalfa crops were studied. These included the plant density, above- and below-ground biomass, maximum plant height and leaf area. Beets (2009) carried out a separate analysis of the vegetation water stress within the same study period, where the Crop-Water Stress Index (CWSI) was calculated for the same Alfalfa crops. The results of the two analyses were combined to determine the effects of the soil on Alfalfa performance in the region.

2.Materials & Methods

2.1.Study location

The study area was located at the “Novy” study site in Marksovsky district located about 75 km East of Saratov, Russia. The measurements were done at two separate fields located along the East bank of the Volga River. The A field (51°50'4.98"N, 47° 5'20.19"E) was located more to the North and the B field (51°38'33.51"N, 46°45'19.78"E) was more to the South-West along the river (Figure 1). At both these fields there existed sparse patches of Alfalfa, where measurements were taken (Figure 5). These were considered to be “unhealthy” spots, with low performance of alfalfa crops. In contrast, measurements were also taken from the “healthier” looking spots to be able to compare the two ends of the spectrum. At each field, four destructive measuring routines consisting of two healthy and two unhealthy spots were completed, for a total of 8 locations where samples and measurements were taken from (Figure 2). The crop being grown at both fields was first year Alfalfa and at both of these fields, crop rotation was practiced. Other crops being grown in the area were sunflower, maize and a mixed legume crop, with which this rotation might have taken place. Both fields were also irrigated using center-pivot irrigation with water pumped from the Volga (Figure 3). Fertilizers were not used at the A field, but no information could be obtained regarding this for the B field. Date of sowing at the A field was the first week of May. For the B field, again this information was not available.

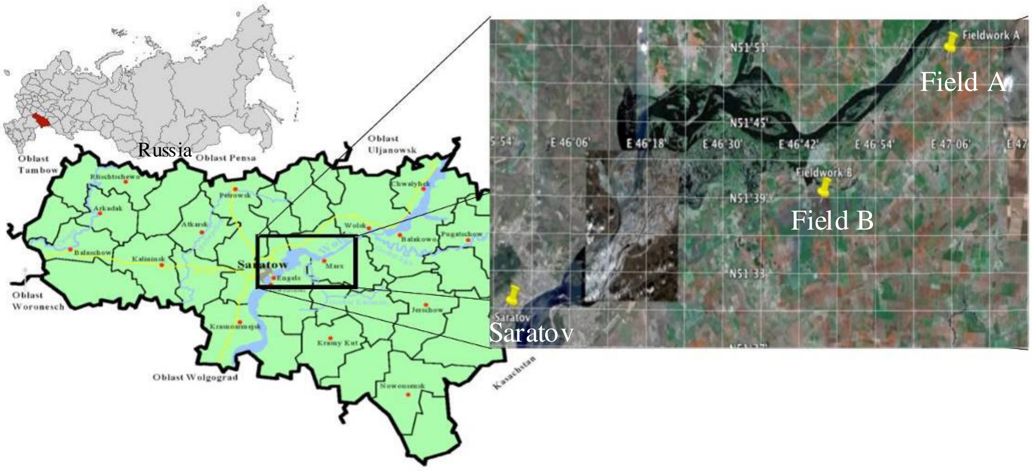


Figure 1: Study location in the center of Saratov oblast (province)

The water that is used for irrigation comes from the “Komsomolsky” irrigation system, which is the biggest sprinkler irrigation system in Russia and the biggest irrigation scheme in the Volga region. The irrigation systems canals extend throughout the area to be readily available for different collective farms spread throughout the area. The Komsomolsky system started out as a project that was supposed to extend all the way to Kazakhstan, but was halted when the USSR collapsed. It has also felt the effects of this collapse, as it has been slowly deteriorating, with leakage from pipes visible throughout the area and working at less than 50% of maximum capacity. It is a station that is over 35 years old, which needs to be renovated, but because of the recent economic crisis, funding from the government is difficult to obtain.

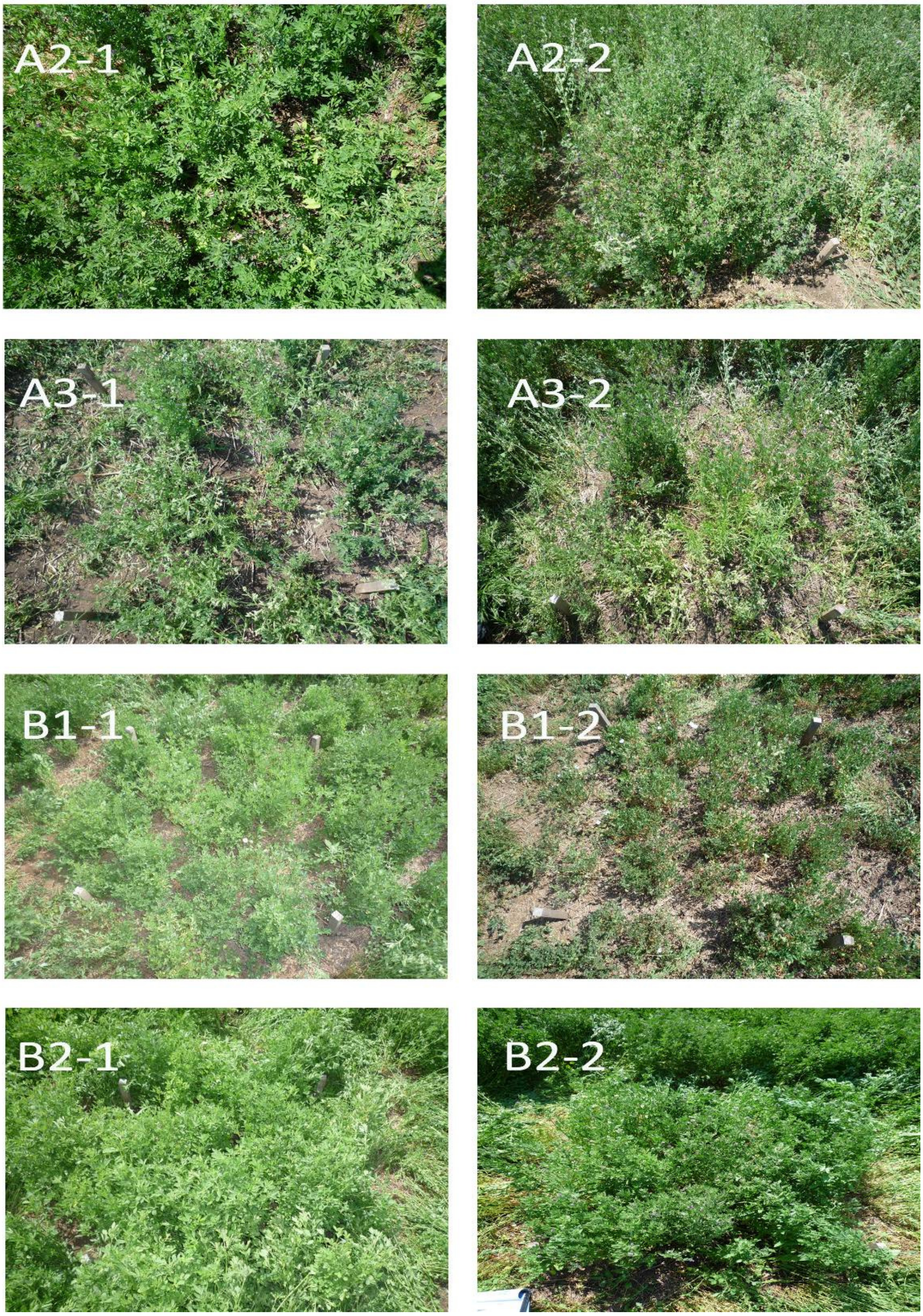


Figure 2: Photos of all plots measured in fields A and B. The photos from plots A2 and B2 represent "healthy" crops, while photos from plots A3 and B1, represent "unhealthy" crops.

Figure 3: Komsomolsky irrigation system canals (left) and center-pivot irrigation (right)

The climate in the area is a moderately continental climate with an annual mean temperature of 5.8° and an annual precipitation of around 470 mm. The difference in mean winter and summer temperatures is about 35°, while the maximum difference between summer and winter can reach up to 80°. The soil type throughout the area is an automorphic (groundwater deeper than 5 m.) chestnut soil, which is known to have a slightly alkaline character in this region (Pankova, 1998). This soil type is classified as a Kastanozem according to the FAO's WRB2006 classification. The alkaline character can be seen at the field locations, especially at the unhealthy spots, as it manifests in large cracks in the soil surface structure due to swelling of sodium carbonate (Figure 4). Certain soil physical properties were measured near to the A field for another study done in conjunction with the DESIRE Project regarding the use of wastewater for irrigation purposes (waterreuse.wur.nl.). These measurements were considered to be representative of the healthy spots at both fields for the current research. The results indicate that the soil consists of about 23% sand, 43% silt and 34% clay, which according to the USDA soil texture classification is a clay loam. The soil organic matter is about 3%, which for a Kastanozem is rather limited and indicates a mineral soil. The saturated hydraulic conductivity is 45.2 cm/d and the bulk density is on average 1.3 g/cm^3. The relief of the entire area is relatively flat and gently slopes towards the river. The ground water table, as mentioned before, sits at least 5 to 7 meters below the surface and has no influence on the vegetation. This is in contrast to the situation 40 years ago when these agricultural lands were intensely irrigated during the 1960's and the groundwater table rose, bringing with it all salts deposited during the previously mentioned regression of the Caspian Sea (Baartman et al. 2007).

Figure 4: Large cracks found in the soil surface at both field sites by unhealthy plots, which are indications of alkaline soils.

2.2. Measurements

All variables measured were taken from 1-m2 plots. At each field, two types of plots were destructively measured twice, representing “healthy” and “unhealthy” crops. These measurements were separated by several days. All measurements were taken in a span of 11 days. The sampling design was a stratified random type, since it was tried to choose plots that represented both “healthy” as well as “unhealthy” crops. Once such crops were found (e.g. healthy and unhealthy), they were selected at random. No GPS coordinates were taken of the measured plots. A visual example of the field situation is given in Figure 5. In this figure, the unhealthy plot is denoted by A3-1, while the healthy plot is denoted by A2-1. As can be seen in the photo, most of the field appeared to be healthy, so these plots were easy to find and measure. The unhealthy Alfalfa plots required some more searching in the field. The plant characteristics measured consisted of the plant density, maximum plant height (MPH), leaf area index (LAI), above ground biomass and below ground (root) biomass. The soil variables measured consisted of soil moisture content (SM), pH and EC.

Plant density was measured by counting the amount of plants per m^2. Shoots growing from the same root system were counted as belonging to the same plant. The method of calculating MPH was similar to Li et al. (2008), where the mean of the five tallest plants was measured with a measuring tape in a square meter plot. To measure the above ground biomass, a pair of scissors was used to clip the entire plot. Only plants rooted in the plot were sampled and any weeds found were separated and discarded. The obtained fresh biomass was weighed and the fresh biomass weight (fresh BM) determined. Subsequently this fresh biomass was dried in an oven at 80° for two days and weighed again to determine the dry above ground biomass (dry BM) (Shiyomi et al. 1998, Cleemput et al. 2004, Bhattarai et al. 2005). It must be noted that during the drying process, two samples, A2-1 and B2-1, were most likely overheated, due to different users using the oven at different temperatures, implying that these measurements have a certain amount of error. Once the fresh BM and dry BM were obtained, the plant moisture content (plant H_2O) could subsequently be calculated by the formula: (BM fresh – BM dry)/BM fresh (Chilcutt et al. 2005). The below ground biomass (root BM) was measured according to methods described by Cornelissen et al. (2003). This involved precisely cutting out blocks of 20 x 20 x 20 cm to a depth of 40 cm under a randomly chosen plant in the plot. This resulted in two layers of root depths being measured. These blocks of soil were first weighed and subsequently washed in a sieve in order to separate the roots. No distinction was made between the types of roots. Once separated, the roots were subsequently dried in an oven at 65° for 3 days and then weighed. Values were recorded in grams per soil volume for each 20 cm core section. To calculate the LAI, the leaves from several representative samples, ranging from the smallest to the tallest plants from the plot, were scanned. The scanned images were processed in Matlab to calculate the total leaf area of these samples. Subsequently, the fresh weight of the representative samples was measured and compared to the total fresh weight of the above ground biomass of the plot. In this manner the LAI from the representative samples could be extrapolated to the whole square meter plot. The weight of the representative samples chosen was always kept at an arbitrarily determined minimum of 5% of the total fresh weight. This was done to keep the LAI measurements for the different study plots consistent.

The soil moisture at each plot was measured with a ThetaProbe ML2x. Measurements were taken at 10 different spots right below the surface of the plot, by vertical insertion of the probe at the surface. Measurements in depth were also taken at 10 cm intervals extending to a depth of 60 cm at one arbitrary spot in the $1m^2$ plot. All measurements in depth were taken horizontally in the soil, except the deepest measurement, which was always taken vertically in the soil. Soil samples were collected for both the EC and pH, which were measured from the same soil samples. The samples were prepared as fixed soil water extracts of a 1:1 ratio based on weight. This method is less time consuming than soil paste extracts and according to Zhang et al. (2005) analogously accurate. The EC's were measured with a Hanna HI 8734 in total dissolved solids (TDS) and converted to dS/m. pH was measured with a Hanna HI 96106. Three samples for pH and EC were taken at the surface and the mean calculated. Samples were also taken in depth at 20 cm intervals up to a depth of 60 cm.

Meteorological measurements were also made so that the CWSI could be calculated. The results of this are covered in Beets (2009). Variables measured included precipitation, evaporation, air temperature, windspeed, relative humidity and radiation. These measurements, especially precipitation, are also important when considering soil moisture measurements. However during the measuring period, no precipitation was observed, hence this data is not shown, but the reader is referred instead to Beets (2009).

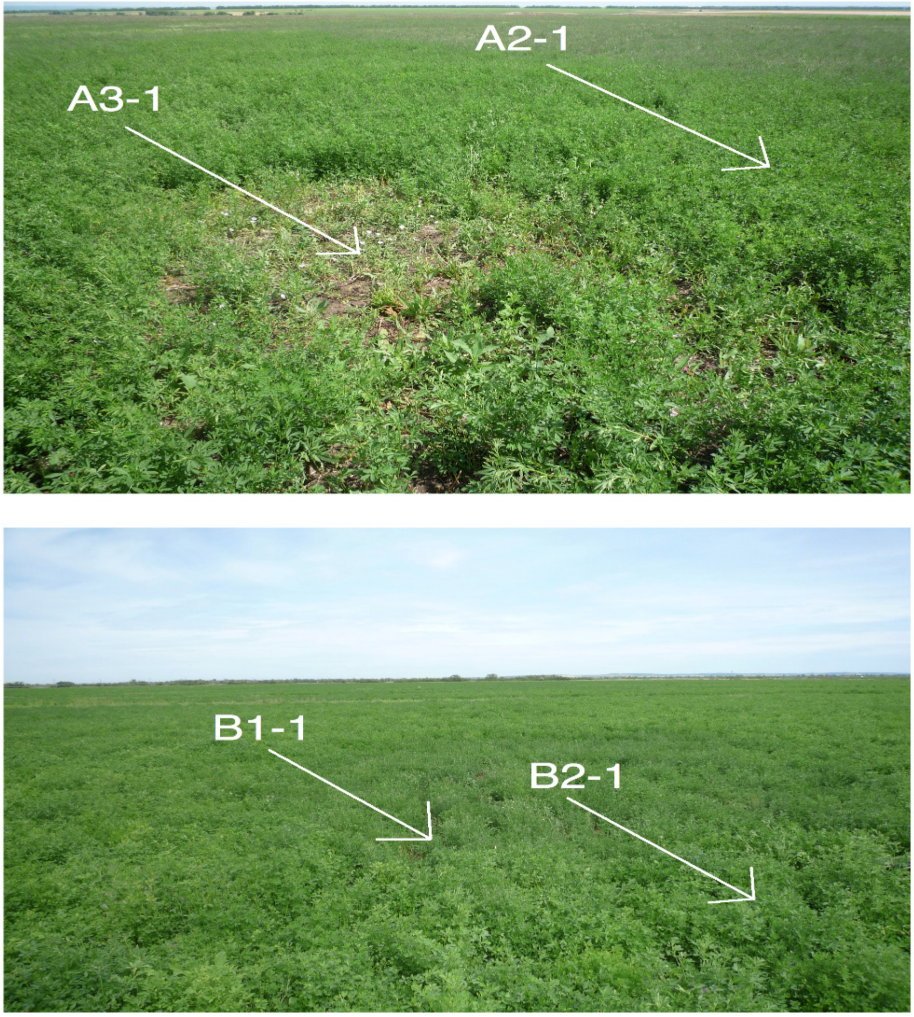


Figure 5: Example of conditions at both the A and B field. The top photo shows an example of the A field with the healthy A2-1 plot as well as the unhealthy A3-1 plot. The bottom photo shows an example of the B field with the healthy B2-1 and the unhealthy B1-1.

2.3. Statistics

Since the amount of sampled plots were small (8 in total), it was chosen to analyze the data with simple and straightforward measures. These consisted of Pearson's pair-wise correlations and partial correlations. A Kolmogorov-Smirnov test was performed on the measured data to test normality. The pair wise correlations were performed between plant characteristics, as dependent variables, and the different soil parameters as the independent variables in order to gauge the separate effect of each soil variable on each plant characteristic. However, it must be added that both types of variables have an effect on one another, so the decision to use the soil variables as the independent variable is an arbitrary decision. The plant characteristics were either measurements of the entire 1m^2 plot (e.g. above ground biomass, plant density) or samples from different spots within the plot (e.g. root biomass, maximum plant height), which were subsequently aggregated to represent the entire plot. The soil parameters, in contrast, consisted of individual measurements performed at the surface and in depth, but were still assumed to represent the entire plot. So it must be kept in mind that all analytical procedures are based on these relationships. The partial correlations were performed in order to deduce any influence from other soil variables in the results of the pair-wise correlations. The means for the three types of soil variables (EC, pH and soil moisture) were calculated from all measurements on the surface and in depth to reduce the amount of variables used in this analysis. In this manner it was easier to assess the effect of one soil variable on the other without having to do too many (fruitless) analyses. The correlations were constantly done with a total of four variables, consisting of one dependent plant characteristic, two independent soil variables and one control soil variable. Significant correlations were assumed at $\alpha < 0.1$. All statistical procedures were performed using SPSS17.

3.Results & Discussion

Table 1 shows the results of the different variables measured. At first glance it can readily be observed that the soil variables have quite some variation between the different plots. The difference between the plots that looked healthy and the plots that looked unhealthy at time of measurement is not so pronounced. What does become evident from looking at table 1 is that both the EC and pH differ more between the A-field and the B-field compared to the unhealthy and healthy plots within both fields. The pH range at the A-field was 6.2 to 8.3 with a mean of 7.2, implying a spectrum of slightly acid to slightly alkaline soils. The EC range was from 0.15 to 0.44 dS/m with a mean of 0.3. The B-field's pH range was from 7.8 to 8.5 with an average of 8.2, implying a slightly more alkaline soil. The EC's here ranged from 0.47 to 1.52 dS/m with a mean of 0.9, which indicates more salts than at the A-field. The soil moisture at the A-field ranged from 8.3 to 35%, while the range at the B-field was from 9.65 to 37.9. There existed a correlation amongst the measured EC and pH values (0.771), which indicated that these two variables increased and decreased together. If these two variables were plotted separately against soil moisture content, however, the correlation was much less pronounced (r (EC) = 0.382 and r (pH) = 0.072). This indicated that the soil moisture content was apparently not influenced by limits on infiltration due to high values of soil EC or pH. The values of the CWSI affirm the first impression of the plots in the field. If a value is higher than 0.5 it represents a plant experiencing crop water stress. All plots that were healthy were below this value. Plot A2-2 was however very close to the threshold. Similarly, all unhealthy plots, except plot A3-1, was above this value.

An overview of the soil moisture, EC, pH measurements and the root biomass is given in Figure 6. It can be observed that the soil moisture content was less at every plot the second time it was measured. This might have been due to an absence of irrigation in this period coupled with accumulated evaporation. For both the EC and pH graphs, a division between the A and B field becomes evident. The A field clearly has overall lower EC values as well as pH values, while the B field displays higher values for both these variables. The root biomass distribution also shows the segregation between the A and B field as the plots from the B field generally show higher root biomass weights compared to the A field, regardless of healthy or unhealthy plots. This is in contrast to the CWSI values for the plots. However, the CWSI is a temporary measure, while root biomass is a more stable variable. This will be discussed later in more detail.

Figure 7 displays pair-wise correlations of plant characteristics and soil properties. It can be observed that two plant characteristics, plant density and maximum plant height (MPH), are not significantly correlated with any of the soil variables. Notwithstanding, graph *a* indicates that the plant density is positively correlated with soil moisture at 30 and 60 cm depths, having correlations of .594 and 0.642, respectively. MPH does not show any apparent relevant correlations with any variable, except EC at the surface, with a negative correlation of -0.477.

The LAI as well as the fresh biomass are significantly correlated with soil moisture at a depth of 20 cm. It can furthermore be noted that both these variables are highly correlated with the rest of the upper 30 cm of soil moisture, including the mean soil moisture over 0-60 cm depth. This relation between LAI and soil moisture has been observed by Ito et al. (2007) where the LAI of different types of trees were coupled to wet and dry seasons. The fresh biomass is in turn also highly correlated with the LAI (Kersebaum et al. 2007). The significant correlations between these two variables and soil moisture at 20 cm depth might indicate that at this depth is where the roots are taking up most water.

	A2-1	A2-2	A3-1	A3-2	B1-1	B1-2	B2-1	B2-2
Date	11/7	20/7	13/7	20/7	09/7	16/7	09/7	16/7
Health Status	+	+	-	-	-	-	+	+
CWSI	0,05	0,43	0,32	0,59	0,66	0,77	-0,06	0,16
Stand Density m^{-2}	26	26	19	14	30	25	20	22
MPH (cm)	66.2	76.4	40.6	55.2	41.6	35.2	57.0	64.4
BM Fresh (g)	1516	1327	199	384	1102	494	1633	1445
BM Dry (g)	264.4	385.5	46.0	141.1	291.6	219.8	260.8	404.6
Plant H20 %	82.6	71.0	76.9	63.3	73.5	55.5	84.0	72.0
LAI (cm^2)	46455	39532	6085	9125	35454	12139	55209	29784
RBM0-20 (g/cm^3)	31.5	29.3	15.5	22.8	37.1	50.5	40.3	67.0
RBM20-40 (g/cm^3)	4.3	6.73	3.43	7.86	13.7	10.1	-	11.8
RBM0-40 (g/cm^3)	35.7	36	18.9	30.7	50.9	60.6	-	78.7
mean EC (dS/m)	0.25	0.30	0.32	0.29	0.74	1.00	0.84	1.28
EC0 (dS/m)	0.28	0.35	0.44	0.28	0.89	-	0.87	-
EC20 (dS/m)	0.29	0.27	0.18	0.23	0.47	1.01	0.75	0.93
EC40 (dS/m)	0.23	0.23	0.21	0.34	0.53	0.96	-	1.38
EC60 (dS/m)	0.15	0.28	0.22	0.29	0.81	1.03	-	1.52
mean pH	7.02	7.56	6.63	7.77	8.28	8.27	8.00	8.27
pH0	7.00	7.35	6.90	7.55	8.23	-	8.07	-
pH20	6.80	7.30	6.20	7.00	8.00	8.10	7.80	8.20
pH40	7.00	7.60	6.60	7.70	8.50	8.20	-	8.30
pH60	7.30	8.20	6.30	8.30	8.50	8.50	-	8.30
mean SM %	32.06	16.30	21.79	16.32	24.40	22.36	34.81	27.96
SM0	29.85	8.28	16.23	13.02	17.88	9.65	33.92	17.94
SM10	33.20	13.90	23.90	16.70	26.60	17.00	32.60	27.50
SM20	32.40	19.10	22.90	14.30	25.60	23.40	37.90	30.90
SM30	35.00	22.10	24.60	15.80	27.50	25.20	-	30.90
SM40	33.00	14.70	23.50	20.60	-	26.80	-	30.60
SM50	32.30	16.60	23.10	17.20	-	28.50	-	29.60
SM60	28.70	19.40	18.30	16.60	-	26.00	-	28.30

Table 1: Different variables and their values at each plot. The plus and minus signs by health status, and the columns in green and red text, denote healthy and unhealthy crops, respectively. Values that were not measured are denoted with a minus sign. All values are instant measurements, except CWSI, which is a mean from several instant measurements and the means for EC, pH and SM, which were calculated from each variable's respective depth measurements displayed in the table. The values of EC, pH and SM at the surface are also means calculated from several measurements as explained in the measurements section.

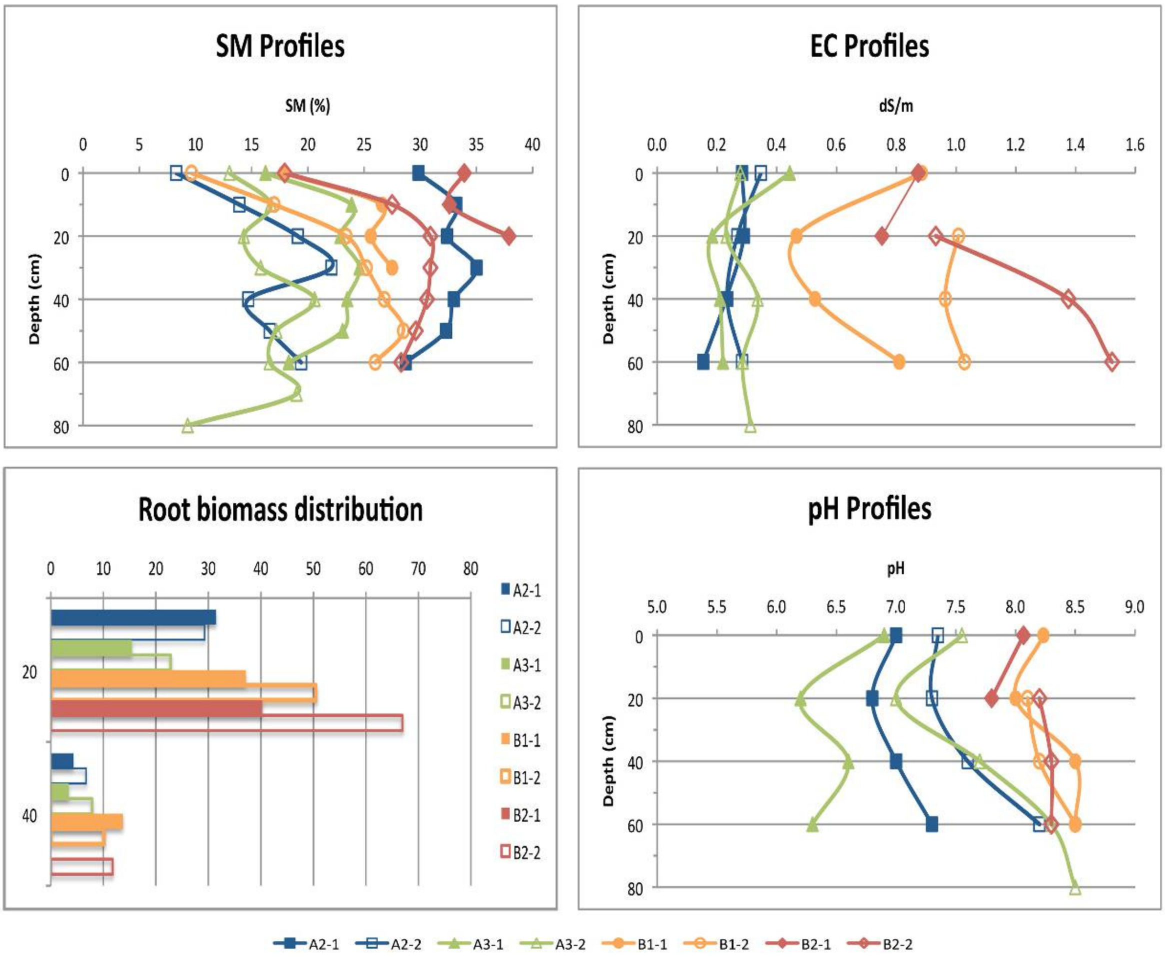


Figure 6: Soil moisture, pH and EC depth measurements, along with root biomass distribution. Legend for the SM, pH and EC profiles is at the bottom.

The dry biomass, on the other hand, is not significantly correlated with any variable and, unlike the fresh biomass, seems to have a higher affinity with both EC and pH rather than soil moisture. It shows relatively high correlations for both pH and EC at all depths except at the surface measurements of both variables. The difference in correlations between dry and fresh biomass emphasizes the different natures of both parameters, as the dry biomass is a somewhat more stable parameter, and represents the woody fraction of the plant. The fresh biomass, on the other hand, fluctuates somewhat more as it is dependant on more factors as temperature, evaporation and available soil moisture.

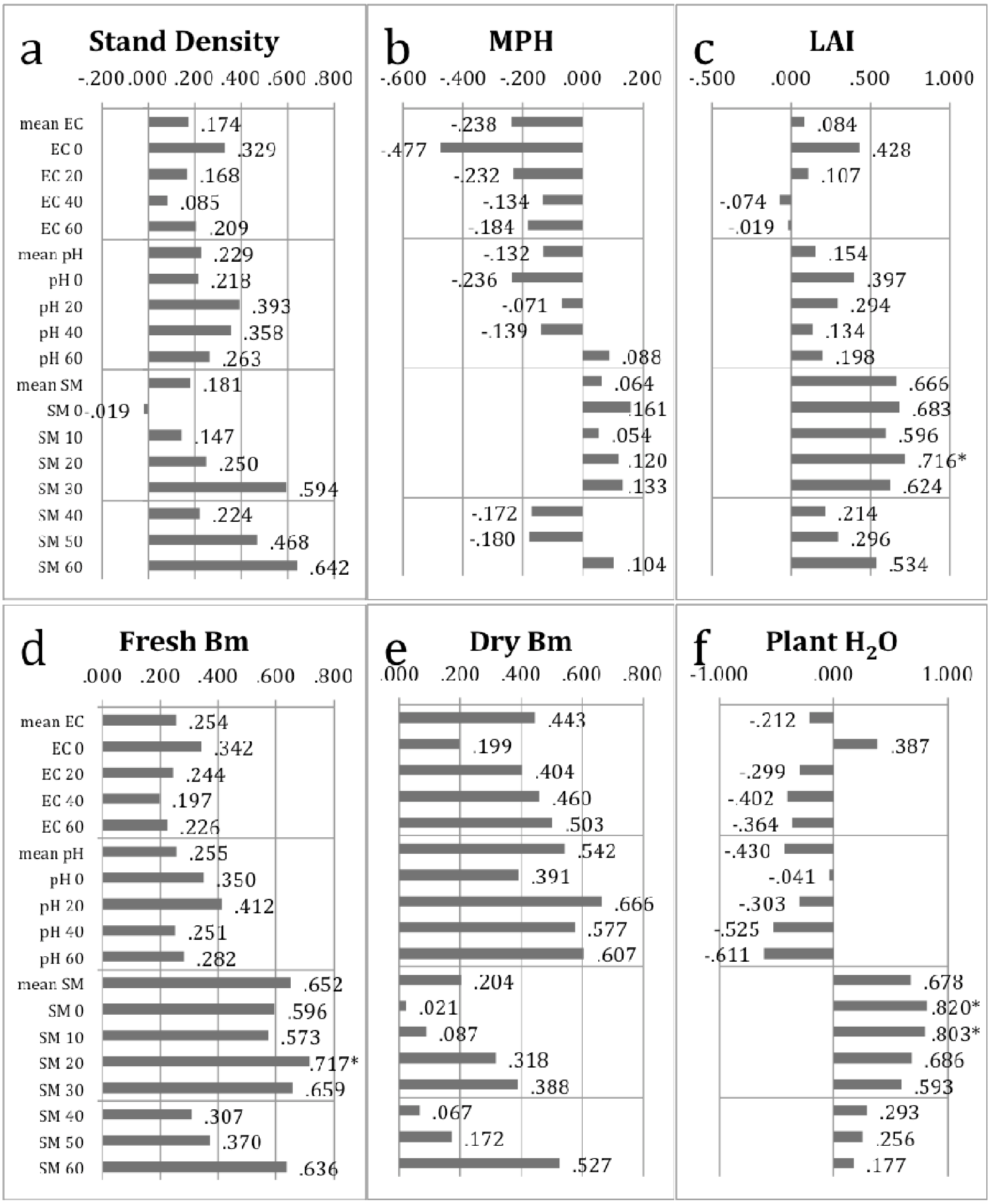
Plant H_2O, similar to the fresh biomass, is as expected, positively correlated with soil moisture, and more specifically, the upper 30 cm. It correlates significantly with soil moisture at the surface and at 10 cm depth. Furthermore, it displays several negatively correlated values for both EC and pH variables. The positive correlation between plant H_2O and soil moisture is expected, as it is generally known that roots are in continuous contact with soil moisture, from which subsequently the rest of the plant can obtain its water. So, even though no soil water potential measurements were done, it can still be presumed that the plants could have used the soil moisture that was measured and that the amount of uptake was dependant on this measured amount. A separate correlation between plant H_2O and the CWSI (r^2= -0.72) also suggest that this water was used for transpiration, assuming that the plant was in balance with its surrounding atmosphere. The negative correlations between plant H_2O and EC could be due to a greater amount of salts (higher EC) leading to increased soil water potential and thus less capacity for water to be taken up by the plant. The negative correlation between plant H_2O and pH could be due to higher pH's resulting in soils with a lower infiltration capacity and consequently decreased water uptake by the roots.

The root BM from 0-20 cm is significantly correlated with several variables, including the mean pH, pH at 20 cm and all EC variables except EC 0. It furthermore also shows several high correlations with the other pH and EC variables as well as soil moisture between a depth of 20 and 60 cm. This indicates that the upper 20 cm of root biomass is positively coupled with both EC and pH and that an increase in both of these variables will result in an increase in the root biomass. This might be due to the available salts that might be present in the form of nutrients for the roots, which result in a higher root biomass. Furthermore, even though no significant correlation exists between root BM 0-20 and soil moisture, several relatively high correlations can be observed, which indicate that this part of the root is to some extent coupled to the soil moisture content.

The root BM at 20-40 cm has more affinity with pH compared to root BM 0-20 and is significantly correlated with all pH variables as well as the mean EC and EC at 60 cm depth. It does not, however, show any substantial correlations with the soil moisture variables, unlike root BM 0-20 cm.

The correlations of the root BM 0-40 cm expose the nature of the variable as being a combination of the two variables: root BM 0-20 and 20-40. This manifests itself by being significantly correlated with the same EC variables as root BM 0-20 and most of the pH variables similar to root BM 20-40. Furthermore, it shows positive correlations with soil moisture variables that lie in between of the root BM 0-20 cm and root BM 20-40 cm.

In general, these correlations show that soil moisture, which represents a more temporary measurement, is also more correlated with the crop parameters that can fluctuate during a single day such as, LAI, fresh biomass and plant H_2O. In contrast variables like dry BM and the root BM, which are more stable parameters have more affinity with pH and EC measurements, which in contrast, tend to fluctuate in a more gradual tempo.


a
Stand Density
-.200 .000 .200 .400 .600 .800
mean EC .174
EC 0 .329
EC 20 .168
EC 40 .085
EC 60 .209
mean pH .229
pH 0 .218
pH 20 .393
pH 40 .358
pH 60 .263
mean SM .181
SM 0 -.019
SM 10 .147
SM 20 .250
SM 30 .594
SM 40 .224
SM 50 .468
SM 60 .642
b
MPH
-.600 -.400 -.200 .000 .200
-.238
-.477
-.232
-.134
-.184
-.132
-.236
-.071
-.139
.088
.064
.161
.054
.120
.133
-.172
-.180
.104
c
LAI
-.500 .000 .500 1.000
.084
.428
.107
-.074
-.019
.154
.397
.294
.134
.198
.666
.683
.596
.716*
.624
.214
.296
.534
d
Fresh Bm
.000 .200 .400 .600 .800
mean EC .254
EC 0 .342
EC 20 .244
EC 40 .197
EC 60 .226
mean pH .255
pH 0 .350
pH 20 .412
pH 40 .251
pH 60 .282
mean SM .652
SM 0 .596
SM 10 .573
SM 20 .717*
SM 30 .659
SM 40 .307
SM 50 .370
SM 60 .636
e
Dry Bm
.000 .200 .400 .600 .800
.443
.199
.404
.460
.503
.542
.391
.666
.577
.607
.204
.021
.087
.318
.388
.067
.172
.527
f
Plant H_2O
-1.000 .000 1.000
-.212
.387
-.299
-.402
-.364
-.430
-.041
-.303
-.525
-.611
.678
.820*
.803*
.686
.593
.293
.256
.177

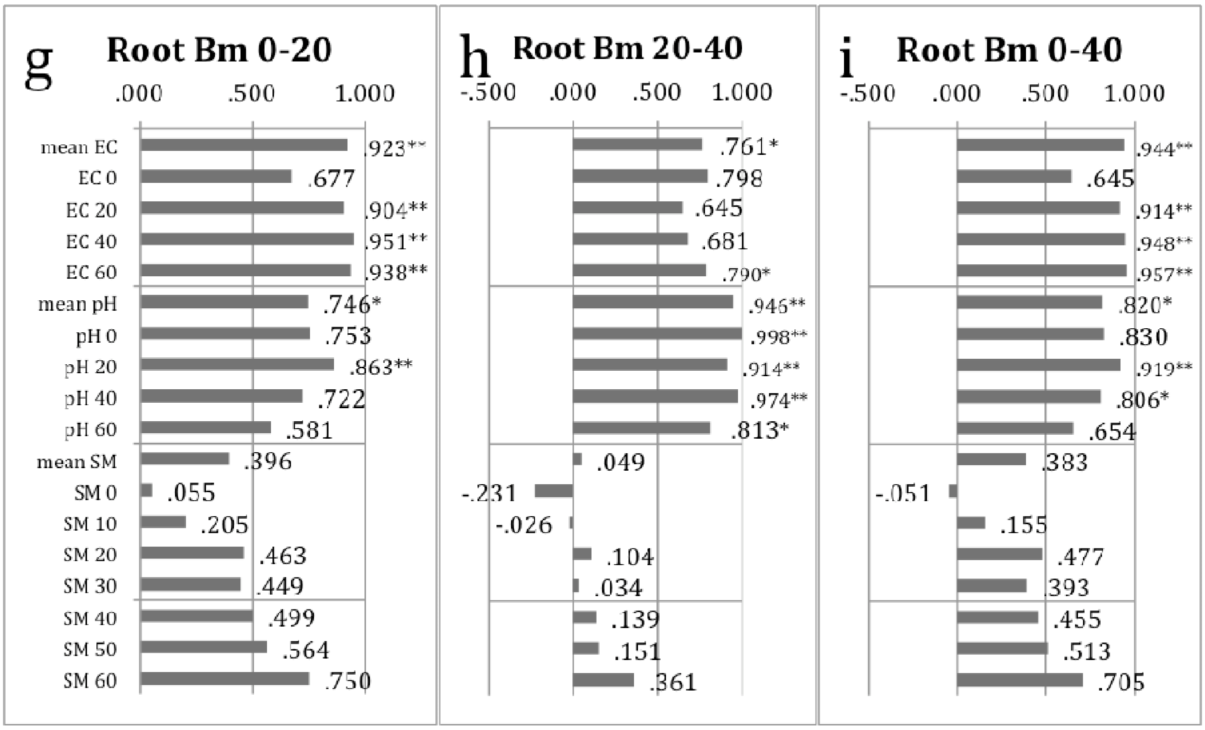


*Figure 7: Pearson pair-wise correlations of soil variables versus plant characteristics. Values with * are significant at $\alpha < 0.05$ and values denoted with ** are significant at $\alpha < 0.01$*

Dependant	X1	X2	Control	r1 (X1)	α1	$r1_0$	r2 (X2)	α2	$r2_0$
PlantH2O	SM	pH	EC	0.841	0.018	0.678	-	-	-
	SM	EC	pH	0.788	0.035	0.678	-	-	-
	pH	EC	SM	-	-	-	-0.694	0.084	-0.212
LAI	SM	pH	EC	0.688	0.088	0.666	-	-	-
	SM	EC	pH	-	-	-	-	-	-
	pH	EC	SM	-	-	-	-	-	-
RBM0-20	SM	pH	EC	-	-	-	-	-	-
	SM	EC	pH	-	-	-	0.819	0.024	0.923
	pH	EC	SM	0.784	0.037	0.746	0.909	0.005	0.923
RBM20-40	SM	pH	EC	-	-	-	0.870	0.024	0.946
	SM	EC	pH	-	-	-	-	-	-
	pH	EC	SM	0.951	0.004	0.946	0.788	0.063	0.761
RBM0-40	SM	pH	EC	-	-	-	-	-	-
	SM	EC	pH	0.741	0.092	0.383	0.862	0.027	0.944
	pH	EC	SM	0.910	0.012	0.820	0.939	0.005	0.944

Table 2: Partial Correlations between plant characteristics and three soil variables. Only significant correlations are displayed, significant correlations were assumed to be at $\alpha < 0.1$. Also shown are the zero-order correlations (denoted with $r1_0$ and $r2_0$) of each significant partial correlation. The stand density, MPH, fresh- and dry biomass are not shown, because of absence of significant correlations. All correlations had 5 degrees of freedom, except RBM20-40 and RBM0-40, which had 4.

Table 2 shows the results of significant partial correlations (assumed to be at $\alpha < 0.1$) between crop performance parameters and the soil variables: soil- moisture, -pH and -EC. In general, these partial correlations concur in almost every case with the pair-wise correlations previously shown, both in their directions and degrees of the respective correlations. This thus supports the previous found correlations in Figure 7. One exception is the relationship between plant H_2O and EC, which is strengthened considerably, when the relationship is controlled for by soil moisture.

The LAI is positively correlated with soil moisture when EC is the control. This relationship was observed previously in the pair-wise correlations. This correlation suggests that leaf growth is dependant on the amount of available soil moisture when EC is constant. This relationship has been observed before (Ismail et al. 1998, Garcia et al. 2002) and its sensitivity has been suggested in a study done by Montazar et al. (2008), which demonstrated that the uniformity of sprinkler irrigation had the most impact on the LAI compared to other crop indicators such as yield and crop height.

Plant H_2O is correlated with soil moisture when the EC or the pH is the control. This was discussed before. Additionally, as mentioned above, plant H_2O is also negatively correlated with EC when soil moisture is the control. This is to be expected as the osmotic stress is increased when EC is increased but soil moisture kept constant (Parida et al. 2004).

All root biomass measurements (root BM 0-20, 20-40 and 0-40) are positively correlated with EC, when controlling for SM. Both root BM 0-20 and root BM 0-40 also significantly correlate with EC when pH is the control. Similarly all root biomass measurements positively correlate with pH when SM is the control. Root BM 20-40 is, furthermore, significantly correlated with pH when EC is the control. Root BM 0-40 is also correlated with soil moisture when pH is the control.

These observations indicate that the root biomass is generally positively correlated with both EC and pH. Different studies have been done on the effect of EC on root biomass and it is generally accepted that a higher EC value results in a decrease in root biomass (Kaya et al. 2002, Ghollarata et al. 2007, Esechie et al. 2002, Peng et al. 2008). In this study, the opposite is true, however. This is due to the relatively low levels of EC observed. According to Sanden et al. (2007) alfalfa can tolerate an EC level of up to 2 dS/m, after which yield starts to decrease by 10% every 2 dS that the EC is increased. The EC samples taken for this study fall far below this limit and consequently reflect a positive relationship between root biomass and EC.

The same positive relationship was found between root biomass and pH. According to McCauley et al. (2009), the optimal pH for alfalfa is around 6.2 - 7.5, or in other words a slightly acid to neutral environment. In the current study, however, the pH ranged from 6.2 to 8.5 (slightly acid to moderately alkaline soils) with most of the samples lying between 7 and 8.5. A study done by Van Lierop et al. (1980) on pH, liming and its effects on the yield of alfalfa growing on organic soils showed a positive relationship between pH and total yield. The range in pH, however, was between 2.6 and 6.5 with the optimal pH being 4.5. Higher pH's did not decrease yield, but the yield remained constant. So yield grew linearly in the range between pH 3 to pH 4.5 and then remained constant up to the study's maximum pH of 6.5. Another study done by Peters et al. (2005) also showed a similar positive correlation between pH and alfalfa yield with a range of pH from 4.5 to 7.0, with the optimum pH being around 6.8. Similar to the current study, the soils had relatively little OM. It could be that in a pH range between 6.2 and 8.5 with these specific soil properties, the same positive relation between growth and pH could exist. However, not many studies exist which have focused on alfalfa root biomass and high pH values with which to compare. Furthermore, in this study the samples with higher pH's, were also accompanied by higher EC's (taken at the B fields). It would then seem plausible to accept that the increase in root biomass could be due to this higher EC, which might be salts in the form of available soil nutrients for the plant. However, the partial correlation between root BM 20-40 and pH did produce a positive correlation when controlling for EC, which rejects the former theory. In any case the relatively high pH value, which is usually not considered optimal for plants, did not produce adverse effects for Alfalfa at this particular site. A chemical analysis would have been required to be able to determine what chemical elements were determining the measured pH and if these elements could subsequently act as nutrients for the plant or if they had a more negative influence at the different plots.

It must be added, however, that these correlations and interpretations must be interpreted with some degree of caution, as even though all assumptions of statistical analyses were adhered to, the amount of samples remained small and the correlations could have very likely been due to coincidence.

4.Conclusion

The aim of the study was to monitor the effects of soil salinity on the performance of Alfalfa. To achieve this, soil properties such as the soil- moisture, -EC and -pH were measured. To monitor crop performance, the stand density, LAI, MPH, above ground biomass as well as root biomass and the CWSI were measured and calculated. Based on the results of the study, it was not possible to state that the soil variables were correlated with the crop performance parameters stand density, MPH and dry above ground biomass. In the case of dry biomass this might have been due to the two failed measurements. Furthermore the results suggest that the EC did have a positive effect on root biomass of alfalfa within the range of 0.15 to 1.52 dS/m. This positive relationship was a result of EC levels being below the threshold to negatively affect Alfalfa, as would be the case in truly saline soils. The pH of the soil also showed a positive correlation with root biomass within the range of pH 6.2 and 8.5. From the literature these pH values are generally believed to be too high to exhibit a positive relationship with root biomass. An alternative explanation was that this positive relationship was attributed to the coupled EC values at the different locations. However, the results of the partial correlations suggest that when EC is kept constant, the positive correlation between pH and root biomass at a depth of 20 to 40 cm is maintained. In any case, the relatively high pH did not seem to adversely affect any plant characteristic, which is in contrast to most studies done concerning the topic. This relationship would have to be studied in more detail to find out what the cause is. Furthermore, it was observed that soil moisture content had a significant effect on the more fluctuating parameters like the fresh biomass, LAI and plant H_2O. It was also shown that plant H_2O was negatively correlated with EC when soil moisture was kept constant, as would be expected due to osmotic stress. There was also no link observed between EC and ph, on one hand, and soil moisture on the other. This indicated that the soil moisture was not dependent on these two variables, which can be expected in an agricultural area suffering from alkanized patches and bad soil structure.

Based on the measured pH and EC values during this research, it might be interesting for future studies to do a chemical analysis of the soils at each location so as to determine what elements are exactly producing the variation in pH and EC and consequently if these elements can be used by the plants as nutrients. If a constrained selection must be made then an analysis of Na, Ca, Mg, Cl and carbonates would be useful in determining the alkalinity in support of pH measurements. This would be desired, since the pH is more specifically a measure of how basic a soil is and not necessarily how alkaline. If more research into the effect of the high pH's measured on nutrient uptake by the plants is desired, then phosphorus and nitrogen would be neccessary to measure, since these are usually limiting factors of plant nutrients, where especially P can become immobile in alkaline soils making them harder to be taken up by plants. Similarly the elements Fe, Zn and Mn all become less mobile in more alkaline environments (Wilkinson, 2000) and would also be desirable. Besides this, measurements of soil bulk density can also shed some light as to why the different locations produced different plant morphological characteristics, since alkaline soils are also known to contribute to high bulk densities, which in turn reduce plant health. Lastly, it would be interesting to know how much higher both the EC and pH could become, before the Alfalfa crops start to show negative performance attributes.

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