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How Does Organic Amendment and NPK Fertilization Improve Forage Yield of Cereals under Salinity and Arid Conditions?: Case of Moroccan Sahara †

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Abstract: The experiment on effect of organic amendment and NPK fertilizer of forage yield of cereals using saline water irrigation (12.4 dS/m) was conducted in Es-Smara province in the South of Morocco during 2020–2021. We found that organic amendments have a great positive impact on increasing forage yield of selected cereals grown under salinity conditions. Compared to the control, the application of amendments improved dry biomass yield by 55, 101, 126%, through the application of compost, sheep manure, and NPK, respectively. The highest increment in dry matter productivity was through the combined application of organic amendment and NPK fertilization: clearly showed that a judicious combined application could improve forage supply in the salt-affected irrigated drylands.

Keywords: salinity; aridity; amendments; cereals; forage

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1. Introduction

The Southern region of Morocco is mostly the Desert which covers more than 317,000 km^2 area. Water scarcity, drought, high temperatures, poor soil health are significantly affecting the region and causing land degradation and desertification [1]. Moreover, with a groundwater salinity exceeding 2 g/L [2] combined with poor irrigation water quality leading to an increase of salts accumulation in the surface horizons, and therefore, a decrease in agricultural production. In the Sahara region of Morocco forage production is highly insufficient and most of the supply meets through transport (>1500 km) from the North at a very high price. Low production, high cost of transport, and poor supply are putting significant pressure to increase the supply through improving local production.

In the Sahara region, cereals are an essential source of energy for animal diets and have been used as grain, hay, silage, or for grazing. In the region, opportunity to increase forage production from cereal crops such as wheat, barley, triticale exists and several agronomic practices have been recommended to improve the production of those crops in salt-affected, saline, and low fertile lands. Among them, application of organic amendments could be a key factor in long-term for improving forage supply alleviating the problem of soil salinization through improving physical, chemical, and biological properties of soils [3]. Thus, the objective of this study was to investigate the effect of different organic amendments and mineral fertilizers to find out the best combination for improving forage supply with improving soil quality (reducing soil salinity and improving fertility) in the Southern region of Morocco.

2. Materials and Methods

2.1. Site Characteristics

On-farm experiment was conducted in Es-smara province, Morocco (Longitude = 12°07′22′′ W; Latitude = 26°32′43′′ N; Altitude = 313 m) during 2020–2021. The soil of the experimental site was a sandy loam with an electrical conductivity (ECe) of >10 dS/m. Soil analysis showed that the contents of major elements are 0.03% for total nitrogen and 28, and 408 ppm for P_2O_5 and K_2O, respectively.

2.2. Experimental Design, Crop Management and Measurement

The experiment was implemented from November 2020 to July 2021. Six major cereal species viz., Barley (*Hordeum vulgare* L.), triticale (*x Triticosecale* Wittmack), oat (*Avena sativa* L.), forage corn (*Zea mays* L.), pearl millet (*Pennisetum glaucum* L.), and sorghum (*Sorghum bicolor* L.) were evaluated under three organic and mineral amendments. The evaluated organic and mineral amendments were sheep manure (30 t·ha^{-1}), compost (5 t·ha^{-1}), and 10-30-10 NPK fertilizer (100 kg·ha^{-1}). During the autumn season, the experiment was conducted using a latin square design with four replications for the three cereals (barley, triticale, and oat). During the spring season, the experiment was conducted with a randomized complete block design with four replications for forage corn, pearl millet, and sorghum. The crops were sown in November 2020 (autumn planting) and March 2021 (spring planting). The trials were irrigated using a drip irrigation system with 50 cm row-to-row and 20 cm dripper spacing. The irrigation water (groundwater) used for irrigation was highly saline (EC = 12.4 dS/m). The recorded amount of irrigation (based on spacing of the dripper and the discharge rate), autumn crops received an amount of 840 mm and spring crops 390 mm irrigation water. Biomass of barley, triticale, and oat was harvested twice, i.e., at flowering and maturity stages, while forage corn, pearl millet, and sorghum were harvested once at maturity (in July 2021). Several agro-morphological parameters were monitored during the crop growing period and at harvest. The measured parameters include plant height, number of tillers, number of leaves, root length, plant fresh weight, and fresh biomass. For the determination of the dry biomass, harvested plants were oven-dried at 60 °C for 72 h. Fresh leaves sampling was carried out to assess chlorophyll and proline content.

2.3. Statistical Analysis

Statistical analysis was performed using R 4.0.5 software. A one-way analysis of variance (ANOVA) was used to assess the effects of amendments on different crop species. The level of significance was set to $p \leq 0.05$. For each crop, when the p-value in ANOVA was significant (<0.05), mean differences between treatments were identified using Tukey's pairwise comparisons test ($p \leq 0.05$).

3. Results

Table 1 shows the effect of organic amendments on different parameters on different crop species during autumn and spring season. Organic amendment had a significant effect on plant height and root length for all crops studied except for sorghum. Plant height was heights under manure combined with NPK fertilizer application for autumn cereals, while effect of different organic amendments was not significant for the height of pearl millet and forage corn. Root length was significantly affected due to the application of organic amendments, where it was longest under manure combined with NPK. In addition, a significant effect of amendments on irrigation water productivity was documented for all evaluated cereal species.

Table 1. Effect of organic amendments and NPK fertilizers on plant height, root length, and irrigation water productivity (IWP) of different crops planted during autumn and spring seasons. Results presented are means ± standard deviation. Means sharing same letters do not differ significantly at $p = 0.05$.

		Autumn			Spring					
Traits	**Treatment**	**Barley**	**Oat**	**Triticale**	**Barley**	**Oat**	**Triticale**	**Maize**	**Pearl Millet**	**Sorghum**
Plant height (cm)	Control	49.4 ± 11.5 c	24.5 ± 0.5 b	62.8 ± 14 b	39.25 ± 8.17 b	20.5 ± 0.9 c	54.5 ± 10.64 a	88.3 ± 4.9 b	48.5 ± 5.5 b	81 ± 0.8 a
	Manure	70.5 ± 12.9 a	54 ± 9 a	83.9 ± 9.3 a	45.25 ± 3.9 ab	51 ± 4 ab	59.5 ± 5.02 a	107.7 ± 6.2 a	114 ± 9 a	89 ± 5.7 a
	NPK	63.6 ± 11 b	52.3 ± 5.7 a	79.3 ± 13.8 a	49.25 ± 6.76 a	50.33 ± 6.7 ab	58.5 ± 9.71 a	99.5 ± 1.5 ab	111 ± 10 a	95 ± 5.7 a
	Manure × NPK	71.2 ± 8.3 a	57 ± 2.2 a	86.3 ± 14.1 a	50 ± 3.54 a	51 ± 2.6 a	60 ± 4.64 a	107 ± 5.7 a	106 ± 11 a	92.3 ± 12.7 a
	Compost	-	-	-	41.5 ± 4.09 ab	38.33 ± 2.3 bc	53.75 ± 7.98 a	105.7 ± 5.3 a	102 ± 6.5 a	84.3 ± 9.7 a
	Compost × NPK	-	-	-	45.25 ± 1.92 ab	49.33 ± 1.7 ab	65.5 ± 9.21 a	104.7 ± 3.9 ab	122.7 ± 3.4 a	85 ± 7.9 a
Root length (cm)	Control	9.9 ± 2.5 ab	4 ± 0 c	8.2 ± 1.8 b	7.25 ± 3.27 a	4.2 ± 0.18 a	5.75 ± 1.64 a	31.3 ± 1.7 ab	12.0 ± 1.0 b	23.7 ± 1.3 a
	Manure	11 ± 3 a	6.5 ± 0.5 b	10.2 ± 2.7 ab	6.5 ± 1.5 a	5.3 ± 0.4 a	5 ± 1.87 a	26.3 ± 1.9 ab	25.0 ± 3.0 a	25.3 ± 4.1 a
	NPK	8.3 ± 1.9 c	7.3 ± 0.5 ab	10.8 ± 4 a	6 ± 1.22 a	6.81 ± 0.53 a	6.25 ± 1.79 a	19.5 ± 4.5 b	27.0 ± 3.0 a	29 ± 8 a
	Manure × NPK	9.7 ± 2.7 bc	8.7 ± 0.5 a	10.4 ± 2.1 ab	7.25 ± 2.49 a	7.5 ± 0.71 a	6.75 ± 2.86 a	34 ± 3.7 a	23.0 ± 1.0 a	24 ± 12.1 a
	Compost	-	-	-	7 ± 2.12 a	7 ± 2.45 a	7 ± 1.58 a	35.3 ± 2.1 a	22.0 ± 1.6 a	20 ± 2.9 a
	Compost × NPK	-	-	-	6.25 ± 3.11 a	7.33 ± 1.25 a	5.25 ± 1.79 a	25.7 ± 4.5 ab	26.0 ± 2.5 a	19.7 ± 2.4 a
IWP (Kg/m3)	Control	0.9 ± 0.33 c	0.56 ± 0.1 ab	0.42 ± 0.16 b	0.67 ± 0.18 b	0.24 ± 0.08 b	0.35 ± 0.24 b	0.7 ± 0.17 d	0.99 ± 0.65 b	0.81 ± 0.73 b
	Manure	1.55 ± 0.34 b	0.51 ± 0.15 b	0.95 ± 0.45 a	1.11 ± 0.03 ab	0.5 ± 0.09 b	0.62 ± 0.14 b	1.62 ± 0.46 cd	2.22 ± 0.9 ab	2.71 ± 0.1 a
	NPK	1.63 ± 0.33 ab	1.3 ± 0.29 a	1.33 ± 0.43 a	1.19 ± 0.47 ab	0.56 ± 0.14 b	0.87 ± 0.39 b	2.96 ± 0.01 ab	4.41 ± 0.46 a	1.57 ± 0.44 ab
	Manure × NPK	1.92 ± 0.33 a	0.93 ± 0.3 ab	1.35 ± 0.35 a	1.43 ± 0.27 ab	0.94 ± 0.22 a	1.23 ± 0.28 a	2.17 ± 0.17 bc	3.48 ± 0.5 ab	2.73 ± 0.76 a
	Compost	-	-	-	1.12 ± 0.4 ab	0.24 ± 0.07 b	0.2 ± 0.02 b	1.78 ± 0.09 cd	2.31 ± 0.4 ab	1.8 ± 0.33 ab
	Compost × NPK	-	-	-	1.6 ± 0.15 a	0.58 ± 0.1 ab	1.13 ± 0.2 ab	3.27 ± 0.39 a	3.63 ± 0.1 ab	2 ± 0.19 ab

4. Discussion

Results indicate that organic amendments had a great positive impact on growth and productivity of cereals grown under salinity conditions (Figure 1). Barley and pearl millet performed better compared to other cereals. The combined application of sheep manure and NPK fertilizer doubled the dry biomass yield of barley to reach 16 T/ha, while the use of deep fertilization on pearl millet increased the production 4 times (17 t/ha) compared to the control.

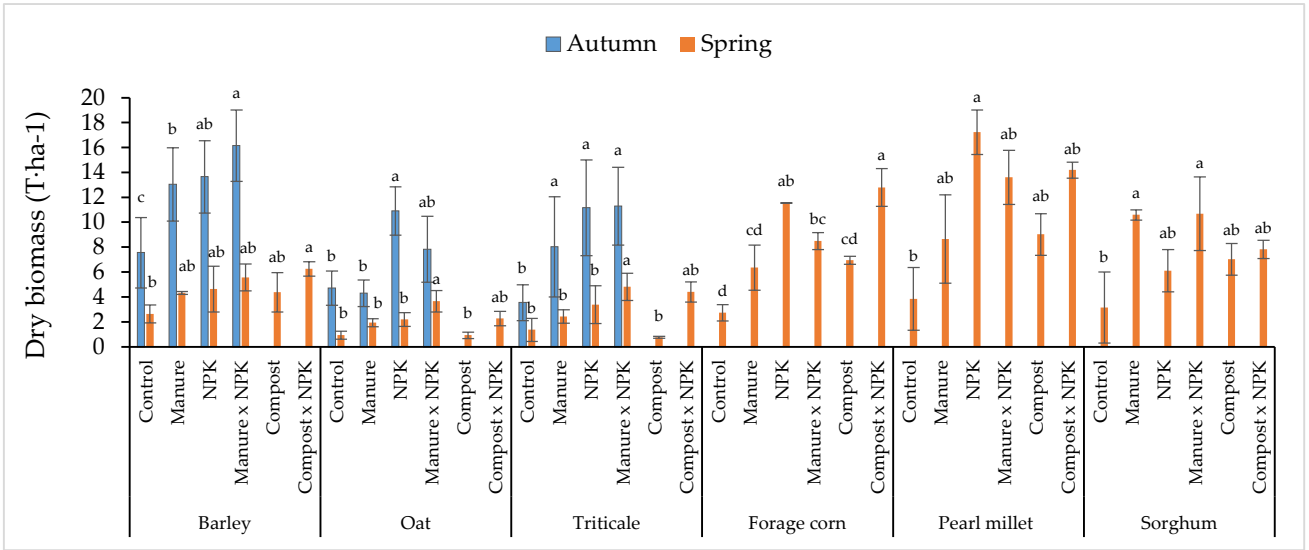

Figure 1. Total dry matter yield of different cereals as affected by different organic and inorganic amendments. Means sharing same letters do not differ significantly at $p = 0.05$. Vertical lines indicate the standard deviation.

Our results are consistent with the results of Saudi et al. [4] who found improved height and dry biomass through the application of organic amendment on barley in salt-affected drylands. Combined application might be preferred over sole application of organic amendment. Inorganic N fertilizer, enhances the forage production of pearl millet by 43% [5]. The high negative charge in animal manure increases the organic carbon content which is associated with a greater cation exchange capacity and, therefore, decrease the loss of nutrients. This is important to enhance organic carbon content, available phosphorus, extractable potassium, and make them available for plants [3].

5. Conclusions

Results of the experiments carried out in Es-smara province indicate that the use of sustainable cropping practices, such as the use of farmyard manure combined with mineral fertilizer, could be a key-element to ensure forage availability in salt-affected lands. There is an immense scope of improving forage productivity and forage supply in such region (Sahara) through improving soil quality especially by the application of organic amendments.

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