American-Eurasian Journal of Agronomy 12 (3): 64-70, 2019
ISSN 1995-896X

DOI: 10.5829/idosi.aeja.2019.64.70

Maize Yield, Water Productivity and Nitrogen Fertilizer Equivalency Under Fertigation System

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Abstract: Field trials were established to investigate the effect of different manure types (air dried raw sludge, digested sludge and farmyard manure) at 5, 10 and 20 m^3 with or without adjusted N rate (75 kg fd^{-1}) through fertigation on maize yield. Another 5 N fertilizer levels: 0, 45, 75, 90 and 105 fd^{-1} were incorporated in the experiment to asses the response curves and fertilizer equivalency of the organic manures. The results showed that highly significant effects of the soil amendment treatments were apparent for all of the measured yield parameters. As expected, the effects of N fertilizer, manure type and rate on grain yield were all highly significant ($P < 0.001$). Yield of maize was linearly related to applied raw sludge, FYM and inorganic N fertilizer and was evident by simple linear regression models. The N equivalency values of the applied organic manures were estimated from the regression coefficients of the linear models and in relation to inorganic N fertilizer and showed that both digested sludge and FYM apparently gave higher maize yields in relation to the amounts of N supplied in the manures compared with inorganic N fertilizer. These results show that the patterns of N release for crop uptake from sewage sludges and FYM may be better synchronized with crop requirements for N compared with soluble inorganic fertilizer application reducing the potential leaching losses of N in drainage. Successive increases in water productivity were reported as N fertilizer level increased. Application of the highest N level increased water productivity by 236 % compared with the untreated control whereas the same level surpassed the reduced level by 108 %. Only digested sludge at 10 and 20 $m^3 fd^{-1}$ plus the reduced N level (75 kg N fd^{-1}) surpassed the highest N level in water productivity by 20 and 26 %, respectively.

Key words: Fertigation · Maize · N replacement Value · Water Productivity

INTRODUCTION

Poor soils in Egypt are characterized with low fertility and poor moisture retention which demands organic amendments. Since animal manure is no longer readily available, other materials such as sewage sludge should be tested and used to meet soil nutrient and organic matter requirements. Many field studies have been conducted to examine main and interaction effects of irrigation and fertilization on maize productivity around the world [1-6]. The optimum combination of water and fertilizer inputs has been proposed to achieve maximum maize grain yield or to achieve maximum water and fertilizer use efficiency [7-10]. Sludge use in agriculture is widely regarded as the best practicable environmental option but is untested under Egyptian conditions [11]. In this regard, several studies have shown that sewage sludge, by their richness in organic matter, improves the mineral and water statuses of soil and therefore increases crop production [12]. The application of sewage sludge (SS) to agricultural land can improve soil fertility and physical properties and enhance crop production [13]. Recently, sludge application in agriculture has been suggested to be used as eco-friendly fertilizer [14]. Abd El Lateef *et al*. [15] reported that the results of sludge experiments gave confidence that all sludges were quite

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acceptable for agricultural use and the yields of crops fertilized with sludge were consistently equal to and often greater than those obtained by the farmer practice. Moreover, the results have shown that sludge has improved the nutrient content of the crops, including that of the trace elements, which are often deficient in crops and the human diet in Egypt. Increases in the heavy metal content of plants were negligible due to the calcareous soil conditions of Egypt. Cairo produces large quantities of sludge (0.4 million t dry solids y^{-1}) and the preferred management option is beneficial use in agriculture which can be reused practically and safely, particularly on newly reclaimed desert land. In order to increase water use efficiency and to shift to a more sustainable use of water in agriculture, improvement in water use efficiency is required [15]. This aim can be reached by: use of water efficient irrigation systems, appropriate irrigation scheduling, watershed management development, growing drought tolerant crops, dry farming, rotational grazing, use of mulch and compost, cover crops, conservation tillage and organic agriculture.

Drip irrigation can be able to save irrigation water from 30 % up to 50 % in case it is properly designed, installed and operated compared to surface irrigation and it can also enable increasing crop yields and crop quality. It can be recommended to substitute chemical fertilization to provide high productivity of wheat, obtain plant safety and reduce the environmental pollution [16]. Fertigation is basically an agricultural technique and application together with water and fertilizer to soil and/or plants. It increases both yield and fertilizer use efficiency; therefore, leaching of nutrients is prevented [17]. The advantages of drip irrigation could be specified as water saving (30 - 50 %), higher crop yield, maximum utilization of available water, no water being available for weeds, high efficiency in the use of fertilizers, less weed growth, lower labor, no soil erosion, possible sophisticated automatic control, no runoff, no leaching of fertilizers into ground water and less evaporation losses compared to surface irrigation.

The aim of these trials was to evaluate the effect of sludge on maize yield, water productivity and nitrogen Fertilizer Equivalency on calcareous sandy reclaimed desert soil under fertigation system.

MATERIALS AND METHODS

Two field trials were conducted in the summer seasons of 2017 and 2018 to study the effect of different manure types composted sewage sludge application on yield and quality of maize (*Zea mays* L.) as well as the nitrogen fertilizer equivalency of the applied manures in the newly reclaimed desert soils. The chemical analysis of the soil was (pH 8.5; EC 0.24 dsm^{-1}; OM 0.73; N 1400 ppm; P132 ppm; K 826 ppm; Fe 3694 ppm; Mn 56.8 ppm; Zn 17.8 ppm; Cu 3.78 ppm; Cd 0.02 ppm; pb 1.36 ppm; Ni 2.9 ppm). The experiment included 22 treatments which were 5 nitrogen fertilizer levels *i.e.*; 0, 45, 75, 90 and 105 kg fd^{-1} and 3 manure levels *i.e.*; 5, 10 and 20 $m^3 fd^{-1}$ with and without adjusted N fertilizer rate (75 kg N fd^{-1}). The experimental design in the trial was complete randomized block. Maize (*Zea mays* L.), three way hybrid-310 was sown in front of each dripper at 30 cm apart and the distance between the tubes was 80cm. N was applied in split doses at 75 kg N fed through fertigation every 3 days at the assigned levels with P at 22 kg fd^{-1} and K at 24 kg fd^{-1}. Maize yields fd^{-1} were determined from a central area of 10.5 m^2 at each plot. The N equivalency value was estimated by the following equation according to [18].

$$\text{N equivalency (\%)} = \frac{1/b\,(y - a)}{N} \times 100$$

where *a* is the regression intercept value), *b* is the regression coefficient, *y* is the mean root yield recorded for the plots supplied with compost at a rate of 10 $m^3 fd^{-1}$ and *N* is the rate of N application at 10 $m^3 fd^{-1}$ of sludge compost.

Water Productivity: WP seed, is indicator of effectiveness use of irrigation treated waste water for crop production. Water productivity seed was calculated according to [19] as follows:

$$WP_{\text{maize seed}} = Ey/Ir$$

where: WP sunflower seed is the water productivity of crop seed (kg seed. m^{-3}irrigation water), Ey is the economical yield (kg maize seed $fed.^{-1}$) and Ir is the amount of applied irrigation water (m^{-3} irrigation water fed^{-1} $season^{-1}$).

The data were statistically analysed using software package (Cohort 6).

RESULTS AND DISCUSSION

The analysis of variance indicated that highly significant effects of the soil amendment treatments were apparent for all of the measured yield parameters.

Table 1: Results of a three-way ANOVA to assess the effects of manure type and rate and N fertilizer application on grain yield of maize.

Source of variation	Significance level	Source of variation	Significance level
Blocks	ns	Interactions	
Main Effects		Fert x Rate	ns
Fertilizer (Fert)	***	Fert x Type	Ns
Manure rate (Rate)	***	Rate x Type	*
Manure type (Type)	***	Fert x Rate x Type	Ns

Table 2: Effect of different soil amendments on maize yield characters under fertigation system (Combined data of 2017 and 2018 seasons)

Treatment	Plant height (cm)	Ear length (cm)	Grain no. cob^{-1} row	Grain yield $plant^{-1}$ (g)	Stover yield $plant^{-1}$ (g)	Grain yield fd^{-1} (t)	WP kg m^{-3}	%
Control	118	10.8	33	41	71	0.459	0.286	100
45 kg N fd^{-1}	154	16.3	40	70	133	0.812	0.507	177
75 kg N fd^{-1}	166	17.4	41	106	167	1.187	0.740	259
90 kg N fd^{-1}	181	18.8	43	137	183	1.534	0.957	334
105 kg N fd^{-1}	169	22.5	43	150	210	1.680	1.048	366
Raw sludge 5 m^3	147	15.5	41	87	100	0.974	0.608	212
Raw sludge 5 m^3 + F	162	16.9	40	106	158	1.187	0.740	259
Raw sludge 10 m^3	180	21.0	40	101	148	1.126	0.702	245
Raw sludge 10 m^3 + F	187	20.6	43	120	170	1.338	0.835	292
Raw sludge 20 m^3	194	21.3	48	138	285	1.546	0.964	337
Raw sludge 20 m^3 + F	195	23.2	38	144	209	1.607	1.002	350
Digested sludge 5 m^3	194	17.6	32	110	144	1.226	0.765	267
Digested sludge 5 m^3 + F	200	19.5	40	115	201	1.282	0.800	279
Digested sludge 10 m^3	208	19.8	44	127	164	1.422	0.887	310
Digested sludge 10 m^3 + F	208	21.3	45	159	177	1.775	1.107	387
Digested sludge 20 m^3	209	22.6	46	128	189	1.434	0.895	312
Digested sludge 20 m^3 + F	188	23.6	44	161	224	1.803	1.125	393
FYM 5 m^3	166	17.5	41	80	116	0.896	0.559	195
FYM 5 m^3+ F	176	18.7	44	98	148	1.092	0.681	238
FYM 10 m^3	185	21.4	47	108	177	1.204	0.751	262
FYM 10 m^3 + F	185	19.1	46	114	291	1.271	0.793	277
FYM 20 m^3	188	15.8	46	114	174	1.277	0.797	278
FYM 20 m^3 + F	194	21.6	46	139	236	1.557	0.971	339
F probability	<0.001	<0.001	0.004	<0.001	<0.001	<0.001	<0.001	
LSD at 0.05	18	7.9	19	33	125	0.354	0.102	
cv (%)	15.3	17.1	17.3	25.3	31.4	25.0	28.2	

F=75 kg N fd^{-1}

As expected, the effects of N fertilizer, manure type and rate on grain yield were all highly significant ($P < 0.001$) when tested by a three-way ANOVA. Table (1) indicate that the Rate × Type interaction was significant at $P = 0.036$ which was explained by the curvilinear response to the highest rate of digested sludge application compared with raw sludge and FYM, which gave linear increases in grain yield across all of the application rates supplied.

Data presented in Table (2) show highly significant due to organic and inorganic combination under fertigation system. The results show that all digested sludge application rates without or with reduced N application (75 kg N fd^{-1}) resulted in taller maize plants compared with the other treatments and the recommended treatment. However, this trend was not evident for ear characters, ear length and number of grains row^{-1}. From the same table, the data show that there were significant differences among the treatments in their effect on grain yield $plant^{-1}$. Raw sludge at 20 m^3 fed and digested sludge at 10 and 20 m^3 fed^{-1} with or without the adjusted N rate were significantly equal to the recommended fertilizer rate treatment indicating that application of the abovementioned treatments could save about 40 kg inorganic N fertilizer. Similar tendency was recorded for stover yield $plant^{-1}$ where raw sludge at 20 m^3 fd^{-1} raw sludge at 20 m^3 fed and digested sludge at 10 and 20 m^3 fed^{-1} with or without the adjusted N rate were significantly equal to the recommended fertilizer rate treatment and digested sludge at 20 m^3 fed^{-1} with the adjusted N rate were significantly equal to the recommended fertilizer rate treatment. The results of grain

Table 3: Nitrogen fertilizer equivalent ratio of different organic manures under fertigation system.

N source	Regression coefficient (b)	Probability	r^2	N equivalence relative to inorganic N (%) ($b_{orgN} \div b_{inorgN}$ x 100)
Raw sludge	0.0112	<0.001***	0.93	94
Digested sludge[1)]	0.0156	<0.005**	0.89	131
FYM[1)]	0.0265	<0.001***	0.97	223
Inorganic N	0.0119	<0.001***	0.96	

[1)] 10 m^3 fd^{-1} was the maximum rate of application used in estimating the regression coefficients for digested sludge and FYM

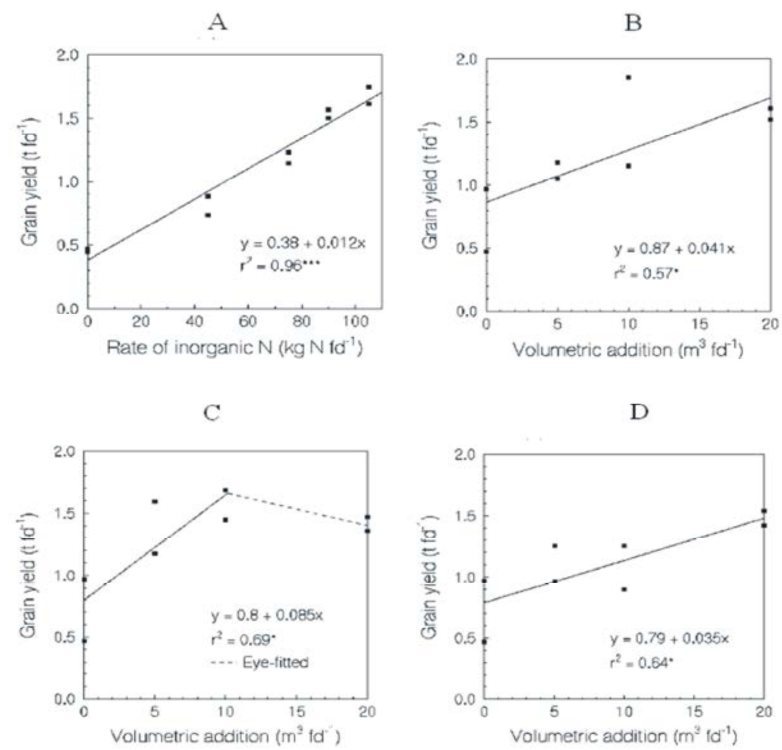

Fig. 1: Relationships between maize grain yield and N application in (a) inorganic N, (b) raw sludge and (c) digested sludge and (d) Farmyard manure.

yield fd^{-1} show significant differences among fertilizer treatment under fertigation system. There were no significant differences between raw sludge at 10 m^3 fd^{-1} combined with the adjusted N rate and either fertilizer rate of 20 m^3 fd^{-1} with or without the reduced N rate (75 kg fd^{-1}) and the recommended fertilizer rate. Similar tendency was reported when digested sludge was applied at 10 and 20 m^3 fd^{-1} with or without the reduced rate of N as well as FYM at 20 m^3 fd^{-1} combined with reduced rate. Mohammad *et al*. [20] reported that wheat grain yield as well as straw yield ton per feddan and consequently biological yield also showed high record as compared with chemical fertilizers. In this respect, Koutroubas *et al*. [21] reported that the application of solid sludge resulted in tall plants with high dry matter than those obtained with chemical fertilizers. Several investigators also showed the enhanced effect of sludge on yield and yield components. In this concern, Ozyazici [22] and Koutroubas *et al*. [21] reported that both straw and grain yield increased with increasing rates of sewage sludge application up to 40 t ha^{-1}.

Nitrogen Fertilizer Equivalency Values: N fertilizer equivalency values for the sewage sludges and FYM are presented in (Table 3). Grain yield of maize was linearly related to applied raw sludge, FYM and inorganic N fertilizer and could be summarized by simple linear regression models. However, maize yield approached a maximum value at a rate of 10 m^3 fd^{-1} of digested sludge with no additional yield benefit at the highest application rate of 20 m^3 fd^{-1}. Consequently, the relationship between maize grain yield rate of applied digested sludge was described using a 'broken-stick' function which combines two linear components explaining the yield increase relationship with increasing rate of addition up to 10 m^3 fd^{-1} and the maximum crop yield plateau (Figure 1c).

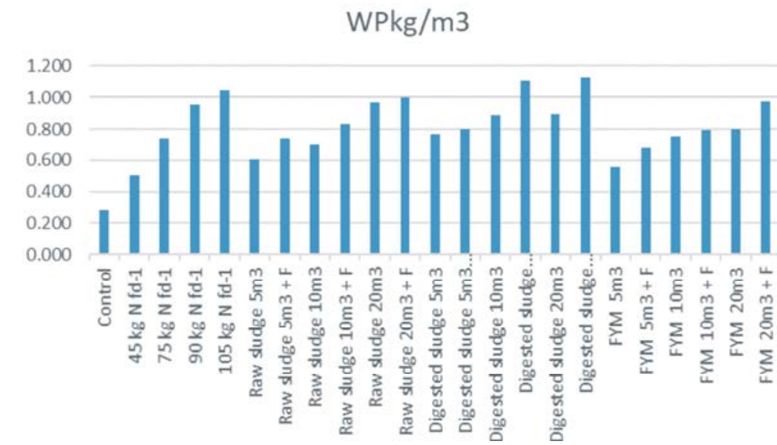

Fig. 2: Effect of different soil amendments on maize water productivity under fertigation system (Combined data of 2017 and 2018 seasons).

The obtained results therefore suggest that the most likely explanations for the high maize yield response to the applied organic materials are that: high leaching losses of soluble N supplied in the inorganic fertilizer reduced the yield response to mineral N whereas the slower release of available N from mineralization of sludge and FYM organic matter was better synchronized to the crop requirement for N. Thus, the organic manures supplied additional growth factors, such as essential trace elements and K, which promoted crop productivity in addition to the beneficial effects of plant available N supply; also the application of organic matter to soil in the manures improved the soil physical environment for root growth and also increased soil water availability to the crop. Similar results of the fertilizer equivalent ratio were obtained on different crops were reported by [23] on cowpea. He reported that organic manures have significant N fertilizer replacement value for cowpea on reclaimed desert soils. Farm yard manure is more effective as a soil amendment at increasing crop yield compared with pant compost product. On the basis of equivalent rates of N application in plant compost, the crop yield response to the Farm yard manure material was 37 % higher compared to the compost product.

Abd El Lateef *et al.* [24] concluded that the clearest picture of N availability for the different manures was obtained for the first crop of the rotation (wheat, winter season). This gave an N equivalency for digested sludge of 50 %. The results also show that the apparent N equivalency of raw and digested sludge increased as the trial progressed associated with the effects of cumulative additions of sludge on soil fertility and crop yields. The N equivalencies estimated for FYM were less consistent than for composted sludges, however, the N equivalency value calculated for FYM was apparently much larger than for sludge with some crops.

Water Productivity: Data presented in Table (3) show significant differences among fertilizer treatments on water productivity (kg m^{-3}) under fertigation system. Successive increases in water productivity were reported as N fertilizer level increased. Application of the highest N level increased water productivity by 236 % compared with the untreated control whereas the same level surpassed the reduced level by 108 %. Only digested sludge at 10 and 20 m^3 fd^{-1} plus the reduced N level (75 kg N fd^{-1}) surpassed the highest N level in water productivity by 20 and 26 %, respectively. However, such increase did not the level of significance.

The increases of water productivity under fertigation system could be attributed to many factors like the healthier plants, quick delivery of nutrients to plant roots, nutrient requirements can be adjusted with immediate effects, uniform distribution and precision application for nutrients, less water use, reduced runoff, increasing fertilizer use efficiency and nutrient availability, saving about 20 - 40 % of fertilizer without affecting growth and yield of crops. Moreover, when using organic manures, fertigation prevents losses of nitrogen due to the fact that there is no leaching, because nutrients are directly supplied to root zone in available forms in the form of portions [17] thus, nutrient concentration in soil solution can be controlled and application cost decreased. Ganat and Somi [25] revealed that fertigation of cotton under the given circumstances improved water use efficiency, nitrogen use efficiency, seed cotton yield, dry matter production, earliness and in some cases lint properties. Under fertigation practices 35 - 55% of the irrigation water was saved in comparison with surface irrigated cotton grown under the same condition. The seed cotton yield was increased by more than 50 % relatively to the surface irrigated cotton. Furthermore, water use efficiency of the fertigated cotton was increased by almost 90 %.

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