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ORIGINAL ARTICLE

Effects of magnetized municipal effluent on some physical properties of soil in furrow irrigation

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Abstract

Due to the water crisis, effluent reuse is an effective method in order to supply crop water requirements. In order to study the impact of treated and magnetic effluent on the soil properties, this research was conducted in randomized complete block design with three irrigation treatments; including "effluent", "magnetic effluent" and "normal water" in four replications. Soil samples were taken from two surface and subsurface soil layers and at the upper and the downstream of each furrow. Evaluating the apparent specific gravity of soil in different water quality treatments showed that this soil property was increased effectively at the upstream part of the furrow. Similar results were also observed in the field capacity but more fluctuations were observed. Simultaneously, effluent treatment showed decreasing effects on soil water holding capacity during the time, which can be attributed to the increasing of soil organic matters. It seems that the high fluctuations between different design blocks are related to the gravelly nature of soil. However, intensification or weakening effect of these changes was not even found by magnetic.

Keywords Effluent · Magnetic · Apparent-specific gravity · Soil water holding capacity · Furrow irrigation

Introduction

In arid and semi-arid regions, due to water scarcity, the replacement of new and reliable water sources for use in agriculture should be considered. In this regard, the implementation of measures for the development and exploitation of unconventional water resources, such as industrial, urban, rural and agricultural effluents can compensate for the deficit of the country's agricultural water shortage, and also prevent the adverse effects of effluents on the environment (Erfani 1996).

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Effects of using effluent on soil density

The results of research show that the use of effluent and sewage sludge has often reduced the apparent density of soil in most studies. One of the reasons for this effect is that the soils irrigated with effluent become porous and spongy due to the presence of organic matter in the effluent. For example, in the study of irrigation with effluent for 9 years and well water in areas with dry climate and clay texture, the results showed that the lands irrigated with effluent have a lower specific gravity than the lands irrigated with well water (Abedi-Koupai et al. 2022; Rabiei et al. 2022; Rouhani Shahraki et al. 2005; Razmi et al. 2022; Nafchi et al. 2021; Fatahi Nafchi et al. 2022; Ostad-Ali-Askari et al. 2017a). In a similar study, the effect of effluent and fresh water in loam silt soil on apparent density was studied. The results showed the effect of effluent on the reduction of this soil characteristic (Tabriz et al. 2011; Ostad-Ali-Askari, 2022b; Shayannejad et al. 2022). In addition to effluent, the effect of sewage sludge on apparent density has also been investigated. The results show that sludge significantly reduces the apparent density of the soil (Shirani et al. 2010; Ostad-Ali-Askari 2022a; Eslamian et al. 2018a). In another study, the effect of effluent and sewage sludge and their interaction on soil apparent density in a cement cylinder were investigated. The results showed that effluent has no significant effect on soil density but the application of different amounts of sewage sludge has significantly reduced soil density (Taghvian et al. 2007; Eslamian et al. 2018b). The presence of plants and the type of irrigation systems also cause changes in soil density under the conditions of using effluent. For example, research results in 100 hectares of wheat cultivation with 29 years of history of effluent irrigation showed that effluent increased soil density in the surface layer but did not cause any specific changes in the subsurface layer (Mollahosseini 2013; Ostad-Ali-Askari 2022h; Fattahi Nafchi et al. 2022). Also, the study of irrigation of three plants (beet, sunflower, corn) with effluent for 11 years and well water under both surface and sprinkler irrigation systems showed that the apparent specific gravity in surface irrigation increased compared to sprinkler irrigation. The reason for this can be explained by the filling of soil pores with small particles of soil (Abedi-Koupai et al. 2006).

Water holding capacity in soil

Using of effluent can increase soil water holding capacity. Irrigation with industrial effluent and river water in loam and clay loam soils in a study showed that by increasing the duration of irrigation, the effluent increases the holding capacity. This increase can be attributed to the presence of organic matter in the effluent. At the same time, this effect decreases with increasing soil depth (Boroumand Nasab and Ghalambaz 2008; Ostad-Ali-Askari 2022c). In another study, wastewater irrigation during a decade showed that the mentioned lands have more moisture than lands irrigated with well water in the field capacity (Rouhani Shahraki et al. 2005; Ostad-Ali-Askari 2022d). Sewage sludge can have a similar effect in significantly increasing soil water holding capacity (Taghvian et al. 2007; Ostad-Ali-Askari 2022e).

Magnetism

Magnetic power can convert plain water into a liquid with special chemical effects. So that the physical properties of water, such as surface tension, viscosity and density change (Fallah 2008; Kiani et al. 2008; Kruse et al., 2018). One of the advantages of using magnetic water in agriculture is soil remediation by reducing the use of chemical and acidic substances and lower cost. In addition to issues related to the reduction of the quantity and quality of water resources and need of using unusual water, reports indicate that the use of magnets can possibly be effective in reducing or exacerbating the effects of effluents. On the other hand, addressing the issue of "surface irrigation" and its technical issues, using unusual water from non-ecological point of view, and combining it with the discussion of magnetism, is one of the works that its emptiness is felt in scientific reports. In this study, by focusing on the expected changes in urban effluents on the characteristics of apparent density and soil water holding capacity, the effect of magnetic field in furrow irrigation conditions was investigated.

Materials and methods

This research was carried out in Bagh-e Anari farm in Isfahan University of Technology of Iran, with a height of 1645 m and a length of 51 degrees and 32 min East and a width of 32 degrees and 42 min North. The experiments were performed with three treatments of usual water (non-wastewater), effluent from the university wastewater treatment pond and effluent with the effect of magnetic field (fixed field) in a randomized complete block design with four replications (for data analysis from Excel and Excel software. SPSS analytical software was used). To store water, two metal tanks (capacity above 6 cubic meters) were used for treated wastewater and water upstream of the farm. The tanks were installed in such a way that the required height could provide the required current intensity. Also, to stabilize the height and intensity of water flow, a smaller tank with an inlet equipped with a float valve was used. Hydro Flume pipes were used to irrigate the furrows. The required and non-abrasive flow of each valve was estimated according to the slope of the soil and soil texture of 1 l per second. The duration of the study was about 2 months during which five irrigation operations were performed for each furrow (60 irrigations in total).

Steps of field operations

At the field, a suitable location was selected for the experiments and the land preparation operations, including plowing and crushing the lumps (with a disc), were performed by the tractor. The land was leveled with a hammer. Finally, 12 furrows with a length of 42 m, at intervals of 60 cm, were created by a furrower. The average longitudinal slope of the furrows was 0.1%. The general characteristics of the soil in the two experimental plots of the field are presented in Table 1.

In order to measure the inflow and outflow current of the furrows, short trapezoidal throat (WSC Flume) fins were installed. Levels were used for horizontal installation of these boats and the soil around the flume was completely compacted to prevent water leakage. The test of each furrow was started by transferring water to it and the time when water reached the 3-m stations was recorded. In each experiment, inlet and outlet flow hydrographs and forward–backward curves were determined. The geometric cross-sectional

Table 1 Some basic soil properties in the experimental lands

Soil particles						Some physical and chemical properties of land soil						
Land number	Depth (cm)	Sand (%)	Silt (%)	Clay (%) %	Soil texture (–)	Gravel (%)	Apparent soil density (gr/cm^3)	Organic materials (%)	EC_e	pH_e	FC (% By volume)	PWP (% By volume)
1	0–15	50.4	21.8	27.8	Sandy clay loam	38	1.57	<1	1.82	7.87	31.57	15
	15–40	52.3	20.3	27.4	Sandy clay loam	49.6	1.68	<1	1.97	7.84	33.71	15
2	0–15	54.2	18.8	27	Sandy clay loam	34.3	1.78	<1	0.98	8.29	20.87	15
	15–40	56.1	17.3	26.6	Sandy clay loam	43.4	1.71	<1	0.89	8.43	19.81	15

EC_e: Electrical Conductivity of Soil Saturated Extract, pH_e: Acid–Base Degree of Soil Saturation Extract

area of the furrow was measured after each irrigation by a tachometer. Samples were taken after the first, third, and fifth irrigations at two soil depths (0–15 and 15–40 cm as surface and subsurface layer) and at two distances (9–12 and 27–30 m) from the beginning of the furrow. A total of 144 samples were transferred to the laboratory according to standard instructions and measurements were made on them.

Measurement of soil physical properties

Modified sampling method was used to measure soil apparent density and moisture holding capacity. Soil samples were first saturated and placed in a compression plate machine. To obtain moisture in field capacity (FC), the samples were placed at a pressure of 0.1 bar. After measuring the sample, the moist soil in the oven was dried at 105° C for 24 h to obtain the weight of the dried soil. By the weight of dry and wet soil, weight moisture in the field capacity (FC) was obtained and the apparent density was calculated from the ratio of dry soil weight to the total volume of soil sample (Jafari Haghighi, 2003; Ghazan Shahi 2006; Talebmorad et al. 2022; Vanani et al. 2022; Eslamian et al., 2018c). Also, the characteristics of usual water, magnetic effluent and effluent used at the beginning, middle and end of the study period, physically (electrical conductivity, total suspended solids,…), chemical (acid–base degree, different actions and anions) And bioavailability (oxygen requirements of bacteria and abundance of pathogenic bacteria) were studied. The results of water quality tests are shown in Table 2.

As can be seen, the quality of non-wastewater was normal and permissible for irrigation. In the case of effluent, except for the total number of coliforms, all variables are within the allowable irrigation limit. Regarding the effect of magnetic field on effluent quality, the amount of positive and negative ions did not change significantly after the effluent passed through the magnetic field. Also, the wastewater standard for biological and chemical oxygen demand (BOD_5 & COD) is within the allowable range and a slight change is observed in them due to the magnetic field. This effect was more significant in the number of coliforms and in two of the three experiments, the amount of coliforms increased significantly.

Discussions and results

Before reviewing the results, there are common issues that need to be addressed:

Note 1: Use of "relative changes" of data: In this study, changes in soil properties after several irrigations compared to the initial conditions were more important than their quantitative values. Accordingly, in analyzing the

Table 2 Some chemical, physical and biological variables of water, effluent and magnetic effluent

Variable	Unit	Usual water	Municipal effluent			Magnetic effluent			Standard boundary in effluent	
			First	Center	End	First	Center	End	Agriculture	Drain to the water
Electrical conductivity (EC)	ds/m	0.7	1.0	1.1	1.1	1.0	1.1	1.1	–	–
Total suspended solids (TSS)	mg/lit	10	60	68	53	61	65	56	100	40
Acid–base degree (pH)	–	7.6	8.3	7.3	8.0	8.3	7.6	7.8	6.0–8.5	6.5–8.5
Na	mEq/lit	5.2	9.5	–	4.8	10.5	–	4.8	–	–
K	mEq/lit	0.1	0.9	–	0.3	0.9	–	0.3	–	–
Ca	mEq/lit	4.6	4.5	–	6.2	4.7	–	6.4	–	75
Mg	mEq/lit	1.4	1.7	–	5.0	0.9	–	6.2	100	100
HCO_3	mEq/lit	7.8	4.4	–	4.9	4.8	–	4.8	–	–
CO_3	mEq/lit	0.0	0.0	–	0.5	0.0	–	0.6	–	–
SO_4	mEq/lit	1.1	1.6	–	0.3	1.6	–	4.2	500	400
Cl	mEq/lit	6.3	10.6	–	10.6	10.6	–	8.1	600	600
Sodium adsorption ratio (SAR)	–	3.0	5.4	–	2.0	6.3	–	1.9	–	–
Dissolved oxygen (DO)	mg/lit	6.8	–	–	–	–	–	–	2	2
Bio-oxygen demand (BOD_5)	mg/lit	0.0	55	66	50	57	61	56	100	30
Chemical oxygen demand (COD)	mg/lit	0.0	92	110	84	95	102	93	200	60
Total number of coliforms	1000 per 100 cc	0.0	233	69	176	356	105	20	1	1

results, instead of raw cultivars, the amount of data change compared to the first irrigation was used.

Note 2: "Significance probability level": for various reasons such as high percentage of gravel (30–50%), non-uniformity and heterogeneity of field soil, the possibility of error in extraction, light soil and high evaporation from the surface, most of the research results are statistically Did not make sense. Therefore, in the statistical analysis report, the "Smallest Level of Significance or *p*-value" was used. The values of *p*, while comparable to the level of significance of five or one percent (coefficient α, which is commonly used and are two special cases of the value of *p*). Have a greater ability to accurately quantify the level of significance and develop its concepts.

Note 3: "Unreliable data": Statistically, outliers data refers to values outside the first quarter and the third quarter within a radius of 1.5 times the interquartile index (Interquartile; $IQ = Q_3 - Q_1$), i.e. outside figures. From distance Q ($Q_1 - 1.5 \times IQ$, $Q_3 + 1.5 \times IQ$). In this study, in order to improve the accuracy of statistical analysis, only a very small number (due to the limited amount of information) of the data that showed conflicting results were removed and statistical analysis was performed again.

Effect of magnetic effluent and effluent on soil density

The mean values of apparent density relative to water density (relative apparent density of soil) in different treatments and turns of irrigation water are presented in Fig. 1.

The results show that at the beginning of the furrow (at a distance of 9–12 m from the beginning) the apparent density of soil in the surface and subsurface layer of the soil and after 5 irrigations in different water quality treatments, mainly has an increasing trend. However, these changes do not have a specific trend at the end of the furrow except for water. It seems that these changes are mainly due to the effect of irrigation on soil structure compaction rather than water quality. Statistical analysis of these results (Table 3) also shows that there is no statistically significant difference between the design treatments. At the same time, after removing the unreliable data, there was a significant difference between the treatments, mainly in the surface layer and at the beginning of the furrow to which more water penetrated. Binary comparison of treatments (Table 4) attributes these changes to effluent and does not show a significant change for the magnetic effect.

Effect of magnetic effluent on moisture holding capacity

The mean values of soil moisture holding capacity in different treatments and turns of irrigation water (along with the range of changes) are shown in Fig. 2. As can be seen in the diagrams, the changes in this soil characteristic in different repetitions of irrigation, especially, in the topsoil, have very sharp fluctuations, so that it is not easy to provide a specific rule for analyzing the results.

Statistical analyzes (Table 5) similarly failed to determine a significant probability for changes in a level. At the same time, among these erratic results, changes in holding

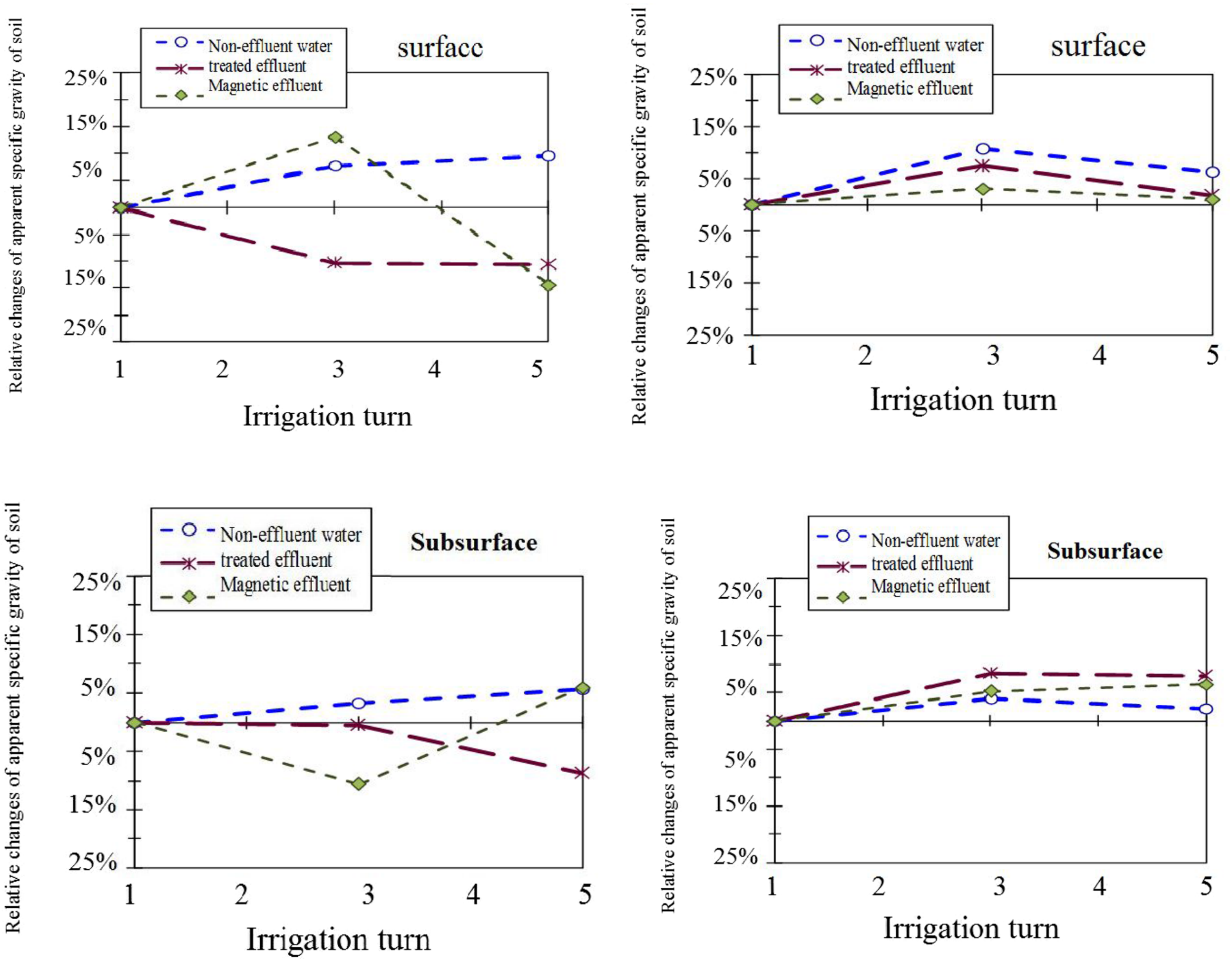

Fig. 1 Relative changes in apparent density of soil during the irrigation period, in two soil layers, and at the beginning (left) and end of furrow (right)

Table 3 The result of statistical analysis of random block design related to "changes in soil specific gravity"

Source of change	Degrees of freedom	Significant level[a]		Degrees of freedom	Significant level by deleting unreliable data	
		Surface soil	Subsurface soil		Surface soil	Subsurface soil
a. Distance 9–12 m from beginning of the furrow						
Treatment	2	67%	87%	2	1%	22%
Block	3	88%	24%	3	2.3%	12%
Trial error	6	–	–	3	–	–
b. Distance 27–30 m from beginning of the furrow						
Treatment	2	97%	21%	3	4%	21%
Block	3	58%	36%	4	12.2%	82%
Trial error	6	–	–	4	–	–

[a]Values less than 5% or 1% of the minimum significance level indicate "significant" or "very significant" differences, respectively

Table 4 Mean of "relative changes" and the level of significance of apparent-specific gravity of soil in different irrigation treatments

Treatments	Mean of relative changes	Significant level			Mean of relative changes	Significant level		
		Treatment 1	Treatment 2	Treatment 3		Treatment 1	Treatment 2	Treatment 3
a. Distance 9–12 m from beginning of the furrow					b. Distance 27–30 m from beginning of the furrow			
Surface soil 0–15 cm					Surface soil 0–15 cm			
1. Water	0.095	100%	–	–	0.063	100%	–	–
2.Effluent	−0.105	0.4%	100%	–	0.018	20%	100%	–
3.Magnetic Effluent	−0.143	0.3%	23%	100%	0.011	17%	81%	100%
a Distance 9–12 m from beginning of the furrow					b .Distance 27–30 m from beginning of the furrow			
Subsurface soil 15–40 cm					Subsurface soil 15–40 cm			
1.Water	−0.035	100%	–	–	0.057	100%	–	–
2.Effluent	0.079	15%	100%	–	−0.087	8%	100%	–
3.Magnetic Effluent	0.142	8%	41%	100%	0.06	97%	9%	100%

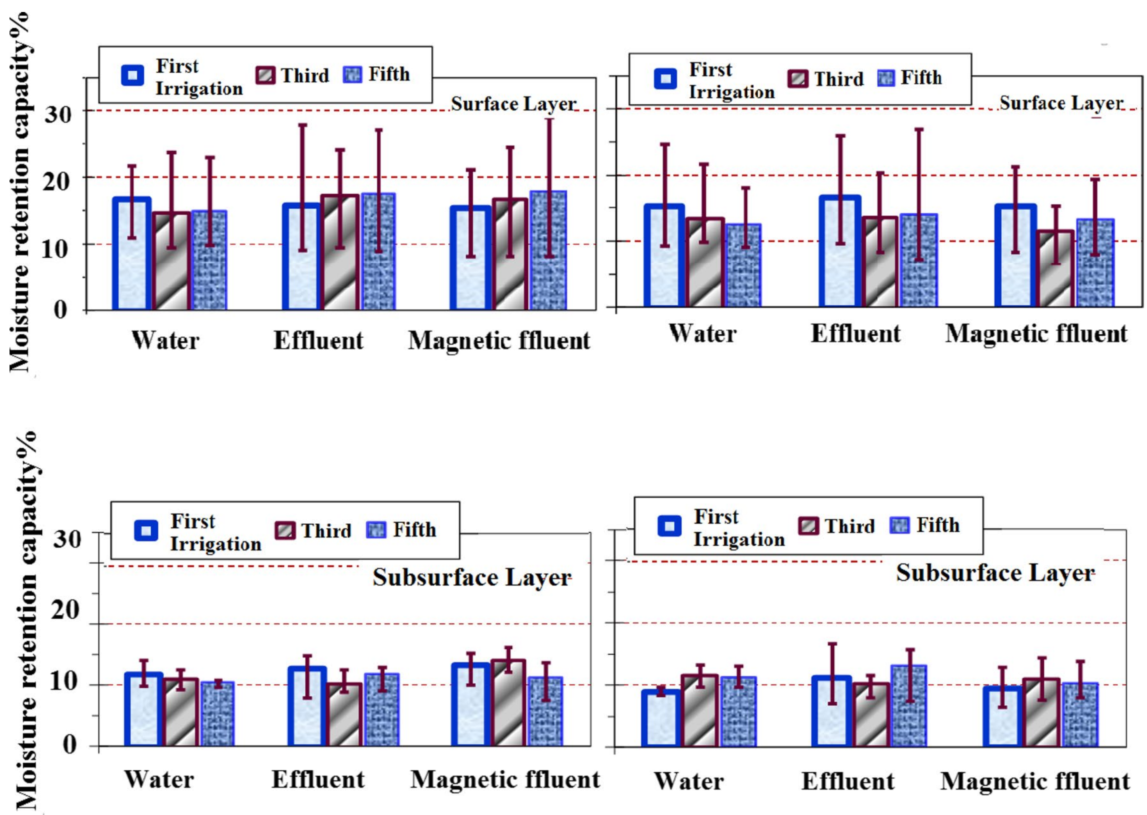

Fig. 2 Soil holding capacity during the irrigation period, at the beginning (left) and the end of the furrow (right)

capacity in conventional water treatment show a decreasing trend that was typically expected as a result of repeated irrigation operations and due to changes in soil structure. The effects of effluent treatments are mainly increasing, which can be attributed to the increase of soil organic matter. It should be noted that in cases where the reverse of this trend is observed in the mean value, it is mainly related to outliers and high fluctuations in repetitions.

Conclusion

Similar results were also observed in the field capacity but more fluctuations were observed. Simultaneously, effluent treatment showed decreasing effects on soil water holding capacity during the time, which can be attributed to the increasing of soil organic matters. It seems that the high fluctuations between different design blocks are related to the

Table 5 The result of statistical analysis of random block design related to "relative changes in soil moisture holding capacity"

Source of change	Degrees of freedom	Significant level[a]		Degrees of freedom	Significant level by deleting unreliable data	
		Surface soil	Subsurface soil		Surface soil	Subsurface soil
a. Distance 9–12 m from beginning of the furrow						
Treatment	2	45%	77%	3	59%	89%
Block	3	59%	6%	2	45.3%	94%
Trial Error	6	–	–	3	–	–
b. Distance 27–30 m from beginning of the furrow						
Treatment	2	97%	33%	3	55%	11%
Block	3	70%	50%	3	61.2%	63%
Trial Error	6	–	–	4	–	–

[a]Values less than 5% or 1% of the minimum significance level indicate "significant" or "very significant" differences, respectively

gravelly nature of soil. However, intensification or weakening effect of these changes was not even found by magnetic. Considering the sensitivity of measuring the two physical characteristics of the soil that were studied in the design (including apparent density and moisture holding capacity) and also due to the gravel and flow of farm soil and the paradoxical fluctuations of these properties in different furrows, the rule is clear. The result of the application of effluent and magnetic effluent in this design was not obtained. At the same time, statistical analysis showed that the changes in these characteristics were also related to the effluent and the magnetic effect did not cause a significant change.

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Availability of data and materials Some or all data, models, or code generated or used during the study are available from the corresponding author by request.

Declarations

Conflict of interest There is no conflict of interest.

Consent to participate All authors designed the study, collected data, wrote the manuscript and revised it.

Consent to publish All authors agree to publish this manuscript. There is no conflict of interest.

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