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Exploring the Potential Options on Salt Affected Soil Management for Crop Production at North Delta Soils, Egypt

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Authors' contributions

This work was carried out in collaboration between all authors. Author AMSK designed the study, performed the statistical analysis, wrote the protocol and wrote the first draft of the manuscript. Authors MMS and GMAES managed the analyses of the study. Author GMAES managed the literature searches. All authors read and approved the final manuscript.

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ABSTRACT

Two field experiments were carried out at Sakha Agricultural Research Station, Kafr El-Sheikh Governorate in salt affected soils during two summer seasons 2014 and 2015. The study aims at investigating the effect of soil multi-amendments combined with different sources of nitrogen on soil properties, yield and water relations. The experiments were carried out in randomized complete block design with four replicates. The results showed that the application of gypsum combined with ammonia gas and farm manure produced the highest grain and straw yield of rice. While the lowest values were obtained from application of gypsum and ammonia gas. At the same time, the application of gypsum and established mole drain combined with injection of ammonia gas, farm manure and bio fertilizer resulted in pronounced increments for the studied plant growth parameters. Also, the highest value of crop water productivity was obtained from application of gypsum, injection of ammonia gas and farm manure. While the lowest one was obtained with application of gypsum combined with ammonia gas in 2014 season and control in 2015 season. In conclusion with most summarized chart, application of gypsum, construction of mole drain at 4 m spacing and 50 cm depth combined with injection of ammonia gas, farm manure and bio fertilizer achieved the highest yield of rice grain and straw, water productivity and nitrogen use efficiency.

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Keywords: Multi-amendments; water productivity; socio-economic; ammonia gas injection; bio fertilizer.

1. INTRODUCTION

Egypt has a total area of 1,001,450 km^2, with a land area of 995,450 km^2 (100.1 million hectares), the vast majority of which is desert. Egypt has a total population of 83.7 million individuals that is growing at 1.9% per year. About 97% of the population lives on the Nile Valley and the Delta, and this yields an average population density of 1,435 persons per km^2. Fifty-seven percent of the population resides in rural areas, and 29% of the total labor force is agricultural. The Nile Delta includes an agricultural area of approximately 2.268 million ha which corresponds to 60% of Egypt's agricultural land. The highly fertile and productive agricultural land of the Delta is under major threats to its sustainable production. The recycling of agriculture drainage water, a deficient drainage system and inappropriate in-field management of applied water contribute to salt loading of the system that has significant negative effects on its productivity. At the same time, the limited agricultural land in the Nile Valley and Delta is being lost at a rate of nearly 30,000 feddans (1 feddan = 0.42 hectare) per year due to urbanization. Soil degradation due to salinization and agricultural land-loss from desertification is also a challenge. Nearly 809,400 hectares in the North Delta alone have already been lost due to rising groundwater levels, unsound drainage practices, and encroaching sand dunes. As much as 35% of the agricultural lands in Egypt may suffer from salinity. The majority of the salt-affected lands are located in the Lower Delta. Indeed, the current situation is serious and threatens not only agricultural sustainability but also the whole ecological system.

In view of the large areas in the Delta which are salt-affected, and in view of the limited available cultivable areas, it becomes necessary to find out ways and means of utilizing and maintaining this natural resource. These means can be achieved through identifying physical and institutional interventions to improve soil and water management in the Nile Delta using an integrated approach across scales (from farm to main canal levels) and encompassing water quantity–quality interactions.

In arid and semi-arid regions, soil salinity and sodicity are common problems under these conditions, moreover, in these soils, there are increased potentials for hazardous accumulation of salts and the productivity of crops and plants are severely limited under such conditions [1]. Furthermore, salinity restricted agriculture production, particularly rice production, whereas, rice is more suitable crop under such conditions.

Therefore, the improvement process of salt affected soils may be achieved by using different practices such as sub soiling, mole drain, soil amendments, farm manure and bio fertilizer. These previous practices are increasing important tools for improving crop productivity in salt affected soils at North delta. Sodium leaching from the root zone is one of the most common and effective methods for controlling sodium accumulation in salt affected soils [2]. The combined application of multi- amendments improves their effectiveness for increasing soil properties [3].

Mole drain can be considered as intermediate system between surface drainage and sub-surface drainage. Moreover, many researchers have reported on the positive results can be obtained after applying adequate mole drain system especially at heavy clay salt affected soils [4,5,6,7]. Mole drain is widely used on heavy clay soils to improve productivity of pastures and crops [8]. The installations of mole drain at 2 spacing with addition of 110 kg fed^{-1}. gave the highest production of wheat and maize at north delta [9]. In Egypt, improving saline-sodic soils are considered as an important part in the agricultural security program. Thus the application of soil amendments becomes essential. [10] concluded that application of 8 ton gypsum per feddan significantly increased flax yield. [11] stated that the best amelioration processes used in salt affected soils at north delta are the application of gypsum requirements and organic manure addition at the rate of 20 $m^3 fed^{-1}$ to improve dry matter of sorghum crop. [12] revealed that the effectiveness of the soil amendments on soil and crop improvement could be arranged in the descending order, gypsum + fym > sugar lime + fym> gypsum> sugar lime> fym> control.

Azospirillum spp. are considered to be important plant growth promotive rhizobacteria that can improve the growth and yield of many plant species [13]. Neverthless, the mechanism by which *Azospirillum* spp. and other promotive rhizobacteria promote plant growth has yet to be elucidated [14] Phytohormone production [15,16], including gibberellins [17].

Nowadays, it's recognizing the importance of improving soil fertility to ensure efficient crop production. Applying organic manure and gypsum to a clayey soil are an important practice in sustaining soil fertility and agricultural productivity [18,19]. [20] stated that the application of farm yard manure showed significant increases in available P and K content of the soil. The bio fertilizers in many plants have been established, which effectively supplement the need of nitrogen and reduce the cost of production and environmental pollution via reducing the rates of mineral-N fertilizers used [21]. Several researchers reported that the inoculation of some plants with biofertilizers (Singly combinations with mineral fertilizers) improved plant growth, yield and chemical composition [22,23].

Tantawy et al. [24] showed that the plant height, number of spikes, spike length and the yield of straw and grains were increased significantly with the increase of add N. The unfavorable conditions as well as inadequate and imbalance use of plant nutrients in salt affected soils cause a considerable decline in paddy yield [25]. No doubt soil salinity alters the uptake of nutrients by plants but the use of fertilizers alleviates to some extent the detrimental effects of moderate salinity and help to improve the economic yield of crops.

Anhydrous ammonia, NH_3 is one of the most efficient and widely used sources of nitrogen for plant growth. The advantages of ammonia relatively easy application and ready availability have led to its increased use as a fertilizer. [26] concluded that injected ammonia gas at level (102 kg acre^{-1}) gave the highest root, sugar and top yields compared with other levels under study (0, 45 and 75 kg acre^{-1}) as well as N, P, K and Na content than urea fertilizer. [27] compared ammonia gas with urea, they found that the first ammonia gas progressed than urea for root yield and gave maximum root yield.

Based on the abovementioned information, we planned a short term study to investigate the effect of multi-amendments application on soil properties, rice yield, some water relations and nitrogen use efficiency in the salt affected soils at North Delta, Kafr El-Sheikh Governorate. Therefore, the main objective of this study is to manage the salt affected soil and improve its productivity using different types of amendments.

2. MATERIALS AND METHODS

Two field experiments were carried out during the summer seasons of 2014 and 2015 at Sakha Agricultural Research Station (Hosha 18, El-Hamrawy farm) in North Delta , kafr El-Sheikh Governorate). The experimental area is 4.2 acres (1.8 ha) and located at 31 05 13.8 Latitude and 30 56 10.6 Longitude (Fig. 1).

Before cultivation of rice, soil samples were collected and some physical and chemical properties were determined according to [28] and the data are presented in Tables (1 and 2).

Rice variety Giza 177 and 178 were planted by drill and transplanting methods in the first season and second season respectively, which grow in salt affected soils under flooded paddy. The date of cultivation on June 19 and 25 in the first and second seasons while, the date of harvesting on the end of October 2014and 2015.

Table 1. Mean physical properties of the studied soil before conducting the experiment

Soil depth cm	Particle size distribution %			Texture	Bulk density Mg m^{-3}	Total porosity %	Soil moisture contents %		
	Sand	Silt	clay				FC	PWP	AW
0-15	17.7	27.1	55.1	Clayey	1.27	52.0	45.66	24.27	21.34
15-30	18.4	28.3	53.3	Clayey	1.35	48.91	44.17	22.92	21.25
30-45	18.5	29.4	52.1	Clayey	1.37	48.34	34.42	21.42	18.0
45-60	20.2	30.3	49.5	Clayey	1.39	47.74	37.17	21.26	15.91

Table 2. Mean chemical properties of the studied soil before conducting the experiment

Soil depth cm	pH 1:2.5 soil water- susp	Ec ds m^{-1}	Soluble cations meq l^{-1}				Soluble anions meq l^{-1}				SAR
			Ca^{2+}	Mg^{2+}	Na^{+}	K^{+}	CO_3^{2-}	HCO_3^{-}	Cl^{-}	SO_4^{2-}	
0-15	8.76	7.02	14.7	8.4	47.7	0.67	-	7.28	33.37	30.87	17.17
15-30	8.8	8.55	17.92	10.27	58.05	0.82	-	5.1	40.65	41.31	18.92
30-45	8.94	6.07	12.75	7.28	41.25	0.6	-	4.43	28.87	28.58	15.93
mean	8.83	7.21	15.12	8.65	49.0	0.7	-	5.6	34.3	33.57	17.34

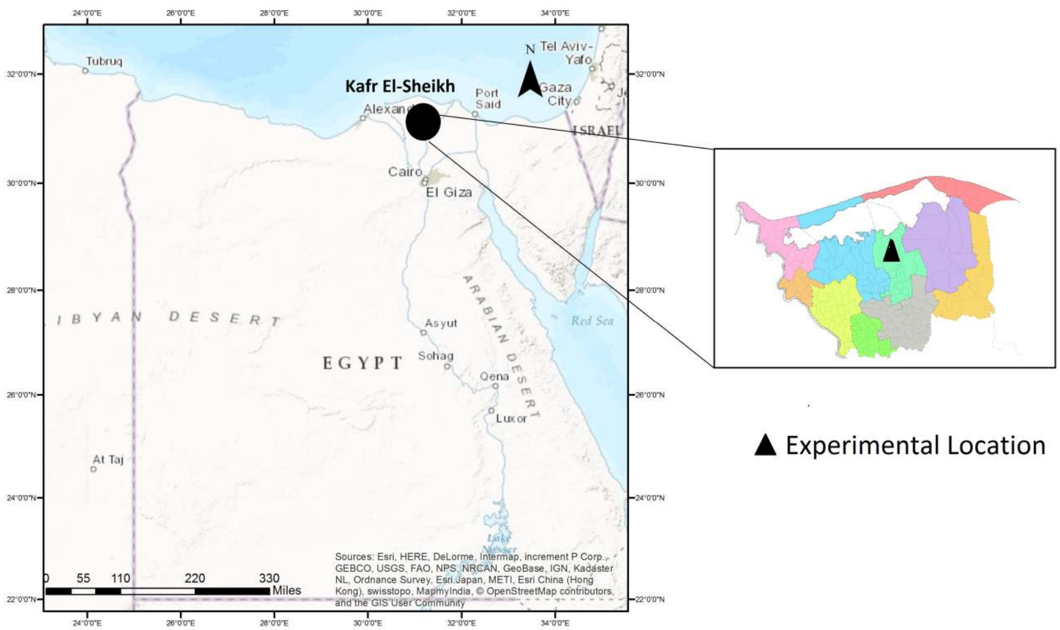

Fig. 1. The map of Egypt which shows the study location

Before transplanting, some plots were plowed, mole drain was established at 4 m spacing at 50 cm depth and gypsum required was incorporated with soil surface. Also, all experimental area was leveled by laser land leveling.

All plots were fertilized by ordinary superphosphate (15.5 % P_2O_5) at a rate of 100 kg acre^{-1} and received nitrogen fertilizer in different forms at a rate of 70 kgN acre^{-1}.

All agricultural practices were carried out as recommended by Ministry of Agriculture. The design of experiment is randomized complete block design with four replications**.**

The treatments were as follows:

1. Control, fertilized by urea (C+U).
2. Gypsum + ammonia gas (G +Ag).
3. Gypsum + biofertilizer, Azospirilium brasilense (NO40) + urea (G+B+U).
4. Gypsum + ammonium sulphate (G+As).
5. Gypsum + urea (G + U).
6. Gypsum + farm manure + ammonia gas (G + F + Ag)
7. Gypsum + mole drain + ammonia gas + farm manure + biofertilizer (G+M +Ag +F + B).
8. Gypsum + mole drain + ammonia gas (G + M + Ag).
9. Gypsum + mole drain + urea (G + M +U).
10. Mole drain + urea (M + U).

The rice plants were removed and separated into grain and straw to measure the following: grain and straw (ton/ha), 1000 grain weight (g), plant height (cm), No of grains in panicle and panicle length (cm) were measured.

2.1 Irrigation Water Applied

Amounts of irrigation water applied were measured using a weir installed in the main irrigation canal. Applied water was calculated according to equation 1 [29]:

$$Q = 1.84\,L\,(\mathrm{H})\hat{}1.5 \qquad (1)$$

where: Q is the amount of water applied (m^3/s), L is the weir's width, and H is the head above the weir.

Irrigation water productivity (IWP) was also calculated according to the following equation:

$$\text{IWP} = \text{Yield (kg)/ Applied water (m}^3\text{)} \qquad (2)$$

Plant materials were oven dried at 70 C° for 24 hours and ground at a fine powder and kept for determination of nitrogen, phosphorus and potassium. The uptake of nutrients (N, P and K) by grain and straw of rice was calculated by multiplying element concentration by yield.

Nitrogen use efficiency (NUE) was calculated according to the following formula:

$$NUE = \frac{\text{Grain Yield (kg/ha)}}{\text{Applied N fertilizer (kg/ha)}} \quad (3)$$

3. RESULTS AND DISCUSSION

3.1 Soil Properties Subjected to Different Treatments

Results in Fig. 2 show the values of soil bulk density and total porosity at different soil layers as affected by soil amendments. The results indicated that, application of soil management practices, i.e. gypsum and mole drain combined with injection of ammonia gas, farm manure and bio-fertilizer decreased the value of bulk density and increased the total porosity compared to control treatment. On the other hand, application of gypsum and installation of mole drain without application of organic fertilizers led to increasing bulk density and decreasing the total porosity.

Infiltration rate and cumulative infiltrated depth as affected by different soil amendments are presented in Figs. (3 to 7). It can be noticed that under soil management practices including application of gypsum and mole drain combined with ammonia gas, farm manure and bio-fertilizer, the values of basic infiltration rate and cumulative infiltration depth after harvesting rice are higher than that obtained before cultivation. It is worthy to mention that under salt affected soils the excess salts keep the clay in saline soils in a flocculated state so that these soils generally have good physical properties. Soil structure is generally good and tillage characteristics and permeability to water are even better than those of non-saline soils. However, as soil salts are leached with a low saline water, some saline soils tend to disperse resulting in low permeability to water and air, particularly when soils are heavy clays.

Results presented in Fig. 8 shows soil salinity (dS m^{-1}) and sodicity (SAR) values as affected by soil amendment treatments. Results indicated that the lowest EC and SAR values were recorded under the control treatment followed by the application of gypsum + Ammonia gas injection for EC and applying gypsum + biofertilizer + urea for the SAR.

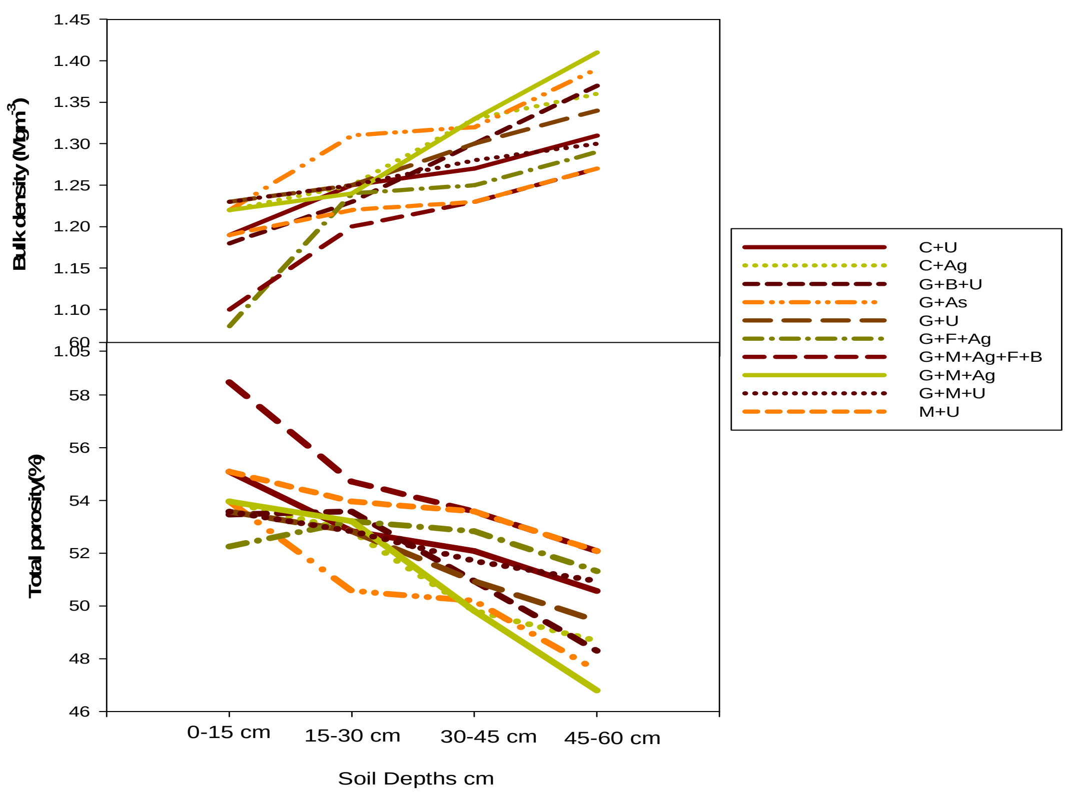

Fig. 2. Soil bulk density and total porosity after rice cultivation in response to soil amendments

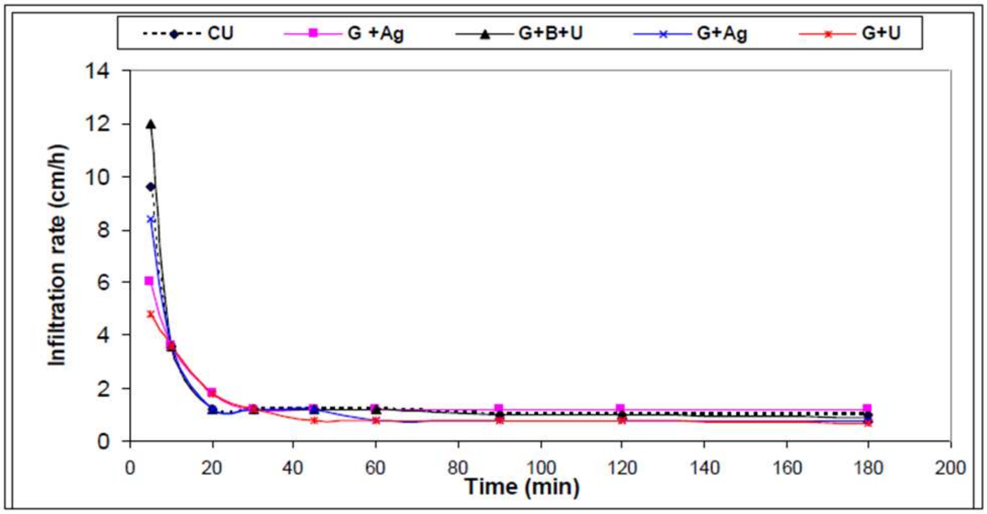

Fig. 3. Infiltration rate as affected by some soil amendment treatments

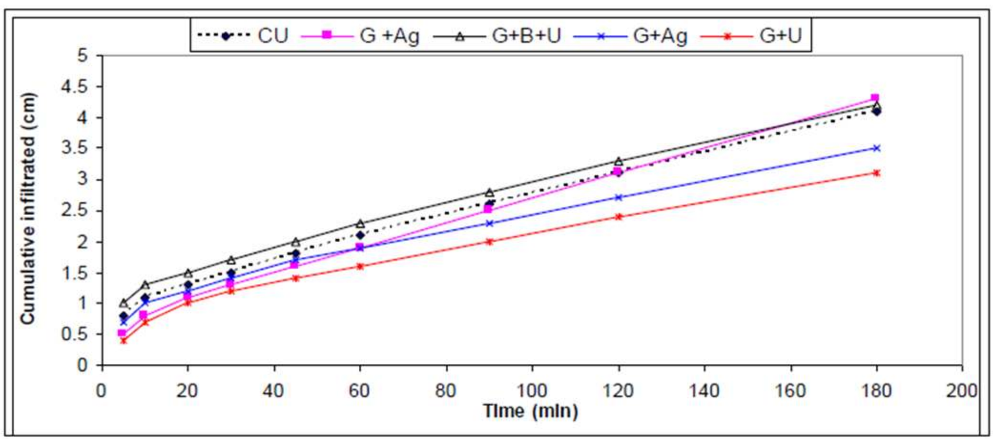

Fig. 4. Cumulative infiltration as affected by some soil amendment treatments

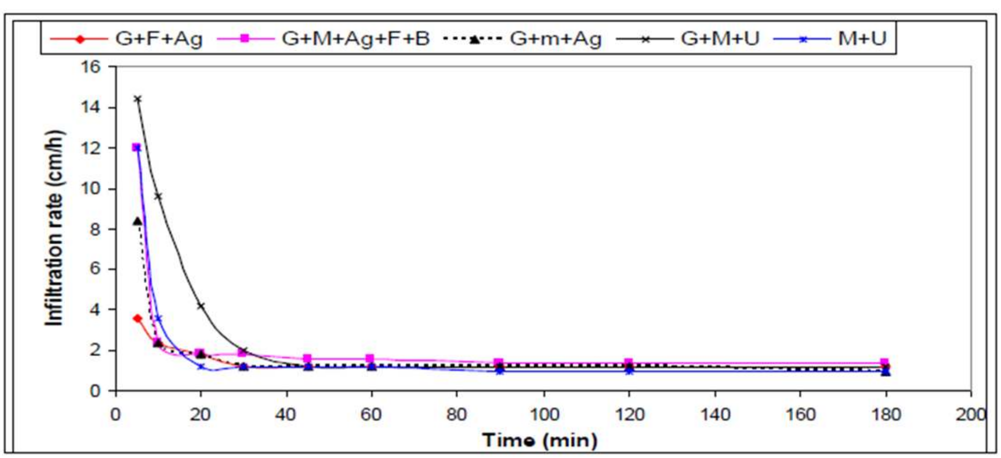

Fig. 5. Infiltration rate as affected by some soil amendment treatments

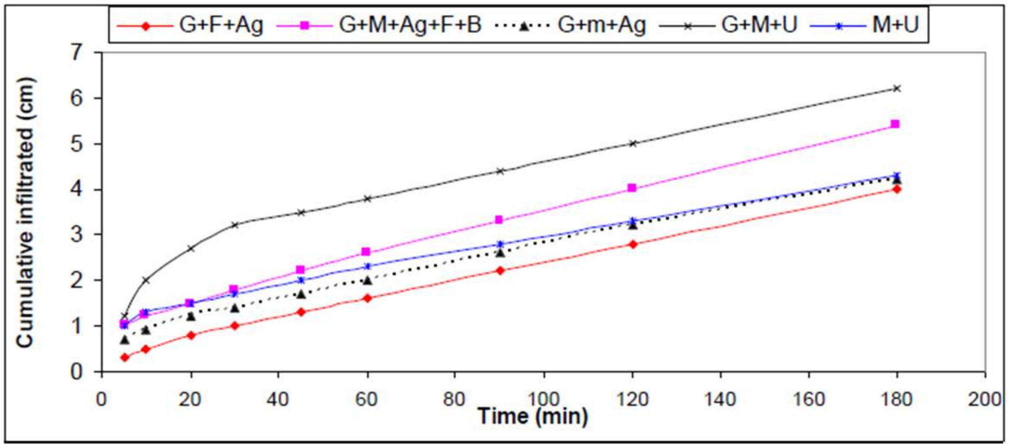

Fig. 6. Cumulative infiltration as affected by some soil amendment treatments

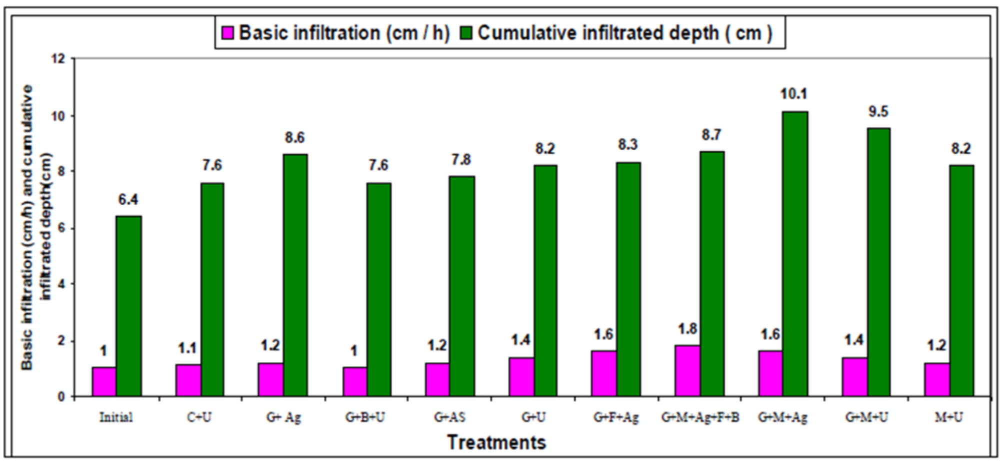

Fig. 7. Effect of tested variables on basic infiltration rate and cumulative infiltration

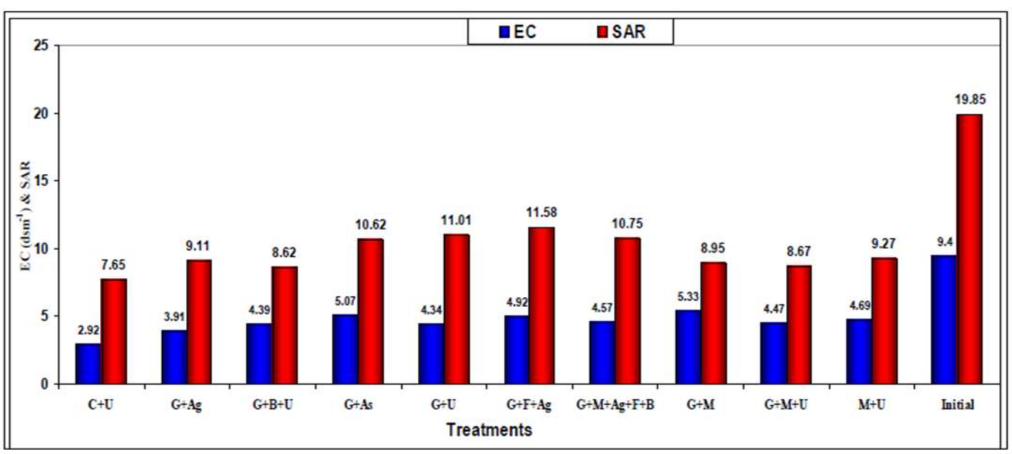

Fig. 8. Soil salinity and sodicity values as affected by tested variables

3.2 Effect of Different Soil Amendments on Rice Yield and Yield Attributes

The effect of soil amendments on grain and straw yields of rice are given in Table 3 and Fig. 9. Data indicated that application of gypsum combined with farm manure and injection of ammonia gas had advantageous in the salt affected soils at the North Delta. Data revealed that there was significant effect due to application of soil amendments on grain and straw yield of rice in the first and second seasons respectively.

Where application of gypsum combined with farm manure and injection of ammonia gas produced the highest values of grain yield of rice (6.81 and 8.44 ton ha^{-1}) and straw yield (9.42 and 11.14 ton ha^{-1}) in the first and second seasons respectively followed by addition of gypsum, established of mole drain at 4 m spacing with farm manure and ammonia gas in both seasons .Whereas, the lowest values were obtained from application of gypsum and ammonia gas in the first season and control treatment in the second season. The decrease in rice yield may be due to variation in soil salinity along the studied area since rice plants are very sensitive to salinity in the seedlings stage.

It is worthy to mention that the increment of rice yield due to application of gypsum , ammonia gas and farm manure may be attributed to significant increases in available P and K content , which had a higher positive effect on microbial biomass , and soil health [30].

Also, these findings are in line with [31] who found that maize yield showed a significant effect under the applied ammonia gas levels in combination with micronutrients mixture treatments as foliar method which had superiority than the other treatments and methods. It can be concluded that the application of gypsum requirement, established mole drain at 4 m spacing combined with farm manure, ammonia gas and bio fertilizer enhanced the productivity of salt affected soils at North Delta.

Data of growth parameters like plant height, No. of grains in panicle, panicle length and 1000 grain weight as affected by different soil amendments are presented in Tables (4 and 5).

Table 3. Rice grain and straw yields (ton ha^{-1}) as affected by different soil amendments in 2014 and 2015 growing seasons

Treatments	Rice yield in 2014 season		Rice yield in 2015 season	
	Grain	Straw	Grain	Straw
C+U	5.12 cd	8.59 ab	6.61 f	8.85 c
G+Ag	3.59 g	6.76 c	6.93 cde	10.0 c
G+B+U	5.28 c	8.35 b	7.0 c	9.9 c
G+AS	4.93 de	8.21 b	6.78 c	10.02 c
G+U	4.64 e	8.43 b	6.82 d	9.33 d
G+F+Ag	6.81 a	8.26 b	8.44 a	11.14 a
G+M+Ag+F+B	5.78 b	9.42 a	7.31 b	10.31 b
G+M+Ag	4.19 f	7.26 c	6.96 cd	9.5 d
G+M+U	4.83 de	8.66 b	7.38 b	10.12 bc
M+U	5.07 cd	8.38 b	7.43 b	9.92 c

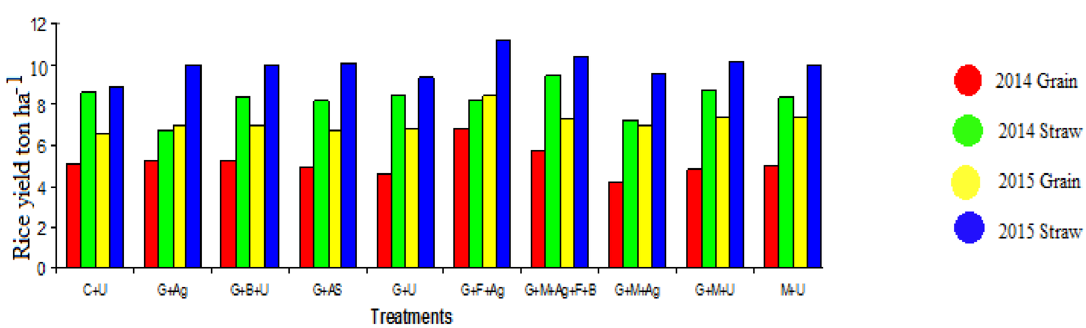

Fig. 9. Rice grain and straw yield as affected by different soil amendments in 2014 and 2015 growing season

The application of gypsum and established of mole drain at 4m spacing combined with injection of ammonia gas, farm manure and bio fertilizer resulted in pronounced increments for the studied growth parameters. The increment of some rice growth parameters is mainly due to power supply of nitrogen from organic sources, moreover the application of such bio-organic manure is not only considered an important storehouse for essential macro and micronutrients of plants but also plays a vital important role for improving soil physical, chemical and biological characteristics.

3.3 Water Relations in Response of Different Amendments Applications

The amount of water applied as affected by different soil amendments are presented in Table 6 and Fig. 10. The obtained data cleared that the amount of water applied to rice crop ranged from 9635.91 to 11063.2 m^3 ha^{-1} in the first season and from 10651.6 to 13501.7 m^3 ha^{-1} in the second season.

It is obvious that the control treatment without addition of soil amendments had the highest amount of water applied in both seasons. On the other hand, the application of gypsum requirement combined with ammonia gas received the lowest amount of water applied in the first season. While the application of gypsum combined with bio fertilizer and urea had the lowest value of water applied in the second season.

It was noticed that the application of gypsum and ammonia gas under precision land leveling saved irrigation water by 12.9 % in the first season while the application of gypsum combined with bio fertilizer and urea saved water by 21.1 % in the second season compared to control. It is worthy to mention that the water saving could be used for irrigating more crops and for horizontal expansion in agriculture.

Irrigation water productivity can be a very broad concept expressing the beneficial output per unit of water input. Increasing irrigation water productivity can significantly reduce the total amount of water will need in the future to produce food.

The application of gypsum in combined with farm manure and ammonia gas resulted in the higher water productivity for rice grain (0.64 and 0.7 kg m^{-3} of water applied) in the first and second seasons respectively and the lowest values were recorded for the application of gypsum and ammonia gas and control in the first and second seasons respectively (Table 7 and Fig. 11).

Concerning the irrigation water productivity for rice straw, data revealed that the highest values were obtained from application of gypsum, mole drain, ammonia gas, farm manure and bio fertilizer in the first season, while in the second season, the application of gypsum with farm manure and ammonia gas achieved the highest value.

3.4 Macro Nutrient Uptake (kg ha^{-1}) by Rice Crop in Response to Different Treatments

Data of nutrients uptake (N, P and K) in rice as affected by different soil amendments combined with different nitrogen sources are given in Fig. 12. Values indicated that there were marked increases in the uptake of N, P and K by grains of rice with application of gypsum, farm manure and ammonia gas followed by application of gypsum, established mole drain at 4 m spacing, bio fertilizer, ammonia gas and farm manure in the two seasons of study.

Table 4. Growth parameters of rice as affected by different soil amendments in 2014 growing season

Treatments	2014 growing season			
	Plant height (cm)	No. of grains in panicle	Panicle length	1000 grain weight
C+U	81 be	50.95 g	18.5 e	26.7 de
G+Ag	76.8 e	60.55 e	21 cd	28.45 abc
G+B+U	85 be	58.1 f	17.5 e	27.53 cd
G+As	83 be	61.75 de	24 b	28.71 abc
G+U	78.3 de	65.3 c	18 e	25.71 e
G+F+Ag	84.8 ab	69.15 b	20.5 d	29.25 ab
G+M+B+Ag+F	88 a	75.53 a	25.5 a	29.65 a
G+M+Ag	79 cde	62.75 d	21 cd	27.88 bcd
G+M+U	81.8 bcd	74 a	22 c	27.85 bcd
M+U	78 de	51.55 g	22 c	28.48 abc

Table 5. Growth parameters of rice as affected by different soil amendments in 2015 growing season

Treatments	2015 growing season			
	Plant height(cm)	**No. of grains in panicle**	**Panicle length**	**1000 grain weight**
C+U	77.88 b	61.05 i	24.5 bc	39.95 a
G+Ag	77.25 b	70.6	24.5 bc	39.6 a
G+B+U	74.75 b	68.15 g	25.25 bc	41 a
G+As	77.38 b	71.85 e	24.5 bc	41.33 a
G+U	72.75 b	75.26 d	21.13 d	38.65 a
G+F+Ag	88.88 a	79.15 c	28.63 a	39.65 a
G+M+B+Ag+F	77.25b	85.68 a	27 ab	40.9 a
G+M+Ag	75.75 b	72.8 e	23 cd	39.9 a
G+M+U	78.75 b	84.05 b	24.88 bc	39.75 a
M+U	77.5 b	64.6 h	26.5 ab	40.15 a

On the other hand, the effective role of application gypsum combined with mole drain, bio fertilizer, ammonia gas and farm manure was almost superior of total N, Pand K uptake than the other treatments and control. These results may be attributed to when oxygen evolved in water by photosynthetic activity of the algae provide an aerobic condition for the growth of the root system of rice plants, and consequently produces more numerous root hairs proportionally increased their absorptive surface that improved nutrients uptake.

Table 6. Amount of water applied to rice crop during 2014 and 2015 growing seasons

Treatments	2014 growing season		2015 growing season	
	Water applied (m^3 ha^{-1})	**Water saving %**	**Water applied (m^3 ha^{-1})**	**Water saving %**
C+U	11063.2	-	13501.7	-
G+Ag	9635.91	12.9	10929.1	19.05
G+B+U	9859.9	10.88	10651.6	21.11
G+Ag	9984.1	9.75	11317.6	16.18
G+U	9916.3	10.37	11388.4	15.65
G+F+Ag	10216.4	7.65	12033.6	10.87
G+M+Ag+F+B	10659.1	3.65	12427.1	7.96
G+M+Ag	10316.6	6.75	11851.6	12.22
G+M+U	10356.8	6.39	12263.5	9.17
M+U	10189.3	7.9	11497.6	14.84

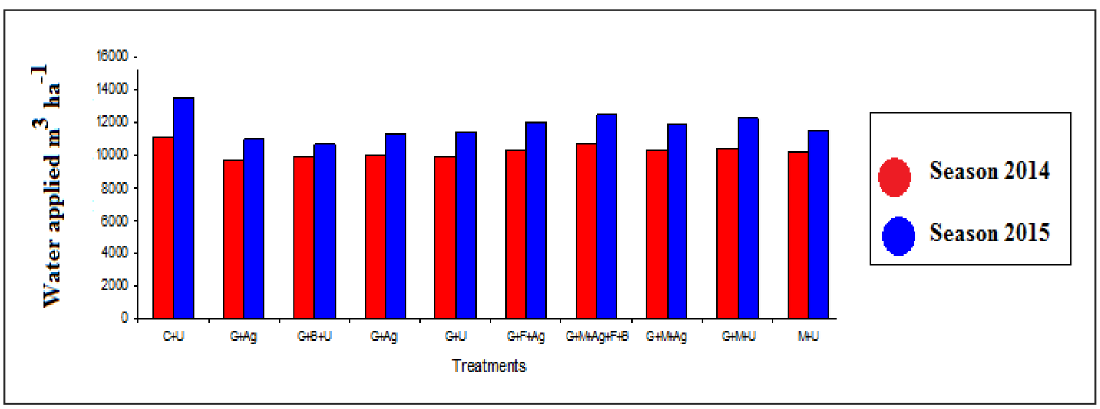

Fig. 10. Amount of water applied to rice crop during 2014 and 2015 growing seasons

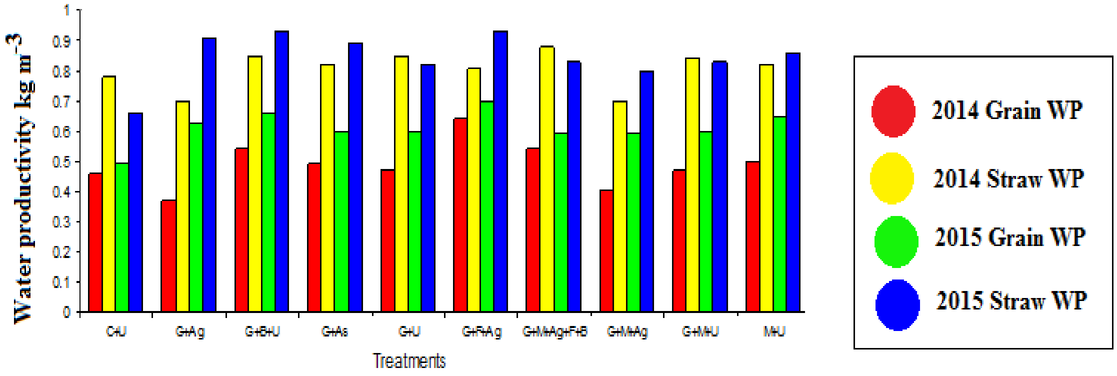

Fig. 11. Irrigation water productivity by rice as affected by different soil amendments through 2014 and 2015 growing seasons

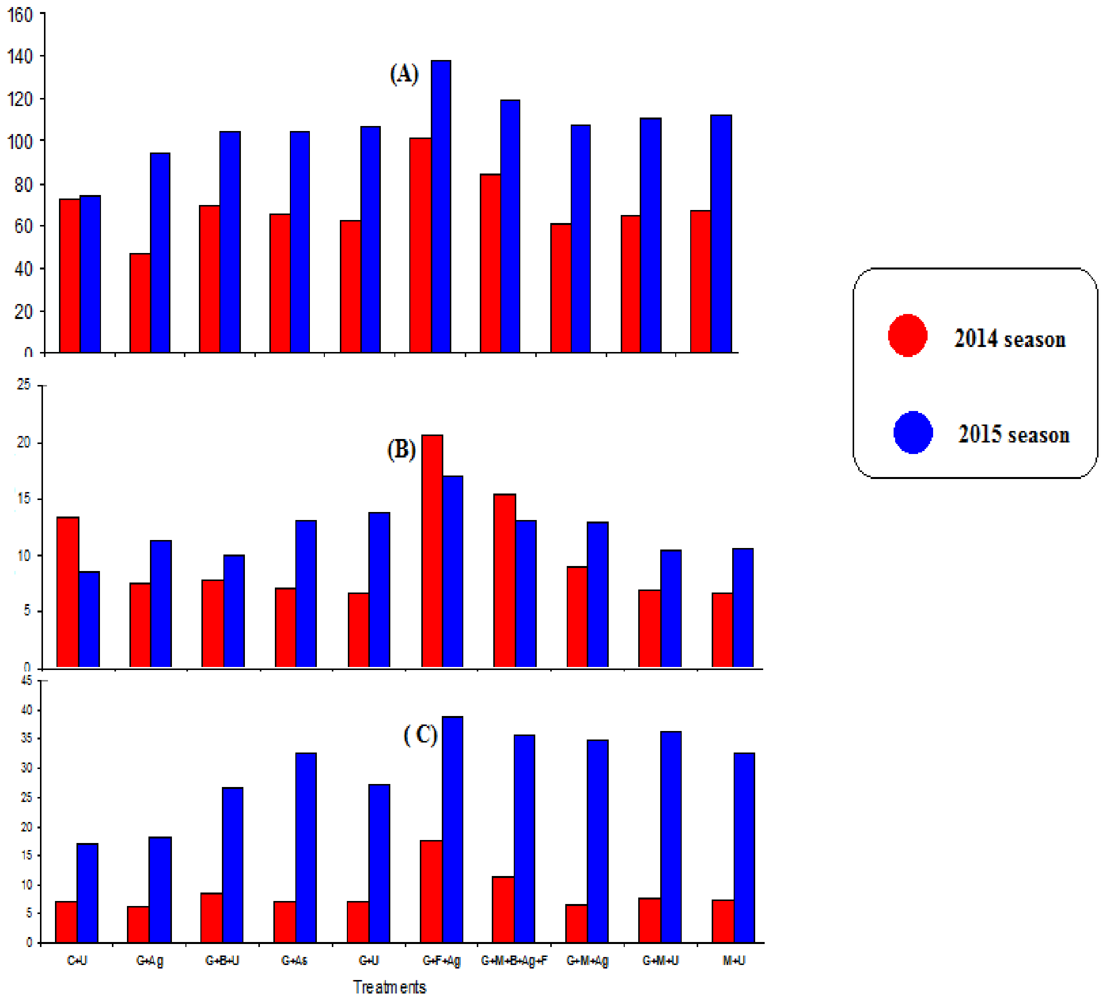

Fig. 12. N (A), P (B) and K (C) uptake kg ha-1 by rice grains as affected by different soil amendments in 2014 and 2015 growing seasons

These findings are confirmed by many investigators which reported that the combination of organic and inorganic N resulted in greater N uptake than those obtained when each was applied singly.

In this concern, [32] reported that when the anhydrous ammonia injected before sowing, gave higher yield and mineral uptake than other nitrogen sources.

Table 7. Irrigation water productivity (kg m^{-3}) for rice crop as affected by different soil amendments in 2014 and 2015 growing seasons

Treatments	2014 growing season		2015 growing season	
	Grain	Straw	Grain	Straw
C+U	0.46	0.78	0.49	0.66
G+Ag	0.37	0.7	0.63	0.91
G+B+U	0.54	0.85	0.66	0.93
G+As	0.49	0.82	0.6	0.89
G+U	0.47	0.85	0.6	0.82
G+F+Ag	0.64	0.81	0.7	0.93
G+M+Ag+F+B	0.54	0.88	0.59	0.83
G+M+Ag	0.41	0.7	0.59	0.8
G+M+U	0.47	0.84	0.6	0.83
M+U	0.5	0.82	0.65	0.86

3.5 Nitrogen Use Efficiency Subjected to Different Soil Amendments Application

Nitrogen use efficiency was defined as the amount of harvested crop that was produced per unit of nitrogen supplied during the two growing seasons. The effect of different soil amendments on nitrogen use efficiency are listed in Fig 13. Nitrogen use efficiency in terms of productivity factor clearly showed that the application of gypsum requirement combined with farm manure and ammonia gas achieved the highest value of nitrogen use efficiency followed by construction of mole drain combined with application of urea in both seasons.

The higher nitrogen use efficiency was occurred due to the applied organic and inorganic fertilizer might be due to lower nitrogen losses.

3.6 Economic Evaluation Studies

Results in Table 8 and Fig. 14 show the rice productivity (ton ha^{-1}), total income (LE ha^{-1}), net profit (LE ha^{-1}), water applied (m^{3} ha^{-1}), water productivity (LE m^{-3}) and economic efficiency values as affected by different soil amendment treatments during the 2015 summer season. Results indicated that the maximum total income (LE ha^{-1}), net profit (LE ha^{-1}) and water applied (m^{3} ha^{-1}), water productivity (LE m^{-3}) and economic efficiency were obtained with the application of gypsum, farm manure and ammonia gas followed by the construction of mole drain combined with urea application. On the other hand, the lowest total income and water productivity values were recorded with control treatment.

It can be concluded that application of gypsum, construction of mole drain at 4 m spacing and farm yard manure are effective practices for improving salt affected soils and improving the farm income at North Delta region.

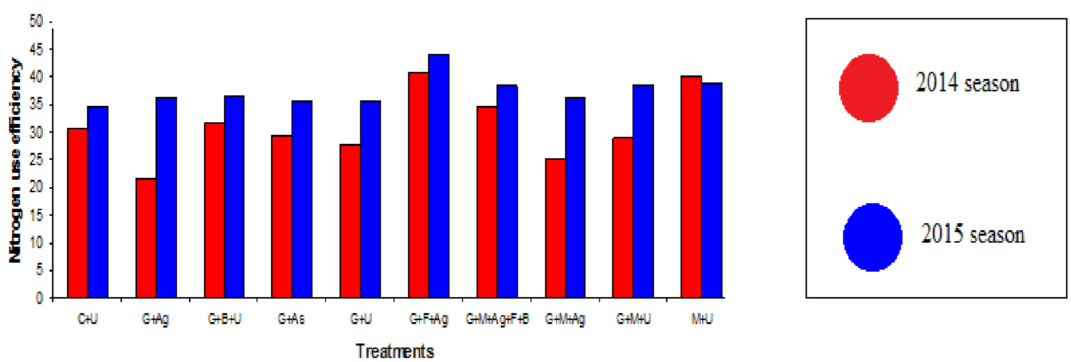

Fig. 13. Nitrogen use efficiency for rice crop as affected by different soil amendments in 2014 and 2015 growing seasons

Table 8. Rice productivity (ton ha^{-1}), total income (LE ha^{-1}), net profit (LE ha^{-1}), water applied (m^3 ha^{-1}), water productivity (LE m^{-3}) and economic efficiency as affected by different soil amendments during 2015 summer season

Treatments	Rice productivity (ton ha^{-1})	Total income (LE ha^{-1})	Variable cost (LE ha^{-1})	Fixed cost (LE ha^{-1})	Total cost (LE ha^{-1})	Net profit (LE ha^{-1})	Water applied (m^3 ha^{-1})	Water productivity (LE m^3)	Economic efficiency
C+U	6.61	13229	6583.5	3571.5	10155	3073.84	13501.7	0.23	0.3
G+Ag	6.93	13857	6333.5	3571.5	9905	3952.42	10929.1	0.36	0.4
G+B+U	7.0	14000	6619.2	3571.5	10190.7	3809.3	10651.58	0.36	0.37
G+As	6.78	13560	7345.4	3571.5	10916.7	2643.1	11317.57	0.23	0.24
G+U	6.82	13640	6583.5	3571.5	10155	3485	11388.4	0.31	0.34
G+F+Ag	8.44	16880	6571.6	3571.5	10143.1	6736.9	12033.59	0.56	0.66
G+F+M+B+Ag	7.31	14620	6607.3	3571.5	10178.8	4441.2	12427.1	0.36	0.44
G+M+Ag	6.96	13920	6333.5	3571.5	9905	4015	11851.6	0.34	0.41
G+M+U	7.38	14760	6583.5	3571.5	10155	4605	12263.5	0.38	0.45
M+U	7.43	14860	6583.5	3571.5	10155	4705	11497.6	0.41	0.46

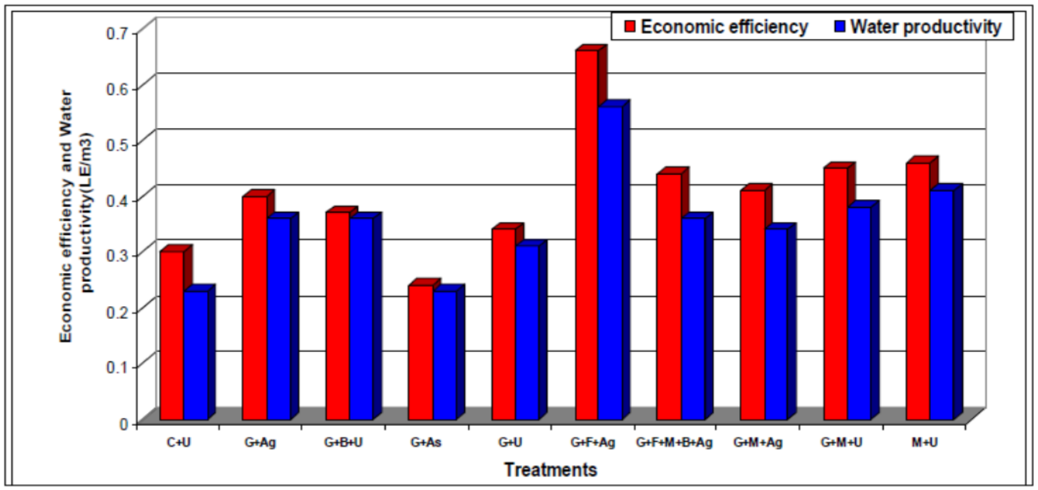

Fig. 14. Economic efficiency and water productivity of rice crop as affected by tested treatments

4. CONCLUSION

The following findings could be summarized as follows:

- Either application of gypsum interacted with farm manure and ammonia gas or application of gypsum and construction of mole drain at 4m spacing interacted with bio fertilizer, farm manure and ammonia gas achieved the highest values of grain and straw yield of rice.
- Application of gypsum combined with ammonia gas and farm manure resulted in increasing the uptake of macronutrients in grain and straw of rice followed by gypsum, construction of mole drain at 4m spacing combined with ammonia gas, farm manure and bio fertilizer.
- The highest value of water applied was recorded with untreated treatment fertilized by urea. While the lowest value was obtained with application of gypsum and injection by ammonia gas.
- The highest value of irrigation water productivity for rice was achieved with application of gypsum, construction of mole drain at 4 m spacing combined with ammonia gas, bio fertilizer and farm manure.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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