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Methodology for assessing the degree and distribution of salts in the soil for ecological balance, determining its causes and evaluating the appropriateness of related management practices

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Abstract One of the global problems of the world is the study of factors influencing soil fertility, one of which is salinity. The traditional method for assessing soil salinity in the Eurasian region was analyzed the composition of water extract. In international practice, evaluation criteria for the specific electrical conductivity of leachate from pastes developed by the USDA Salinity Laboratory are widely used. Since the preparation of pastes and extracts from pastes is a laborious process, the electrical conductivity in an aqueous suspension is often measured (1:2.5, 1:5, 1:10). These methods for determining salinity are diversed but their incorrected and gave an erroneous result, which in turn leaded to an inappropriate decision. The conducted research made to create the dataset and analyse the three most common types and degrees of soil salinity: chloride, sulfate-chloride, and chloride-sulfate. The obtained experimental studies proved the possibility of using mathematical models for the actual determination of the salt content when determining the electrical conductivity of the soil solution, namely: for chloride salinization was $Y=0.1286x+0.6165$ ($R^2=0.9972$); for chloride-sulfate salinization is $Y=0.207x+0.5265$ ($R^2=0.9962$); for sulfate-chloride salinization is $Y=0.1738x+0.7461$ ($R^2=0.9961$).

Keywords: Degree of salinity, Electrical conductivity, Soil solution

Introduction

One of the world's global problems is soil salinization, which affects the quality and health of arable land, and significantly affects the productivity of crops (Qadir *et al.,* 2006; Wong *et al.*, 2010; Mohamed *et al.*, 2023). This negatively affects soil productivity, crop yields, and the overall balance of ecosystems (Mohamed *et al.*, 2023). To date, the total area of saline soils in the world is more than 1 billion hectares, which is approximately 25% of the world's

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irrigated land, and almost 50% of the land suffers from secondary soil salinization of various degrees (Ivushkin *et al.*, 2019). At present, almost 30% of the total production of crops in the world is grown on irrigated lands. According to the FAO, by 2040 the percentage of production will increase to 50% (FAO, 1988). Continuous land monitoring shows that the number of degraded lands from secondary salinization is increasing annually. This is a consequence of the irrational use of land, outdated technologies, and failure to control irrigation water quality (Dregne, 2002; Ghassemi *et al.*, 1995).

Salt-affected soils include containing readily soluble salts in quantities exceeding the toxicity threshold. This is the maximum permissible number of salts, which does not cause suppression of plants (Ivanyuk, 2017; USDA Agriculture handbook, 1954) and for now still is a rather complex issue and there is no unambiguous assessment of the state of salinity.

Saline includes soils with a concentration of salts in the soil solution of 3-5 g/l (USDA Agriculture handbook, 1954; Kupchik *et al.*, 2007); the number of toxic salts obtained by the method of aqueous extracts of 0.05-0.15% (Bazilevich and Pankova, 1972); and specific electrical conductivity of filtrates from water-saturated soil pastes of 2-4 mS/cm (USDA Agriculture handbook, 1954; Bresler *et al.*, 1987). To assess the suitability of soils for growing crops, various classifications are used, developed considering the salt resistance of plants (Ivanyuk, 2017; USDA Agriculture handbook, 1954; Bresler *et al.*, 1987).

Salinity is associated with disruption of nitrogen absorption processes, deterioration of plant growth and development, and inhibition of soil biological activity. In this case, yield losses due to soil salinity reach from 18-26% to 43% (Kupchik *et al.*, 2007). It should be noted that the influence of salinity is closely related to changes in the exchange of sulfur compounds. It is known that with chloride salinization, plants experience a sharp deficiency of sulfur compounds. Typical signs of sulfur starvation appear (Bresler *et al.*, 1987., Fernández-Buces *et al.*, 2006; Project (IDNP), 2002; Metternicht and Zinck, 2003; Mougenot *et al.*, 1993; Rao *et al.*, 1995).

Under the influence of salts, violations of the ultrastructure of cells occur, in particular, changes in the structure of chloroplasts (Bresler *et al.*, 1987; Csillag *et al.*, 1993). The harmful effect of a high concentration of salts is associated with damage to membrane structures, in particular the plasmalemma, as a result of which its permeability increases, and the ability to selectively accumulate substances is lost (Bresler *et al.*, 1987; Pankova *et al.*, 2016).

Measures to reduce and counteract the negative impact of salinization are the priority of climate-smart agriculture (Kupchik *et al.*, 2007). The basis of such works is the planning of complex land reclamation measures using a system of simulation models and methods of making long-term forecasts of changes in the condition of irrigated lands.

Modern methods of determining salinity are diverse, but their incorrect use gives an erroneous result, which in turn leads to the adoption of an inappropriate decision. This leads to the deterioration of the ecological balance in the agrophytocenosis and severe ecological consequences.

The importance of controlling the salt content lies in the fact that it increases the osmotic potential of the soil solution, thereby impairing the water consumption of plants due to the insufficient absorption power of the root systems. Also, under the influence of salts, violations of the ultrastructure of cells occur changes in the structure of chloroplasts. This is especially evident in the case of chloride salinization. The harmful effect of a high concentration of salts is associated with damage to membrane structures, particularly the plasma membrane, because of which its permeability increases, and the ability to selectively accumulate substances is lost (Fernández-Buces *et al.*, 2006; Project (IDNP), 2002; Metternicht and Zinck, 2003; Mougenot *et al.*, 1993; Rao *et al.*, 1995). It should be noted that the effect of salinization is closely related to changes in the exchange of sulfur compounds. It is known that with chloride salinization, plants experience a sharp deficiency of sulfur compounds. Typical signs of sulfur starvation appear. In the stem, the cells of the conductive system are most susceptible to the action of salts, by which the solution of salts rises to the shoots. Such negative effects of salts strongly affect the quantity and quality of the crop (Lavrenko *et al.*, 2019; Didenko *et al.,* 2023; Didenko *et al.*, 2022; Bazaluk *et al.*, 2022). Soil salinization is one of the main factors contributing to land degradation, affecting the ecological balance, the state of the environment, and the sustainable development of agriculture. Due to spatial and temporal heterogeneity of soil characteristics and environmental conditions, the accuracy of monitoring salt content in soil and their composition is difficult. Therefore, a practical methodology is needed for the timely assessment of soil salinity, identification of its causes, and assessment.

The objective was to create a set of data and conduct a comparative analysis of the most common types and degrees of salinity (chloride, sulfate-chloride, and chloride-sulfate) in the world and on the territory of Ukraine; to create mathematical models for the actual determination of the content and composition of salts based on the electrical conductivity of the soil solution, which is an important aspect for maintaining ecological balance.

Materials and methods

Determination of the degree of salinity with a conductometer

The sensor of the conductometer is immersed in a saline solution and the electrical conductivity is determined. The temperature of the solution should be 20°C; for this condition, the temperature of the compensator is k = 1 and there is no need to recalculate the indicators. The Oakton ecoNestr EC high conductometer was used in the experiments.

When the temperature is increased by 1°C, the value of electrical conductivity increases by approximately 2%. Most often, it is listed in relation to 20ºC according to the correction table or is referred to it using empirical formulas (Table 1).

Table 1. Correction data for calculating conditional electrical conductivity

Solution temperature, °C	Coefficient of temperature correction	Solution temperature, °C	Coefficient of temperature correction	Solution temperature, °C	Coefficient of temperature correction
5	1.492	14	1.151	23	0.937
6	1.444	15	1.132	24	0.919
7	1.400	16	1.095	25	0.901
8	1.359	17	1.071	26	0.840
9	1.319	18	1.046	27	0.810
10	1.282	19	1.023	28	0.790
11	1.247	20	1.000	29	0.770
12	1.213	21	0.979	30	0.750
13	1.182	22	0.958	-	-

Soil water extract preparation

Soil samples weighing 30 g, weighed with an error of no more than 0.1 g, are placed in containers installed in ten-position cassettes or in conical flasks. Pour 150 cm^3 of distilled water into the samples with a dispenser or cylinder. Mix the soil with water for 3 minutes on a shaker, rotator, or with the help of a propeller stirrer, and leave for 5 minutes for advocacy. When using scales for proportional dosing of the extractant, it is allowed to take a sample weighing 25-30 g. A proportional change in the weight of the soil sample and the volume of distilled water is allowed, while maintaining the ratio between them of 1:5 and with a dosing error of no more than 2%.

Determination of electrical conductivity

After a 5-minute settling, the conductometer sensor is immersed in the suspension and the electrical conductivity is determined. After each determination, the sensor is thoroughly washed with distilled water. If the device does not have an automatic temperature compensator, the temperature of the analyzed hoods or distilled water under the same conditions is determined. In the absence of a conductometer, the dense residue of the hood is determined.

Processing of results

The result of the analysis is taken as the value of a single definition. The specific electrical conductivity of the analyzed hood (X), mS/cm, is calculated by the formula:

$$X=a\times C\times k, \qquad (1)$$

where: a - is the measured electrical conductivity of the hood, mSm; C - is a constant of the conductometric sensor, cm-1; k - is a coefficient of temperature correction for bringing the electrical conductivity measured at a given temperature to 20°C.

Since there is objectively a correlation between the result and the factors that cause it, for the comprehensive study of the influence of each of the factors, the method of correlation-regression analysis, the linear equation of multiple regression, were used. Production functions obtained because of such calculations are used during programming and yield planning.

Yield planning was the determination of the possible increase in yield because of changes in dynamic factors followed by an increase in the actual average annual yield by the amount of the calculated increase.

The multiple regression equation has the form:

$$Y=bo+b_1X_1+ b_2X_2+ b_3X_3+\ldots+ b_nX_n, \qquad (2)$$

where: Y - is a dependent variable (yield); bo - is a free member of the model; b_n - are coefficients of the model; X_n - are model factors.

Regression coefficients (b_1, ..., b_n) indicate the size of the impact of individual factors on the yield level; b_0 has no semantic load, means dimensionality, and depends on the unit of measurement of the resulting and factor characteristics adopted in the model. The regression coefficients (b_1, ..., b_n) can be interpreted as the values of quantitative changes in productivity in the case of a change in the factor characteristic (Y) per unit of measurement adopted in the model.

The tightness of the connection of the characteristic Y (resultative) with the characteristics X_1, ..., X_n is estimated using the multiple correlation coefficient R which measured by formula:

$$R=\sqrt{\frac{r_{yx1}^2-2\cdot r_{yx1}\cdot r_{yx2}\cdot r_{x1x2}+r_{yx2}^2}{1-r_{x1x2}^2}} \qquad (3)$$

Depending on the value of the calculated correlation coefficient, the strength of the connection is determined, and the direction is determined by its sign (+ or -) (Table 2).

Table 2. Classification of correlation relations

r	Evaluation
- 1,0 ≤ r< 0	Reverse
0 ≤ r < 0,1	Absent
0,1 < =r < 0,3	Weak
0,3 < = r < 0,5	Moderate
0,5 < =r < 0,7	Noticeable
0,7 < = r < 0,9	Strong
0,9 < = r < 0,99	Very strong
0,99 < r ≤1,0	Full (fuctional)

In the case of multiple regression analysis, the coefficient of general determination is also calculated as $D=R^2$, which shows the degree of variability of the resulting factor from the studied factors X_1, ..., X_n. It is also indicated as a percentage as $D=R^2\times100$, %.

Results

Types and degrees of soil salinity

Research on soil salinization: causes, composition, methods of study, measures to prevent and reduce their amount is always materially expensive and takes a lot of time. The efficiency of determining the type of salinity and reducing costs allows timely implementation of remedial measures to prevent salinity. In agronomic science, six types of salinization are distinguished, of which three are the most common: chloride, sulfate-chloride, and chloride-sulfate (Table 3). Also, an important aspect is knowledge about the degree of soil salinization and, accordingly, the loss of the future crop.

Irrigation in Ukraine is mainly carried out from surface sources (rivers, reservoirs, etc.) and groundwater, which chemically belong to chloride, chloride-sulfate, and sulfate-chloride mineralization. The chemical composition of irrigated waters is formed mainly from industrial enterprises located within the basin of water bodies. Basically, the mineral part of water consists of sodium (Na^+), calcium (Ca^{2+}), potassium (K^+), chlorine (Cl^-), bicarbonate (HCO^{3-}), sulfate (SO_4^{2-}) ions, and their combination changes electrical conductivity and as a result, it can incorrectly determine the degree of salinity with the same number of salts.

Table 3. Soil classification by the degree of salinity depending on the chemistry of salinity

Degree of soil salinity	Chemistry of salinization (by ion ratio, mmol (eq) / 100 g of soil)		
	Neutral salinity (pH <8.5)		
	chloride, sulfate-chloride	sulfate-chloride	sulfate
	HCO_3< Ca+Mg	HCO_3<Ca+Mg	HCO_3<Ca+Mg
Toxicity threshold (non-saline soil)	<0.1	<0.2	<0.3(1.0)
	<0.05	<0.1	<0.15
Weak	0.1-0.2	0.2-0.4(0.6)	0.3(1.0)-0.6(1.2)
	0.05-0.12	0.1-0.25	0.15-0.3
Average	0.2-0.4	0.4(0.6)-0.6(0.9)	0.6(1.2)-0.8(1.5)
	0.12-0.35	0.25-0.5	0.3-0.6
Strong	0.4-0.8	0.6(0.9)-1.0(1.4)	0.8(1.5)-1.5(2.0)
	0.35-0.7	0.5-1.0	0.6-1.5
Very strong	>0.8	>1.0(1.4)	>1.5(2.0)
	>0.7	>1.0	>1.5

Degree of soil salinity	Chemistry of salinization (by ion ratio, mmol (eq) / 100 g of soil)		
	Alkaline salinity (pH> 8.5)		
	soda and sodium chloride	sulfate-sodium and soda-sulfate	sulfate chloride-carbonate
	HCO_3> Ca+Mg	HCO_3> Ca+Mg	HCO_3< Ca+Mg
Toxicity threshold (non-saline soil)	<0.1	<0.15	<0.2
	<0.1	< 0.15	<0.15
Weak	0.1-0.2	0.15-0.25	0.2-0.4
	0.1-0.15	0.15-0.25	0.15-0.3
Average	0.2-0.3	0.25-0.4	0.4-0.5
	0.15-0.3	0.25-0.4	0.3-0.5
Strong	0.3-0.5	0.4-0.6	Not found
	0.3-0.5	0.4-0.6	
Very strong	>0.5	>0.6	Not found
	>0.5	>0.6	

Note: above the line - the total amount of salts, below the line - the number of toxic salts, %; water extract 1: 5. Calculations of the number of toxic salts are given in (1, 3).
The numbers in parentheses correspond to the degree of salinization by the sum of salts in gypsum-containing soils containing more than 1% $CaSO_4 \times 2H_2O$.

Chloride salinity of the soil

The quality of water and its suitability for irrigation in Ukraine are regulated by the State Standards of Ukraine, as well as other regulatory documents (USDA Agriculture handbook, 1954; UNDP, 2007; DSTU 2730:2015, 2016; VND 33-5.5-02-097, 1998; DSTU 3866-99, 2016). Three classes of water are distinguished: I - when there is no threat of irrigation salinity and the water can be used without restrictions according to scientifically based irrigation regimes; II - when there is a threat of irrigation salinization of the soil in the 0-100 cm layer to a weak and medium degree and water can be used only together with certain engineering and amelioration measures; III - when there is a danger of irrigation salinization of the soil to a strong degree and water can be used only on the condition that it is improved to III classes in various ways.

Table 4. Comparative of the degree of chloride salinity and electrica conductivity

Degree of salinity	Cl^-/SO_4^{2-} ratio, mg-eq	Salt content, g/l	Electrical conductivity, mS/cm
Distilled water	0/0	0.00	0.00±0.000
Unsalted	0.3/0.12	0.26	0.50±0.073
Weakly salted	0.4/0.16	0.35	0.71±0.072
	0.5/0.20	0.44	0.90±0.060
	0.6/0.24	0.52	1.10±0.079
	0.7/0.28	0.61	1.22±0.075
	0.8/0.32	0.70	1.40±0.065
	0.9/0.36	0.79	1.62±0.059
	1.0/0.40	0.87	1.72±0.077
Medium salted	1.1/0.44	0.96	1.79±0.064
	1.2/0.48	1.05	1.83±0.044
	1.3/0.52	1.14	2.14±0.088
	1.4/0.56	1.22	2.21±0.094
	1.5/0.60	1.31	2.40±0.092
	1.6/0.64	1.40	2.52±0.075
	1.7/0.68	1.49	2.70±0.076
	1.8/0.72	1.57	2.70±0.076
	1.9/0.76	1.66	2.79±0.045
	2.0/0.80	1.75	3.10±0.073
	2.1/0.84	1.84	3.02±0.059
	2.2/0.88	1.92	3.22±0.067
	2.3/0.92	2.01	3.50±0.069
	2.4/0.96	2.10	3.60±0.069
	2.5/1.00	2.19	3.78±0.070
	2.6/1.04	2.27	3.99±0.064
	2.7/1.08	2.36	3.90±0.076
	2.8/1.12	2.45	4.30±0.076
	2.9/1.16	2.53	4.28±0.064
	3.0/1.20	2.62	4.49±0.064
Strongly salted	3.1/1.24	2.71	4.71±0.076
	3.2/1.28	2.80	4.89±0.088
	3.3/1.32	2.88	4.91±0.072
	3.4/1.36	2.97	5.10±0.089
	3.5/1.40	3.06	5.20±0.079
	3.6/1.44	3.15	5.40±0.065
	3.7/1.48	3.23	5.47±0.049
	3.8/1.52	3.32	5.61±0.076

	3.9/1.56	3.41	5.71±0.060
	4.0/1.60	3.50	5.79±0.064
	4.1/1.64	3.58	5.83±0.086
	4.2/1.68	3.67	6.01±0.072
	4.3/1.72	3.76	6.28±0.079
	4.4/1.76	3.85	6.32±0.081
	4.5/1.80	3.93	6.49±0.067
	4.6/1.84	4.02	6.58±0.062
	4.7/1.88	4.11	6.79±0.059
	4.8/1.92	4.20	6.81±0.072
	4.9/1.96	4.28	6.90±0.079
	5.0/2.00	4.37	7.12±0.062
	5.1/2.04	4.46	7.22±0.075
	5.2/2.08	4.54	7.39±0.064
	5.3/2.12	4.63	7.62±0.077
	5.4/2.16	4.72	7.71±0.083
	5.5/2.20	4.81	7.80±0.076
	5.6/2.24	4.89	7.89±0.064
	5.7/2.28	4.98	7.91±0.064
	5.8/2.32	5.07	8.10±0.069
	5.9/2.36	5.16	8.21±0.060
	6.0/2.40	5.24	8.32±0.062
	6.1/2.44	5.33	8.40±0.065
	6.2/2.48	5.42	8.67±0.059
	6.3/2.52	5.51	8.78±0.077
	6.4/2.56	5.59	8.89±0.075
	6.5/2.60	5.68	9.02±0.075
	6.6/2.64	5.77	9.31±0.069
	6.7/2.68	5.86	9.30±0.079
	6.8/2.72	5.94	9.59±0.079
	6.9/2.76	6.03	9.58±0.077
	7.0/2.80	6.12	9.82±0.077
Very strongly salted	7.1/2.84	6.21	9.91±0.079
	7.2/2.88	6.29	9.89±0.079
	7.3/2.92	6.38	10.01±0.069
	7.4/2.96	6.47	10.06±0.060
	7.5/3.00	6.55	10.10±0.073
	7.6/3.04	6.64	10.30±0.073
	7.7/3.08	6.73	10.38±0.072
	7.8/3.12	6.82	10.42±0.081
	7.9/3.16	6.90	10.50±0.086
	8.0/3.20	6.99	10.70±0.069
	8.1/3.24	7.08	10.91±0.064
	8.2/3.28	7.17	11.00±0.073
	8.3/3.32	7.25	11.12±0.062
	8.4/3.36	7.34	11.20±0.076
	8.5/3.40	7.43	11.32±0.070
	8.6/3.44	7.52	11.63±0.057

8.7/3.48	7.60	11.70±0.065
8.8/3.52	7.69	11.70±0.069
8.9/3.56	7.78	11.78±0.070
9.0/3.60	7.87	11.85±0.069
9.1/3.64	7.95	11.91±0.079
9.2/3.68	8.04	12.01±0.064
9.3/3.72	8.13	12.16±0.094
9.4/3.76	8.22	12.21±0.069
9.5/3.80	8.30	12.51±0.076
9.6/3.84	8.39	12.73±0.047
9.7/3.88	8.48	12.90±0.073
9.8/3.92	8.57	12.90±0.060
9.9/3.96	8.65	12.99±0.072
10.0/4.00	8.74	13.21±0.055
LSD_{05}		0.012

Measuring the electrical conductivity of aqueous solutions gave a value from 2 to 5 μS/m for distilled water, from 6 to 30 or more μS/m for atmospheric precipitation, and for fresh river and lake waters in those areas where the air environment is strongly contaminated, the electrical conductivity value can vary between 20-80 μS/cm.

In the stem, the cells of the conductive system are most vulnerable to the effects of salts, by which the salt solution rises to the above-ground organs. Such negative consequences of salt activity strongly affect the quantity and quality of the crop.

The electrical conductivity increased with different ratios of chlorides and sulfates in the aqueous solution and accordingly, with different amounts of salts (Figure 1). However, a clear dependence (proportionality) was not observed.

Due to the mobility of ions, the conductivity of sulfates was higher than that of chlorides. The conductivity of sulfates was greater only at a single molar equivalent concentration because the molar concentration of sulfates was much greater than that of chlorides, but at a single weight concentration, chlorides would be more mobile. Therefore, 72 grams of sodium sulfate and 58 grams of sodium chloride, the sulfate are revealed more electrical conductivity, but if the same mass, then the electrical conductivity would be greater in chlorides because its equivalent mass is less.

The linear trends were indicated that the formula as$Y=0.1286x+0.6165$ can be used to make a clear decision about the amount of salt content for chloride salinization. The coefficient of determination indicated that the reliability of the obtained results was 99.7%. Therefore, the use of the formula would be appropriated, and the results would correct when determining the value of the salt content with a conductometer. It would make it possible to quickly regulate and manage the production process and improve the environmental condition in agro-industrial production.

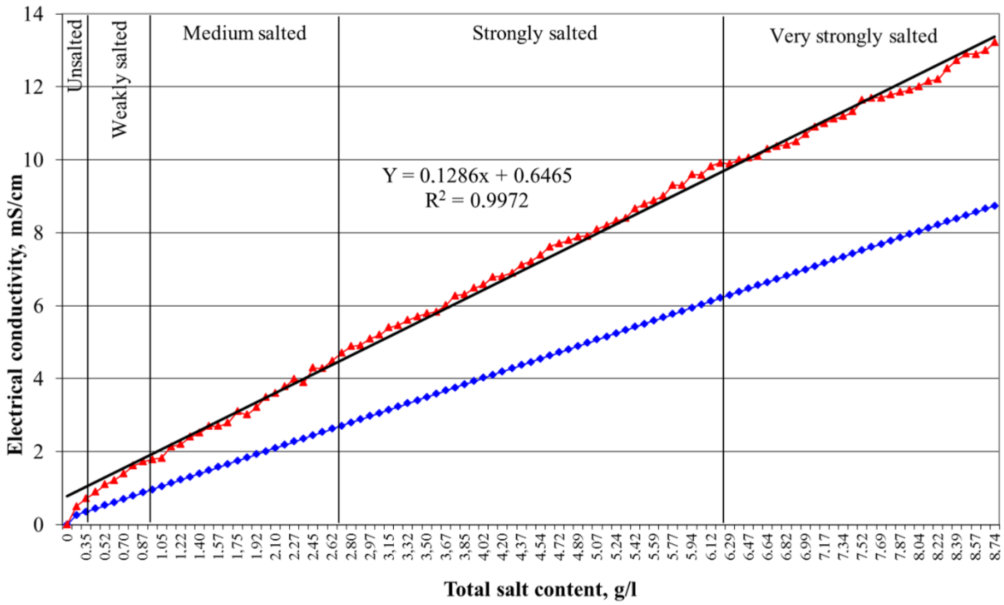

Figure 1. Comparison of the degree of chloride salinity and electrical conductivity (ratios of $\frac{Cl^-}{SO_4^{2-}}$ given in Table 1): **red line** is salt content, g/l; **blue line** is electrical conductivity, mS/cm; **black line** – linear trend of indicators (approximation and smoothing), based on the indicators of which a mathematical model and a deterministic indicator (R^2) were created)

Chloride-sulfate salinity of the soil

Knowing soil salinity levels allows for estimating crop losses and taking measures to reduce or prevent salt accumulation. According to our research, the chloride type of salinity is characteristic of soils with progressive salt accumulation, the chloride-sulfate type of salinity is typical of soils with a medium level of salt accumulation, and the sulfate type is characteristic of soils with signs of desalination (with gypsum accumulation). The condition of medium-resistant plants of field crops at different degrees of salinity is described in Table 5.

Table 5. The degree of salinity and the condition of crops

Degree of soil salinity	The condition of medium-resistant plants
Unsalted	Good growth and development (plants do not fall, yield is normal)
Weakly saline	Weak inhibition (plants fall, yield decrease by 10-20%)
Medium saline	Medium suppression (plants falling, yield reduction by 20-50%)
Strongly saline	Severe suppression (plant falls, yield reduction by 50-80%)
Very strongly saline	Single plants survive (plant falls, yield reduction by 95-100%)

Application of the same mathematical model for different types of soil salinity is unacceptable because the solutions have different ion ratios, hence their dielectric properties vary.

Table 6. Comparative of the degree of chloride-sulphate salinity and electrical conductivity

Degree of salinity	Cl^-/SO_4^{2-} ratio, mg-eq	Salt content, g/l	Electrical conductivity, mS/cm
Distilled water	0/0	0.00	0.00±0.000
Unsalted	0.1/0.15	0.17	0.40±0.083
	0.2/0.30	0.33	0.73±0.066
	0.3/0.45	0.50	0.99±0.075
	0.4/0.60	0.66	1.30±0.065
	0.5/0.75	0.83	1.50±0.065
Weakly salted	0.6/0.90	0.99	1.71±0.069
	0.7/1.05	1.16	2.05±0.110
	0.8/1.20	1.32	2.21±0.100
	0.9/1.35	1.49	2.50±0.076
	1.0/1.50	1.66	2.69±0.081
	1.1/1.65	1.82	3.02±0.062
	1.2/1.80	1.99	3.21±0.079
	1.3/1.95	2.15	3.48±0.064
	1.4/2.10	2.32	3.69±0.079
Medium salted	1.5/2.25	2.48	4.01±0.069
	1.6/2.40	2.65	4.20±0.079
	1.7/2.55	2.81	4.51±0.069
	1.8/2.70	2.98	4.70±0.060
	1.9/2.85	3.14	4.89±0.064
	2.0/3.00	3.31	5.11±0.076
	2.1/3.15	3.48	5.30±0.079
	2.2/3.30	3.64	5.61±0.072
	2.3/3.45	3.81	5.80±0.073
	2.4/3.60	3.97	5.99±0.059
	2.5/3.75	4.14	6.19±0.067
	2.6/3.90	4.30	6.40±0.060
	2.7/4.05	4.47	6.61±0.055
	2.8/4.20	4.63	6.83±0.080

Strongly salted	2.9/4.35	4.80	6.99±0.075
	3.0/4.50	4.97	7.28±0.055
	3.1/4.65	5.13	7.43±0.057
	3.2/4.80	5.30	7.61±0.079
	3.3/4.95	5.46	7.82±0.067
	3.4/5.10	5.63	8.00±0.069
	3.5/5.25	5.79	8.19±0.064
	3.6/5.40	5.96	8.40±0.089
	3.7/5.55	6.12	8.50±0.073
	3.8/5.70	6.29	8.71±0.110
	3.9/5.85	6.45	8.90±0.092
	4.0/6.00	6.62	9.01±0.064
	4.1/6.15	6.79	9.32±0.075
	4.2/6.30	6.95	9.39±0.055
	4.3/6.45	7.12	9.61±0.079
	4.4/6.60	7.28	9.82±0.070
	4.5/6.75	7.45	9.99±0.059
	4.6/6.90	7.61	10.20±0.065
	4.7/7.05	7.78	10.40±0.065
	4.8/7.20	7.94	10.62±0.067
	4.9/7.35	8.11	10.78±0.070
	5.0/7.50	8.28	11.00±0.073
Very strongly salted	5.1/7.65	8.44	11.20±0.069
	5.2/7.80	8.61	11.41±0.076
	5.3/7.95	8.77	11.59±0.055
	5.4/8.10	8.94	11.80±0.069
	5.5/8.25	9.10	12.01±0.064
	5.6/8.40	9.27	12.20±0.073
	5.7/8.55	9.43	12.32±0.062
	5.8/8.70	9.60	12.50±0.076
	5.9/8.85	9.76	12.72±0.070
	6.0/9.00	9.93	12.93±0.057
	6.1/9.15	10.10	13.10±0.065
	6.2/9.30	10.26	13.20±0.069
	6.3/9.45	10.43	13.38±0.070
LSD_{05}			0.0093

Studies under chloride-sulfate salinization showed that it was advisable to use the formula to determine the salt content of Y=0.207x+0.5265 with R^2 = 0.9962 (Figure 2 and Table 6).

Sulfate-chloride salinity of the soil

The last of the most common salinities is sulfate-no-chloride. Even with a total salt content of 1.17 g/l, soils are classified as medium saline, and with 3.64 g/l as highly saline. With a total salt content in the aqueous solution of 8.45, the soil is considered very highly saline.

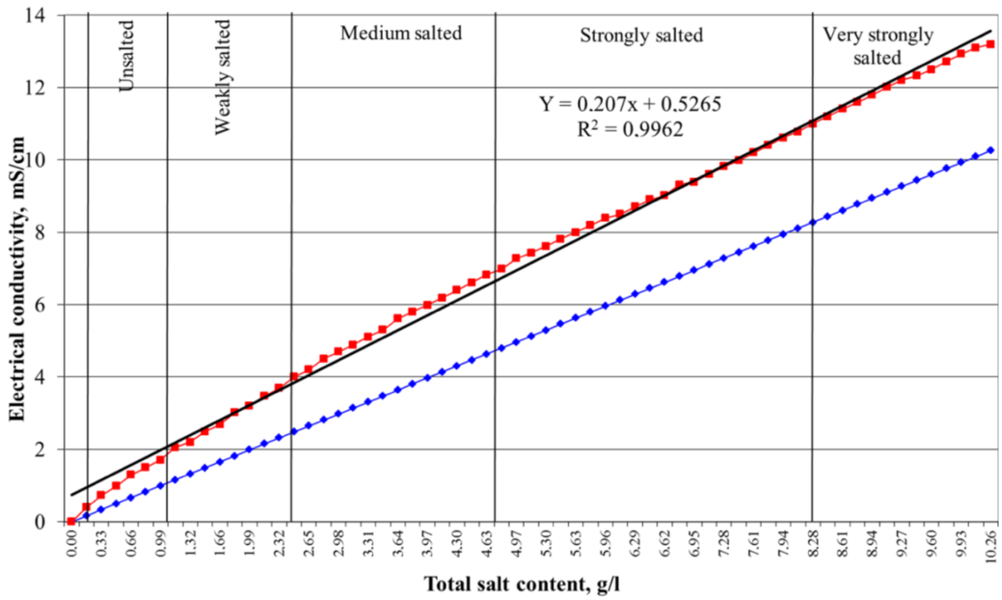

Figure 2. Comparison of the degree of chloride-sulfate salinization and electrical conductivity (ratios of $\frac{Cl^-}{SO_4^{2-}}$ given in Appendix B): **red line** is salt content, g/l; **blue line** is electrical conductivity, mS/cm; **black line** – linear trend of indicators (approximation and smoothing), based on the indicators of which a mathematical model and a deterministic indicator (R^2) were created)

Table 7. Comparative of the degree of sulphate-chloride salinity and electrical conductivity

Degree of salinity	Cl^-/SO_4^{2-} ratio, mg-eq	Salt content, g/l	Electrical conductivity, mS/cm
Distilled water	0/0	0.00	0.00±0.000
Unsalted	0.3/0.30	0.39	0.89±0.064
Weakly salted	0.4/0.40	0.52	1.11±0.079
	0.5/0.50	0.65	1.31±0.064
	0.6/0.60	0.78	1.53±0.086
	0.7/0.70	0.91	1.66±0.060
	0.8/0.80	1.04	1.92±0.093
Medium salted	0.9/0.90	1.17	2.15±0.083
	1.0/1.00	1.30	2.33±0.086
	1.1/1.10	1.43	2.43±0.091
	1.2/1.20	1.56	2.71±0.089
	1.3/1.30	1.69	2.80±0.079
	1.4/1.40	1.82	2.91±0.076
	1.5/1.50	1.95	3.12±0.111
	1.7/1.70	2.21	3.29±0.067

	1.8/1.80	2.34	3.41±0.060
	1.9/1.90	2.47	3.61±0.069
	2.0/2.00	2.60	3.78±0.077
	2.1/2.10	2.73	4.10±0.086
	2.2/2.20	2.86	4.31±0.076
	2.3/2.30	2.99	4.53±0.079
Strongly salted	2.4/2.40	3.12	4.69±0.075
	2.5/2.50	3.25	4.92±0.062
	2.6/2.60	3.38	5.07±0.073
	2.7/2.70	3.51	5.19±0.075
	2.8/2.80	3.64	5.40±0.060
	2.9/2.90	3.77	5.59±0.072
	3.0/3.00	3.90	5.79±0.079
	3.1/3.10	4.03	5.99±0.045
	3.2/3.20	4.16	6.12±0.081
	3.3/3.30	4.29	6.39±0.064
	3.4/3.40	4.42	6.51±0.069
	3.5/3.50	4.55	6.82±0.067
	3.6/3.60	4.68	7.02±0.075
	3.7/3.70	4.81	7.21±0.079
	3.8/3.80	4.94	7.31±0.064
	3.9/3.90	5.07	7.41±0.060
	4.0/4.00	5.20	7.51±0.069
	4.1/4.10	5.33	7.69±0.081
	4.2/4.20	5.46	7.79±0.072
	4.3/4.30	5.59	8.12±0.077
	4.4/4.40	5.72	8.20±0.065
	4.5/4.50	5.85	8.31±0.072
	4.6/4.60	5.98	8.40±0.076
	4.7/4.70	6.11	8.60±0.069
	4.8/4.80	6.24	8.73±0.055
	4.9/4.90	6.37	8.88±0.072
	5.0/5.00	6.5	8.98±0.072
	5.1/5.10	6.63	9.22±0.062
	5.2/5.20	6.76	9.28±0.052
	5.5/5.50	7.15	9.91±0.089
	5.6/5.50	7.28	10.11±0.069
	5.7/5.50	7.41	10.20±0.069
	5.8/5.50	7.54	10.33±0.079
	5.9/5.00	7.67	10.51±0.060
	6.0/5.50	7.80	10.59±0.081
	6.1/5.50	7.93	10.76±0.069
	6.2/5.50	8.06	11.01±0.072
	6.3/5.50	8.19	11.19±0.072
	6.4/5.50	8.32	11.29±0.064
Very strongly salted	6.5/5.50	8.45	11.42±0.070
LSD_{05}			0.011

Research on sulfate-chloride salinity showed that it was advisable to use the formula of $Y=0.1738x+0.7461$ with $R^2=0.9961$ to determine the salt content (Figure 3 and Table 7).

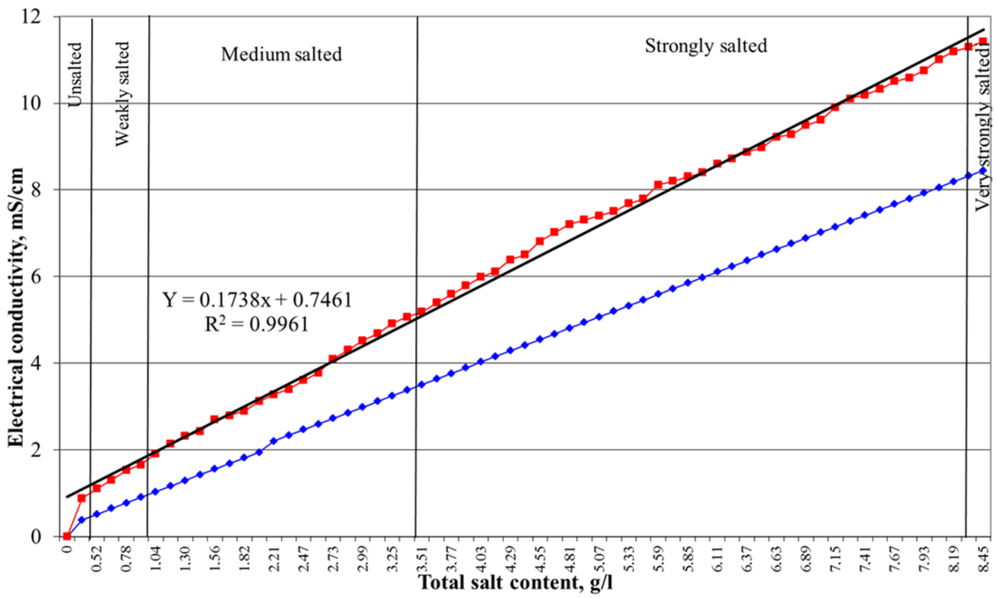

Figure 3. Comparison of the degree of sulfate-chloride salinity and electrical conductivity (ratios of $\frac{Cl^-}{SO_4^{2-}}$ given in Appendix C); **red line** is salt content, g/l; **blue line** is electrical conductivity, mS/cm; **black line** – linear trend of indicators (approximation and smoothing), based on the indicators of which a mathematical model and a deterministic indicator (R^2) were created)

Discussion

The importance of controlling the salt content lies in the fact that it increases the osmotic potential of the soil solution, thereby worsening the water consumption of plants due to the insufficient absorption power of the root systems.

Saline soils are widespread in almost all countries of the world (Kupchik *et al.*, 2007) the total area of land prone to salinization in Eurasia is approximately 242 million hectares.

The saline soils of Ukraine occupy a relatively small share of the arable land (about 7%) but require special attention in farming for several reasons (Qadir *et al.*, 2009; Lavrenko *et al.*, 2021; Zhuikov *et al.*, 2022; Lykhovyd *et al.*, 2022). The naturally saline soils of Ukraine are limited to two tectonic depressions of the Dnipro-Donetsk (Forest Steppe zone) and the Black Sea (Steppe), where the general insufficient drainage of the territory causes the accumulation of salts in the root zone and the development of secondary salinization.

The area of saline lands without a morphologically separate saline horizon is 1.92 million hectares, with a morphologically pronounced saline horizon (salted saline) of 2.8 million hectares. Among the irrigated lands, there are from 50 to 200 thousand ha of re-salted lands (UNDP, 2007; Wichelns, 1994; Didenko *et al.*, 2021).

Modern methods of determining salinity are diverse, but their incorrect use gives an erroneous result, which in turn leads to the adoption of an inappropriate decision. This leads to the deterioration of the ecological balance in the agrocenosis and severe ecological consequences (Ladychuk *et al.*, 2021a; Ladychuk *et al.*, 2021b).

Thus, land reclamation problems require the development of plans for integrated management and conservation and effective use of land resources.

The conducted studies showed the possibility of using the created mathematical models to determine the amount of salts and their composition. With this, we have solved the urgent need of agricultural producers to obtain accurate and fast information about soil salinity to support local agricultural production.

Comparison of traditional salt content monitoring methods is based on time-consuming analysis and manual sampling. In addition, their number and composition, according to scientists, can change significantly due to irrigation, precipitation, evaporation, fertilization, and production activities or meteorological changes (Tibhirine *et al.*, 2023; Qadir *et al.*, 2006). Failure to promptly determine the health of water and soil leads to degradation (Seckler, 1996; Rhoades, 1997a; Rhoades, 1997b).

The comparative assessment of the degree and distribution of salts for different types of salinization of the aqueous soil solution made it possible to build prognostic comparative mathematical models of the actual salt content and electrical conductivity of the saline solution, namely:

i - for chloride salinization was $Y=0.1286x+0.6165$ ($R^2=0,9972$);

ii - for chloride-sulphate salinization was $Y=0.207x+0.5265$ ($R^2=0,9962$);

iii - for sulphate-chloride salinization was $Y=0.1738x+0.7461$ ($R^2=0,9961$).

These models make it possible to quickly determine possible crop losses due to the salt content in the soil solution in production conditions and a scientific laboratory, to determine the correct remedial measures to reduce soil salinity.

References

Bazaluk, O., Havrysh, V., Nitsenko, V., Mazu, Y. and Lavrenko, S. (2022). Low-Cost Smart Farm Irrigation Systems in Kherson Province: Feasibility Study. Agronomy, 12:1013.

Bazilevich, N. I. and Pankova, E. I. (1972). Experience in soil classification based on the content of toxic salts and ions. Bulletin of the Soil Institute V.V. Dokuchaeva, 5:36-40.

Bresler, E., McNeil, B. L. and Carter, D. L. (1987). Salt marshes and salt licks. Leningrad: Gidrometeoizdat, 286 p.

Csillag, F., Paszto, L. and Biehl, L. L. (1993). Spectral band selection for the characterization of salinity status of soils. Remote Sensing of Environments, 43:231-242.

Diagnosis and improvement of saline and alkaline soils: USDA Agriculture handbook, 1954, 60, 160 p.

Didenko, N., Lavrenko, S., Lavrenko, N., Sardak, A., Didenko, S. and Mrynskii, I. (2022). Economic efficiency of corn grain cultivation with the new technologies of tillage and irrigation. Scientific Papers Series Management, Economic Engineering in Agriculture and Rural Development, 22:187-194.

Didenko, N., Mosiichuk, Ya., Islam, R., Zosymchuk, M., Mazurenko, B., Lavrenko, S., Kharytonov, M. and Babenko, M. (2023). Prospect of Growing Energy Crops on Biosolids-Amended Marginal Soils in Ukraine. In book: Green Energy, Environment and Sustainable Development. Series: Advances in Transdisciplinary Engineering, Editors - Chongqing Wang, Xiaoshuan Zhang, Hongyu Ren, Yingfa Lu., 38:875-882.

Didenko, N. O., Mosiichuk, Y. B., Zosymchuk, M. D., Kharytonov, M. M., Babenko, M. G., Mazurenko, B. O., Lavrenko, S. O., Rahman, M. A. and Islam, K. R. (2021). Recycling biosolids to improve marginal lands for bioenergy feedstock production in Ukraine. Reclamation and water management, 2:79-86.

Dregne, H. E. (2002). Land degradation in the drylands. Arid Land Res. Manag., 16:99-132.

DSTU 2730:2015 (2016). Environmental protection. Quality of natural water for irrigation. Agronomic criteria. Kyiv: SE "UkrNDNC", 24 p.

DSTU 3866-99 (2016). Soils. Classification of soils according to the degree of secondary salinity. Kyiv: SE "UkrNDNC", 24 p.

FAO. (1988). World Agriculture Toward 2000: An FAO Study. N. Alexandratos (ed.). Bellhaven Press, London, 338 pp.

Fernández-Buces, N., Siebe, C., Cram, S. and Palacio, J. L. (2006). Mapping soil salinity using a combined spectral response index for bare soil and vegetation: A case study in the former lake Texcoco, Mexico. Journal of Arid Environments, 65:644-667.

Ghassemi, F., Jakeman, A. J. and Nix, H. A. (1995). Salinization of Land and Water Resources: Human Causes, Extent, Management and Case Studies, CAB International, 526 pp.

Indo-Dutch Network Project (IDNP). (2002). Result #1. A Methodology for Identification of Waterlogging and Soil Salinity Conditions Using Remote Sensing. CSSRI, Karnal and Alterra- ILRI, Wageningen; pp. 78.

Ivanyuk, G. S. (2017). Classification and diagnosis of soils: a study guide. L'viv: LNU Ivan Franko, 334 p.

Ivushkin, K., Bartholomeus, H., Bregt, A. K., Pulatov, A., Kempen, B. and De Sousa, L. (2019). Global mapping of soil salinity change. Remote Sens. Environ, 231:111260.

Kupchik, V. I., Ivanina, V. V., Nesterov, G. I., Tonha, O. L., Lee, M. and Mathews, G. (2007). Soils of Ukraine: genesis properties, fertility management: study guide. Under the editorship V.I. Kupchik Kyiv: Condor, 414 p.

Ladychuk, D., Lavrenko, S. and Lavrenko, N. (2021a). Methods for determining expenses of horizontal drainage under production conditions. Scientific Papers. Series E. Land Reclamation, Earth Observation & Surveying, Environmental Engineering, X:94-102.

Ladychuk, D., Shaporynska, N., Lavrenko, S. and Lavrenko, N. (2021b). The methods for determining agrolandscape typicality for projects of water supply construction. AgroLife Scientific Journal, 10:121-129.

Lavrenko, S. O., Lavrenko, N. M. and Lykhovyd, P. V. (2019). Effect of degree of salinity on seed germination and initial growth of chickpea (*Cicer arietinum*). Biosystems Diversity, 27:101-105.

Lavrenko, S. O., Lavrenko, N. M., Maksymov, D. O., Maksymov, M. V., Didenko, N. O. and Islam, K. R. (2021). Variable tillage depth and chemical fertilization impact on irrigated common beans and soil physical properties. Soil and Tillage Research, 212:105024.

Lykhovyd, P. V., Vozhehova, R. A., Lavrenko, S. O. and Lavrenko, N. M. (2022). The Study on the Relationship between Normalized Difference Vegetation Index and Fractional Green Canopy Cover in Five Selected Crops. Hindawi: The Scientific World Journal, Article ID 8479424. https://doi.org/10.1155/2022/8479424

Metternicht, G. I. and Zinck, J. A. (2003). Remote sensing of soil salinity: Potentials and constraints. Remote Sensing Environm, 85:1-20.

Mohamed, S. A., Metwaly, M. M., Metwalli, M. R., Abdelrahman, M. A. E. and Badreldin, A. N. (2023). Integrating active and passive remote sensing data for mapping soil salinity using machine learning and feature selection approaches in arid regions. Remote Sens. (Basel), 15:1751.

Mougenot, B., Pouget, M. and Eperma, G. (1993). Remote sensing of salt-affected soils. Remote Sensing Reviews, 7:241-259.

Pankova, E. I., Soloviev, D. A., Rukhovich, D. I. and Savin, I. Yu. (2016). Organization of monitoring of soil salinity in irrigated areas of Central Asia using remote sensing data. Land resources and food security of Central Asia and Transcaucasia. Edited by P.V. Krasilnikov, M.V. Konyushkova, R. Vargas. Rome: FAO:309-369.

Qadir, M., Noble, A., Schubert, S., Thomas, R. J. and Arslan, A. (2006). Sodicity-induced land degradation and its sustainable management: Problems and prospects. Land Degradation & Development, 17:661-676.

Qadir, M., Noble, A.D., Qureshi, A.S., Gupta, R., Yuldashev, T. and Karimov, A. (2009). Salt-induced land and water degradation in the Aral Sea basin: A challenge to sustainable agriculture in Central Asia. Natural Resources Forum, 33:134-149.

Rao, B., Sankar, T., Dwivedi, R., Thammappa, S., Venkataratnam, L., Sharma, R. and Das, S. (1995). Spectral behaviour of salt-affected soils. International Journal of Remote Sensing, 16:2125-2136.

Rhoades, J. D., Lesch, S. M., LeMert, R. D. and Alves, W. J. (1997a). Assessing irrigation/drainage/salinity management using spatially referenced salinity measurements. Agricultural Water Management, 35:147-165.

Rhoades, J. D., Lesch, S. M., Burch, S. L., LeMert, R. D., Shouse, P. J., Oster, J. D. and O'Halloran T. (1997b). Salt transport in cracking soils: Salt distributions in soil profiles and fields and salt pick-up by run-off waters. J. Irrig. & Drainage Engineering, ASCE, 123:323-328.

Seckler, D. (1996). The New Era of Water Resources Management: From "Dry" to "Wet" Water Savings, Consultative Group on International Agricultural Research, Washington, D C.

Tibhirine, Z., Ibno, N. K., Bouasria, A., Bourhrami, B. El and Ettayeb, H. (2023). Geospatial and temporal assessment of the variability of soil organic matter and electrical conductivity in irrigated semi-arid area. Geology, Ecology, and Landscapes, 2023:1-12.

UNDP (2007). Water - Critical Resource for Uzbekistan Future, Tashkent, Uzbekistan, 121 p.

VND 33-5.5-02-097 (1998). Water quality for irrigation. Ecological criteria. Kharkiv: State Committee of Ukraine on Water Management, 24 p.
Wichelns, D. (1994). The World Bank Report: Economic Evaluation of Agricultural Water Resources in Uzbekistan. University of Rhode Island, Kingston, Rhode Island, 35 p.
Wong, V. N., Greene, R., Dalal, R. C. and Murphy, B. W. (2010). Soil carbon dynamics in saline and sodic soils: A review. Soil Use Manag., 26:2-11.
Zhuikov, O., Kyrylov, Yu. and Lavrenko, S. (2022). The efficiency of sunflower cultivation on different levels of biologization. Scientific Papers Series Management, Economic Engineering in Agriculture and Rural Development, 22:807-814.

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