Effects of soil amendment on soil characteristics and maize yield in Horqin Sandy Land

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Abstract. A 4-year experiment was conducted to investigate the inter-annual effects of sandy soil amendment on maize yield, soil water storage and soil enzymatic activities in sandy soil in Northeast China in 2010 to 2014. We applied the sandy soil amendment in different year, and investigated the different effects of sandy soil amendment in 2014. There were six treatments including: (1) no sandy soil amendment application (CK); (2) one year after applying sandy soil amendment (T1); (3) two years after applying sandy soil amendment(T2); (4) three years after applying sandy soil amendment(T3); (5)four years after applying sandy soil amendment(T4）; (6) five years after applying sandy soil amendment（T5）. T refers to treatment, and the number refers to the year after application of the sandy soil amendment. Comparing with CK, sandy soil amendments improved the soil water storage, soil urease, invertase, and catalase activity in different growth stages and soil layers, the order of soil water storage in all treatments roughly performed: T3 > T5 > T4 > T2 > T1 > CK. the order of soil urease, invertase, and catalase activity in all treatments roughly performed: T5 > T3 > T4 > T2 > T1 > CK. Soil application of sandy soil amendment significantly (p≤0.05) increased the grain yield and biomass yield by 22.75%-41.42% and 29.92%-45.45% respectively, and maize yield gradually increased with the years go by in the following five years. Sandy soil amendment used in poor sandy soil had a positive effect on soil water storage, soil enzymatic activities and maize yield, after five years applied sandy soil amendment (T5) showed the best effects among all the treatments, and deserves further research.

1. Introduction

The Horqin Sandy Land located in the southeast part of Inner Mongolia, becoming the most seriously desertified areas in northeast China [1]. Sandy soil is the major soil type in this area, and sandy soils are defined by poor physical properties which leading to low water-holding capacity, high evapotranspiration and excessive drainage of rain and irrigation water below the root zone [2]. Due to its poor physical structure, soil water content and soil nutrient status are unable to meet the plant demands, which restricts plant growth, soil productivity and local economic development.

In recent years, soil amendments (such as PAM, humic acid, Biochar, et al.,) have been widely used in agriculture development to improve the soil quality and increase crop yield [3-5].To date, the published results have reported that soil amendments play a vital role in improving soil water and fertilizer retention properties. Such as Cross-linked chained PAM and PAA have superior ability to absorb and retain ultra-high amounts (1000–100,000 %) of water in comparison to their own weight, so they can improving water holding capacity of soil, at the same time they can curb the elution of nutrients by reducing the percolation of water. Humic acid not only can substantial increase yield, but also found it related to biochemical activity [6]. Bentonite is a clay soil that usually contains at least 70% of the three-layered (2:1) clay mineral montmorillonite [7]. As a result of its special layered structure [8], it is characterized by considerable swelling behaviour and high water absorbing capacity. Therefore, sodium bentonite is a good material for reducing infiltration [9], and it was extensively used in a number of applications, such as coatings [10], cosmetics, medicines and drilling fluids [11].   However, limited study is reported for bentonite as a soil amendment.

Soil water storage plays a vital role in maize growth through impact on anatomical, morphological, physiological and biochemical processes [12]. Soil enzymatic activities plays a crucial role in nutrient cycling and elements transfer [13]. Soil enzymes is also regarded as the main regulator of soil biological processes and also regarded as sensors, to reveal the effects of soil physico-chemical changes of soil quality [14]. Some studies argued that crop rotation, amendments, tillage and agricultural management affect the activity of soil enzyme [15].

The objective of this study was to determine whether the amendment of sandy soil has a positive effects on soil water storage, the soil profile distribution, microbiological soil quality indicators, and maize yield; and also if these amendment have increasing trend as the years goes by after application.

2. Materials and Methods

2.1. Study area

The effects of sandy soil amendment of this field experiment was conducted at the experimental base of the Inner Mongolia Trirock Co. Ltd, Nanman banner, Inner Mongolia, China (42° 50′ 0.03″ N , 120° 41′ 46.14″ E), located in the South of the Horqin Sandy Land. The local climate is continental monsoon with an annual average rainfall of 364.6 mm, concentrated over the months of June-September. However, the annual evapotranspiration can reach up to 1934.4 mm, and the annual average temperature was 6.4 ℃, the frost-free period was around 151 days. The soil type was aeolian sandy soil and contained 27.15 mg · kg^{-1} available nitrogen, 4.68 mg · kg^{-1} available phosphorus, 65.31 mg · kg^{-1} available potassium.

2.2. Material

The soil amendment is a novel product named sandy soil amendment, produced by the Inner Mongolia Trirock Co. Ltd, and its ingredient constitutes: Na-bentonite (91%), Humic acid (6%), Na_2co_3 (2%), Plant cellulose (1%). The application rate is 30 t · hm^{-2}, which is the optimal quantity conducted by this company with multiple field trials. The treatment is usually applied by spreading the sandy soil amendment evenly in the field before planting in spring, and mixed with 0-25 cm soil via tillage by rotary tiller before maize was seeded.

2.3. Experimental design

The experimental base was established in 2010 by the Inner Mongolia Trirock Co. Ltd. The experiment commenced from spring 2014 when the maize seeded to autumn 2014 when the maize was harvested. The field was laid out in randomized complete block design with three replications. Each plot was 40 ㎡. In this study, all the amendment treatments (T1, T2, T3, T4, and T5) were applied to the sandy soil only in their first year, so we can observe all the effects in different years in the same year. We added a new treatment in the spring every year planting season ,whereby, from two treatments in 2010 up-till six treatments in 2014 (Table 1). There were six treatments: (1) no sandy soil amendment application (CK); (2) one year after applying sandy soil amendment (T1); (3) two years after applying sandy soil amendment(T2); (4) three years after applying sandy soil amendment(T3);(5) four years after applying sandy soil amendment(T4); (6) five years after applying sandy soil amendment（T5）.

We used the "zhengdan 958" as the maize variety in 2014, which is a common, promoted local cultivar with high yield among the farmers. A standard seed rate of 45 kg · hm^{-2}, were used and all the treatments were broadcast with diammonium phosphate at a rate of 270 kg · hm^{-2} while seeding, and urea used as a top-dressing at a rate of 300 kg · hm^{-2} and 150 kg · hm^{-2} in huge bellbottom and tasseling stage, respectively. Seeds were at placed 6 cm depth, between-row spacing of 50 cm and within-row spacing of 30 cm. During the growing period, irrigation was applied uniformly across all plots when required according to the local practice. Maize was seeded in April 28 and harvested in September 28.

Table 1. The experimental design from 2010 to 2014.

Year	Treatment					
2010	CK	T1				
2011	CK	T1	T2			
2012	CK	T1	T2	T3		
2013	CK	T1	T2	T3	T4	
2014	CK	T1	T2	T3	T4	T5

Treatments: CK, T1, T2, T3, T4 and T5, T refers to treatment, and the number refers to the year after the application of sandy soil amendment. CK— no sandy soil amendment application.

2.4. Soil sampling and analysis

During Maize jointing stage, huge bell-bottom period and tasseling stage, there was an interval of 5 days between each irrigation. Soil samples were collected using soil auger at the depth of 0-100 cm from each replicated plot. The topsoil was taken at 0-20 cm with a 10 cm intervals and 20 cm intervals in the depth of 20-100 cm. Each sample was divided into two portions, where, one portion was placed in an aluminum box and then immediately

transported to the laboratory for drying at 105 ℃ The other portion was stored on ice in the field and then immediately sieved through a 2-mm mesh in the laboratory, and stored at 4 ℃ in preparation for enzyme analysis.

The soil bulk density was measured by the method of cutting ring. The water storage (W) was calculated as follows:

$W_i = h \times d \times b_i\% \times 10$

where, W (mm), the soil water storage; h (cm), soil depth; d (g $\cdot$ cm^{-3}) soil bulk density; b%, the gravitational water content. Soil water storage was calculated at 0–100 cm soil profile; subscript i referred to the soil layer.

There were three soil enzymes activity observed including urease, invertase and catalase. The soil enzyme activities was assayed as described by Guan [16], and all the enzyme activities were determined from air-dried samples. The urease activity was determined with sodium phenate colorimetry, and expressed as mg $\cdot$ g^{-1} $\cdot$ 24 h^{-1}. The invertase activity was determined with constant temperature incubation, and expressed as mg $\cdot$ g^{-1} $\cdot$ 24 h^{-1}. The catalase activity was determined with potassium permanganate titration, and expressed as mg $\cdot$ g^{-1} $\cdot$ 30 min^{-1}.

2.5. Statistical analysis

All the data were analyzed by SAS ver. 9.0 software package. Significant difference were determined by the Duncan's multiple range test at P<0.05.

3. Results

3.1 Soil water storage

The soil water storage of different treatments at different growth stages of maize in 0 - 100 cm profile is shown in Figure 1. The results showed that the soil water storage from 0 − 40 cm was significantly (p＜0.05）increased by sandy soil amendment compared with CK in all the three critical growth stages. The trend of variation in soil water storage of amendment treatments in 0 − 40 cm profile performed: 20 − 40 > 0 − 10 > 10 − 20 cm, but the soil water storage of CK was increasingly raised in 0-40 cm profile. The order of soil water storage in all treatments roughly performed was : T3 > T5 > T4 > T2 > T1 > CK. Applying sandy soil amendment increased soil water storage at the jointing, huge bell-bottom, tasseling stages compared with CK. Soil water storage increased by 167.65 - 258.24%, 95.88 - 126.75 %, and 73.71 - 197.94% in 0 − 10 cm profile, respectively, by15.53 - 53.24%, -1.67 - 30.69%, and 8.25 - 40.71% in 10 - 20cm profile, respectively ,and by 16.81 - 52.59%, 16.79 - 33.21%, and 14.14 - 39.9% in 20 − 40 cm profile.

The soil water storage of CK was significantly higher than any other treatments below the soil depth of 40 cm. but there was not a certain trend among the amendment treatments. The soil water storage of all the treatments reached the peak in 20-40 and 60-80 cm profile, respectively.

(a)   **(b)**   **(c)**
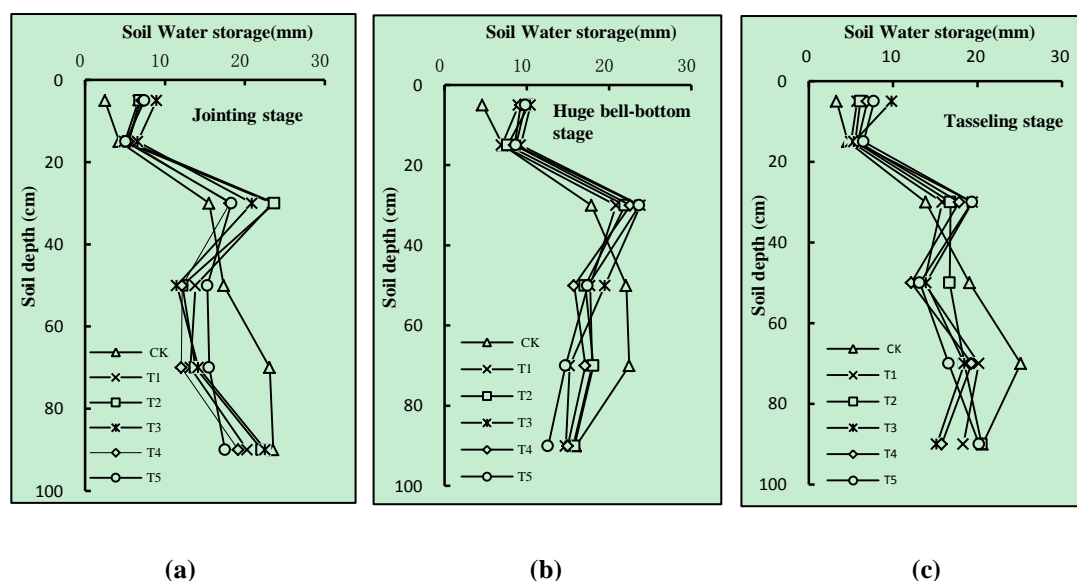
Figure 1. Soil water storage at different growth stages of maize in 0 – 100 cm profile.

Treatments: CK, T1, T2, T3, T4 and T5, T refers to treatment, and the number refers to the year after the application of sandy soil amendment. CK— no sandy soil amendment application.

3.2 Soil enzymatic activities

The soil enzymatic activities of different treatments at different growth stages of maize in different soil layers are given in (Table 2, 3, 4). Soil urease, invertase and catalase activities in all treatments displayed the same trend in the three growth stages. Application of sandy soil amendment had a positive effect on soil enzymatic activities. All the treatments had a high activity in huge bell-bottom stage and in 10 – 20 cm soil profile, and all the amendment treatments were significantly higher than CK. All the treatments had a low activity in jointing stage and in 0 – 10 cm soil profile, and there were no significant differences between the all treatments.

After applying the sandy soil amendment, the soil enzymatic activities of amendment treatments showed an increasing trend with time. The T5 always had the highest soil enzymatic activities in different growth stages in 0 – 40 cm soil profile. The order of soil enzymatic activities performance in all treatments was: T5 > T3 > T4 > T2 > T1 > CK.

In the 0 - 10cm soil profile, T5 treatment significantly improved the soil urease, invertase, and catalase activity compared with CK by 4.88 - 7.05%, 8.99 - 17.72%, and 45.81 - 65.13% at the three critical stages, respectively. The soil enzymatic activities of T3 and T4 treatment were lower than T5, and they had no significant difference between them in soil urease and catalase activity, and in soil invertase activity of jointing and tasseling stage.

In the 10 – 20 cm soil profile, all the treatments significantly improved the soil enzymatic activities and had the highest values than in the other two soil profiles. The T5 treatment significantly improved the soil urease, invertase, and catalase activity compared with CK by 20.36 - 21.71%, 13.82 - 25.34%, and 39.89 - 48.65% at the three critical stages, respectively. The T3 and T4 treatment significantly and 23.29%, 17.12% and 15.82%, 10.09% and 10.56% at the three stages, respectively. Conversely, the differences between the two treatments were not significant at the huge bell-bottom and tasseling stage, and also significantly improved the soil invertase activity compared to CK by 35.31 - 45.27% and 35.88 - 43.80%, but there were no significant difference between the two treatments in all the three stages.

In the 20 – 40 cm soil profile, all the amendment treatments increased the soil enzymatic activities compared to CK by 0.21 - 5.92%, 0.66 - 15.38%,and 25.29 - 60.15% in soil urease, invertase and soil catalase activity (it is expected that the T1 treatment of soil urease was lower than CK at jointing stage), respectively

Table 2. Soil urease activity at different growth stages of maize in 0-40 cm profile.

Soil Layer	Treatments	Soil Urease activity （mg.g^{-1}.24h^{-1})		
		Jointing stage	Huge bellbottom stage	Tasseling stage
0-10	CK	0.492bc	0.511dc	0.494c
	T1	0.485c	0.515c	0.480d
	T2	0.496bc	0.509d	0.502b
	T3	0.503b	0.528b	0.505b
	T4	0.493bc	0.525b	0.508b
	T5	0.516a	0.547a	0.520a
10-20	CK	0.496e	0.514d	0.502e
	T1	0.518d	0.604c	0.524d
	T2	0.521d	0.609bc	0.530d
	T3	0.574b	0.615ab	0.583c
	T4	0.560c	0.605bc	0.595b
	T5	0.597a	0.621a	0.611a
20-40	CK	0.473c	0.479d	0.483a
	T1	0.469c	0.485c	0.485a
	T2	0.474c	0.489c	0.492a
	T3	0.501a	0.506b	0.495a
	T4	0.485b	0.507b	0.500a
	T5	0.491b	0.518a	0.496a

Values in the same column followed by different letters indicate significant differences (p<0.05). Treatments: CK, T1, T2, T3, T4 and T5, T refers to treatment, and the number refers to the year after the application of sandy soil amendment. CK— no sandy soil amendment application

Table 3. Soil catalase activity at different growth stages of maize in 0-40 cm profile.

Soil Layer	Treatments	Soil Catalase activity （mg.g^{-1}.30min^{-1})		
		Jointing stage	Huge bellbottom stage	Tasseling stage
0-10	CK	0.133c	0.170d	0.163d
	T1	0.178b	0.216c	0.207c
	T2	0.186b	0.221c	0.210c
	T3	0.213a	0.241b	0.219b
	T4	0.214a	0.239b	0.219b
	T5	0.219a	0.252a	0.238a
10-20	CK	0.148e	0.174d	0.165d

	T1	0.187d	0.224c	0.219bc
	T2	0.201c	0.228c	0.216c
	T3	0.215ab	0.246b	0.223b
	T4	0.213b	0.243b	0.224b
	T5	0.220a	0.254a	0.231a
	CK	0.084c	0.167e	0.152d
	T1	0.126b	0.209d	0.196bc
20-40	T2	0.129ab	0.216c	0.193c
	T3	0.131ab	0.227b	0.199ab
	T4	0.135a	0.226b	0.202a
	T5	0.136a	0.239a	0.201ab

Values in the same column followed by different letters indicate significant differences ($p<0.05$). Treatments: CK, T1, T2, T3, T4 and T5, T refers to treatment, and the number refers to the year after the application of sandy soil amendment. CK— no sandy soil amendment application

Table 4. Soil invertase activity at different growth stages of maize in 0-40 cm profile.

Soil Layer	Treatments	Soil Invertase activity（mg.g^{-1}.24h^{-1}）		
		Jointing stage	Huge bellbottom stage	Tasseling stage
	CK	10.964e	12.861e	12.310e
	T1	10.650d	12.931e	12.413d
0-10	T2	11.184c	13.270d	12.612c
	T3	11.573b	14.472b	13.162b
	T4	11.624b	14.351c	13.125b
	T5	11.939a	15.140a	14.260a
	CK	10.357f	12.594d	12.180e
	T1	11.247e	13.426c	13.141c
10-20	T2	12.036d	13.706c	12.976d
	T3	12.542c	14.75ab	13.409b
	T4	12.769b	14.586b	13.466b
	T5	12.981a	15.236a	13.863a
	CK	9.866d	12.428f	11.540d
	T1	9.931d	12.564e	11.760c
20-40	T2	10.150c	12.963d	11.583d
	T3	10.266b	13.640b	11.931b
	T4	10.513a	13.564c	12.140a
	T5	10.540a	14.340a	12.080a

Values in the same column followed by different letters indicate significant differences ($p<0.05$). Treatments: CK, T1, T2, T3, T4 and T5, T refers to treatment, and the number refers to the year after the application of sandy soil amendment. CK— no sandy soil amendment application

3.3 Maize grain and biomass yield
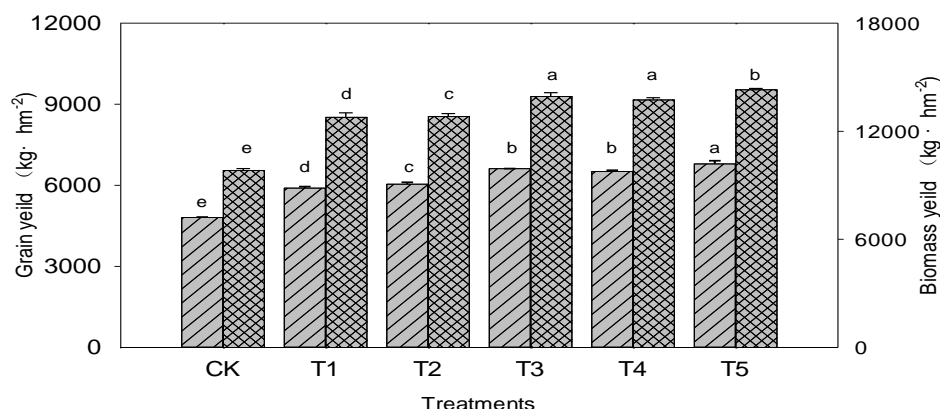
Figure 2. Maize grain yield and biomass yield in 2014.

Means followed by the same letter are not significantly different at (p<0.05). Treatments: CK, T1, T2, T3, T4 and T5, T refers to treatment, and the number refers to the year after the application of sandy soil amendment. CK— no sandy soil amendment application.

All the treatments amendment significantly improved the Maize grain yield and biomass yield (Figure 2.). The grain and biomass yield were gradually increased in the first three years. The T4 treatment a bit higher than the T3. However, there was no significant difference between them, and T3 and T4 treatments significantly increased grain and biomass yield by 41.67 and 39.71%, 37.71 and 35.57%, respectively, compared to CK. The T5 treatment had the highest grain and biomass yield, while, the T1 treatment performed least within the amendment treatments. The T5 and T1 significantly improved grain and biomass yield by 45.45 and 29.92%, 41.42 and 22.75%, respectively, compared to CK.

3.4 Relativity among water storage, grain yield and enzyme activities of soil

A correlation matrix (Table 5) shows that some significant relationships exist among the water storage, enzymatic activities and grain yield in three soil layers (0 - 10, 10 - 20, 20 – 40 cm). In 0 – 10 cm soil layer, the grain yield was strongly correlated (r = 0.809, P < 0.001; r = 0.864, P < 0.001), with the water storage and catalase activity of the soil, respectively. However, the soil invertase and urease activity have no significant effect (p > 0.05) on grain. In 10 – 20 cm soil layer, there was no significant effect between water storage and grain yield, however, the grain yield shared a strong correlation (r = 0.774, P < 0.001; r = 0.863, P < 0.001; r = 0.616, P < 0.01) with urease, catalase and invertase activities, respectively. In 20 – 40 cm soil layer, grain yield was correlated with urease activity (r = 0.608, P < 0.001), and (r = 0.574, P < 0.01) with water storage.

Table 5. Linear correlation coefficient among water storage , grain yield and enzyme activities of soil.

		WT	Ure	Inv	Cat	GY
	WT	1				
	Ure	0.610[**]	1			
0-10 cm	Inv	0.574[*]	0.837[***]	1		
	Cat	0.860[***]	0.688[**]	0.748[***]	1	
	GY	0.809[***]	0.436	0.378	0.864[***]	1

	WT	1				
	Ure	0.705[**]	1			
10-20 cm	Inv	0.807[***]	0.835[***]	1		
	Cat	0.684[**]	0.879[***]	0.907[***]	1	
	GY	0.368	0.774[***]	0.616[**]	0.863[***]	1
	WT	1				
	Ure	0.319	1			
20-40 cm	Inv	0.321	0.716[***]	1		
	Cat	0.329	0.717[***]	0.931[***]	1	
	GY	0.574[*]	0.608[**]	0.226	0.428	1

*, **, *** significant at 0.05, 0.01 and 0.001 probability levels. WT—water storage, Ure—urease, Inv—invertase, Cat—catalase, GR—grain yield.

4. Discussion

4.1 Water storage

Soil water storage is a vital soil quality indicator, and it plays a significant role in a series of hydrological and biological processes [17]. It has widely been reported that both synthetic and natural water absorbing soil amendments can increase water retention capacity of soils and regulate the plants available water supplies [18-19]. In our study, application of sandy soil amendment increased the soil water storage in the top-soil compared to CK, and had a little effect on deeper soil, and this might due to the application of sandy soil amendment in the deeper layers. However, it had also changed the distributions of soil water storage in 100 cm soil layer, and soil water storage of all the amendment treatments. The 0 – 100 cm soil profile had the highest values in 20 – 40 cm soil layer and higher than CK during 0 – 40 cm soil depth. However, soil water storage of CK reached its peak in 60 -100 cm soil layer and higher than any other treatments in 40 -100 cm soil depth. This might be attributed to the sandy soil which has a poor ability of retaining the water and reducing the infiltration [2, 20].

The long-term effects on soil water storage among the amendment treatments had increasing trend in the first three years. The order of soil water storage between T3, T4 and T5 was: T3 > T5 > T4. High level of water needed by maize [21], soybean [22] and Pueraria [23] at productive stage has been reported. The one reason why T5 had the highest yield but with the lower soil water storage compared T3 may be explained by much water demanded by the maize at productive stage. The other reason may be attributed to the soil bulk density as many studies have proved that soil amendments lower the soil bulk density [24-25].

4.2 Soil enzymatic activities

Soil enzymatic activities originated from active microorganisms [26], and plays a vital part in depolymerization of structurally diverse polymeric macromolecules [27]. Previous studies have indicated that soil amendments could increase the soil enzymatic activities [28]. In our study, we observed the three soil enzymatic activities during the three growth stages of maize in different soil layers. Evidence in this study showed that adding sandy soil amendment could improve the three soil enzymatic activities in all three soil layers, and as the applied years went on, the soil enzymatic activities had an increasing trend. This phenomenon maybe

due to the improved soil physical properties (e g. soil bulk density, soil aggregates, and pH).

4.3 Grain and biomass yield

Soil amendments increased the yield, mainly due to the reduce irrigation water consumption and improve fertilizer retention in the soil [29]. In our study, Application of sandy soil amendment increased the grain and biomass yield compared to CK. Although the grain and biomass yield of T3 were higher than T4 in values, they have no significant difference between them. Hence, the long-term effects on yield are gradually increasing as the years goes by in 5 years. However, to ascertain the longer effects on sandy soil amendment further studies on continuing observation in the future is recommended.

5. Conclusions

1. The distribution of soil water storage in $0-100$ cm soil layer was changed by adding sandy soil amendment, application of sandy soil amendment improved the water storage in $0-40$ cm soil layer, and reduced the water storage below the 40 cm compared with CK. The T3 treatment performed best.

2. Sandy soil amendment on sandy soil can enhance enzymatic activities in the three crucial stages of maize and three soil layers (0 - 10, 10 - 20, $20-40$ cm).and all the enzymatic activities had a similar trend. The T5 treatment possessed the highest values (soil urease and invertase were 0.621 and 5.23 mg $\cdot$ g^{-1} $\cdot$ 24 h^{-1}, soil catalase activity was 0.254 mg $\cdot$ g^{-1} $\cdot$ 30 min^{-1}).

3. We observed that sandy soil amendment can increase maize biomass and grain yield, and improved with the year increases. The order of maize yield in all treatments roughly performed: T5 > T3 > T4 > T2 > T1 > CK.

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