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Effects of Manure-Based Nitrogen Substitution for Chemical Nitrogen Fertilizers on Economic Benefits and Water-Use Efficiency of Maize

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Abstract: How to use nitrogen fertilizer is crucial for farmers in boosting crop yield and fostering sustainable agricultural development. We hypothesized that replacing the nitrogen (N) provided by mineral fertilizer with manure would enhance the soil water storage, increase water use efficiency (WUE), maintain maize yield, and improve economic benefits. We performed the experiment by replacing 0% (CK), 25% (M_{25}), 50% (M_{50}), 75% (M_{75}), and 100% (M_{100}) of mineral N fertilizer (225 kg ha^{-1}) with an equivalent amount of N from manure during 2016–2019. M_{25} and M_{50} increased the soil water storage at 0–2 m depth after maize harvest, while M_{25} significantly decreased the evapotranspiration by 5.27–22.14% compared with CK. The replacement treatments significantly increased maize yield and WUE by 6.58–13.62% and 5.68–18.00%, respectively, during the fourth fertilization year. Meanwhile, the net benefits of the replacement treatments were significantly higher than that of CK in the year of higher precipitation and irrigation water. M_{75} significantly increased net benefits by 8.47–35.51% compared with CK. M_{75} had the highest comprehensive evaluation score. Thus, the study proposes a combination of 75% N from manure with 25% N from mineral fertilizer to achieve a high maize yield and benefits.

Keywords: evapotranspiration; fertilization; maize yield; net income; soil moisture

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1. Introduction

Applying chemical fertilizer is an important farming measure in agricultural production. Long-term and excessive application of mineral fertilizer reduces the cultivated land quality, wastes water resources, pollutes the agricultural environment, increases production costs, and restricts crop yield [1–3]. A study that used the crop model EPIC (Environmental Policy Integrated Climate) to assess soil water dynamics and rice crop growth as affected by bunding and fertilizer application indicated that fertilizer application could cause changes in soil water storage [4]. Meanwhile, manures improve soil physical properties, promote root growth, maintain soil moisture, and enhance crop yields [5,6]. Therefore, a combined application of manure and mineral fertilizer is necessary for the sustainable development of agriculture.

Numerous studies have analyzed the effects of the combined application of manure and mineral fertilizer. Hati et al. [7] found that the balanced fertilizer and manure or lime improved soil water retention, microporosity, and available water capacity (0–30 cm depth) compared with no fertilizer under a soybean–wheat rotation system. A study reported that the combined application of manure and mineral fertilizer significantly increased water-use efficiency (WUE). The 2000 kg ha^{-1} of manure and 20 kg ha^{-1} of diammonium phosphate appeared to be the most effective combination for improving millet yield, nutrient, and water use efficiency in the Sahelian millet-based systems [8]. Moreover, Chen et al. [9] observed that an increase in the organic matter content of manure using maize straw modified via animal feeding improved summer maize production. The increase rate for organic matter, phosphorus, and potassium for the treatments with manure addition was higher than that for the treatments without manure application. Both biomass and grain yield of summer maize were improved with the continuous addition of manure. Meanwhile, an experiment reported that a positive yield trend was observed in the mineral nitrogen, phosphorus, and potassium fertilizer combined with farmyard manure treatment compared with unfertilized plots in sub-humid and semi-arid tropical India. The annual increase in wheat yields at Ranchi and Akola were +6.3 and +10.3% per year under farm yard manure combined with nitrogen, phosphorus, and potassium fertilizer treatments, respectively [10]. As for a sustainable rainfed wheat practice, partial manure substitution with an appropriate N rate improves soil quality, crop productivity, and net ecosystem economic benefit [11]. Twenty-one multi-locational trials that combined the application of mineral fertilizer and organic (farm yard manure) inputs on cassava growth and yields to evaluate the economic benefits of the use of the improved variety and fertilizer in cassava production, and the findings reveal that more positive effects on cassava growth and yields and economic benefits from farm yard manure [12]. During the six years (2016–2021) of the study, only three of those years saw treatment differences in silage corn yields, with yields being the highest for solid dairy manure only [13]. Then, we can know that a certain amount of organic fertilizer combined with chemical fertilizer can significantly improve soil water storage and water use efficiency, promote the efficient use of fertilizer, and obtain high crop yields.

In recent years, the research on organic fertilizer instead of chemical fertilizer has increased. The effect of organic fertilizer instead of chemical fertilizer will be affected by factors such as crop species, test years, and proportion of combined application. However, little is known about the effects of replacing the N provided via mineral fertilizer with an equal amount of N in the form of manures on soil water storage, evapotranspiration, WUE, yield, and economic benefits. Thus, a four-year field experiment was set up under a maize planting system using different combinations of organic fertilizer (sheep manure) and mineral fertilizer, maintaining an equivalent amount of N under all treatments. We hypothesized that replacing the N provided by mineral fertilizer with manure would enhance soil water storage, increase WUE, maintain maize yield, and improve economic benefits. The objectives of this study were: (1) to analyze the effects of replacing N from mineral fertilizer with sheep manure on soil moisture, WUE, maize yield, and economic benefits; and (2) to determine the optimum fertilization pattern for maize production.

2. Materials and Methods

2.1. Site Description and Experimental Design

A four-year field experiment was conducted from 2016 to 2019 on maize grown in clay loam soil (sand 39.8%, silt 31.1%, and clay 29.1%) at the Dongyang Research Station of Shanxi Agricultural University, Jinzhong, Shanxi, China (37°56′ N, 112°69′ E; 800 m altitude). The mean annual air temperature of this region was 9.8 °C. The mean minimum air temperature of the coldest month (January) was −6.1 °C; the mean maximum air temperature of the hottest month (July) was 28.1 °C. The experimental site was characterized by low and erratic rainfall, with droughts occurring at different stages of maize growth. The long-term mean annual rainfall at the site was 430.2 mm, and the mean annual evaporation was 1860.1 mm. The rainfall during 2016, 2017, 2018, and 2019 was 319.3, 361.6, 277.3, and 209.8 mm, respectively, in the maize growth period (Figure 1). The rainfall was over the maize requirement during 2016 and 2017, and therefore, the plants were not irrigated. Meanwhile, the plants received 146.2 mm and 225.0 mm of irrigation water in 2018 and

2019 due to less precipitation (Figure 1). Analysis of the soil samples collected from the experimental site in April 2016 showed that the top 20 cm of soil had the following features: pH 8.4, soil organic matter 13.0 g kg^{-1}, total N 1.3 g kg^{-1}, total phosphorus 0.9 g kg^{-1}, total potassium 27.1 g kg^{-1}, available N 51.2 mg kg^{-1}, available phosphorus 7.7 mg kg^{-1}, and available potassium 176.4 mg kg^{-1}.

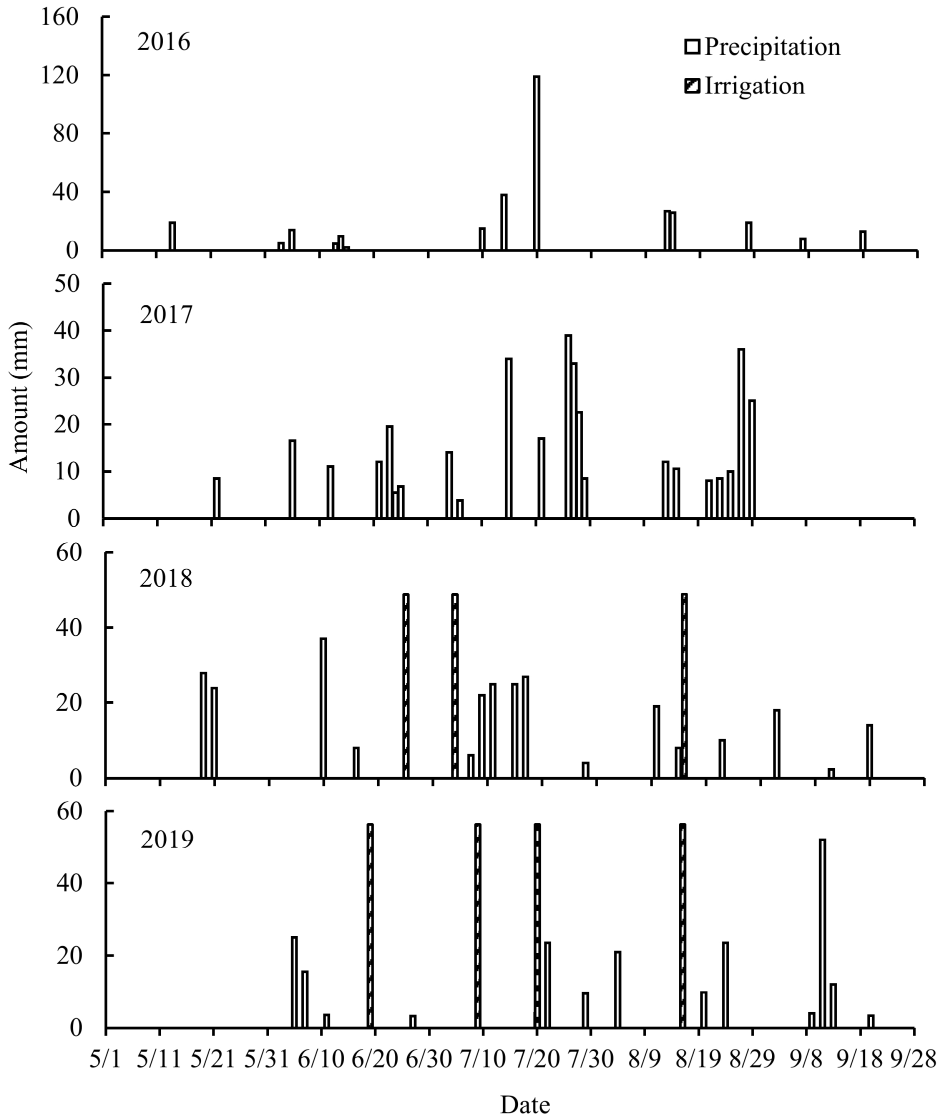

Figure 1. Time and amount of precipitation and irrigation in 2016–2019.

The field experiment was carried out in a completely randomized block design with five treatments and three replicates, and a plot size of 5 m × 6 m. The five treatments were as follows: (i) 100% of N (225 kg ha^{-1}) as mineral fertilizer alone (CK); (ii) 25% of N (56.25 kg ha^{-1}) as manure combined with 75% of N (168.75 kg ha^{-1}) as mineral fertilizer (M_{25}); (iii) 50% of N (112.50 kg ha^{-1}) as manure combined with 50% of N (112.50 kg ha^{-1}) as mineral fertilizer (M_{50}); (iv) 75% of N (168.75 kg ha^{-1}) as manure combined with 25% of N (56.25 kg ha^{-1}) as mineral fertilizer (M_{75}); (v) 100% of N (225 kg ha^{-1}) as manure alone (M_{100}). Sheep manure was incorporated into the soil at approximately 0–15 cm depth in late October of each experimental year (Table 1). In addition, 105 kg ha^{-1} phosphorus was applied to CK in the form of mineral fertilizer. The amount of mineral phosphate fertilizer used in M_{25}, M_{50}, and M_{75} treatments was 105 kg ha^{-1} minus the phosphorus content of manure. There was no mineral fertilizer in the M_{100} treatment. Before sowing, the mineral N and phosphorus fertilizers were applied separately as basal fertilizers, and urea and monoammonium phosphate were used as the mineral fertilizers. We applied herbicides during the maize jointing stage every year. The forecrop for the maize crops in this experiment were all maize. In each experimental year, the maize variety Dafeng 30 was planted at 49,500 plants ha^{-1} density in late April or early May and harvested in late September.

Table 1. The rate of manure inputs in t ha^{-1} in treatments.

Treatment	Year			
	2016	**2017**	**2018**	**2019**
CK	0	0	0	0
M_{25}	2.50	2.63	2.75	2.35
M_{50}	5.01	5.27	5.51	4.69
M_{75}	7.51	7.90	8.26	7.04
M_{100}	10.01	10.53	11.01	9.39

2.2. Sampling and Analysis Methods

Soil water storage was measured gravimetrically (drying method, w/w) to a depth of 200 cm at 20 cm increments before sowing and after harvest at the center of each plot [14]. Soil bulk density was determined according to the method described by Robertson et al. [15]. Twenty maize plants were harvested from the center of each plot to measure the grain yield.

Soil water storage was calculated as follows:

$$\theta = h \times \gamma \times b \times 10 \tag{1}$$

where θ (mm) is the soil water storage, h (cm) is the soil depth, γ (g cm^{-3}) is the soil bulk density at different layers, and b (%) is the percentage of soil moisture in weight [14].

Evapotranspiration was calculated as follows:

$$ET = P + I + G - D - R - \triangle W \tag{2}$$

where ET (mm) is the evapotranspiration, P (mm) is the precipitation, I (mm) is the irrigation volume, G (mm) is the groundwater recharge, D (mm) is the drainage from the root zone, R (mm) is the surface runoff, and ΔW (mm) is the difference in soil water storage between before sowing and at harvest [16]. G and D were ignored in this study because the groundwater contribution from the water Table 50 m below the surface and drainage out of the root zone were not considered [17]. Surface runoff was zero because the topography was flat. ΔW was either positive or negative. Therefore, evapotranspiration was calculated based on precipitation, irrigation volume, and the change in soil water storage as follows:

$$ET = P + I - \Delta W \tag{3}$$

WUE was defined as follows:

$$WUE = Y \div ET \tag{4}$$

where WUE (kg ha^{-1} mm^{-1}) represents the water-use efficiency for the grain yield, Y (kg ha^{-1}) is the grain yield, and ET (mm) represents evapotranspiration [18].

Finally, the net benefit was calculated using the following equation:

$$N = YI - TI \tag{5}$$

where N ($ ha^{-1}) is the net benefit, YI ($ ha^{-1}) is the yield income, and TI ($ ha^{-1}) is the total input. The total input considered fertilizer, seed, seeding cost, harvest cost, and the cost of tillage.

2.3. Statistical Analysis

Analysis of variance (ANOVA) and principal component analysis (PCA) were carried out using the SAS 6.2 program. The statistical significance of a treatment effect was determined using the F-test. Duncan's multiple range test was used for multiple comparisons of means ($p \leq 0.05$) [19].

3. Results

3.1. Soil Water Storage

In 2016, the soil water storage after maize harvest significantly increased under M_{25} and M_{50} treatments (8.40% and 7.79%, respectively) (Figure 2). Meanwhile, compared with the M_{100} treatment, the M_{25} and M_{50} treatments increased the soil water storage by 8.79% and 8.17%, respectively. In 2017, the replacement treatments increased soil water storage by 9.21–18.30% compared with CK. The M_{25} treatment resulted in the highest soil water storage (7.92%, 7.27%, and 8.32% higher than the M_{50}, M_{75}, and M_{100} treatments). The M_{25}, M_{50}, and M_{100} treatments significantly increased the soil water storage by 7.94%, 12.60%, and 12.47%, respectively, compared with CK, and 10.85%, 15.64%, and 15.51%, respectively, compared with M_{75} treatment. In 2019, the M_{75} treatment slightly reduced soil water storage; however, the M_{25}, M_{50}, and M_{100} treatments slightly increased the soil water storage compared with CK. The soil water storage under M_{50} treatment was 6.93% higher than in M_{75} in 2019.

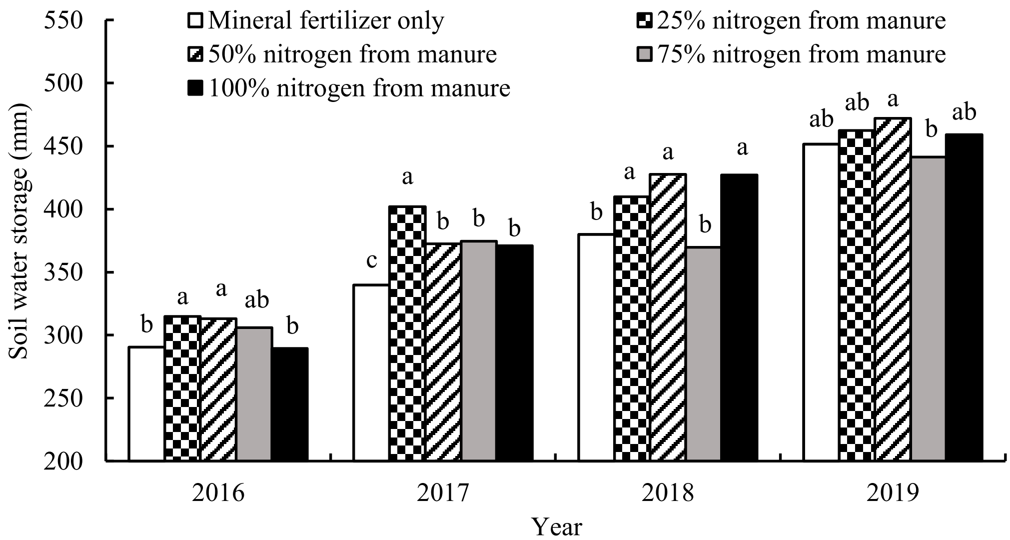

Figure 2. Soil water storage after replacement of mineral fertilizer with manure. Years × experimental variants equal 20. Different lowercase letters for the same year indicate significant differences at $p \leq 0.05$.

3.2. Evapotranspiration

The M_{25} and M_{50} treatments significantly decreased evapotranspiration by 6.92% and 6.41%, respectively, compared with CK, and by 7.19% and 6.68%, respectively, compared with the M_{100} treatment in 2016 (Figure 3). In 2017, the replacement treatments resulted in a 9.40–22.14% decrease in evapotranspiration. The M_{25} treatment significantly decreased evapotranspiration by 14.07%, 8.47%, and 9.12% compared with the M_{50}, M_{75}, and M_{100} treatments, respectively, whereas the M_{75} and M_{100} treatments significantly reduced evapotranspiration by 6.12% and 5.45%, respectively, compared with M_{50} treatment. In 2018, the M_{75} treatment significantly increased evapotranspiration by 7.10%, whereas the M_{25} and M_{100} treatments significantly decreased it by 5.27% and 9.43%, respectively, compared with CK. The M_{100} treatment significantly decreased evapotranspiration by 7.31% relative to the M_{50} treatment. The M_{25}, M_{50}, and M_{100} treatments significantly decreased evapotranspiration by 11.55%, 9.07%, and 15.72%, respectively, compared with the M_{75} treatment. In 2019, evapotranspiration significantly increased by 7.52% under the M_{75} treatment compared with CK, whereas it significantly decreased by 8.39% and 5.52% under the M_{25} and M_{50} treatments. Compared with M_{75}, the M_{25}, M_{50}, and M_{100} treatments significantly reduced evapotranspiration by 14.80%, 12.12%, and 10.52%, respectively.

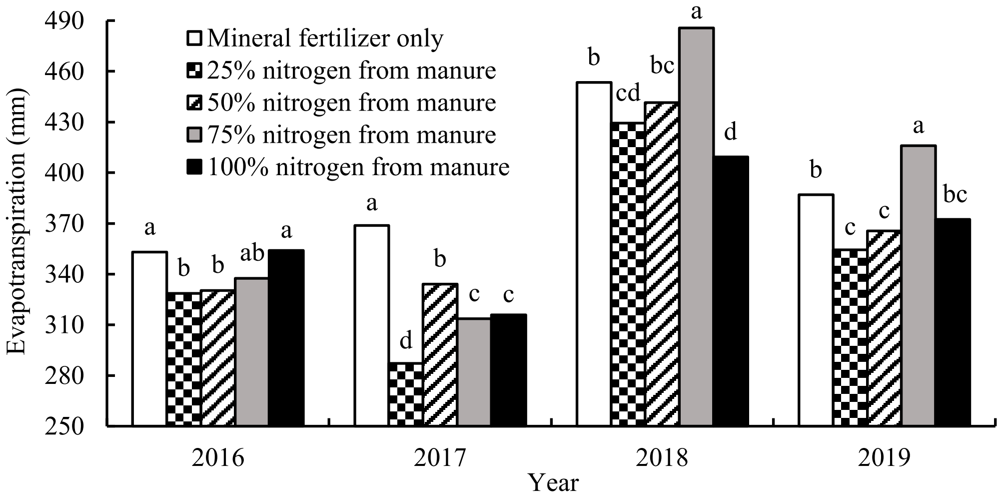

Figure 3. Evapotranspiration after replacement of mineral fertilizer with manure. Years × experimental variants equal 20. Different lowercase letters for the same year indicate significant differences at $p \leq 0.05$.

3.3. Maize Yield

M_{75} treatment slightly increased maize yield (grain dried to 14% moisture level) compared with CK in 2016, whereas the M_{25}, M_{50}, and M_{100} treatments slightly reduced the yield (Figure 4). The M_{25} treatment slightly increased maize yield, whereas the M_{100} treatment slightly decreased it compared with CK. In 2017, the M_{50} and M_{75} treatments significantly reduced maize yield by 9.58% and 7.91%, respectively, compared with CK. Meanwhile, the M_{25} treatment significantly increased maize yield by 19.90%, 17.72%, and 14.01% compared with the M_{50}, M_{75}, and M_{100} treatments, respectively. In 2018, the M_{100} treatment significantly decreased yield by 8.45% compared with CK. Maize yields under M_{25} and M_{75} treatments were 7.75% and 9.97% higher than M_{100} in 2018. In 2019, the replacement treatments significantly increased maize yield by 6.58–13.62% compared with CK. Among the various treatments, M_{75} significantly increased maize yield by 16.53% compared with the M_{25} treatment.

3.4. Water Use Efficiency

The M_{75} treatment significantly increased WUE by 5.56%, 8.18%, and 11.70% compared with CK, M_{50} and M_{100} treatments, respectively, in 2016 (Figure 5). The M_{25} treatment significantly increased WUE by 6.55% and 10.02% compared with the M_{50} and M_{100} treatments, respectively. In 2017, the M_{25} treatment significantly increased WUE by 39.20%, 39.51%, 28.64%, and 25.38% compared with CK, M_{50}, M_{75} and M_{100} treatments, respectively. The M_{75} and M_{100} treatments significantly increased WUE by 8.21% and 11.02%, respectively, compared with CK, and by 8.45% and 11.27%, respectively, compared with the M_{50} treatment. In 2018, the M_{75} treatment significantly decreased WUE by 6.01% relative to CK. The M_{25} significantly increased WUE by 6.32% and 10.78% compared with the M_{50} and M_{75} treatments, respectively. The M_{100} treatment significantly increased WUE by 7.89% relative to the M_{75} treatment. In 2019, the replacement treatments significantly increased WUE by 5.68–18.00% compared with CK. The M_{25}, M_{50}, and M_{100} treatments significantly increased WUE by 10.09%, 11.66%, and 6.63%, respectively, relative to the M_{75} treatment.

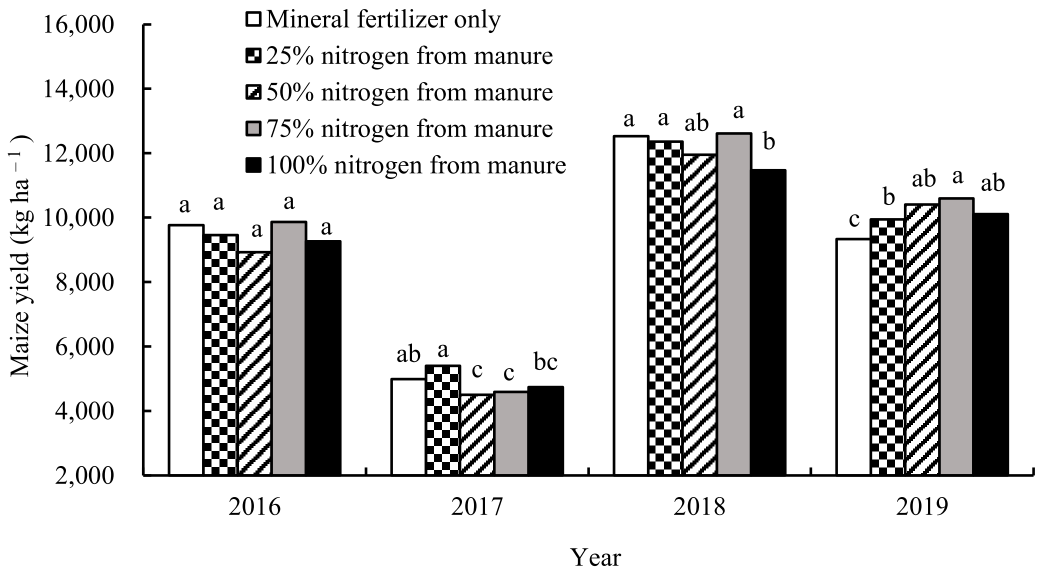

Figure 4. Maize yield after replacement of mineral fertilizer with manure. Years × experimental variants equal 20. Different lowercase letters for the same year indicate significant differences at $p \leq 0.05$.

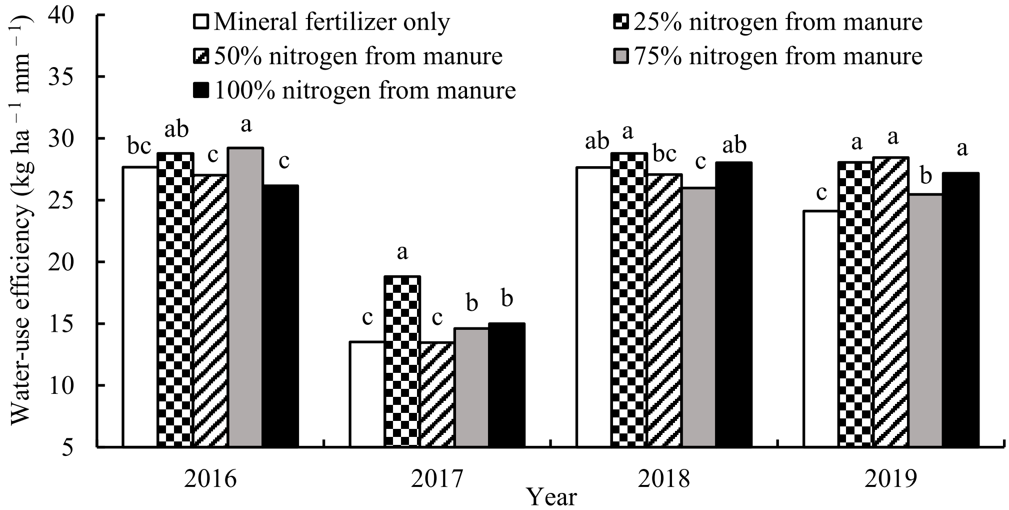

Figure 5. Water use efficiency after replacement of mineral fertilizer with manure. Years × experimental variants equal 20. Different lowercase letters for the same year indicate significant differences at $p \leq 0.05$.

3.5. Economic Benefit

The M_{75} treatment significantly increased net benefit by 11.13% (141.27 \$ ha^{-1}) compared with CK in 2016 (Figure 6). The replacement treatments significantly increased the net benefit by 6.87–38.01% (29.90 \$ ha^{-1}–165.39 \$ ha^{-1}) compared with CK in 2017. Meanwhile, the M_{25} treatment significantly increased net benefit by 29.14% (135.49 \$ ha^{-1}), 25.89% (123.48 \$ ha^{-1}), and 28.16% (131.94 \$ ha^{-1}) compared with M_{50}, M_{75}, and M_{100} treatments, respectively. In 2018, the M_{75} treatment significantly increased net benefit by 8.47% (171.67 \$ ha^{-1}) compared with CK. In 2019, the M_{25}, M_{50}, M_{75}, and M_{100} treatments significantly increased the net benefit by 16.29% (199.79 \$ ha^{-1}), 29.71% (364.44 \$ ha^{-1}), 35.51% (435.56 \$ ha^{-1}), and 23.27% (285.50 \$ ha^{-1}) compared with CK. The M_{75} treatment significantly increased net benefit by 6.60% (235.77 \$ ha^{-1}) and 9.92% (150.06 \$ ha^{-1}) compared with the M_{25} and M_{100} treatments, respectively, while the M_{50} treatment significantly increased net benefit by 11.54% (164.65 \$ ha^{-1}) compared with M_{25} treatment. These observations indicated that the net benefit increased from the first year under the M_{75} treatment and from the second year under the M_{25} and M_{50} treatments.

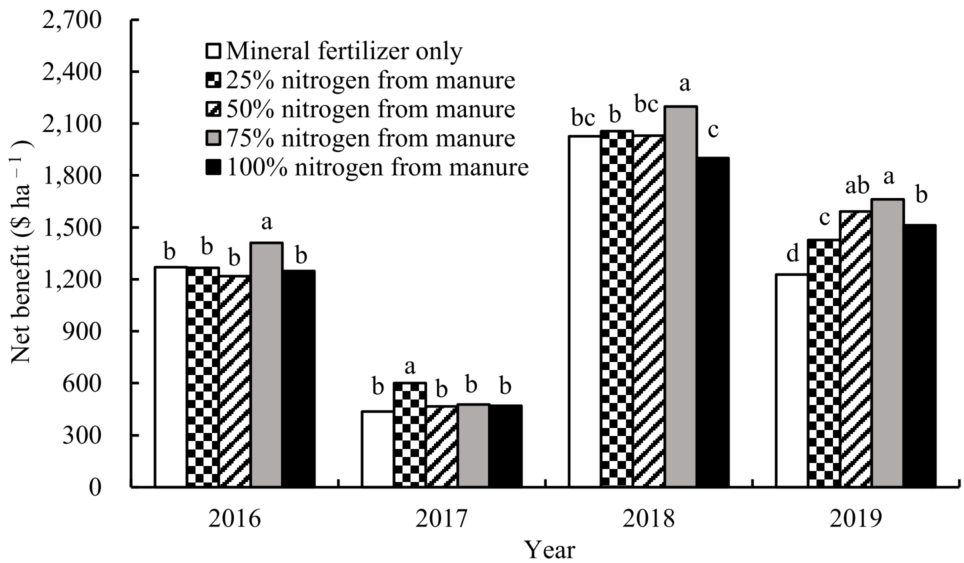

Figure 6. Net benefit after replacement of mineral fertilizer with manure. Years × experimental variants equal 20. Different lowercase letters for the same year indicate significant differences at $p \leq 0.05$.

3.6. Comprehensive Evaluation

Further, to evaluate the influence of each treatment, principal component analysis was performed using soil water storage (X_1), evapotranspiration (X_2), yield (X_3), WUE (X_4), and net benefit (X_5) as the evaluation variables. Principal components with characteristic values greater than 1.0 were selected for analysis based on all data from four years (Table S1). The first principal component replaced the original five indexes for comprehensive evaluation. Consequently, the first principal component contribution rate reached 69.83%, which mainly reflected the influence of evapotranspiration, yield, WUE, and net benefit (Table S2). Ranking based on the comprehensive score of principal components demonstrated that CK slipped down from the second position to the last during the experiment (Table S3). However, M_{25} treatment moved from the third position in 2016 to the first in 2017, back to third in 2018, and fourth in 2019. The M_{50} treatment moved from the fifth in 2016 to the fourth in 2017 and 2018 and then to the second in 2019. The M_{75} treatment moved from the first position in 2016 to the fifth in 2017 and then to the first in 2018 and 2019. The M_{100} treatment shifted from the fourth position in 2016 to the third in 2017, the fifth in 2018, and the third in 2019. On average of four years, the analysis identified M_{75} as the optimal treatment, followed by M_{25}, M_{50}, and CK treatments, whereas M_{100} was the poorest. These results indicated that combining manure with mineral fertilizer is better than mineral fertilizer alone in terms of soil water storage, evapotranspiration, yield, WUE, and the net benefit from the fourth year of fertilization. According to principal component analysis based on four-year average data, M_{25}, M_{50}, and M_{100} positively correlated with the first principal component (Figure 7). CK and M_{75} negatively correlated with the first principal component. M_{50} and M_{100} had a close distance, both located in quadrant IV, belonging to the same category. M_{25}, M_{75}, and CK were far apart, located in quadrants I, II, and III, respectively, belonging to different categories.

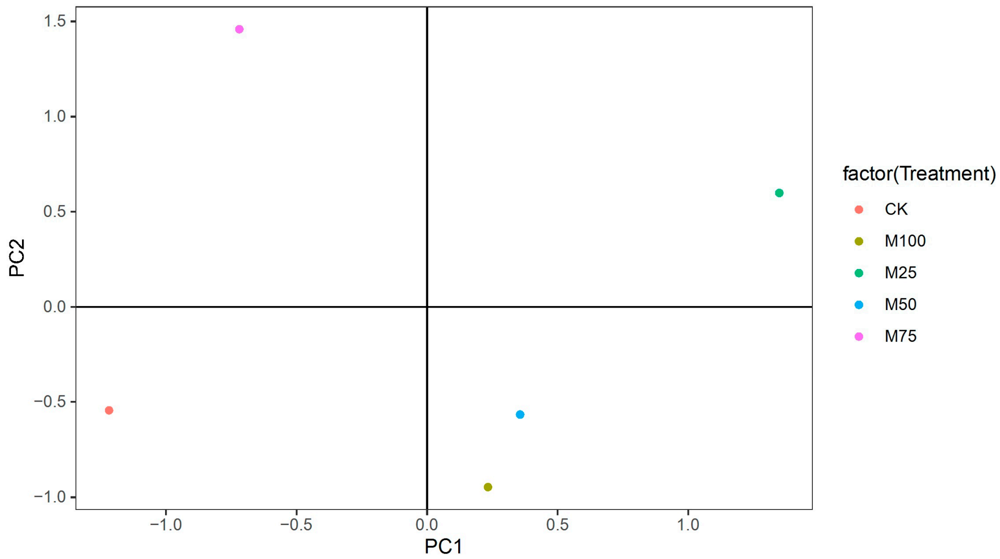

Figure 7. Principal component analysis based on four-year average data. Years × experimental variants equal 5.

4. Discussion

Rational proportional organic fertilizer instead of chemical fertilizer can improve soil moisture status. Soil structure also has a profound impact on soil moisture. The aggregate structure is related to the content of soil organic matter and the amount of organic fertilizer applied [20]. Bio-organic fertilizer substitution significantly reduced soil bulk density by 4.0–5.6% and enhanced soil porosity by 4.2–5.9% in the 0–40 cm soil layer. Moreover, bio-organic fertilizer substitution significantly increased soil-saturated hydraulic conductivity, and water content improved aggregate size distribution [21]. Water-stable aggregate texture can ensure the looseness of the soil surface, which is conducive to soil water permeability. The high rates of poultry manure alone could increase erodibility and decrease water retention [22]. This structure is characterized by loose aggregates and large non-capillary porosity, which can reduce the height and speed of water capillary movement in the soil and reduce the evaporation of water on the soil surface. Liu et al. [23] reported that manure combined with mineral fertilizer conserved the water content of the 0–100 cm soil profile compared with no fertilizer. Then, manure management significantly increased soil water stable macro-aggregates (>0.25 mm) compared to groups without manure in the 0–20 and 20–40 cm soil layers. Organic matter can change the soil's single-grain structure to the aggregate structure, thereby increasing the soil's ability to retain water and fertilizer and reducing the deep leakage of water and fertilizer [24]. Compared with no fertilization, the leaching solution volume of organic fertilizer treatment decreased 1.25–6.78%. Organic fertilizer can improve the harm of soil acidification and compaction caused by a single application of chemical fertilizer [25]. Soil porosity is one of the main factors affecting soil water evaporation capacity, and the large number of pores can promote the continuity of water rising movement [26]. Also, bio-organic fertilizer can improve soil water and fertilizer retention capacity by improving soil structure and achieving the effect of improving crop water and fertilizer use efficiency and yield [27,28]. In this study, the M_{75} treatment resulted in higher soil water storage and lower evapotranspiration in the first two fertilization years; meanwhile, the same treatment resulted in lower soil water storage and higher evapotranspiration in the third and fourth fertilization years. These could indicate that replacing 75% N chemical fertilizer with manure has an important influence on soil porosity percentage and soil structure. Then, the difference in soil water storage and evapotranspiration under the same replacement treatment is probably due to precipitation in different years and soil water vapor conditions. The replacement treatment significantly reduced the consumption of crop growth on the original water storage of farmland soil and showed that it could make full use of limited precipitation.

Reasonable fertilizer management is the key to high and stable yield of crops and soil fertility [29]. Good soil structure also provides the basis for the long-term use of organic fertilizer; thus, it promotes crop growth and yield formation and improves water use efficiency. On the other hand, the organic fertilizer itself contains a certain amount of nitrogen, phosphorus, and potassium content. The superposition effect of organic fertilizer and chemical fertilizer after application improves the soil moisture condition and also contributes to the transformation and accumulation of nutrient elements in the soil, which improves the soil nutrients, adds nutrients to the growth of aboveground crops, and realizes the increase of crop yield [30]. Zhang et al. [31] showed that the application of cattle waste compost for three years improved grain yields. The field water holding capacity of the soil changed when organic fertilizer was applied in combination with inorganic fertilizer. In this study, the difference in yield observed with the replacement of mineral fertilizer with manure was not the same in the four fertilization years. In 2019, the replacement treatments significantly increased maize yield by 6.58–13.62% compared with CK. Among the various treatments, M_{75} significantly increased maize yield by 16.53% compared with the M_{25} treatment. This inconsistency among the years may be due to the uneven distribution of precipitation among the months and years, which led to differences in the manurial effect. Moreover, we could presume the M_{75} treatment provided the most suitable water environment for mineralization decomposition and nutrient release of organic fertilizer. The replacement treatment coordinated the relationship between crop water consumption and grain yield and then caused the different WUE. The present study found that the M_{75} treatment significantly increased WUE in the first, second, and fourth years, whereas the same treatment significantly decreased WUE in the third fertilization year. This inconsistency may be due to the slight increase in yield and significantly higher evapotranspiration under M_{75} than CK in the third fertilization year.

Soil moisture is one of the factors of soil fertility. Soil moisture has a direct impact on soil air conditions and soil thermal conditions. Tillage soil with high fertility levels has good water holding capacity, which can better meet the needs of crop growth and development for water. Through the application of organic fertilizer and other soil management measures, proper regulation of soil moisture, water fertilizer, and water temperature control is conducive to improving the level of effective soil fertility and promoting crop yield [32]. In this study, replacement treatments significantly increased net benefit in 2017 and 2019, probably due to the higher precipitation and irrigation water. The observation thus indicated that replacement treatments could substantially enhance the net benefit in years with high rainfall and irrigation. In the case of increasing the application of organic fertilizer, reducing the application of chemical fertilizer can achieve the balance between fertilizer input income and reducing the amount of chemical fertilizer, which can not only take into account the income but also minimize the amount of chemical fertilizer.

Soil moisture is an important component affecting soil fertility and the material basis for plant survival and growth. Effectively increasing soil moisture content and reducing water consumption are the primary factors in improving soil productivity, improving the soil environment, and increasing crop yield [33]. Soil microbial flora and related enzyme activities also affect soil structure [34]. However, this study is mainly about fertilization and fertilization to ensure the normal supply of soil moisture in farmland under the premise that the changes in soil chemical and biological characteristics are still unknown. The next step is to make a comprehensive and in-depth analysis of the variation characteristics of soil structure, soil nutrients, soil microorganisms, soil moisture, and dissipation mechanism.

5. Conclusions

Replacing 50% or less of N provided by mineral fertilizer with the equivalent nitrogen provided by manure increased soil water storage after maize harvest and decreased evapotranspiration compared with mineral fertilizer alone. Meanwhile, 25% N as manure combined with 75% N as mineral fertilizer enhanced WUE. Moreover, N as manure instead of mineral fertilizer significantly increased maize yield over time. The net benefit under the replacement treatment was significantly high in the years with excess precipitation and irrigation. Meanwhile, 75% N as manure combined with 25% N as mineral fertilizer significantly increased net benefit in both the dry year and the wet year, indicating that this combination was the optimal one to increase maize yield and economic benefit.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/agronomy13123031/s1, Table S1: Explained variance in principal component analysis based on all data from four years. Years × experimental variants equal 20; Table S2: Component matrix for principal component analysis based on all data from four years. Years × experimental variants equal 20; Table S3: Comprehensive scores and ranking of the different treatments. Years × experimental variants equal 25.

Author Contributions: Conceptualization, X.W.; Funding acquisition, X.W.; Investigation, L.X.; Methodology, X.W.; Software, X.W.; Writing—original draft, X.W.; Writing—review and editing, X.W. and L.T. All authors have read and agreed to the published version of the manuscript.

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