Hindawi
International Journal of Agronomy
Volume 2024, Article ID 6355929, 10 pages
https://doi.org/10.1155/2024/6355929

Research Article

Investigating the Effects of Various Soil Amendments on Forages Production in the Field

Hana'a Burezq

Research Scientist, Environment and Life Sciences Research Centre, Kuwait Institute for Scientific Research, P.No. 24885, Safat 13109, Kuwait

Correspondence should be addressed to Hana'a Burezq; haborizq@kisr.edu.kw

Received 19 November 2023; Revised 28 February 2024; Accepted 15 March 2024; Published 31 March 2024

Academic Editor: Tauseef Anwar

An initial investigation into the utilization of recycled plant and animal residues as soil amendments (SAs), including compost, biochar, and soil conditioner, was conducted using alfalfa crops. This study evaluated the impact of SAs on alfalfa seed germination, resulting in an 87% germination rate for biochar, 82% for soil conditioner, and 82% for compost. In comparison, untreated seeds displayed a 78% germination rate. After successful germination, the SAs were employed to enhance soil health, with a focus on water conservation and increased forage yield. The study used sandy-textured soil with moderate alkalinity, very slight salinity, slight calcareousness, and high permeability. The germination trial confirmed that SAs usage did not hinder seed germination, even for salt-sensitive crops like alfalfa. Two field experiments were carried out in Al-Wafra, using different application rates of compost, biochar, and soil conditioner at 5, 7.5, and 10 tons per hectare. The results highlighted the positive impact of SAs application on increasing forage production, with varying degrees of enhancement, and confirmed a 40% reduction in water usage compared to treatment without SAs but under 100% irrigation (100% ETc). In conclusion, SAs show promising potential for local forages intensification and water conservation.

1. Introduction

Over half of the agricultural land across the globe is currently grappling with the complexities of drought [1, 2]. Drought has emerged as a primary limiting factor that significantly hampers agricultural production [2, 3]. In arid regions, the role of irrigation is pivotal in maintaining agricultural productivity. However, the scarcity of water resources in these areas necessitates more prudent approaches for effectively managing irrigation in agricultural production. These approaches may involve changes in the irrigation system, reducing the frequency or volume of irrigation, and other such strategies. The inland arid regions of Midwestern China have long been contending with severe drought stress due to extremely low rainfall and high rates of evapotranspiration [4]. In recent years, a shift in crop structure has been implemented in these regions, with an increased focus on cultivating forage crops. This adjustment is considered a solution to sustain productivity in the face of limited water resources. However, it remains crucial to implement well-managed irrigation practices to ensure optimal productivity for agricultural systems that include forage crops, both in this region and in similar areas facing comparable challenges. Therefore, excessive irrigation not only results in the wastage of water resources but can also lead to issues such as crop lodging or reduced tolerance to flooding, ultimately compromising crop growth and yields [2, 5]. In contrast, deficit irrigation, which involves using less water but ensuring it is applied at the right time, can conserve water resources while striking a balance between crop yield and water input [6, 7]. Typically, when the total available water content in the soil drops to around 50–60%, it begins to impact crop growth and yield [5, 8, 9]. Forage crops such as alfalfa yield aboveground vegetative parts used as forage [10]. Employing deficit irrigation approach can sustain high yields in the early part of the year while reducing water usage during the summer months [11, 12]. Frate et al. [13] discovered that yields from a midsummer termination treatment were 65–71% of those under fully-irrigated conditions. However, yields rebounded the following year when all treatments received full irrigation [14].

Flood irrigation has traditionally been the dominant irrigation method on most irrigated farms worldwide [15]. However, it is gradually being replaced by alternative irrigation systems such as subsurface drip irrigation. Despite the practicality, cost-effectiveness, and traditional preference for flood irrigation among farmers, it is known to be less efficient in water utilization due to significant runoff and percolation [16]. Several studies have demonstrated that subsurface drip irrigation can mitigate issues related to irrigation runoff, deep percolation, and soil evaporation [17–21]. Both of these irrigation systems are utilized in the arid regions of Midwestern China.

In arid regions, irrigation serves as an effective strategy to ensure robust biomass production and high-quality forage for alfalfa [16, 22, 23]. Within an optimal range, increased irrigation volume is associated with enhanced evapotranspiration by alfalfa, resulting in linear increases in dry matter accumulation [22, 24]. Cavero et al. [25] observed that both dry matter yield and plant height of alfalfa showed linear increases with greater irrigation volume although the nitrogen content exhibited a linear decrease. Conversely, Lamm et al. [26] found that the annual dry matter yield remained relatively stable across varying water deficit levels. Furthermore, a research by the authors in [27] revealed that alfalfa could be irrigated at 70% or 85% of its potential evapotranspiration rate using a subsurface drip irrigation system without adversely affecting yield or quality, underscoring the importance of well-regulated irrigation for alfalfa productivity.

Kuwait is renowned for its arid climate and limited water resources, both of which pose significant constraints on the country's agricultural sector. Our focus in Kuwait is on technologies that can contribute to the advancement of the agricultural industry, ultimately ensuring food security. To address these challenges, we have developed the following three soil amendments: compost, biochar, and soil conditioner. Our objective is to evaluate the impact of these products under open-field conditions using deficit irrigation, specifically examining their effects on alfalfa production. The utilization of biochar for rehabilitating deteriorated soils and enhancing plant productivity is acknowledged as a promising technology. However, there is limited understanding of the effects of biochar, particularly when combined with other compounds such as different organic fertilizers, on both alfalfa yield and soil quality in arid regions. To address this gap, two open-field experiments were conducted to investigate the influences of these soil amendments on the biomass production of alfalfa [28]. We hypothesize that the utilization of these amendments will enhance crop production and potentially contribute to water conservation in irrigation.

2. Materials and Methods

2.1. Location and Climate of the Experimental Site. Two field trials were conducted over a span of two years, from 2019 to 2020, in Al-Wafra, a privately owned farm in Kuwait located at a latitude of 28.580091°N and longitude of 48.114027°E. The total area of the designated plot is 324 m^2 (18 m × 18 m). This region is characterized by sandy soils and a climate featuring scorching summers and cold, dry winters. Kuwait typically experiences high summer temperatures, brief and temperate winters, intense sunlight, low humidity, and an overall arid environment.

2.2. Recycling Agricultural Residues into Three Products

2.2.1. Production of Biochar. Poultry and sheep manure were utilized in the production of biochar through a biochar production system as described by [29]. Drying plays a pivotal role in this process; the collected manure undergoes air drying to reduce the moisture content, as discussed in [30]. This drying stage concentrates nutrients in the solid phase, resulting in a higher nutrient content in the biochar produced. Animal manure is converted into biochar through high-temperature pyrolysis (>400°C) carried out in an oxygen-free environment. The utilization of biochar derived from animal manure has the potential to significantly enhance soil fertility, improve soil water retention capabilities, and safeguard essential nutrient preservation. Incorporating biochar derived from animal manure into the soil proves to be an effective strategy for strengthening nutrient retention. Moreover, biochar derived from animal manure has shown effectiveness in reducing the presence of both organic and inorganic nutrients in the soil [2]. However, it is important to note that biochar production can also generate pollutants such as polycyclic aromatic hydrocarbons (PAHs), toxic inorganic elements, dioxins (DFs), and PFRs, posing risks to human health and the environment, as highlighted in [31].

2.2.2. Production of Organic Fertilizer. The production method described in [32] (conducted at a private facility) served as the foundation for this method. In brief, this method involved a combination of microorganisms that require various nutrients for their growth, including organic carbon sources, nitrogen sources, and a range of other elements dissolved in water. Seaweed was also utilized to capture atmospheric CO_2. The mixture contains all compounds that can fulfill the aforementioned growth requirements for different microorganisms. This method resulted in a final product with an acidic pH (3.8). In addition, electrical conductivity (EC) was measured to assess soluble nutrient levels, and the EC value of the produced product was recorded at 3.77 mS/cm (slightly saline). The elevated EC value indicates the release of nutrients from the organic materials, confirming the production of a nutrient-rich final product.

2.2.3. Production of Compost. Pilot-scale compost production commenced with the inclusion of prepared organic fertilizer from the previous step as an inoculant. The foundational materials consisted of alternating layers of organic matter or biodegradable waste, such as animal manure, arranged in a heap structure. This organized layering technique facilitated efficient composting progress. This approach, previously described by Burezq et al. in [33], incorporates various components.

2.2.4. Production of Soil Conditioner. The biochar produced in the previous section was utilized to create a soil conditioner. It was mixed with organic fertilizer produced earlier, and the resulting mixture was left to air-dry for a day. This method, previously described by Burezq et al. in [33], involved using various organic fertilizers.

2.2.5. Experimental Design. Two field experiments were carried out with three replications for each treatment, applying the following two different irrigation rates: ETc 100% and ETc 60%. The experimental area was subdivided into six main plots, corresponding to the following six distinct treatments: (T1) commercial compost, (T2) compost, (T3) biochar, (T4) soil conditioner, (T5) control treatment with ETc 100% (full irrigation), and (T6) another control treatment with ETc 60% (deficit irrigation). For each treatment, the crop was cultivated using the following two different irrigation systems: 60% and 100% ETc. Within each primary plot, three subplots were designated to implement three distinct application rates of the treatments as follows: 5.0 (R1), 7.5 (R2), and 10 (R3) tons per hectare. Alfalfa was sown during 2019-2020. All cuts were carried out manually. Cut (1) was carried out after 65 days, cut (2) was carried out 35–45 days later, and then alfalfa was harvested every 45 days until October-November of year 1, continuing until the next spring (year 2) (see Table 1)

2.2.6. Collecting Soil Samples. Employing a soil sample representative of the entire designated area for the field experiment is crucial when collecting soil samples for laboratory analysis. This approach mitigates the risk of bias that could arise from using a nonrepresentative sample.

2.3. Collecting Alfalfa Crop. All cuts were conducted manually. Cut (1) occurred after 65 days, cut (2) took place between 35 and 45 days later, and thereafter, alfalfa was harvested every 45 days from October to November of year 1 until the following spring (year 2). Alfalfa crops were harvested from each plot separately, and weights were promptly recorded to prevent moisture loss. The average of the three replicates (R1, R2, and R3) was calculated for each treatment using GraphPad Prism 10 software. Subsequently, p values were calculated to determine if the differences between treatments were significant.

2.3.1. Alfalfa Water Requirements. Alfalfa requires a certain level of soil moisture to consistently yield high crop production no less than 50%. Irrigation is usually discontinued 3–10 days before the harvesting period. Alfalfa boasts deep roots, which enable it to endure extended intervals between irrigation cycles. Daily irrigation water requirements were determined using the equation mentioned previously by [16] for full irrigation at ETc 100% and ETc 60% (for deficit irrigation) during the field experiment, employing a drip irrigation system. In the context of the irrigation period, ETc 100% denoted the essential irrigation volume required to meet the evapotranspiration demands of the crop [16, 34].

2.3.2. Water-Deficit Irrigation. Water-deficit irrigation in alfalfa management involves the purposeful implementation of controlled water scarcity. This strategy enhances the efficient utilization of irrigation water resources and stimulates the development of a deeper root system, thereby extending the area of soil explored by the plant's roots. The amount of water administered during each irrigation cycle is intentionally maintained below the crop's full water requirement. However, it is precisely adjusted to avoid any significant adverse impact on alfalfa growth and productivity. This precise control over water volume is achieved by using crop coefficient values set lower than the recommended values [35]. In this irrigation management approach, which employs an irrigation water meter, the controlled water deficit is established by regulating the water level in the evaporation reservoir. More specifically, the marker on the sliding rod is positioned at a lower point on the level ruler than the manufacturer's recommended value for crop development. Consequently, reducing the water level in the evaporation reservoir results in a reduced evaporating surface area, which in turn lead to a decreased estimation of evapotranspiration for alfalfa.

3. Results and Discussion

In this study, we evaluated the effects of applying three soil amendments under open-field conditions using deficit irrigation, with a specific focus on their impact on alfalfa biomass production. Biochar is recognized as a promising technology for rehabilitating degraded soils and boosting plant productivity. However, there is still limited understanding of its effects, especially when combined with other organic fertilizers, on alfalfa yield and soil quality in arid regions. To address this knowledge gap, we conducted two open-field experiments to comprehensively examine the effect of various soil amendments on biomass production and soil quality. We hypothesize that the utilization of these soil amendments will not only enhance crop production but also contribute to water conservation through reduced irrigation requirements. The study revealed the following findings.

3.1. Chemical and Physical Analysis of Native Soil Samples. In the field experiment, native sandy soil served as the primary soil type. This soil underwent a comprehensive analysis of its key physical and chemical properties. According to Kuwait Soil Taxonomy, as outlined by [36], the soil was classified as Typic Torripsamments, mixed hyperthermic. Soil pHs and salinity (ECe) were assessed using electronic probe to measure pHs and ECe of the saturated

Table 1: Experimental Design.

T1R1-60ETc	T1 R1-100ETc	T1R2-60ETC	T1R2-100ETc	T1R3-60ETc	T1R3-100ETc	T2R1-60ETc	T2R1-100ETc	T5-1
T1R11-60ETc	T1R11-100ETc	T1R22-60ETc	T1R22-100ETc	T1R33-60ETc	T1R33-100ETc	T2R11-60ETc	T2R11-100ETc	T5-2
T1R111-60ETc	T1R111-100ETc	T1R222-60ETc	T1R222-100ETc	T1R333-60ETc	T1R333-100ETc	T2R111-60ETc	T2R111-100ETc	T5-3
T2R2-60ETc	T2R2-100ETc	T2R3-60ETc	T2R3-100ETc	T3R1-60ETc	T3R1-100ETc	T3R2-60ETc	T3R2-100ETc	T5-4
T2R22-60ETc	T2R22-100ETc	T2R33-60ETc	T2R33-100ETc	T3R11-60ETc	T3R11-100ETc	T3R22-60ETc	T3R22-100ETc	T6-1
T2R222-60ETc	T2R222-100ETc	T2R333-60ETc	T2R333-100ETc	T3R111-60ETc	T3R111-100ETc	T3R222-60ETc	T3R222-100ETc	T6-2
T3R3-60ETc	T3R3-100ETc	T4R1-60ETc	T4R1-100ETc	T4R2-60ETc	T4R2-100ETc	T4R3-60ETc	T4R3-100ETc	T6-3
T3R33-60ETc	T3R33-100ETc	T4R11-60ETc	T4R11-100ETc	T4R22-60ETc	T4R22-100ETc	T4R33-60ETc	T4R33-100ETc	T6-4
T3R333-60ETc	T3R333-100ETc	T4R111-60ETc	T4R111-100ETc	T4R222-60ETc	T4R222-100ETc	T4R333-60ETc	T4R333-100ETc	T6-5

R1: 0.5 tons/ha; R2: 7.5 tons/ha; R3: 10 tons/ha.

paste, as detailed in Table 2. The pHs of the native sandy soil was found to be moderately alkaline, measuring 7.8, and the soil exhibited a very slight degree of salinity, as reported by [37, 38].

3.2. Effect of the Soil Amendments on Soil EC and pH. Table 3 illustrates the dynamic variations in EC and pH values for soil mixed with various soil amendments used in the present study. The pH of the native sandy soil (control) registered at 7.8, indicating a moderately alkaline nature. Upon the application of the compost, biochar, and soil conditioner, there was increase in pH although it still retained a distinctly alkaline pH level. In addition, the EC values displayed a similar trend, exhibiting an increase when compared to the native sandy soil; there was a gradual rise in EC with increasing quantities of the soil amendments, with the highest values occurring at elevated application rates (10 tons/ha) for all of the soil amendments (Table 3). Particularly noteworthy were the maximum EC values of 3.32 and 2.83 mS/cm, recorded in soils where compost was applied at rates of 10 and 7.5 tons/ha, respectively. This suggests that the use of compost may potentially raise concerns about salinity in the root zones in comparison to other amendments, necessitating careful consideration. However, it is important to note that this increase is primarily attributed to soluble nutrients rather than the typical ions that induce soil salinity. This aspect represents an additional advantage of the soil amendment. When applying soil amendments at a 1: 10 ratio, all combinations of soil and soil amendments remained classified as either non-saline or very slightly saline. The general pattern of EC changes observed was as follows: compost > biochar > soil conditioner.

The biochar itself has high salinity due to the release and concentration of minerals during its production. However, the application of biochar will not affect the salinity of the soil or hinder plant growth. This is because plants are not directly grown in the biochar; instead, it is mixed with soil. For instance, if we apply biochar at a rate of 5 tons/ha, meaning we dilute 0.5 kg of biochar in 250 kg of soil (i.e., highly diluted and will not impact plant growth). In contrast, the application of organic fertilizer "compost" will release acids such as humic acids due to the decomposition of organic matter. In the present study, salinity is attributed to salts in the irrigation water. Although we used freshwater for irrigation, the salinity was still less than 2 Sm/cm, thereby not significantly affecting the growth of alfalfa crops. If it exceeds 2 Sm/cm, it will reduce alfalfa crop production significantly. Regarding the application of the compost, the production of compost was carried out using organic fertilizer rather than water, which contains high concentrations of microorganisms. The high concentration of microorganisms leads to the release of more nutrients, making them more available to the plants. Therefore, the best growth was observed with the application of the produced compost. Using normal compost, which is produced using water in the presence of microorganisms in the soil, will also release nutrients but to a lesser extent compared to the nutrient-rich compost because some nutrients may be fixed, such as P and Cu.

3.3. Hydraulic Properties of Native Soil. Hydraulic conductivity plays a significant role in determining the duration of water presence in soils, greatly influencing its suitability for seedlings and trees. The results reveal a wilting point of 2% of water per 100 g of soil, indicating the soil's low ability to retain water and the threshold at which plants may experience water stress or wilting due to insufficient moisture. In addition, the field capacity is measured at 5% (5 gm of water per 100 g of soil). This low value signifies the soil's limited ability to retain water under normal field conditions, setting an upper limit on water availability for plants before drainage occurs. This parameter is crucial for understanding the soil's water-holding capacity and plays a vital role in plant growth and development. Furthermore, the draining rate is determined to be 180 mm/hour, reflecting the speed at which water drains through a particular medium or soil. This high draining rate indicates that water can move quickly through the medium, while a lower rate suggests slower drainage, implying a high leaching rate. Table 4 presents the estimated hydraulic characteristics, including permanent wilting point, field capacity, available water, bulk density, and hydraulic conductivity (measured in millimeters per hour).

3.3.1. The Efficacy of the Soil Amendments on Seed Germination. Table 5 compares seed germination across various rates of distinct soil amendments and the control treatment. Alfalfa seed germination was observed in all treatment groups, with minor discrepancies. Across these treatments, germination rates showed a slight increase (ranging from 82% to 87%) compared to the control group (78%), represented by the native sandy soil (Table 5). Results indicated that germination of alfalfa seeds varied insignificantly with different treatments, ranging from 82% with soil conditioner, 82% with composts application, to 87% with biochar application. This suggests that marginal variations in germination among the amendments can be attributed to disparities in seed quality rather than the influence of the soil amendments.

3.3.2. Yield Production. Table 6 represents the fresh biomass of alfalfa, quantified in tons per hectare, and the percentage increase in fresh biomass due to the utilization of various soil amendments compared to the control treatment, both at 60% and 100% of crop evapotranspiration (ETc). The fresh biomass produced in the control treatments irrigated with 100% ETc and 60% ETc reaches 20 and 16.32 tons per hectare, respectively. Generally, Table 6 demonstrates a significant increase in fresh biomass when utilizing any of the previously mentioned soil amendments with different application rates as follows.

The increase in fresh biomass varies significantly, ranging from a minimum of 9.68%, 11.98%, and 14.87% (noted with the application of commercial compost at rates of 5, 7.5, and 10 tons per hectare, under deficit irrigation of 60% ETc) to a substantial increase of 103%, 117%, and 115.8% (observed with compost applications at rates of 5, 7.5, and 10 tons per hectare, respectively, compared to the

Table 2: Chemical analysis of native soil [37].

Soil parameters	Value (unit)	Class
pH_s	7.8	Moderately alkaline
EC_e	0.8 mS/cm	Very slightly saline
Organic carbon	0.2%	Very low
$CaCO_3$ equivalent	7.1%	Slightly calcareous
Munsell soil color	10 YR 7/3	Light yellowish brown
Sand	%	92
Silt + clay	%	8
Texture class	USDA-NRCS	Sand

Table 3: pH and EC of soil mixed with soil amendments.

Treatments	pH	pH class	EC mS/cm	Salinity class
Native soil	7.8	Moderately alkaline	0.8	Nonsaline
Compost				
5.0 t/ha	8.10	Moderately alkaline	1.33	None-saline
7.5 t/ha	8.20	Moderately alkaline	2.83	Slightly saline
10 t/ha	8.23	Moderately alkaline	3.32	Slightly saline
Biochar				
5.0 t/ha	8.52	Strongly alkaline	1.65	Nonsaline
7.5 t/ha	8.57	Strongly alkaline	1.72	Nonsaline
10 t/ha	8.59	Strongly alkaline	1.89	Nonsaline
Soil conditioner				
5.0 t/ha	8.7	Strongly alkaline	1.38	Nonsaline
7.5 t/ha	8.80	Strongly alkaline	1.87	Nonsaline
10 t/ha	8.87	Strongly alkaline	2.11	Nonsaline

Table 4: Soil hydraulic properties [33, 37].

Hydraulic properties	Values (unit)
Sand	92%
Silt + clay	8%
Wilting point	2%
Field capacity	5%
Available water	3%
Saturation	18.9%
Bulk density	1.8 g/cm^3
Porosity	32%
Draining rate	180/hour

control treatment irrigated at 60% ETc). This notable increase in biomass was achieved while consistently reducing irrigation water usage by 40% across all treatment conditions.

The increase in fresh biomass was observed to be 5%, 15%, and 27% when utilizing commercial compost at rates of 5, 7.5, and 10 tons per hectare, respectively, with 60% ETc compared to the control receiving 100% ETc. Similarly, when applying compost with 60% ETc, the increase reached 72%, 70%, and 58% at rates of 5, 7.5, and 10 tons per hectare, respectively, in comparison to the control with full irrigation. This variation ranges from a minimal 58% increase (associated with the use of compost at 10 tons per hectare) to a significant surge of 72% when utilizing compost at 5 tons per hectare, demonstrating the effectiveness of the produced compost on biomass production.

In addition, when assessing the increase in fresh biomass due to the application of biochar under 60% ETc irrigation, it fluctuates from 17.89% to 18.36% compared to the control treatment irrigated at 60% ETc and from 25% to 37% when compared to the control treatment irrigated at 100% ETc.

Similarly, the increase in fresh biomass resulting from the application of soil conditioner irrigated with 60% ETc ranges between 15.11% and 16.12% when compared to the control treatment irrigated with 60% ETc and 19%–25% when compared to the control treatment irrigated with 100% ETc.

It could be concluded from Table 6 that the highest yield production is achieved when applying compost at different rates in combination with deficit irrigation, resulting in yield production ranging from 103% to 117% compared to the control (ETc 60%). In addition, the fresh biomass produced after the application of compost represents a 58%–72% increase over the control treatment irrigated with 100% ETc.

The third-highest yield production for alfalfa crops is observed when using soil biochar, which results in a fresh biomass increase ranging from 17.89% to 18.36% when compared to the control (ETc 60%) and 25% to 37% when compared to the control treatment (ETc 100%).

Based on the findings from our field experiments in Kuwait regarding the application of various soil amendments (compost, commercial compost, biochar, and soil conditioner) to amend sandy soil, we can firmly conclude that the use of these soil amendments can lead to a significant 40% reduction in irrigation water and an impressive

Table 5: Performance of the soil amendments on the germination of alfalfa seeds [33].

Soil amendments	5.0 tons/ha	7.5 tons/ha	10 tons/ha	Germination (%)
	Number of seeds germinated out of 15 in each			
Compost	14	13	10	82
Commercial-compost	14	13	10	82
Biochar	12	15	12	87
Soil conditioner	14	13	10	82
Control				78

Table 6: Percentage increase in fresh alfalfa biomass due to the application of various soil amendments compared to control treatments (100% and 60% ETc).

Control-60% ETc	16.32 tons/ha		
Control-100% ETc	20 tons/ha		
Soil amendments	5 tons/ha	7.5 tons/ha	10 tons/ha
	% increase of fresh biomass over control treatment with irrigation (ETc 60%)		
Commercial compost (60% ETc)	9.68	11.98	14.87
Compost (60% ETc)	103	117.0	115.8
Biochar (60% ETc)	17.89	18.36	17.93
Soil conditioner (60% ETc)	15.32	15.11	16.12
	% increase of fresh biomass over control treatment with irrigation (ETc 100%)		
Commercial compost 60% ETc	5	15	27
Compost (60% ETc)	72	70	58
Biochar (60% ETc)	25	37	27
Soil conditioner (60% ETc)	19	21	25

increase in fresh biomass exceeding 117% with compost application at 7.5 tons per hectare. In addition, the recycling of green waste into valuable resources such as compost, biochar, and soil conditioner has dual benefits as follows: (1) reducing landfill waste and (2) mitigating climate change by lowering greenhouse gas emissions. A previous research [39] conducted a study highlighting the pivotal role of compost in maintaining and enhancing the stability and fertility of agricultural soils. Reference [40] also emphasized various advantages associated with compost application, including disease management, stimulation of beneficial microorganisms, and the development of disease resistance in plants. Furthermore, compost's organic matter serves as a crucial energy source for bacteria, fungi, and earthworms [41]. These factors underscore the importance of preserving soil fertility for sustainable food production. Reference [42] revealed that the application of organic fertilizers, such as compost, enhances soil organic matter content, promotes microbial activity, and provides essential macro- and micronutrients for plant growth. Composting is known for its ability to enhance soil fertility and provide long-term nutrients through gradual decomposition, contributing significantly to increased crop production [43]. These findings align with our current investigation. The introduction of our homemade compost in our study resulted in substantial crop yield increases of 103%–117% and 58%–72% when applying the compost at rates of 5 tons per hectare, 7.5 tons per hectare, and 10 tons per hectare, at ETc 60% and ETc 100%, respectively.

Furthermore, as reported by [44], biochar is a composite material, not limited to carbon (C) but also containing elements such as ash, hydrogen (H), oxygen (O), nitrogen (N), and sulfur (S). Incorporating biochar into agricultural soils offers multifaceted advantages, including substantial reductions in greenhouse gas (GHG) emissions, the adsorption of contaminants, and enhanced soil fertility and crop productivity [45]. Once introduced into soils, biochar exhibits stability, capable of retaining soil carbon for centuries and offering benefits such as improved water retention capacity (WHC) and nutrient availability [46]. Biochar application enhances soil nutrient availability, microbial activity, and curbs nutrient leaching [47], which is consistent with the results of [48, 49], who reported significant increases in biomass and grain yields. Biochar also improves specific surface area, cation exchange capacity (CEC), soil porosity, water-holding capacity, nutrient retention, and liming effect, all of which contribute to enhanced crop productivity.

Combining biochar with fertilizers has been shown to significantly boost crop yield, as observed in various studies [50, 51]. Biochar not only enhances crop productivity under normal conditions but also under challenging conditions such as salinity and drought [52]. It improves soil-plant-water relations, mitigates salt stress, and increases plant-available water [53]. The potential of biochar to alleviate the adverse effects of salinization in arable and contaminated soils has been noted [54]. Moreover, biochar affects soil properties, including pH, which can help control soil erosion [55]. In our current research, the amendment of sandy soil with biochar and soil conditioner led to a significant increase ranging from 17.89% to 18.36% and 15.11% to 16.12% above the control ETc 60% and 25%–37% and 19%–25% increase in fresh biomass over the control treatment with ETc 100%.

Table 7: Soil analyses after harvesting.

Soil-amendment	pH	EC	Soil salinity class	Available *K* (mg/kg)	Olsen *P* (mg/kg)
Control-60%	8.0	0.53	Nonsaline	26.9	0.6
Control-100%	7.9	0.40	Nonsaline	26.30	0.4
Commercial compost					
5 tons/ha	8.31	1.40	Nonsaline	77.54	16.4
7.5 tons/ha	8.38	2.33	Slightly saline	78.01	22.6
10 tons/ha	8.65	2.78	Slightly saline	80.34	30.7
Compost					
5 tons/ha	8.24	1.36	Nonsaline	92.43	30.34
7.5 tons/ha	8.32	2.01	Slightly saline	95.01	44.08
10 tons/ha	8.41	2.12	Slightly saline	97.0	45.09
Biochar					
5 tons/ha	8.11	1.8	Nonsaline	78.12	24.78
7.5 tons/ha	8.0	2.3	Slightly saline	82.37	29.87
10 tons/ha	8.33	2.7	Slightly saline	85.17	32.74
Soil conditioner					
5 tons/ha	8.01	1.63	Nonsaline	67.43	22.54
7.5 tons/ha	8.23	1.76	Nonsaline	70.22	28.65
10 tons/ha	8.40	2.11	Slightly saline	74.01	32.78

3.4. Soil Characteristics after the Harvest of Alfalfa. Table 7 presents an overview of soil characteristics after harvesting the alfalfa crop. Notably, there is no significant influence of the application of the three soil amendments on elevating soil salinity, as indicated by electrical conductivity (EC) and pH levels; soil salinity was kept nonsaline to slightly saline. Consequently, it is established that the utilization of compost, biochar, or soil conditioner poses no risk, confirming their safety in enhancing soil health to promote water conservation and amplify alfalfa crop production. A positive effect has been observed in terms of the heightened Olsen P levels evident in all treatments compared to the control treatments. This enhancement can be attributed to the organic composition of the soil amendments, which eventually initiate the release of organic acids and consequently facilitate the liberation of phosphorus (P).

In the current study, the potassium content of the control treatment 60% ETc is 26.9 mg/kg (Table 7). As shown in Table 7, the soil potassium content significantly increased compared to the control treatment 60% ETc after the application of biochar and soil conditioner, ranging from 78.12 to 85.17 mg/kg and 67.43 to 74.01 mg/kg, respectively. Moreover, compost application resulted in a significant increase in potassium levels compared to the control treatment 60% ETc, ranging from 92.43 to 97.0 mg/kg. Furthermore, the application of biochar, soil conditioner, and compost led to varying ranges of Olsen P content increases in the soil, ranging from 24.78 to 32.74 mg/kg, 22.54 to 32.78 mg/kg, and 30.34 to 45.09 mg/kg, respectively. The elevated levels of potassium and phosphorus in the soil positively influenced the overall crop production rate. The most significant increases in both potassium and phosphorus were observed with compost application. Consequently, the highest fresh biomass production occurred after applying compost at different rates, reaching 103%, 117%, and 115.8% for rates of 5, 7.5, and 10 tons per hectare, respectively.

4. Conclusions

The application of various soil amendments successfully increased the fresh biomass of alfalfa crops in the arid environment of Kuwait. The most significant increase in alfalfa fresh biomass occurred following the application of compost at different rates, surpassing the control treatment (60% ETc). In addition, the use of biochar, soil conditioner, and compost resulted in an elevation in the Olsen P content of the soil by varying percentages compared to the control treatment irrigated with ETc 60%. The heightened levels of potassium (K) and phosphorus (P) in the soil positively impacted the overall crop production rate. The most significant enhancements in both K and P were observed with the application of compost. Consequently, the highest fresh biomass production was achieved after applying compost at different rates. Future studies will be carried out to investigate the effect of applying the same soil amendments to different crops under Kuwaiti conditions.

Data Availability

The readers of the article can use the data published in the manuscript with permission from the author of the article.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

References

[1] G. Geng, J. Wu, Q. Wang et al., "Agricultural drought hazard analysis during 1980–2008: a global perspective," *International Journal of Climatology*, vol. 36, 2015.

[2] M. Z. Liu, Z. Wang, L. Mu, R. Xu, and H. Yang, "Effect of regulated deficit irrigation on alfalfa performance under two irrigation systems in the inland arid area of midwestern China," *Agricultural Water Management*, vol. 248, Article ID 106764, 2021.

[3] M. Pelling, "A review of global risk index projects: conclusions for sub-national and local approaches," 2004, https://books.google.com.kw/books?hl=en&lr=&id=ICzUxp-BiSEC&oi=fnd&pg=PA151&dq=Pelling+et+al.,+2004,+drought&ots=boaxs_47UG&sig=ofxd7vYykKslHigrHY3-OUhYw84&redir_esc=y#v=onepage&q&f=false.

[4] W. Meng and Y. Wang, "A diagnostic study on heavy rainfall induced by Typhoon Utor in South China: 1," *Rainfall Asymmetry At Landfall*, vol. 15, 2013.

[5] P. Steduto, T. C. Hsiao, E. Fereres, and D. Raes, "Crop yield: response to water," 2012, https://www.researchgate.net/profile/D-Moot/publication/260164750_Alfalfa/links/544ea3320cf26dda0890184e/Alfalfa.pdf.

[6] X. Cui, "Climate change and adaptation in agriculture: evidence from US cropping patterns," *Journal of Environmental Economics and Management*, vol. 101.

[7] S. Ors, M. Ekinci, E. Yildirim, U. Sahin, M. Turan, and A. Dursun, "Interactive effects of salinity and drought stress on photosynthetic characteristics and physiology of tomato (Lycopersicon esculentum L.) seedlings," *South African Journal of Botany*, vol. 137, pp. 335–339, 2021.

[8] I. Farré and J.-M. Faci, "Deficit irrigation in maize for reducing agricultural water use in a Mediterranean environment," *Agricultural Water Management*, vol. 96, no. 3, pp. 383–394, 2009.

[9] J. B. Passioura and J. F. Angus, "Chapter 2- improving productivity of crops in water-limited *environments*," *Advances in Agronomy*, vol. 106, pp. 37–75, 2010.

[10] G. Testa, F. Gresta, and S. L. Cosentino, "Dry matter and qualitative characteristics of alfalfa as affected by harvest times and soil water content," *European Journal of Agronomy*, vol. 34, no. 3, pp. 144–152, 2011.

[11] B. Hanson, D. Putnam, and R. Snyder, "Deficit irrigation of alfalfa as a strategy for providing water for water-short areas," *Agricultural Water Management*, vol. 93, no. 1–2, pp. 73–80, 2007, https://www.sciencedirect.com/science/article/abs/pii/S0378377407001710.

[12] B. Hanson, K. Bali, S. Orloff, H. Carlson, B. Sanden, and D. Putnam, "Midsummer deficit irrigation of alfalfa as A strategy for providing water for water-short areas," 2008, https://www.witpress.com/elibrary/wit-transactions-on-ecology-and-the-environment/112/19146.

[13] C. A. Frate, B. A. Roberts, and V. L. Marble, "Imposed drought stress has no long-term effect on established alfalfa," *California Agriculture*, vol. 45, no. 3, pp. 33–36, 1991.

[14] Z.-Y. Cheng and Z.-H. Zhang, "Research on the soil water and salt dynamics of the purple medic grassland and the mode of an optimal ecological irrigation control in the qinwangchuan irrigated regions," *Gansu Province*, vol. 14, no. 3, pp. 295–297, 2005.

[15] M. Akbari, M. Gheysari, B. Mostafazadeh-Fard, and M. Shayannejad, "Surface irrigation simulation-optimization model based on meta-heuristic algorithms," *Agricultural Water Management*, vol. 201, pp. 46–57, 2018.

[16] M. H. Almarshadi and S. M. Ismail, "Effects of precision irrigation on productivity and water use efficiency of alfalfa under different irrigation methods in arid climates," *Journal of Applied Sciences Research*, vol. 7, no. 3, pp. 299–308, 2011, https://www.researchgate.net/publication/266347733_Effects_of_Precision_Irrigation_on_Productivity_and_Water_Use_Efficiency_of_Alfalfa_under_Different_Irrigation_M.

[17] S. Ali, A. Jan, P. Zhang et al., "Effects of ridge-covering mulches on soil water storage and maize production under simulated rainfall in semiarid regions of China," *Agricultural Water Management*, vol. 178, pp. 1–11, 2016.

[18] T. Gebremedhin, "Effect of drip and surface irrigation methods on yield and water use efficiency of onion (Allium cepa L.) under semi-arid condition of Northern Ethiopia," *Journal of Biology Agriculture and Healthcare*, vol. 5, no. 14, pp. 88–94, 2015, https://core.ac.uk/download/pdf/234661574.pdf.

[19] S. Onder, M. E. Caliskan, D. Onder, and S. Caliskan, "Different irrigation methods and water stress effects on potato yield and yield components," *Agricultural Water Management*, vol. 73, no. 1, pp. 73–86, 2005.

[20] T. Selim, R. Berndtsson, and M. Persson, "Simulation of soil water and salinity distribution under surface drip irrigation," *Irrigation and Drainage*, vol. 62, no. 3, pp. 352–362, 2013.

[21] Y. Xiao, G. Zhao, T. Li, X. Zhou, and J. Li, "Soil salinization of cultivated land in Shandong Province, China—dynamics during the past 40 years," *Land Degradation and Development*, vol. 30, no. 4, pp. 426–436, 2018.

[22] Y. Kuslu, U. Sahin, T. Tunc, and F. M. Kiziloglu, "Determining water-yield relationship, water use efficiency, seasonal crop and pan coefficients for alfalfa in a semiarid region with high altitude," *Bulgarian Journal of Agricultural Science*, vol. 16, no. 4, pp. 482–492, 2010.

[23] X. Feng, B. Fu, S. Piao et al., "Revegetation in Chinas Loess Plateau is approaching sustainable water resource limits," *Nature Climate Change*, vol. 6, no. 11, pp. 1019–1022, 2016.

[24] R. E. Sojka, D. L. Bjorneberg, J. A. Entry, R. D. Lentz, and W. J. Orts, "Polyacrylamide in agriculture and environmental land management," *Advances in Agronomy*, vol. 92, pp. 75–162, 2007.

[25] J. Cavero, J. M. Faci, E. T. Medina, and A. Martínez-Cob, "Alfalfa forage production under solid-set sprinkler irrigation in a semiarid climate," *Agricultural Water Management*, vol. 191, pp. 184–192, 2017.

[26] F. R. Lamm, K. R. Harmoney, A. A. Aboukheira, and S. K. Johnson, "Alfalfa production with subsurface drip irrigation in the central great plains," *Transactions of the ASABE*, vol. 55, no. 4, pp. 1203–1212, 2012.

[27] K. R. Harmoney, F. R. Lamm, S. K. Johnson, and A. A. Aboukheira, "Reducing water inputs with subsurface drip irrigation may improve alfalfa nutritive value," *Forage and Grazinglands*, vol. 11, no. 1, pp. 1–8, 2013.

[28] Q. Cui, J. Xia, L. Peng, X. Zhao, and F. Qu, "Positive effects on alfalfa productivity and soil nutrient status in coastal wetlands driven by biochar and microorganisms mixtures," *Frontiers in Ecology and Evolution*, vol. 9, 2022.

[29] International Biochar Initiative (Ibi), "A guide to conduct biochar trials. Box 1: quick tests to determine whether a biochar material contains compounds that are potentially harmful to plants," *Germination Test*, vol. 8, 2009.

[30] J. Meng, H. Zhang, Z. Cui et al., "Comparative study on the characteristics and environmental risk of potentially toxic elements in biochar obtained via pyrolysis of swine manure at lab and pilot scales," *Science of the Total Environment*, vol. 825, Article ID 153941, 2022.

[31] R. Zhang, R. Zhang, A. R. Zimmerman, H. Wang, and B. Gao, "Applications, impacts, and management of biochar persistent free radicals- A review," *Environmental Pollution*, vol. 327, Article ID 121543, 2023.

[32] S. Mohod, G. P. Lakhawat, S. K. Deshmukh, and R. P. Ugwekar, "Production of liquid biofertilizers and its quality control," *International Journal of Emerging Trend in Engineering and Basic Sciences (IJEEBS)*, vol. 2, no. 2, pp. 158–165, 2015.

[33] H. Burezq, S. Shahid, and K. Khalil, *Soil Bio-Fertility Final Report. KISR No. 18204*, Kuwait Institute for Scientific Research, Al Ahmadi, Kuwait, 2022.

[34] A. Alhashimi, A. A. Al-Huqail, M. H. Hashem et al., "Using deficit irrigation strategies and organic mulches for improving yield and water productivity of mango under dry environment conditions," *Agriculture*, vol. 13, no. 7, p. 1415, 2023.

[35] Fao, *Crop Evapotranspiration. Guidelines for Computing Crop Water Requirements*, FAO Irrigation and Drainage, Rome, Italy, 1998.

[36] S. A. Shahid and S. A. S. Omar, *Kuwait Soil Taxonomy*, Springer, Berlin, Germany, 2022.

[37] Soil Survey for the State of Kuwait, *Semi-Detailed Survey*, AACM International, Adelaide, Australia, 1999.

[38] H. A Burezq, *Method Manual Soil Chemistry Laboratory*, The State of Kuwait, Al Ahmadi, Kuwait, 2019.

[39] I. Angin, R. Aslantas, A. Gunes, M. Kose, and G. Ozkan, "Effects of Sewage sludge amendment on some soil properties, growth, yield and nutrient content of raspberry (Rubus idaeus L.)," *Erwerbs-obstbau*, vol. 59, no. 2, pp. 93–99, 2017.

[40] A. Ebrahimi, H. Hashemi, H. Eslami et al., "Kinetics of biogas production and chemical oxygen demand removal from compost leachate in an anaerobic migrating blanket reactor," *Journal of Environmental Management*, vol. 206, pp. 707–714, 2018, https://www.sciencedirect.com/science/article/abs/pii/S0301479717310320.

[41] J. G. Davis and C. R. Wilson, *Choosing a Soil Amendment*, Colorado State University, Fort Collins, CO, USA, 2005.

[42] L. M. Shuman, S. Dudka, and K. Das, "Zinc forms and plant availability in a compost amended soil," *Water, Air, and Soil Pollution*, vol. 128, no. 1/2, pp. 1–11, 2001.

[43] F. Gaiotti, P. Marcuzzo, N. Belfiore, L. Lovat, F. Fornasier, and D. Tomasi, "Influence of compost addition on soil properties, root growth and vine performances of Vitis vinifera cv Cabernet sauvignon," *Scientia Horticulturae*, vol. 225, pp. 88–95, 2017.

[44] J. Lehmann and S. Josef, *Biochar Environmental Management. Science, Technology and Implementation*, Taylor and Francis group, London, UK, 2nd edition, 2015.

[45] I. Stavi and R. Lal, "Agroforestry and biochar to offset climate change: a review," *Agronomy for Sustainable Development*, vol. 33, no. 1, pp. 81–96, 2013, https://link.springer.com/article/10.1007/s13593-012-0081-1.

[46] S. P. Sohi, E. Krull, E. Lopez-Capel, R. Bol, and D. L. Sparks, "A review of biochar and its use and function in soil," *Advances in Agronomy*, vol. 105, pp. 47–82, 2010.

[47] M. Ventura, G. Sorrenti, P. Panzacchi, E. George, and G. Tonon, "Biochar reduces short-term nitrate leaching from A horizon in an apple orchard," *Journal of Environmental Quality*, vol. 42, no. 1, pp. 76–82, 2013.

[48] B. Glaser, J. Lehmann, and W. Zech, "Ameliorating physical and chemical properties of highly weathered soils in the tropics with charcoal – a review," *Biology and Fertility of Soils*, vol. 35, no. 4, pp. 219–230, 2002, https://link.springer.com/article/10.1007/s00374-002-0466-4.

[49] F. P. Vaccari, S. Baronti, E. Lugato et al., "Biochar as a strategy to sequester carbon and increase yield in durum wheat," *European Journal of Agronomy*, vol. 34, no. 4, pp. 231–238, 2011.

[50] M. Yamato, Y. Okimori, I. F. Wibowo, S. Anshori, and M. Ogawa, "Effects of the application of charred bark of Acacia mangium on the yield of maize, cowpea and peanut, and soil chemical properties in South Sumatra, Indonesia," *Soil Science and Plant Nutrition*, vol. 52, no. 4, pp. 489–495, 2006, https://www.tandfonline.com/doi/abs/10.1111/j.1747-0765.2006.00065.x.

[51] O. Dunsin, C. MuyiwaAboyeji, A. O. Adekiya, M. Omolol, G. Agbaje, and A. Oluwaseun, "Effect of biochar and npk fertilizer on growth, biomass yield and nutritional quality of kale (Brassica oleracea) in a derived agro-ecological zone of Nigeria," *PAT June*, vol. 12, no. 2, pp. 135–141, 2016, https://www.patnsukjournal.net/currentissue.

[52] G. Haider, D. Steffens, C. Müller, and C. I. Kammann, "Standard extraction methods may underestimate nitrate stocks captured by field-aged biochar," *Journal of Environmental Quality*, vol. 45, no. 4, pp. 1196–1204, 2016.

[53] Z. Liu, B. Dugan, C. A. Masiello, and H. M. Gonnermann, "Biochar particle size, shape, and porosity act together to influence soil water properties," *PLoS One*, vol. 12, no. 6, https://journals.plos.org/plosone/article?id=10.1371/journal.pone.0179079, 2017.

[54] H.-S. Kim, K.-R. Kim, J. E. Yang et al., "Effect of biochar on reclaimed tidal land soil properties and maize (Zea mays L.) response," *Chemosphere*, vol. 142, pp. 153–159, 2016.

[55] Q. Wang, B. Wang, X. Lee, J. Lehmann, and B. Gao, "Sorption and desorption of Pb(II) to biochar as affected by oxidation and pH," *The Science of the Total Environment*, vol. 634, pp. 188–194, 2018, https://www.sciencedirect.com/science/article/pii/S0048969718309483.