PAN
POLSKA AKADEMIA NAUK

JOURNAL OF WATER AND LAND DEVELOPMENT

e-ISSN 2083-4535

ITP-PIB

Polish Academy of Sciences (PAN) Institute of Technology and Life Sciences – National Research Institute (ITP – PIB)

JOURNAL OF WATER AND LAND DEVELOPMENT
DOI: 10.24425/jwld.2023.143742
2023, No. 56 (I–III): 37–44

The study of the fertilising power of urban sludge from the Dar Gueddari Wastewater Treatment Plant: Case of maize (*Zea mays*)

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RECEIVED 16.11.2021 ACCEPTED 09.02.2022 AVAILABLE ONLINE 10.02.2023

Abstract: The objective of this study is to recover sludge from the Dar Gueddari sewage treatment plant and use it in the cultivation of corn in the open field on clay soil. To do this, four doses were tested against two types of controls: a control without addition of sludge and another with the addition of nitrogen-based fertilisers (200 kg N, 100 kg P and 100 kg K). The short-term effects indicated that the application of the sludge had a beneficial effect on the fertilising qualities of the soil and therefore on the crop yield. The monitoring of the agronomic parameters of the maize plant showed that the growths and the yields varied according to doses of the sludge. In grain yield, the difference between plot E4 and E0 was around 3.3 $Mg \cdot ha^{-1}$. In addition, the plots treated with large sludge doses experienced improvements in total nitrogen and organic matter. During the second season, the results obtained showed decrease in nutrients (nitrogen and phosphorus). It emerged from the C:N ratio which was <8. This indicated a good mineralisation of the organic matter (OM) which was average of 2.48 ±0.04% and 2.5 ±0.01%, respectively in the E4 and E5 treatments. In addition, the amounts of N, P and Ca in dry matter (DM) increased with increasing the dose of sludge. During the 2017 season, the highest values were detected in plot E5 with averages of 1.6% in N and 0.53% in P.

Keywords: agronomic parameters, crop yield, Dar Gueddari sewage, dry matter, fertilisation, urban sludge

INTRODUCTION

The purification of domestic or industrial wastewater is accompanied by the production of sludge in different quantities depending on the treatment process [Ashekuzzaman *et al.* 2019]. The sludge quality is closely linked to the origin of wastewater. Indeed, sludge from industrial wastewater treatment has poor quality compared to domestic wastewater [Richard, Pradel 2014; Tao *et al.* 2012]. Sludge, in general, is composed of organic matter (OM) and fertiliser elements, water, and dry matter (DM) which contains macronutrients (nitrogen, phosphorus) and sometimes harmful elements, such as metallic trace elements and organic traces, and pathogenic microorganisms [Lau *et al.* 2017; Tao *et al.* 2012]. The significant increase in the quantity of sludge requires managers to find solutions to dispose of such waste while respecting economic, environmental, and public hygiene constraints [Klein 1981]. On the economic level, planners still face a challenge to reduce sludge disposal cost. Moreover, the environmental side depends on the quality of sludge and its suitable use (spreading, energy production, incineration or landfilling) [Deleris 2001]. The wastewater treatment plant (WWTP) sludge is used on cultivated land to improve its fertility and increase yields. This could represent one of solutions for the recovery of sludge. Nevertheless, the fertilisation of crops with such organic matter poses problems for soil and human health [Mohammad, Athamneh 2004]. This agronomic valorisation of sewage sludge constitutes an alternative to help the community to avoid excessive storage. In this sense, several studies have shown that organic products contained in the sludge improve soil fertility. Indeed, it is generally accepted that sewage sludge improves physical, chemical and biological properties of soils [Boudjabi *et al.* 2019; Soudani *et al.* 2017]. Along the same lines, several studies have shown that the reuse of treated by-products in agriculture significantly improves yields and soil nutrient reserves. Irrigation with treated wastewater increased the nitrogen and phosphate reserve by 200 and 150% in two years [Njimat *et al.* 2021]. For sludge, the yield of sunflower (*Helianthus annuus* L.) observed in a plot treated with 120 Mg·ha^{-1} is eight times higher than that of the control without any chemical substances added [Mohamed *et al.* 2018]. The use of sludge cannot be sustained in terms of its harmlessness (content of micro pollutants and pathogens).

Our experimental work fits into this context. Its main objectives are: the evaluation of effects produced by different doses of sewage sludge compared to two types of controls, a control without addition of sludge and another with the addition of NPK fertilisers. It was done to find an optimal dose that improves physicochemical characteristics of the soil substrate in relation to the growth and yield of maize.

MATERIAL AND METHODS

EXPERIMENTAL DEVICES

The experiment involved maize (*Zea mays* variety) and took place in the open field in the Dar Gueddari Region during the two campaigns between May and September, summer of 2017 and 2018.

The experimental set up included six units with a surface area of 10 m^2 each. The first was the control and the second plot was fertilised with nitrogen fertilisers, the other remaining units received four doses of sludge for the cultivation of maize as follows:
- E0 = control without any addition of fertiliser or sludge;
- E1 = control with addition of nitrogen-based fertilisers (200 kg·ha^{-1} N, 100 kg·ha^{-1} P and 100 kg·ha^{-1} K);
- E2 = 15 Mg·ha^{-1};
- E3 = 17 Mg·ha^{-1};
- E4 = 22 Mg·ha^{-1};
- E5 = 22 Mg·ha^{-1} + 50 kg·ha^{-1}

In this experiment, each treatment was performed twice. In order to properly assess the effect of sludge doses, the experimental units were widely spaced to avoid all forms of contamination. On the other hand, irrigation practices, water quantities, number of kernels per unit and the spacing between kernels and lines were all uniform.

ANALYSIS METHOD

Irrigation water analysis

Irrigation water samples were taken twice per campaign. All samples, which were point types at the time of irrigation, were taken to polyethylene bottles. The conditions of sampling, fixation and conservation according to standard DR – 09-04 of the Center of Expertise in Environmental Analysis of Quebec (Fr. Centre d'expertise en analyse environnementale du Québec, CEAEQ), [CEAEQ 2010] and the rules of good practice of the National Drinking Water Office of Morocco (Fr. Office national de l'Eau potable, ONEP) [ONEP 2003] were well respected. Temperature (*T*), pH, dissolved oxygen (*DO*) and electrical conductivity (*EC*) were measured on site. Other parameters such as total nitrogen, ammonium, nitrates, total phosphate, sulphates, sodium, chlorides and dry residue were determined in the laboratory.

Soil and sludge analysis

The physicochemical characteristics of soils were determined on composite samples over a 0–30 cm horizon. The analyses were carried out in the soil analysis laboratory of the Regional Office for Agricultural Development of Morocco (Fr. Office régional de mise en valeur agricole du Gharb, ORMVAG) and in the Moroccan Agriculture Laboratory (Fr. Laboratoire Marocain d'Agriculture, LABOMAG). Parameters of the sludge were defined before the beginning of the first season. For the soil, soil sampling was done at the beginning of the first season before cultivation, and the other samples were taken at the end of each experiment.

The pH was measured with a pH meter in a suspension of soil diluted 1/5 with distilled water, whereas the *EC* was determined on a filtered extract 1/5 (m/v) and the results were corrected at a temperature of 25°C. The phosphorus content was determined by a spectrometer after the extraction of soluble forms with a solution of sodium hydrogen carbonate (Oslen method). Sodium, magnesium and potassium were extracted with ammonium acetate at pH = 7 and determined by the atomic absorption spectroscopy (Standard NF X 31-108- September 2002). The organic carbon present in the soil was determined by a quantity of excess potassium dichromate (0.27 mol) in a chromic-chromic medium at 135°C. Cr^{3+} ions thus drilled were assayed spectrophotometrically at a wavelength of 585 nm. The organic matter (OM) content is evaluated by the organic carbon content thus determined in the international standard for determination of organic carbon by sulfochromic oxidation.

RESULTS AND DISCUSSION

SLUDGE AND SOIL COMPOSITION

The sludge used for spreading during this study was collected from anaerobic ponds of the Dar El Gueddari WWTP in 2013 and stabilised by storage for three years in Geotube® bags.

The results in Table 1 show that the humidity varies between 24 and 35%, with a slightly neutral pH of around 7.2. According to Gobat *et al.* [2010], these pH values are within the desirable range for the culture. The values of electrical conductivity reflect a very high salinity (3.3 to 3.6 mS·cm^{-1}). These types of sludge are rich in mineral matter and organic matter, respectively 20 and 40%. These results reflect their urban origin [Klein 1981]. The nitrogen concentration, which fluctuates between 0.89 and 0.96%, and the average C:N ratio (around 11.2 to 10.5) indicate that these types of sludge have been correctly stabilised and reflect their ability to release nitrogen [Chaussod 1981]. They also have the advantage of being rich in total phosphorus (1.1–1.8%) and potassium (1.30–1.36%). They contain sufficient phosphorus to present a certain agricultural interest. The content of major elements shows an almost stable average content of Ca and Mg, respectively from 5.8 to 6.1% and from 1.01 to 1.50%.

Table 1. Initial physicochemical characteristics of soils and sludge

Parameter	Unit	Initial soil[1)]	Initial sludge[1)]
Equivalent humidity	–	32.90 ±0.86	23 ±0.72
Clay	%	66.53 ±0.12	–
Fine silt	%	12.33 ±0.31	–
Coarse silts	%	16.50 ±0.08	–
Fine sand	%	2.67 ±0.05	–
Coarse sand	%	21.10 ±0.08	–
Total limestone $CaCO_3$	%	10.92 ±0.17	–
Active limestone	%	6.80 ±0.22	–
OM	%	1.9 ±0.01	22 ±0.06
C:N	–	9.91	11.7
pH H_2O	–	8.07 ±0.01	7.1 ±0.06
pH KCl	–	7.12 ±0.02	–
EC	$dS\cdot cm^{-1}$	0.2 ±0.01	3.7 ±0.01
CaO	$mg\cdot kg^{-1}$	8432.00 ±39.73	9450 ±207.75
Na_2O	$mg\cdot kg^{-1}$	379.00 ±54.49	1000 ±25.94
MgO	$mg\cdot kg^{-1}$	872.77 ±14.40	5360 ±99.95
N_{tot}	%	2.2	8.9 ±0.5
$N\text{-}NH_4$	$mg\cdot kg^{-1}$	21.07 ±0.21	137 ±1.05
$N\text{-}NO_3$	$mg\cdot kg^{-1}$	140.06 ±2.86	1078 ±1.24
K	$mg\cdot kg^{-1}$	477.203 ±11.04	2200 ±0.06
P	$mg\cdot kg^{-1}$	13.83 ±0.24	5500 ±0.02
Cl	$mg\cdot kg^{-1}$	132.55 ±3.42	141 ±2.2
SO_4	$mg\cdot kg^{-1}$	122.50 ±3.93	–
ESP	%	6.07 ±0.02	–

[1)] Average values ± standard deviation.
Explanations: OM = organic matter, *EC* = electrical conductivity, N_{tot} = total nitrogen, *ESP* = exchangeable sodium percentage.
Source: own study.

IRRIGATION WATER ANALYSIS

The physicochemical results mentioned in Table 2 show that pH values are within the range of the Moroccan standard for irrigation water [Arrêté … n° 1276-01]. These are between 7.26 and 7.74 with an average of 7.5. The values of electrical conductivity (*EC*), which vary between 0.61 and 0.94 $mS\cdot cm^{-1}$ with an average of 0.77 $mS\cdot cm^{-1}$, are lower than the threshold value for irrigation (3 $mS\cdot cm^{-1}$) [Ayers, Westcot 1985]. These waters are also characterised by low N, P and K contents. The maximum nitrogen value does not exceed 1.07 $mg\cdot dm^{-3}$. These values have given us an idea about the actual fertility of the sludge. In addition, the values of the sodium absorption ratio (*SAR*) are low and too far from the maximum value set by the Moroccan irrigation standard, the average value found at the level of 1.2.

EVOLUTION OF AGRONOMIC PARAMETERS

The agronomic parameters taken into consideration during this experiment included the length of the plant, number of leaves, leaf surfaces, and finally the grain yield (grain weight, number of grains per ear and grain yield per hectare). The macronutrient contents were determined on the aerial part in the maturation phase.

Effect of sludge on agronomic parameters

The results illustrated in Figures 1 and 2 show that the length of stems, leaf area, and the number of leaves have variations proportional to the applied dose, Indeed, the highest values are obtained in the plot E5, the difference recorded between the two plots E5 and E4 is small, which explains why the fortification by nitrogen of the E5 supported the growth of the plant better than the spreading of the sludge alone (plot E4). The difference recorded in the stem lengths between these two plots does not exceed 12 cm and 34 cm^2 in the leaf area. Indeed, organic amendments significantly increase the yield and quality of crops. On the other hand, too high or poorly targeted nitrogen supply can cause opposite effects [Richner *et al.* 2010]. During the second season the number of leaves remained unchanged. On the

Table 2. Results of the irrigation water analysis

Parameter	Unit	N	Min	Max	*SD*	Average	Limit value
EC	$mS\cdot cm^{-1}$	4	0.61	0.94	0.23	0.77	3
N_{tot}	$mg\cdot dm^{-3}$	4	0.92	1.22	0.21	1.07	–
NH_4	$mg\cdot dm^{-3}$	4	0	0	0	0	–
NO_3	$mg\cdot dm^{-3}$	4	0.94	1.16	0.16	1.05	–
P_{tot}	$mg\cdot dm^{-3}$	4	0.56	0.64	0.06	0.6	–
P_2O_5	$mg\cdot dm^{-3}$	4	0.05	0.15	0.07	0.1	–
K	$mg\cdot dm^{-3}$	4	0.66	1.34	0.48	1.0	–
SAR	–	4	0.99	1.41	0.30	1.2	9
Dry residue	$g\cdot dm^{-3}$	4	0.2	0.4	0.14	0.3	2

Explanations: *N* = number of samples, *SD* = standard deviation, *EC* = electrical conductivity, N_{tot} = total nitrogen, P_{tot} = total phosphore, *SAR* = sodium absorption ratio.
Source: own study.

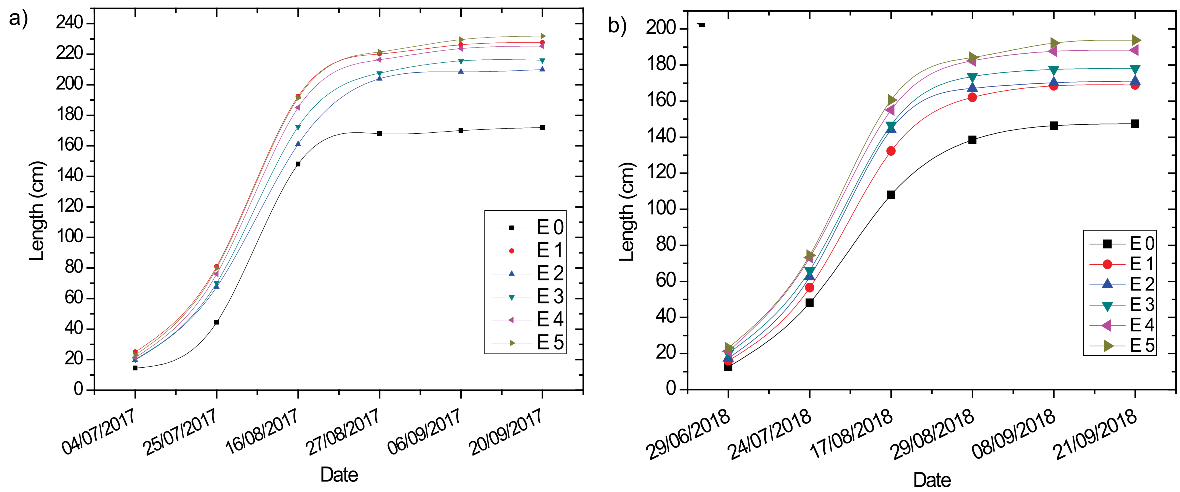

Fig. 1. Evolution of plant stem lengths during the experimental period: a) 2017 season, b) 2018 season; E0 = control without any addition of fertiliser or mud, E1 = control with addition of nitrogen-based fertilisers, E2 = 15 Mg·ha^{-1}; E3 = 17 Mg·ha^{-1}; E4 = 22 Mg·ha^{-1}; E5 = 22 Mg·ha^{-1} + 50 kg·ha^{-1} N; source: own study

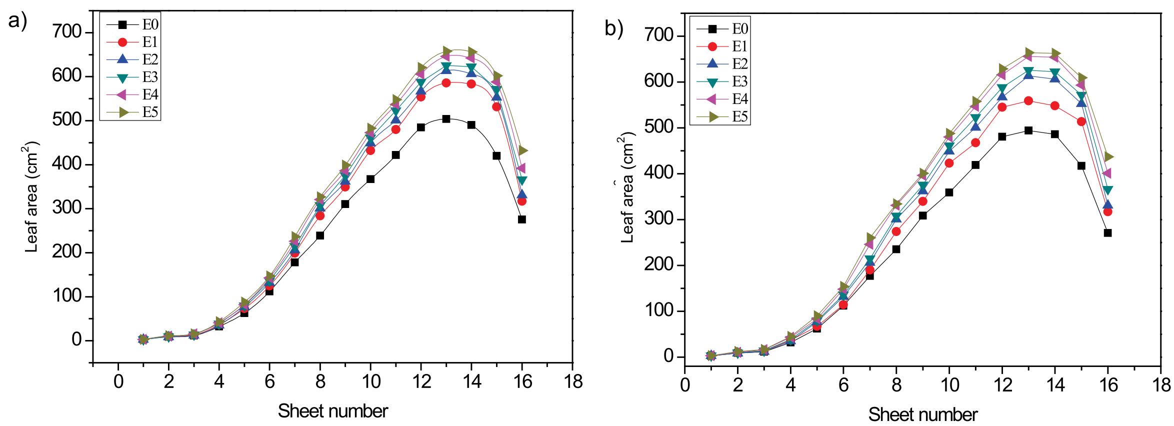

Fig. 2. Evolution of the leaf area of the maize plant during the experimental period: a) season 2017, b) season 2018; E0–E5 as in Fig. 1; source: own study

other hand, the plots devoid of any amendment (control) gave the lowest results. In this sense, it can be seen that the higher the dose of sludge, the higher the growth rate of plants. In other words, [Jocić, Sarić 1983] confirmed that the corn is more efficient than sunflower and sugar beet in the utilisation of nitrogen, phosphate, potassium, and calcium. It was found that the corn had the lowest concentration of these elements studied (13% N, 20% P, 30% K and 29% Ca) than the sunflower (12% N, 36% P, 27% K and 47% Ca) and sugar beet (13% N, 26% P, 32% K and 27% Ca). However, it had the highest dry matter content [Jocićn, Sarić 1983].

During the second season, it was noted that all stems in the studied plots were shorter than those studied during the first season (Fig. 2). This is due to the depletion of nutrients (N_{tot} and OM) by the corn. Moreover, the difference recorded between the maize plants of the same plots E4 and E5 during the two seasons was small. It was respectively around 16 cm and 12 cm while the number of leaves in the order of 16 remained stable in the two plots. This was perhaps due to the mineralisation of OM which was in high proportion to the sludge spread. A similar study conducted on irrigation by wastewater from the same station showed that stems exceed 240 cm, especially in plots irrigated by wastewater diluted to 50% by conventional water [Njimat *et al.* 2021].

Effect of sludge on crop yield

The production of each plot is harvested manually, the yields for each year are determined under ordinary harvest conditions after complete drying in the ripening cycle. The results found are shown in Table 3.

Analysis of the grain corn yield revealed an important approach between the treatment of plots E4 and E1. This approach was linked to the satisfaction of the plant's nutrient requirements (around 210 kg of nitrogen). The abstraction of fertilisers by maize during the first season caused a deficit for the crops during the second season, which led to the reduction of yield for all types of treatment. In addition, the lowest deviations were recorded in the plots where high doses of sludge were spread, 18% in E5 and 17.8% in E4. Likewise, the highest yield components were detected in plot E5 where the number of grains per ear varied between 458 and 689. These values remained the highest of all plots. This situation was linked to the morphologies of plants. On the other hand, several authors show that the number of grains/plant varies according to the aerial biomass of corn at flowering [Garza 1984; Njimat *et al.* 2019; Plénet 1995]. In the same plot (E5), the mass of 100 grains had an average of 35.5 g during the 2017 season. During the first season, the control plot recorded an overall yield of around 4.17 Mg·ha^{-1} and

Table 3. Characteristics of maize in 2017–2018 seasons

Plot	Year	Average number of ears	Average ear length (cm)	Ear perimeter (cm)	Number of grains per ears		Weight of 100 grains (g)	Yield ($Mg \cdot ha^{-1}$)
					min	max		
E0	2017	1.3	22.33	13.33	267	361	30.3	4.17
	2018	1.2	20.40	12.50	241	300	27.4	4.10
E1	2017	2.1	36.70	18.50	449	663	35.2	8.29
	2018	1.7	28.10	16.60	310	503	31.7	5.42
E2	2017	1.9	31.50	16.50	405	535	32.6	4.86
	2018	1.6	27.60	15.80	330	476	29.7	4.30
E3	2017	2.0	27.40	16.60	437	541	32.4	5.57
	2018	1.7	23.50	16.00	378	462	30.5	4.60
E4	2017	2.1	34.12	17.60	484	600	34.1	7.47
	2018	1.8	30.20	16.90	397	537	31.4	6.14
E5	2017	2.3	42.58	19.20	536	689	35.5	7.63
	2018	1.8	36.80	18.60	458	611	32.6	6.94

Explanations: E0-E5 as in Fig. 1.
Source: own study.

a number of grains between 267 and 361. ARRAYO *et al.* [2002] observed a 20% increase in the yield in plots treated with 12 $Mg \cdot ha^{-1}$ of sludge compost mixed with 350 $kg \cdot ha^{-1}$ of urea compared to plots treated with 12 $Mg \cdot ha^{-1}$ of the same compost without any addition of urea. In addition, another study has shown that sludge generated by aerobically treated domestic wastewater was more suitable for agriculture than limed sludge [ASHEKUZZAMAN *et al.* 2019].

Evolution of major nutrients in the soil

Samples taken after spreading and before cultivation reveal an increase in the rates of major elements in the amended soils; these increases are linked to the richness of the sludge in these elements (Fig. 3). The most attractive content is observed in the E4 treatment with a total nitrogen value of 0.45 ±0.02%. Over time, gradual decreases in nutrient levels in all plots were observed.

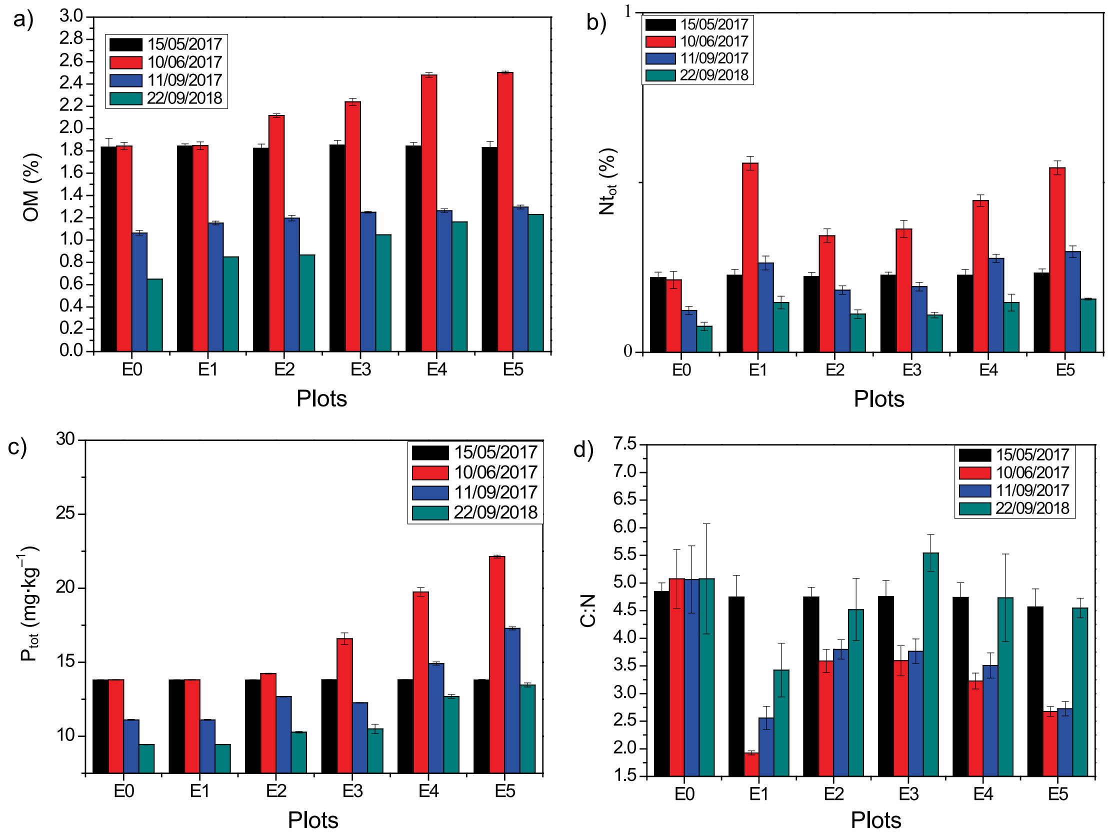

Fig. 3. Evolution of nutrients in the soil during the experimental period: a) organic matter, b) total nitrogen, c) total phosphate, d) C:N ratio; E0–E5 as in Fig. 1; source: own study

These decreases were very slow and differed from unit to unit depending on the dose applied. In addition, it was very acute in unit E1 because the amended fertilisers are in mineral form easily assimilated by the plant. In addition, the decrease in the sludge amended plots which was considered slow and could be explained by the slow mineralisation of OM (Fig. 3d). This compensated for the amount of nitrogen absorbed by the plant. In this sense, several authors have shown that the fertilising power of sludge decreases from year to year. Some confirm that the percentage of decrease varies between 20 to 25%, between 10 and 15% in the second year, and around 5% during the third year [FAO 2003; SOUDI, XANTHOULIS 2007]. The C:N ratio decreases with time, indicating a conversion of organic matter into nitrogen. Values found at the end of the second season reveal an increase in the ratio, which may be the result of nitrogen depletion [GONZALEZ-PRIETO *et al.* 1991]. It indicates a good release of N during the decomposition of sludge. The highest final content is detected in the E5 plots with averages of around 0.16 ±0.01% in N_{tot}, 13.39 ±0.01 in P. In Brazil, a study estimated that the spreading of 4.5 Mg·ha^{-1}·y^{-1} of well dehydrated sludge would save 1.3 Mg of ammonium and phosphate fertiliser [BREDA *et al.* 2020].

From the results above (Fig. 4), it was observed that the maize cultivated in the plots which were treated with high doses of sludge absorbed higher amounts of N, P, K and Na than the others, particularly those of the control. The quantities of N, P and Na in the dry matter of the plants cultivated in plot E4 were respectively 1.51, 0.50 and 2.07% of the DM. These contents varied proportionally with the quantities of sludge for each treatment. During the second season these values were reduced almost by half due to the use of nutrients by the maize during the previous season. Control plots E0 and E1 recorded lower contents than those detected during the first season, which translated into a weak evolution of the organic matter in the latter. Another similar study on the fertilising effect of compost on corn confirmed that the increase in doses enriched plants with N compared to plants irrigated by groundwater without any addition of either amendment or mineral wiggling. In addition, we found that the nitrogen content in plant tissues was closely related to the nitrogen content in the soil [MORETTI *et al.* 2020]. The initial quantities of K in the soil do not allow us to make a good evaluation of the element. For this reason, it is not taken into account.

CONCLUSION

The results obtained in this study show that the sludge from the Dar Gueddrai WWTP has a significant effect on the growth and yield of maize (*Zea mays*), the statistical analysis reveals that the correlation between doses of sludge and morphological components of the plant (length of stem, leaf area) is linear and significant (R^2 = 0.975 and p = 0.037). As mentioned before, the fertilising elements in soil have improved the rates of N_{tot} and P to go respectively from 0.47 to 1.61%, from 0.1 to 0.53% in the E4 plot.

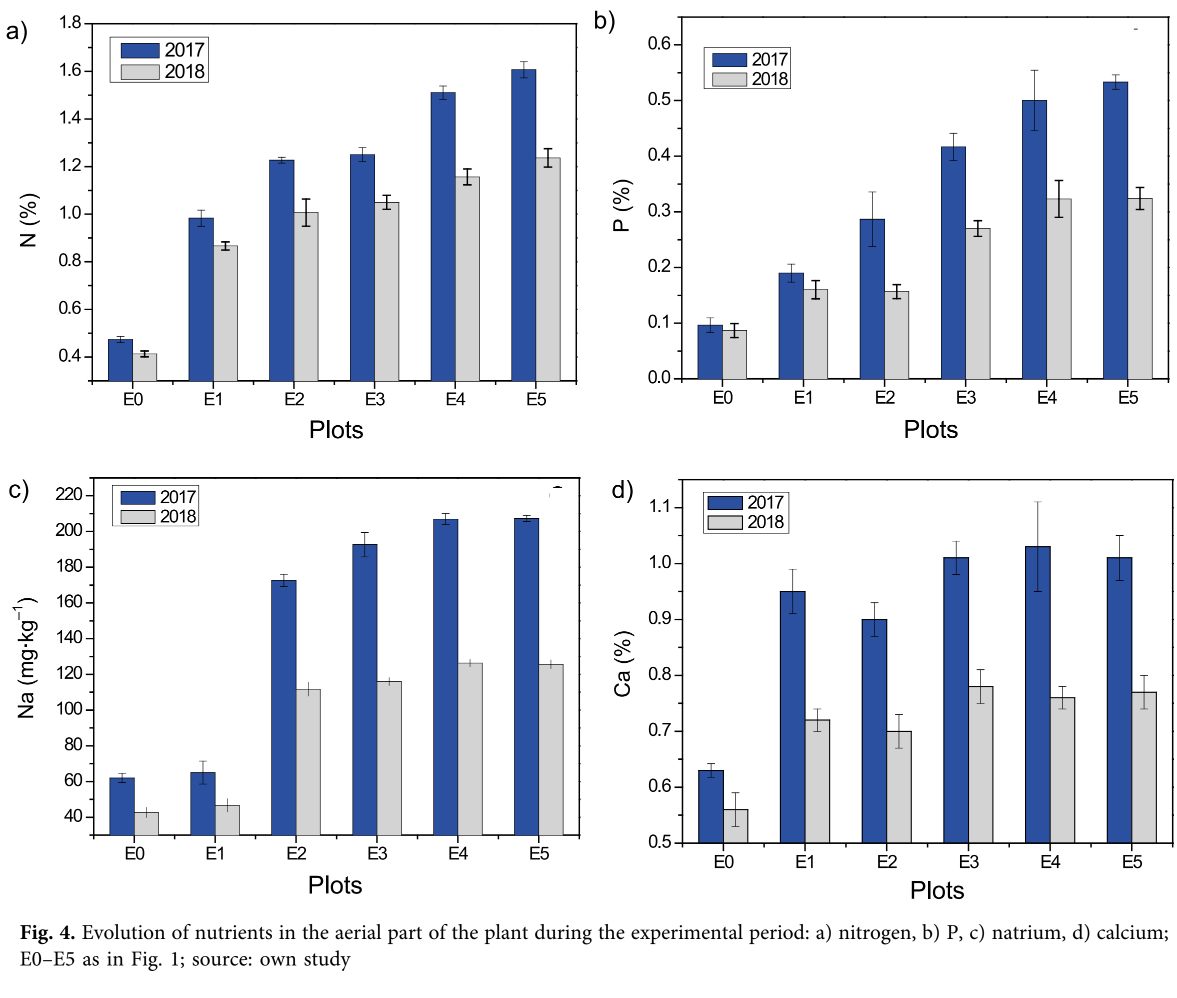

Fig. 4. Evolution of nutrients in the aerial part of the plant during the experimental period: a) nitrogen, b) P, c) natrium, d) calcium; E0–E5 as in Fig. 1; source: own study

The C/N ratio shows that sludge has the ability to mineralise rapidly. During the second season, values show that the sludge has a durable impact on matter necessary for the plants, which makes the sludge suitable for spreading.

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