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The Effect of Sewage Sludge on Productivity of a Crop Rotation of Wheat, Maize and Vetch) and Heavy Metals Accumulation in Soil and Plant in Aleppo Governorate

[1]M.M. Al Zoubi, [1,2]A. Arslan, [2]G. Abdelgawad, [1]N. Pejon, [1]M. Tabbaa and [2]O. Jouzdan

[1]General Commission for Scientific Agricultural Research (GCSAR)
[2]Arab Center for Studies of Arid Zones and Dry Lands (ACSAD)
Syrian Arab Republic, Ministry of Agric.and Agra. Reform (MAAR)

Abstract: A set of field experiments were conducted in order to study the effects of sludge application to agricultural soil on the heavy metal accumulation in soil and plant and on availability of certain nutrients for plant together with the productivity of wheat, maize and vetch, The experiment included four treatments i.e., (control; inorganic fertilizer according to Ministry of Agric. and Agra. Reform (MAAR) recommendation; sludge (the amount of sludge containing MAAR recommendation of N without any addition of mineral N; and double the amount of sludge without any addition of mineral N) with four replications at Kamari Research station in Aleppo for the seasons 2004-2005. The applied sludge was described and soil was analyzed prior to cultivation. Upon harvesting, the heavy metals (Cd, Pb, Ni and Cr) were estimated in soil and plant in addition to certain nutrients (Total N, P, macronutrients) and organic matter. Significant build up of some heavy metals in soil and plant was noticed by increasing the addition of sludge as compared to the control. Significant increase in organic matter of soil in sludge-fertilized treatment was noticed as compared to the control. Moreover, a significant increase in soil available P was also noticed by increasing the addition of sludge. No significant difference in total N and macronutrients. There were no significant differences in sludge-fertilized treatments on wheat productivity (2.66 and 2.86 ton ha^{-1}) as compared to mineral-fertilized treatment (2.93 ton ha^{-1}). Maize production significantly increased in sludge-fertilized treatments as compared to the control (3.88 ton ha^{-1}) and the best was that fertilized with double the amount (6.34 kg ha^{-1}). Vetch production increased in sludge-fertilized treatment as compared to the control (11.41 ton ha^{-1}) and the best was that fertilized with double the amount (12.97 ton ha^{-1}). It may be concluded from this study that sludge application to the soil is effective in improving crop productivity. It is unlikely that a single factor in sludge was responsible for this but is more likely to be due to the mixture of nutrients, micronutrients and organic matter that sludge supplies. The arable crops also grown in rotation in these trials may have also substantial cumulative and residual benefits. The addition of heavy metals to the soil during the trial was very small from a triple application of sludge and had minimal effect on crop and soil concentrations. The nature of the Syrian soils and the relatively low concentrations of heavy metals in Aleppo sludges means that it is unlikely that heavy metals from sludge will pose a significant threat, even in the long-term.

Key words: Sludge · heavy metal · fertilization · soil · crop productivity

INTRODUCTION

Sewage sludge is a good source of micro/macronutrients of plant besides its richness in organic matter. Its irrationalized and unscientific application severely affects plant growth, animal nutrition and human health; moreover crops responses to sludge application vary by source, application rate, plant species, soil type, weathering conditions and application management [1].

It has been stated that the application of treated-sewage sludge improves soil structure and organic matter content and provides nutrients [2], organic matter from sewage sludge has favorable effects on physical, chemical and microbiological properties of soil. Sewage sludge improved soil structure, increases infiltration rate, aggregate stability and soil water holding capacity [3].

Concentration of Zn, Cd, Cu and Mn in faba bean leaves increased by increasing sludge application rate

Corresponding Auhtor: Dr. M.M. Al Zoubi, General Commission for Scientific Agricultural Research (GCSAR)

while Pb concentration decreased and no change in Ni concentration [4]. However, the presence of heavy metals in sludge may be a limiting factor its use [5]. It can add high concentrations heavy metal (Cd, Cu, Ni, Pb and Zn) to the soil that can cause serious problems in plants and its consumers [6]. Sewage sludge, moreover, may contain large amounts of heavy metals [7] whose presence in soil may negatively affect enzyme activities [8]. Cadmium which is present in sludge can move in food chains as one of the large risks to humans and animals. There is a number of factors that control its concentration in plant, namely: application rate, soil reaction and plant species. Because sewage sludge are not designed for agricultural use, contain some level of industrial and commercial discharge and are of variable and unpredictable composition, it would be fortuitous indeed if virtually none of them contained contaminants detrimental to soils or the environment in the short or long term [9].

The Syrian government established and is still establishing sewage treatment plants in towns and districts, therefore, the amounts of solid organic wastes (bio-solids) produced from these plants as dry matter are expected to reach 200 thousand ton/year at the end of this decade. This will result in grave environmental problem unless these amounts are disposed safely using low cost and socially and environmentally accepted methods. As sludge studies are limited in Syria, we find it is necessary and useful to study its effect on crop productivity and heavy metals accumulation in soil and plant.

MATERIALS AND METHODS

Soil description: A composite sample was taken to specify the following nutrient characteristics of soil: Available P was determined according to Olsen method [10], Total N was estimated by Kjeldahl's method [11], Organic matter was estimated by wet oxidation [12] and Available K was extracted by ammonium acetates at ratio 1:5 (concentration 1 mole) by using flame photometer.

Sludge characteristics: Table 1 presents some characteristics for the average of three replicates used in the experiment, where sludge is mostly municipal from Aleppo city, it received secondary treatment and air dried under the sun for 3 months. Sample acidity was measured by pH meter of water/sludge suspension at 1:5 ratio. Electronic conductivity was also estimated in the same mixture using EC meter. The samples were digested through wet method [28] and total N and total P were estimated using autoanalyzer (*Skalar)*. Total K was estimated using flame photometer. Inorganic N was estimated using KCl of the extract (1:10) and amounts were assessed using autoanalyzer *Skalar*. Sludge was digested by $HclO_4$ for micronutrients determination and digested with Aqua regia to determine heavy metal by using Atomic Absorption Spectrophotometer *(Varian model)*.

Table 1: Results of soil analysis

	%		mg/kg	
Soil	Organic matter	Total N	Available P	Available K
Kamari-Aleppo	1.23	0.06	7.5	469

The sludge was bacterially analyzed (wet sample and dry sample) and total E. Coli and Salmonella bacteria were counted by proper gradual dilution and spread in plates [14] containing dispersion agent (SS agar, EMB, nutrient agar). The plates were incubated at ± 28 Cú for three days.

Experimental design: Complete Randomized Block Design(CRBD) was adopted with four replicates. The experiment contained four treatments namely:

1. Control (no fertilizers and sewage sludge added)
2. Mineral fertilized addition (as per MAAR's) recommendations.
3. Sewage sludge addition (as per crop N requirements and N content of sludge in conformity with Syrian standard 2665)
4. Sewage sludge (twice crop N requirements).

Means were compared by using LSD.

Cultivation: Wheat (*Douma 1*), maize(*hybrid*) and vetch (*vicia sativa*) were cultivated at Kamari stations, in Aleppo province in a cropping rotation at 22/12/2004, 17/6/2005 and 29/12/2005 respectively. Wheat and vetch were drilled at 20 cm apart, while maize was planted on furrows 70 cm apart. Sewage sludge was applied before planting as mixing with upper 15 cm.
All crops were using sprinclur irrigation system.

Fertilization: Mineral N and P were added just to $treatment_2$ as per MAAR's recommendations (150 kg urea/ha and 120 kg superphosphate/ha for wheat, 180 kg urea/ha and 75 kg superphosphate/ha for maize, 43 kg urea/ha and 120 kg superphosphate/ha for vetch). The sludge was also added to soil prior to cultivation after calculating the needed amount using the following formula:

$$\text{Applied sludge tons/ha} = \frac{\text{Available N in sewage sludge (kg/ton)}}{\text{N plant needs (kg/ha)-content N in soil (kg/ha)}}$$

To estimate sludge amount it is essential to know and assess organic N amount in sludge computed by the following formula: NO = T. N-Ni

Where, NO = Organic N, T. N = Total N, Ni = Mineral N (NO_3^-, NH_4^+)

So the rates of sludge application (treatment$_3$ and treatment$_4$) were 15 and 30 ton/ha for wheat, 17 and 34 ton/ha for maize, 10 and 20 ton/ha for vetch respectively.

RESULTS AND DISCUSSION

Soil properties: It is worthy to mention that the physical analysis of the experimental soil indicated that soil texture is clay with 26% sand, 18% silt and 56% clay. Table 1 shows the results of soil chemical analysis. The soil was calcareous with 23.3% $CaCO_3$, 7.7 pH and 0.4 $EC_{1:5}$

Sludge characteristics: Table 2 and 3 show some characteristics of the sludge applied in the experiments:

The above table shows high values of EC, K and P in sludge compared to the soil.

Table 3 shows that heavy metals concentration is under allowable limits.

Table 4 reveals that the number of bacterial species in Aleppo sludge is very low and under allowable limits. Once sludge dried, the microbiological loading reduced as these microorganisms are non-sporic and can adapt to inappropriate medium conditions accordingly.

The effect of sludge on organic matter and some nutrients in soil: Table 5 shows no significant differences in organic matter content of soil under wheat and maize due to good initial organic matter content, Table 1.

At the third season(vetch), the addition of sludge enriched soil with organic matter especially in treatment$_4$ where organic matter increased significantly up to 75% vs. control, meanwhile in treatment$_3$ organic matter increased significantly up to 51% vs. control and chemically fertilized treatment. Consequently sludge enriches soil with organic carbon [15] and nutrients positively affecting physical, chemical and biological characteristics of soil, a meaningful increase in the production of dry matter and N, P, Ca, Mg and Zn absorption by maize using 40 and 80 ton/ha of dry matter [5].

Sludge might increase the soil OM significantly but in a much longer time [7].

The same table shows an increase in total N in soil by increasing sludge addition (agree with [16]), as in wheat season that total N increased up to 23% vs. control because of the high content of N in sludge Table 2. It has been found that 28-48% of sludge content from total N can be directly used by plant after mixing sludge with soil [17] as indicated by Syrian Standard 2665 [18]. The results seems to be better in the last cropping season

Table 2: Some sludge physical and chemical characteristics

				%			mg/kg		
Sludge source	Bulk density (g/cm^3)	pH	EC 1:5 dS/m	O.M	T.N	K_2O	P	Mineral N	Moisture (%)
Aleppo plant	0.86	6.37	3.38	40.5	3.70	1.35	132	8.49	6.5

Table 3: Total content of trace elements and heavy metals in the applied sludge

	mg/kg										
Sludge source	Cd	Cr	Ni	Pb	B	Cu	Fe	Mn	Mo	Zn	Moisture (%)
Aleppo plant 2004	2.30		78.4	71.6	117	230	2400	159	30	1025	6.5
Allowable limits (mg/kg)	20.00	1000	200.0	800.0		1000			30	3000	-

(Syrian Standardization Commission 2002)

Table 4: Bacteriological analysis of sludge samples

Sludge source	Bacteria count x 10 ^{3}	*E. coli* x 10 ^{3}	Salmonella x 10 ^{3}	Moisture (%)
Aleppo plant	234	1.1	0	4.8

Table 5: Shows total N, av. P and organic matter in soil (0-30 cm) at harvesting (wheat, maize and vetch)

	Wheat			Maize			Vetch		
	%		mg/kg	%		mg/kg	%		mg/kg
Treatments	OM	N	Av. P	OM	N	Av.P	OM	N	Av. P
Treatment 1	2.10	0.084b	4.1c	2.13	0.106	3.96b	1.65c	0.018b	3.48b
Treatment 2	1.90	0.110a	7.7a	1.97	0.100	6.89b	2.23b	0.033ab	7.68a
Treatment 3	2.20	0.092ab	6.3ab	2.06	0.103	8.33b	2.49ab	0.055a	6.15a
Treatment 4	2.18	0.103ab	5.2bc	2.13	0.107	19.1a	2.90a	0.044a	5.73ab
LSD 0.05	-	0.023	2.02	-	-	8.03	0.447	0.024	2.28

Means in a column followed by the same small latter are not significantly different at $_{0.05}$ level

Table 6: Cd, Ni, Pb and Cr (mg/kg)

	Wheat				maize				Vetch			
Treatments	Cd	Ni	Pb	Cr	Cd	Ni	Pb	Cr	Cd	Ni	Pb	Cr
$Treatment_1$	0.125	101.7	8.6	104	0.068b	124.9	7.87	95.75	0.41	59.2b	3.72b	58.30b
$Treatment_2$	0.140	105.7	8.0	104	0.152a	120.8	4.70	96.25	0.53	75.7a	3.93ab	84.75a
$Treatment_3$	0.135	96.5	8.0	104	0.129ab	124.2	8.30	93.25	0.60	68.5ab	4.50a	85.25a
$Treatment_4$	0.130	103.5	7.0	103	0.179a	124.8	10.40	97.00	0.77	65.0ab	4.13ab	75.50a
$LSD_{0.05}$	-	-	-	-	0.07	-	-	-	-	13.2	0.66	13.70

Table 7: Cadmium, Ni, Pb and Cr concentration of wheat, maize, vetch(mg/kg)

	Wheat				Maize				Vetch			
Grains	Cd	Ni	Pb	Cr	Cd	Ni	Pb	Cr	Cd	Ni	Pb	Cr
$Treatment_1$	0.09	0.8	0.2	0.97	0.06	0.27	5.73	3.82	0.51b	2.75	0.93	59.2b
$Treatment_2$	0.09	0.8	0.2	0.95	0.09	0.31	6.27	4.00	0.55b	2.34	1.07	75.7a
$Treatment_3$	0.08	0.8	0.2	0.97	0.08	0.16	6.20	3.87	0.61ab	1.82	1.08	68.5ab
$Treatment_4$	0.09	0.8	0.2	1.04	0.11	0.15	4.45	3.84	0.79a	1.75	1.09	65.0ab
LSD	-	-	-	-	-	-	-	-	0.208	-	-	13.2
Straw												
$Treatment_1$	0.18	1.8	0.95	2.1	0.2	0.21	11.1	4.70	0.05b	3.1	0.29 ab	0.84
$Treatment_2$	0.19	1.2	0.97	2.3	0.21	0.25	11.5	4.70	0.09ab	3.3	0.23 b	1.10
$Treatment_3$	0.18	1.2	0.98	2.2	0.18	0.18	10.6	3.57	0.117a	6.6	0.47 a	0.17
$Treatment_4$	0.19	1.3	0.98	2.4	0.21	0.17	12.2	3.80	0.09ab	6.2	0.40 ab	0.50
$LSD_{0.05}$	-	-	-	-	-	-	-	-	0.05	-	0.24	-

where total N increased significantly in the 3rd season in soil by increasing sludge addition, total N at $treatment_3$ increased significantly up to 205% and up to 144% at $treatment_4$ vs. control.

This table shows significant differences in available P in soil. At wheat season available P increased by adding sludge and the increase for $treatment_3$ and treatment $_4$ reached 53.6 and 26.8% compared to the control respectively. For maize this increase in $treatment_3$ and $treatment_4$ was 110% and 382% as compared to the control respectively. For the vetch the increase for $treatment_3$ and $treatment_4$ reached 77 and 65% compared to the control respectively. This clarifies the role of sludge in increasing available P. Sludge addition may noticeably rise soil content from N and available P [11]. Increasing the application rate of sludge will increase the available amounts of N and P [17]. Recently the application of sewage sludge to agriculture soils could be considered as an alternative to urea fertilization [20] due to their high contents in organic matter and essential nutrients such as nitrogen and phosphorus (agree with [21] who found in a pot experiment, the application of sewage sludge significantly increased available phosphorus, soil pH, Zn and Cu).

The effect of sewage sludge on heavy metals accumulation in soil: Table 6 shows Cd, Ni, Pb and Cr concentration in soil at harvesting of wheat, maize and vetch.

Table 6 shows there is no effect due to sludge application on heavy metals concentration in soil of wheat and maize growing seasons except Cd in maize cropping season [22] clarify that sludge also contain a range of potentially toxic metals, such as Cu, Cd, Pb, Zn and Ni.

The same table reveals slightly significant Cd increase in soil concentration by increasing sludge application. Cadmium is the most hazardous contaminant in terms of food-chain contamination [23]. At maize cropping season Cd increased 163% vs. control. Cd increase in $treatment_4$ was 38.8% vs. $treatment_3$. Mineral fertilized treatment resulted in Cd significant accumulation vs. control because triple superphosphate contain Cd. Phosphate fertilizers are Cd source in soil and plant resulting in an increase in Cd concentration in soil [24]. Comparing $treatment_4$ with $treatment_2$, high Cd amount at 18% was noticed in the $treatment_4$ vs. $treatment_2$.

At vetch cropping season, heavy metals accumulation was noticed in soil by increasing sludge application in case of sludge application vs. control. Cd, Ni, Pb and Cr concentrations increased up to 46, 15.7, 21 and 46% respectively in $treatment_3$ vs. control while this increase for $treatment_4$ was 88, 9.8, 11 and 29.5% respectively vs. control. Cd increase in $treatment_4$ was 28% vs. $treatment_3$. Comparing $treatment_4$ with $treatment_2$, high Cd amount at 45% was noticed in the first vs. the last. Also lead increase in $treatment_3$ was 14.5% vs. $treatment_2$.

In general, Cd, Ni, Pb and Cr accumulation is under allowable limits because they are present in soil at concentration 0.01-2; 5-500; 2-200 and 10-150 mg/kg respectively [25].

The effect of sewage sludge on heavy metals accumulation in the crops: Table 7 shows Cd, Ni, Pb and Cr concentration in plant parts (straw, grains)at harvest. This table shows no effect of sludge on heavy metals concentration in wheat and maize (grains and straw).

For vetch, Cd accumulation has been noticed in plant by increasing sludge application. Cd increased significantly in $treatment_4$ up to 55 and 80% in grains and straw respectively vs. control, while the increase for $treatment_3$ was 19.6 and 134% in grains and straw respectively vs. control. Cd increased significantly in vetch grains in $treatment_4$ up to 43.6% vs. $treatment_2$ and up to 11% in $treatment_3$ vs. $treatment_2$. while this increase for $treatment_4$ was 35% vs. $treatment_3$. Cd increased in vech straw in $treatment_3$ up to 30% vs. $treatment_2$. Generally, Cd accumulation in the tested crops was under allowable limits and its concentration ranged between 0.05-1.2 mg/kg. Also, (7) mentioned that Cd increased in soil and plant by increasing sludge application.

Table 7 shows there is no effect due to sludge application on Ni increase in vetch seeds, while Ni accumulation in straw was noticed with sludge application. Nickel concentration increased in $treatment_3$ up to 113% vs. control, whereas the increase in $treatment_4$ was 100% vs. control. Comparing $treatment_4$ with $treatment_2$ (chemically fertilized one), it has been shown an increase at 88% in Ni concentration in plant of $treatment_4$ as compared to $treatment_2$ and up to 100% in $treatment_3$ compared to $treatment_2$.

In this respect significant increase in Ni in plant by increasing sludge application was noticed [1]. Generally,Ni accumulation in the treated crops was under allowable limits and its concentration ranged between 0-4 mg/kg.

Data in the same table show that Pb increased in $treatment_4$ up to 17 and 37.9% in grains and straw respectively vs. control, while this increase for $treatment_3$ was 16 and 62% in grains and straw respectively vs. control.Pb significantly increased in straw in $treatment_3$ up to 104% vs. $treatment_2$ Lead concentration in the treated crops was under the allowable limits which is peck and ranged between 0.1-30 mg/kg.

Chromium concentration increased in $treatment_3$ up to 15.7% vs. control, while the increase in $treatment_4$ was 9.8% vs. control.

Significant Cr increase in maize roots by increasing sludge application was noticed by [1]. Chromium accumulation in the treated crops was under allowable limits and its concentration ranged between 1-5 mg/kg [25].

Plant productivity: Figure 1-3 show wheat, maize and vetch productivity (grain).

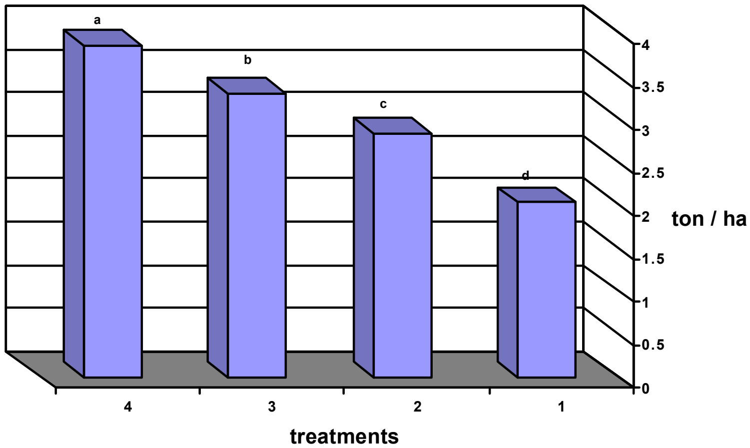

Fig. 1: Wheat productivity ton/ha. $LSD_{0.05} = 0.2$

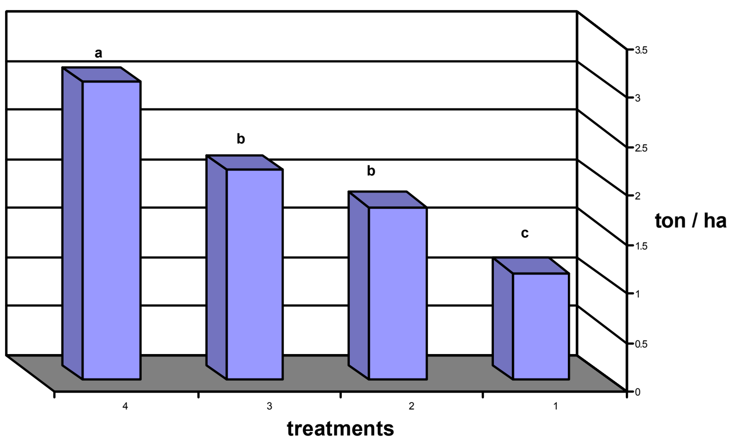

Fig. 2: Maize productivity ton/ha. $LSD_{0.05} = 0.45$

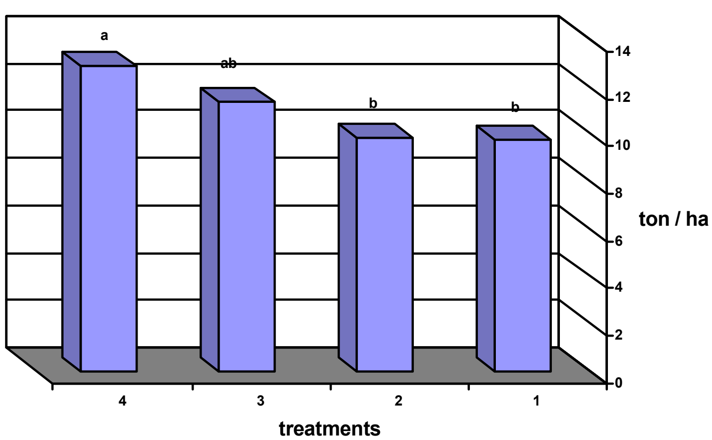

Fig. 3: Vetch productivity ton/ha. $LSD_{0.05} = 1.878$

Figure 1-3 show {significant increases (where is the LSD bar in the figure or present the table which indicates the significance) }that sludge-fertilized wheat, maize and vetch ($treatment_4$) gave the best productivity. The yield of wheat, maize and vetch increased in $treatment_3$ by 62.6, 95 and 16.4% respectively vs. control, while increase in $treatment_4$ was 89.7, 177, 32.3% respectively vs. control.

Increase in production for $treatment_4$ was equal to 16.7, 48 and 16.7% respectively vs. $treatment_3$.

Treatment3 fertilizing with sludge has shown on increase in yield by 16.6, 21 and 16% respectively compared with chemically fertilized treatment. Moreover, comparing $treatment_4$ with chemically fertilized treatment has shown also increase in wheat grains for $treatment_4$ by 36, 71.8 and 31% respectively over $treatment_2$.

Oudeh [17] found that Maize productivity increased by increasing sludge application and Berton *et al.* [26] detected a meaningful increase in the production of dry matter and N, P, Ca, Mg and Zn absorption by maize using higher sludge doses (40 and 80 t/ha of dry matter), meanwhile [5] detected that there was no absorption of lead by maize plants after being cultivated in soil treated twice with sewage sludge contaminated by this metal.

Nevertheless, some studies have shown a high yield after sludge application, because its content of macro/ micronutrients [5, 15] According to Berti *et al*. [27], sludge may be used in agriculture for increasing product yield.

It is well documented that sewage sludge application to soils substantially increases nutrient content and crop growth [29] as well as improves soil physical properties

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