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ORIGINAL SCIENTIFIC PAPER

Advanced monitoring system for agroecosystems threatened by salinization and pollution

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Abstract
Although the problem of sea intrusion and salinization of surface and groundwater, and thus the risk of land degradation, occurs throughout the coastal area of Croatia. The objective of this paper was to investigate and compare two different soil monitoring approaches, classical long-term monitoring and monitoring using automatic soil sensors at two locations in Neretva River Valley. For SMS1 mean values for EC were similar both in long-term and automatic sensor monitoring. At SMS2, mean EC value obtained by the sensors was higher compared to long-term monitoring. Variation coefficient on SMS1 vas low in both monitoring approaches indicating low soil EC varibality in the profile. On the other hand, variation coefficient was high at SMS2 especially in the long-term monitoring indicating high soil EC variability in the profile.

Key words: soil salinity, sea water intrusion, climate change

Introduction
The Strategy for Adaptation to Climate Change of the Republic of Croatia until 2040 with a view to 2070 (OG 46/2020) proposes a wide range of climate change adaptation measures for the sectors of fisheries and hydrology, as well as water and marine resource management, agriculture, biodiversity, forestry and health. It also highlights that climate change will have significant direct and indirect impacts on agriculture due to the trend of rising sea levels and salinization of karst aquifers. Although the problem of seawater intrusion and salinization of surface and groundwater occurs in all Croatian coastal areas, increasing the risk of land degradation, these processes are most evident in the Neretva River Delta area, which is considered one of the most vulnerable areas to climate change in Croatia. Monitoring the state of the environment is extremely important for the delta Neretva River due to the diversity of ecological zones, which alternate spatially, have different degrees and intensities of use, and are generally very sensitive to the effects of climate change. Moreover, the establishment of a good monitoring system is necessary because it allows for high quality and timely decision making. In this sense, two types (i.e. levels) of water quality monitoring systems are established at the national level by Croatian waters (OG 66/2019), surveillance and operational monitoring. There is also research monitoring that can be established at individual sites, such as the scientific research monitoring set in the Neretva River valley. The water and soil salinity monitoring system was established in 2009 to monitor surface and groundwater salinity and soil salinity at multiple sites in the valley, and monitoring is therefore still in operation (Romić et al., 2017). Although there are several types of monitoring systems that collect valuable data on the status of this specific agroecosystem in the area, it is important to develop and implement automatic, continuous monitoring that can provide data in real time and includes a range of sensors to monitor various parameters.The

goal of this paper is to investigate the dinamics of soil electrical conductivity in two different monitoring approaches, classical long-term monitoring and monitoring using soil sensors.

Materials and methods

Study area

The study area is located in the Neretva River Valley (NRV) (43°00 N, 17°30 E) in the Mediterranean part of Croatia. The area is semi-arid with Mediterranean climate with hot, dry summers and wet winters. Most of the precipitation falls in the period from October to April, with an annual mean of 1203 mm (1980-2010) (Romić et al., 2012). The average annual temperature is 15.7 ºC with the highest value of 25.2 ºC occurring in July (Romić et al., 2012).

As mentioned above, the long-term monitoring system, established in 2009, is organized as a comprehensive monitoring of surface water, groundwater and soil (Romić et al., 2014). It covers the entire valley, divided into 5 reclamation areas or subsystems (Vrbovci, Luke, Vidrice, Opuzen ušće and Komin). Two melioration areas, Luke and Vidrice, were selected as part of the Advanced agroecosystem monitoring system at risk of salinization and contamination project (acronym DELTASAL), funded by the European Union through European Regional Development Fund, to be upgraded with advanced automated monitoring equipment in late 2020. The equipment installed includes the installation of a shallow piezometer (4 m deep) at each site and an automatic agrometeorological station at the Vidrice site. In addition, 4 automatic radar systems were installed at the Vidrice subsystem, which are designed to provide continuous real-time measurements of water levels, water velocity, and water flow in open channels. Soil and water quality sensors were installed at both sites. The soil monitoring system includes sensors that measure soil water content, electrical conductivity, temperature, and water potential, installed at four depths, each ranging from 25 cm to 1 m. In addition to the soil sensors, multi-parameter water quality probes were installed at both sites in both shallow piezometers to monitor shallow groundwater and open channels to monitor surface water quality with a focus on electrical conductivity, i.e. salinity. Data from each station and sensor is collected at 10-minute intervals and sent to the newly developed platform. This platform contains real-time data from each installed sensor as well as historical data on soil and water quality mentioned above, historical climate data from three stations (Ploče, Opuzen and Metković) and hydrological data (water levels) from six stations in the valley (Picture 1).

Picture 1. Map of long-term and automatic continuous monitoring locations (meteorological, hydrological and soil and water quality data)

Soil sampling in the long-term monitoring

Soil sampling at 7 different sites is carried out twice a year, after the wet winter season (end of March/beginning of April) and after the dry summer season (end of September/beginning of October). Soil samples are taken at 25 cm intervals up to 1 m and the physical and chemical parameters are analyzed in the laboratory.

Soil sensors

At the end of 2020 frequency domain sensors (FDR) were installed at two representative soil monitoring sites (SMS), site Vidrice (SMS1) and Luke (SMS2) collecting data in 10 minute intervals. The TEROS 12 (Meter Group) sensors measure soil temperature, bulk electrical conductivity (EC_b), and volumetric water content using frequency-domain technology. The sensors are installed every 25 cm up to 1 m. SMS1 and SMS2 were selected due to the pronounced risk of soil salinity and the two sites differ in soil texture, organic matter content, depth of the Gleyc horizon, salinity and land use, with SMS1 mainly used as a fruit growing area and SMS2 mainly used for vegetable production. An automatic weather station (Pinova Meteo agriculture weather station) was installed at SMS1 site to record rainfall, air temperature and moisture, wind speed and global radiation. For data vizualization and analysis Microsofte Excel and XLSTAT (Addinsoft, 2021) statistical software plug-in were used.

Results and discussion

In the long-term seasonal monitoring (2009-2021) soil in the entire profile (up to 100 cm) at SMS1 was slightly saline both in wet and in dry season with mean values of electrical conductivity (EC) of 3.28 dS m^{-1} and 3.78 dS m^{-1} respectively (Table 1). At SMS2 soil was non saline since mean value of EC in wet season was 1.30 dS m^{-1} and 1.48 dS m^{-1} in dry season (Table 1). Although mean value of EC was higher in both wet and dry season at SMS1 it showed lower variability with coefficient of variation ranging from 0.35 in wet and 0.21 in dry season. Coefficient of variation was considerably higher at SMS2 both in wet (0.76) and dry season (0.60).

Table 1. Soil electrical conductivity at monitoring stations SMS1 and SMS2 obtained by long-term monitoring within NRV

	Electrical conductivity at SML1 and SML2 (dS m^{-1})			
	SMS1 wet 0-100 cm	SMS1 dry 0-100 cm	SMS2 wet 0-100 cm	SMS2 dry 0-100 cm
Mean	3.28	3.78	1.30	1.48
Median	3.35	3.86	0.89	1.09
Min.	0.97	2.21	0.38	0.52
Max	6.38	5.41	4.79	3.62
Variance	1.31	0.62	0.99	0.78
St. dev.	1.14	0.78	0.99	0.89
Var. coeff.	0.35	0.21	0.76	0.60

Since soil sensors were installed in mid-November 2020, results for first seven months are presented (to June 2021). On SMS1 average daily value of EC_b was 3.89 dS m^{-1} with maximum value of 6.16 dS m^{-1} at 75-100 cm (Table 2). SMS2 had lower daily average of 2.28 dS m^{-1} with maximum of 4.77 dS m^{-1} also at 75-100 cm (Table 2). Variation coefficient was significantly lower at SMS1 indicating low soil EC_b variation in all horizons. At SMS2 variation coefficient ranged from 29 % to 39 % indicating high EC_b variability in all horizons (Table 2).

Table 2. Soil electrical conductivity at monitoring stations SMS1 and SMS2 obtained by FDR sensors within NRV

	Electrical conductivity at SMS1 ($dS\ m^{-1}$)					Electrical conductivity at SMS2 ($dS\ m^{-1}$)				
	0-25 cm	25-50 cm	50-75 cm	75-100 cm	0-100 cm	0-25 cm	25-50 cm	50-75 cm	75-100 cm	0-100 cm
Mean	2.44	3.57	4.19	5.15	3.89	1.85	2.57	2.66	2.05	2.28
Median	2.42	3.49	4.00	5.10	3.91	1.59	2.42	2.65	1.94	2.13
Min.	1.89	3.20	3.80	4.57	1.89	1.35	0.99	0.47	0.55	0.47
Max	3.26	4.58	5.63	6.16	6.16	4.36	4.46	4.50	4.77	4.77
Var.	0.06	0.08	0.18	0.12	1.08	0.53	0.80	0.67	0.35	0.70
St. dev.	0.24	0.29	0.42	0.34	1.04	0.73	0.90	0.82	0.59	0.84
Var. coeff.	0.10	0.08	0.10	0.07	0.27	0.39	0.35	0.31	0.29	0.37

Daily variation of soil EC_b at both SMS1 and SMS2 along with precipitation is given at Chart 1. As shown in the Chart 1.the EC_b varied differently on each location, but on both locations rainfall caused changes in EC_b values indicating the movement of salt through the profile. After the end of May, values of EC_b stabilised in all horizons at both locations.

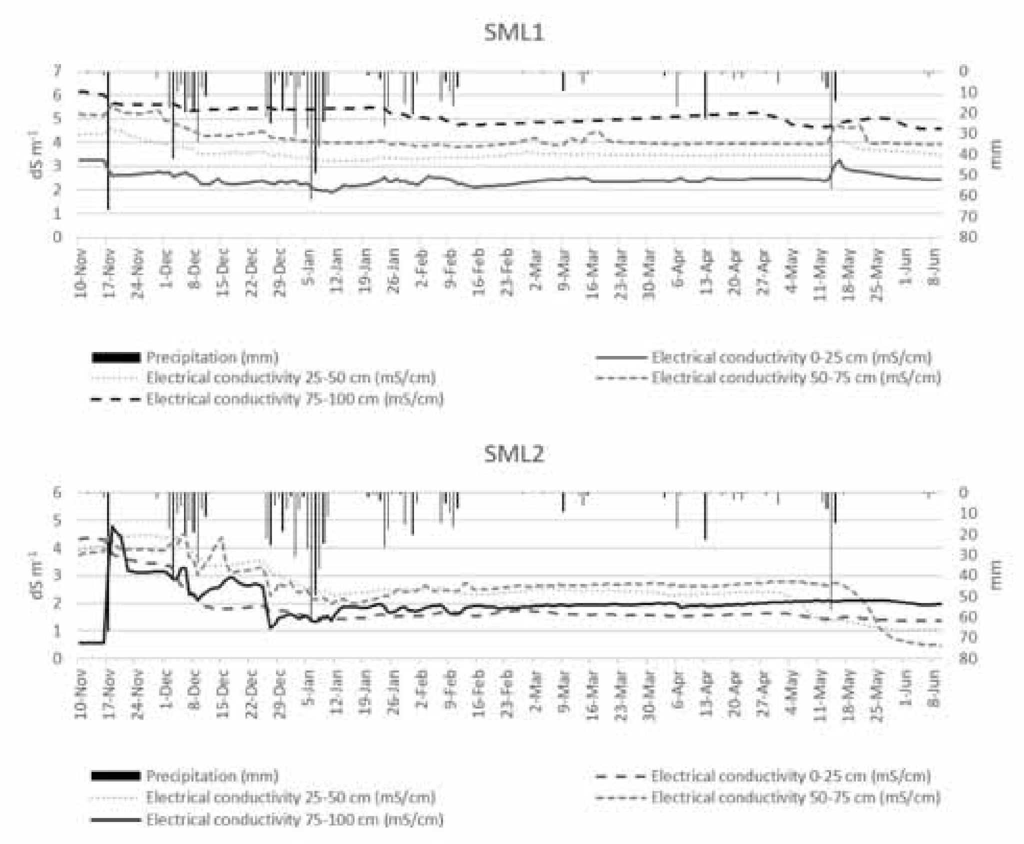

Chart 1. Daily variation of soil EC_b at monitoring stations SMS1 and SMS2 obtained by FDR sensors and daily rainfall (November 2020 – June 2021)

Conclusion

Classical soil monitoring with sampling and laboratory analysis gives us most accurate results, but it is costly and labor intensive. Implementing modern technologies like soil sensors can give us an insight at data in high temporal resolution. This can make decision making much more accurate and precise, especially in vulnerable agro environments such as river deltas. At SMS1 mean EC values were similar in both monitoring approaches and higher then at SMS2. On the other hand, variability of EC in the soil profile was higher at SMS2 in both approaches compared to SMS1. The similarity in obtained results indicate that soil sensor data may be used as an alternative to classical soil salinity monitoring.

Acknowledgment

The work presented in this paper was funded by the European union from the European Regional Development Fund within the Operational Programme Competitiveness and Cohesion (OPCC) 2014-2020, as well as the Environmental Protection and Energy Efficiency Fund through the project "Advanced agroecosystem monitoring system at risk of salinization and contamination" (K.K.05.1.1.02.0011).

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