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Article

The Effects of Different Rotations of Beans, Maize, and Cabbage on Soil Moisture and Economic Benefits

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Abstract: The article investigates the effects of different cropping rotations on soil moisture and economic benefit. Cabbage–maize–cabbage (CMC), beans–maize–cabbage (BMC), and cabbage–cabbage–cabbage (CCC) treatments were set up to study the effects of different crop rotation combinations on soil water storage, evapotranspiration (ET), water use efficiency (WUE), and economic benefit. The results showed that the average soil moisture content decreased initially and then increased with crop rotation, whereas it continued to decrease with continuous cabbage cropping as the crop grew. CMC reduced ET, whereas BMC increased ET from the nodulation to maturation stages of cabbage compared with CCC in the third experimental year. WUE of different crops showed that cabbage > maize > beans. The economic benefit of the CMC was higher than the other treatments in the third planting year. Therefore, the best crop rotation combination in this area is cabbage–maize–cabbage.

Keywords: crop rotation; evapotranspiration; soil moisture; water use efficiency; net income

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1. Introduction

Knotty cabbage (*Brassica oleracea* L. var. *capitata* L.) is often used as an economical vegetable. Its economic benefit is susceptible to the influence of the farming system [1]. This can reflect the degree of system suitability over time and improve the agricultural planting pattern dominated by maize and other food crops [2]. Maize (*Zea mays* L.) is one of the most important food crops in China. Fresh maize, also known as fruit maize, has more advantages than ordinary maize. Beans (*Phaseolus vulgaris* L.) are one of China's three major fruit and vegetable crops. It is a crop of the legume family that is susceptible to continuous cultivation barriers, has high economic benefits, and is often included in crop rotation [3]. Proper crop rotation can alleviate high soil water depletion caused by faulty planting patterns, improve the soil water environment to some extent, improve soil water utilization efficiency, and promote stable and increased crop yields [4]. China's water resources are chronically scarce, and irrigated agriculture is the dominant type of water use, with legume crops having the largest water deficit, followed by maize. Only 10% of the Loess Plateau is irrigated [5,6]. Shanxi is situated in the eastern region of the Loess Plateau. The area is characterized by severe soil erosion and a fragile ecological environment. The most significant challenge in crop cultivation is water scarcity. The only water that can be used in this region is atmospheric rainfall and soil water [7]. The initial soil water storage and the dynamic changes in rainfall and rainfall period will affect the root growth of crops, which will affect the yield [8]. Appropriate use of the Loess Plateau's unique ability to retain, store, and regulate crop water demand can significantly reduce the impact of drought due to the uneven spatial and temporal distribution of water [9]. Appropriate crop rotation can actively regulate soil moisture, reduce damage to soil physicochemical properties, form a good soil structure, improve soil water retention and moisture holding capacity [4], fully and effectively utilize soil moisture, achieve high yields and high economic benefits, and maintain sustainable development.

Previous studies have shown that under rain-fed conditions, cereal–legume rotation has higher yields, a strong ability to regulate soil moisture, and a greater potential for water production compared to continuous cropping. The rotation of different crops has a certain role in regulating the soil–water balance [10], Soil–plant water dynamics is an important determinant of crop yield. It can be improved with optimized irrigation strategies [11]. Wang et al. showed that the longer the number of years rotated, the more favorable the soil moisture recovery [8]. The dynamics of soil moisture are mainly influenced by rainfall distribution and evaporation throughout the year. The distribution of soil moisture during the critical reproductive period of crops has an important impact on their growth and development [12]. Drought and water scarcity, low soil quality, and low rainfall utilization are the primary factors limiting grain production in the Loess Plateau region [13]. Drylands cover over 41% of the world's land area, providing sustenance for approximately 40% of the global population. In China alone, dry lands support around 580 million people. Additionally, there has been an annual increase in dry land area [14]. Crop yield and water use efficiency in dry areas are influenced by natural precipitation and various factors, resulting in spatial and temporal heterogeneity. Appropriate crop rotation patterns may differ depending on the area. In this experiment, three crops with wide cultivation and high economic benefits were selected for open-air rain-fed cultivation in the semi-arid region of the eastern Loess Plateau after years of continuous maize cropping. The study analyzed the temporal and spatial characteristics of soil moisture changes and studied the effects of the cultivation pattern on the water-use efficiency and economic benefits of the crops. with an emphasis on the impacts in the third year of the experiment, to explore reasonable crop rotation combinations that can make full use of the rainfall during the crop's reproductive period, improve the efficiency of water use, enhance the yield of the crop, alleviate the depletion of soil moisture due to continuous cropping, and safeguard the health of a good soil environment.

2. Materials and Methods

2.1. Site Description

The experiment took place at the Shanxi Organic Dry Farming Research Center, located at the base of He Village in Yangqu County. The center is affiliated with Shanxi Agricultural University (112.89° E, 38.04° N). The location has an altitude of 1248.5 m and experiences an average annual precipitation of 440–450 mm. Rainfall is concentrated mostly in the summer, with less rain in the other three seasons. This area is typical of a semi-arid region in the eastern part of the Loess Plateau and has a temperate continental monsoon climate. The annual average temperature ranges from 6–7 °C, with frequent rain and temperature fluctuations between day and night exceeding 10 °C. The sum of temperatures at base temperature is approximately 2600 °C, and the area receives an annual sunshine of 2662 h. The frost-free period lasts for about 120–140 days. The site is flat, and there is no runoff. The soil is loess light brown soil. The basic physicochemical parameters before the start of the experiment at the 0–20 cm soil layer were as follows: Field water capacity 20.92%, pH 7.72, total nitrogen content 1.19 g/kg, total phosphorus content 0.7 g/kg, total potassium content 20.7 g/kg, available nitrogen content 54.63 mg/kg, available phosphorus content 9.57 mg/kg, and available potassium content 103.8 mg/kg. The main crops grown in this region are maize, cabbage, and beans, with one type cultivated per year. The cultivation of these crops is dependent on natural precipitation.

2.2. Experimental Design

The experiment was conducted from 2018 to 2020. The previous crop before the experiment was maize. It was a one-factor test that involved different crop rotations, culminating in the planting of cabbage in the third year. The experiment had three groups of treatments (Table 1), three replications, and a randomized block arrangement. Each plot measured 5 m north–south and 6 m east–west, with a total planted area of 30 m^2 or 0.003 ha. Compound fertilizer was applied each year before planting crops. The availability of nutrients in compound fertilizer was greater than or equal to 54%. The ratio of nitrogen, phosphorus pentoxide, and potassium oxide in compound fertilizer was 18:18:18. Cabbage was fertilized with 600 kg/ha compound fertilizer. Maize or beans were fertilized with 1200 kg/ha compound fertilizer. The fertilizers were applied annually. The experiment utilized "Shinong 307" nodular cabbage, "Red Pearl" beans, and "Jingke Glutinous 2000" fresh maize. The planting densities for cabbage, beans, and maize were 33,400 plants/ha, 64,000 plants/ha and 60,000 plants/ha, respectively. All three crops are flat planting. Beans were planted with plastic film mulch, whereas maize and cabbage were planted without plastic film mulch. During the 3 years, maize and beans were planted in the experimental plots on or about 13 May, and cabbage was sown on 10 June. The sowing was conducted after the precipitation had sufficiently wetted the top 0–10 cm layer of soil, ensuring that the crop could emerge. During the bean growth period, mature pods were harvested in a timely and batch manner. All crops were harvested before mid-September. The entire life cycle of the experimental field was dry cultivated without irrigation. The amount of precipitation during the reproductive period was automatically recorded by the weather station (Figure 1).

Table 1. Processing settings for the experiment.

Treatment	2018	2019	2020
CMC	Cabbage	Maize	Cabbage
BMC	Beans	Maize	Cabbage
CCC	Cabbage	Cabbage	Cabbage

Notes: CMC, BMC, and CCC mean cabbage–maize–cabbage, beans–maize–cabbage, and cabbage–cabbage–cabbage, respectively.

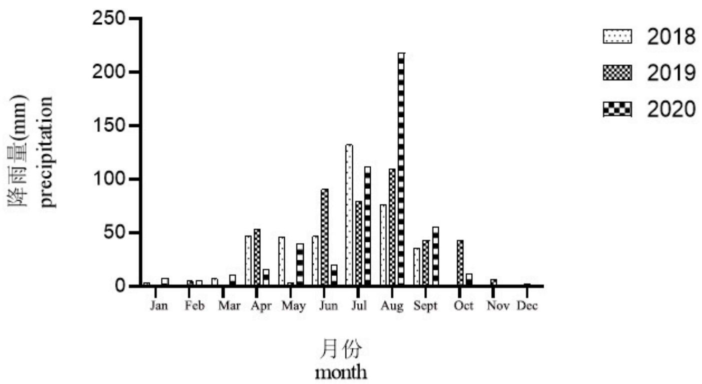


Figure 1. Precipitation in the experimental site.

2.3. Determination Items and Methods

2.3.1. Soil Water Content

The soil moisture content was determined to a depth of 200 cm at 20 cm increments at various growth stages of cabbage using the oven drying method in 2018 and the neutron meter method in 2019 and 2020. The stages for determination included before sowing, at the rosette stage, nodulation stage, and maturation stage. The stages of cabbage development were used as a criterion for determining the stages.

The sampling method of the oven drying method involved several steps. First, a 5 cm diameter soil drill was used to extract soil samples at regular intervals of 20 cm. These samples were then placed into aluminum boxes, which had a diameter of 5 cm and a height of 3 cm. Next, the weight of each soil sample was measured. After that, the samples were placed in an oven set at a temperature of 105 °C. They were dried until there was no further change in their weight, indicating that they had reached a constant weight. Finally, the samples were weighed again to determine the final weight.

The neutron meter method involved pre-burying a tube (one end is open and the other end is closed) with dimensions of 5 cm in diameter and 2.1 cm in length in the middle of each plot. The distance of the tube port from the ground was 10 cm. During measurement, the neutron meter was placed on the tube, and measurements were taken at 20 cm intervals.

The measured values were used to calculate the soil water storage capacity (mm) by converting them to either soil volumetric water content or soil mass water content, using the provided formula:

$$B = (m_1 - m_0)/m_0 \times 100\% \quad (1)$$

$$W = H \times D \times B \times 10 \quad (2)$$

where: m_1 represents the original soil weight (g), m_0 represents the drying soil weight (g), B represents the moisture content of the soil (%), H represents the depth of the soil (cm), D represents the soil bulk density (g/cm^3), and W represents the soil water content (mm).

2.3.2. Evapotranspiration and Water Use Efficiency

In the semi-arid test area, deep groundwater has little to no effect on runoff and deep seepage.

The formula is:

$$ET = P + \Delta W \quad (3)$$

$$WUE = Y/ET \quad (4)$$

where: ET is the evapotranspiration (mm); P is the rainfall (mm); ΔW is the difference in soil water storage between sowing and harvesting (mm); Y is the yield of the crop per unit area (kg/ha); and WUE is the water use efficiency (kg/(ha·mm)).

2.3.3. Crop Yield

During the three years, the following methods were employed: 20 plants per plot of cabbage were randomly selected and weighted at maturation. For the beans, pods were picked from 8 plants per plot and weighed. For maize, 20 plants per plot were randomly selected, and the female bracts of the ears were removed and weighed together with the maize cob shafts. The total weight was then converted to the required area yield.

2.3.4. Economic Benefit

After the crop has matured and been harvested over 3 years, the economic benefit = value of crop production per hectare obtained—the cost of cultivation per hectare.

2.4. Data Statistics and Analysis

The experimental data were processed, and graphs were created using Excel 2003 software (Charles Simonyi, Budapest, Ungarn). The ANOVA was analyzed using SPSS 18.0 software (IBM, Chicago, IL, USA), and the significance of the difference was tested using Tukey's method ($p < 0.05$).

3. Results

3.1. The Impact of Various Crop Rotation Combinations on Soil Water Retention

Soil moisture is closely related to crop type, period of duration, and precipitation during the period of duration. The soil water storage showed fluctuations over time (Figures 2–4). The pre-sowing soil water storage differed in 2019 and 2020. Precipitation was available for crop growth consumption from crop planting to the cabbage nodulation stage in both 2018 and 2020. However, it was not available for growth consumption from the cabbage nodulation stage to maturation. Precipitation was available for crop growth consumption from crop seeding to cabbage rosette, but not from cabbage rosette to maturation in 2019. Between the harvesting season of 2018 and the sowing season of 2019, the area received 62 mm of rainfall. Similarly, between the harvesting season of 2019 and the sowing season of 2020, the area received 90.9 mm of rainfall. The table shows that the soil's ET during the fallow period was higher after planting beans than after planting cabbage. In the 2018 experiment, differences in soil water storage from 0–200 cm were not significant among treatments at the pre-sowing, cabbage rosette, nodulation stage, and maturation stages. There were no differences in 0–200 cm soil water storage among CMC, BMC, and CCC treatments at the pre-sowing and cabbage rosette stages. At the nodulation stage of cabbage, 0–200 cm soil water storage was 0.87% higher in the BMC treatment compared to the CMC and CCC treatments. At maturation, the 0–200 cm soil water storage was 0.35% lower in the BMC treatment compared to the CMC and CCC treatments.

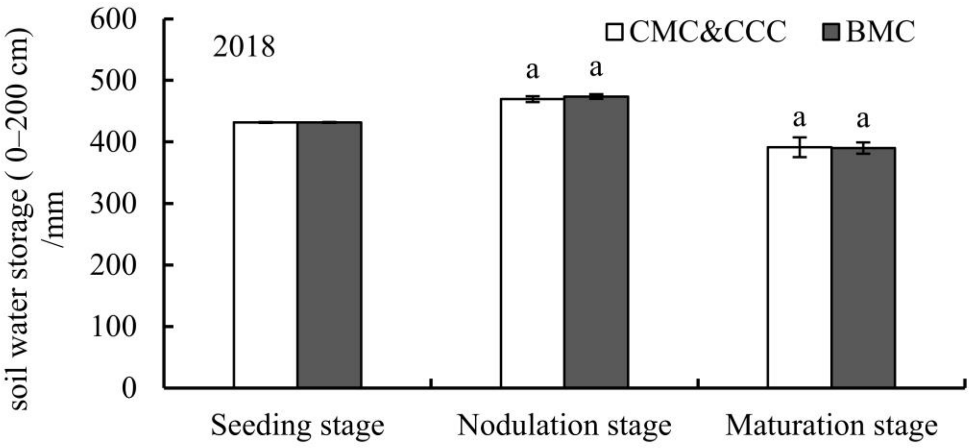


Figure 2. Soil water storage in 0–200 cm in 2018.

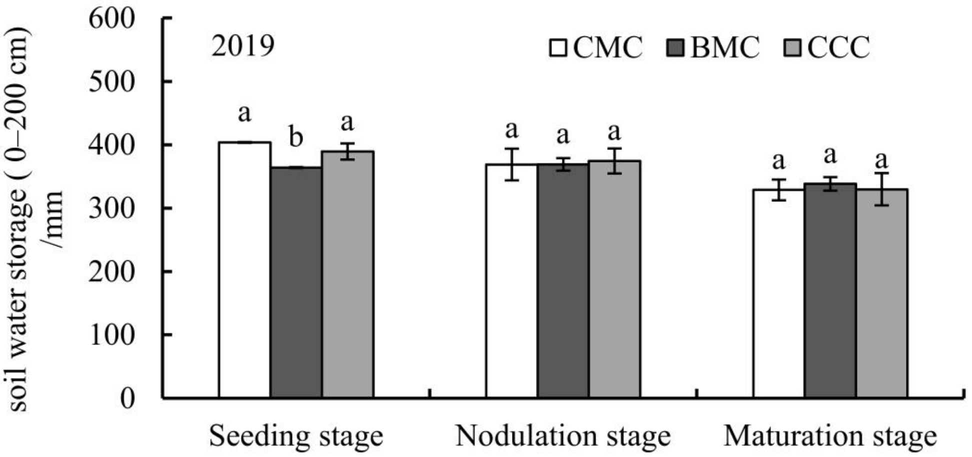


Figure 3. Soil water storage in 0–200 cm in 2019.

In the 2019 experiment, the 0–200 cm soil water storage was 3.68% higher in the CMC treatment than in the CCC treatment before planting, and significantly lower in the BMC treatment than in the CMC and CCC treatments, by 9.81% and 6.49%, respectively. There were no significant differences in soil water storage from 0–200 cm at the rosette, nodule, and mature stages of cabbage. The CMC and BMC treatments were reduced by 1.50% and 1.43%, respectively, compared to the CCC treatment at the cabbage nodulation stage. At maturation, the CMC treatment was 0.34% lower and the BMC treatment was 2.57% higher than the CCC treatment.

In the 2020 trial, differences in soil water storage from 0 to 200 cm were not significant among treatments at the pre-sowing, cabbage rosette, nodulation, and maturation stages. The 0–200 cm soil water storage of each treatment at the pre-sowing, cabbage rosette, and nodulation stages showed BMC > CC > CMC, whereas the 0–200 cm soil water storage of each treatment at the maturation stage showed CCC > BMC > CMC.

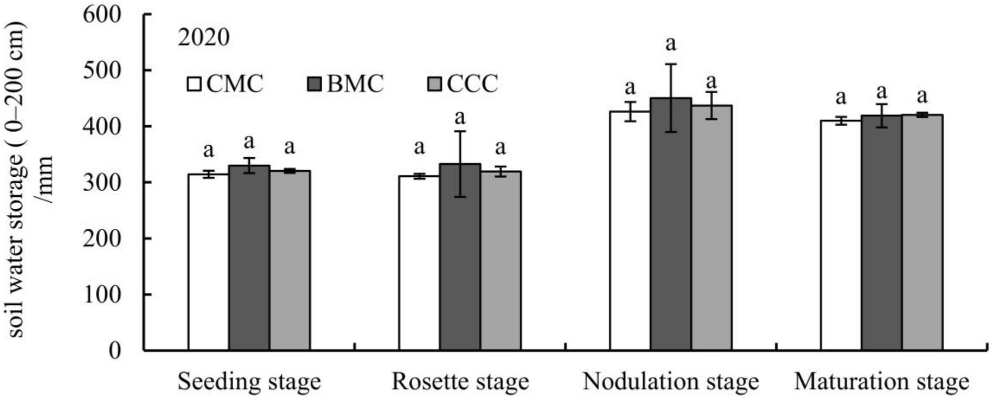
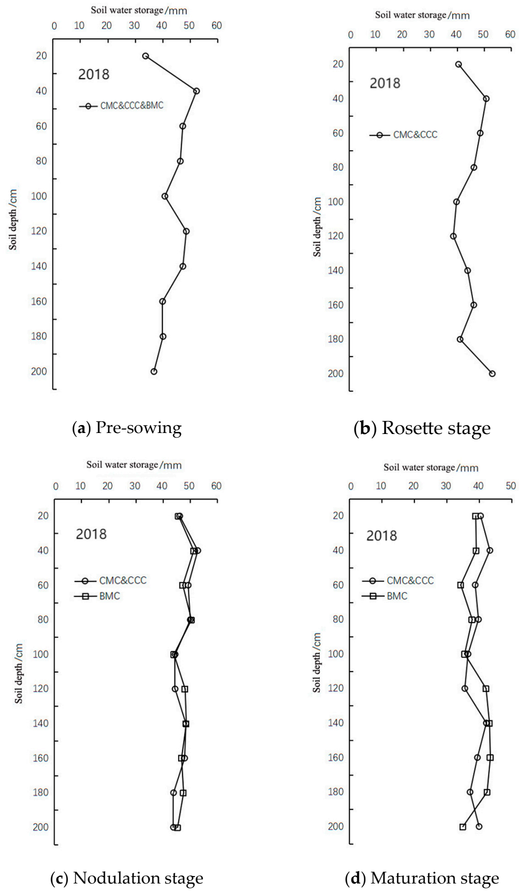


Figure 4. Soil water storage in 0–200 cm in 2020.

3.2. Effect of Various Crop Rotations on Vertical Changes in Soil Water Potential in the 0 to 200 cm Soil Horizon

The vertical analysis of soil moisture in the 0–200 cm soil layer during the crop reproductive period in 2018–2020 showed that the root system of cabbage was mainly concentrated in the 0–30 cm tillage layer, the main root of beans can grow up to 60 cm below the ground, the lateral root system was well developed with a wider radius of distribution, and the root system of maize could penetrate deeper into the ground with the main distribution area in the 0–80 cm soil layer. During the growth period of the crops, the changes in soil water storage in 0–80 cm of each treatment were more obvious, with a significant pattern of increasing and then decreasing, after which the changes in soil water storage in the soil layer were relatively small, and the soil water storage in 0–200 cm of each soil showed an overall trend of increasing, then decreasing, and then increasing with the depth of the soil layer in the different growth periods of crops, and the soil water storage was highest in the 20–40 cm layer of the soil before sowing.

Figure 5 shows the vertical variation of soil water storage in the 0–200 cm soil layer in 2018. The test site has been planted to maize for a long period, and the vertical change in soil water storage was the same across plots in 2018 for the different crops before planting (Figure 5a) and at the cabbage rosette stage (Figure 5b), with differences in soil water storage at the cabbage nodulation stage (Figure 5c) and maturation stage (Figure 5d). CMC and CCC treatments are the same, and CMB treatments are different. Soil water storage was lowest in the 0–20 cm soil layer before seeding, decreased in the 20–40 cm and 60–140 cm soil layers before seeding up to the cabbage rosette stage, and increased in the remaining layers. From the cabbage rosette stage to the cabbage nodule stage, soil water storage decreased in the 180–200 cm soil layer in the CMC, CCC, and BMC treatments, decreased in the 40–60 cm soil layer in the BMC treatment, and increased in the remaining soil layers. Soil water storage decreased in different soil layers in all treatments, from nodulation to cabbage maturation.

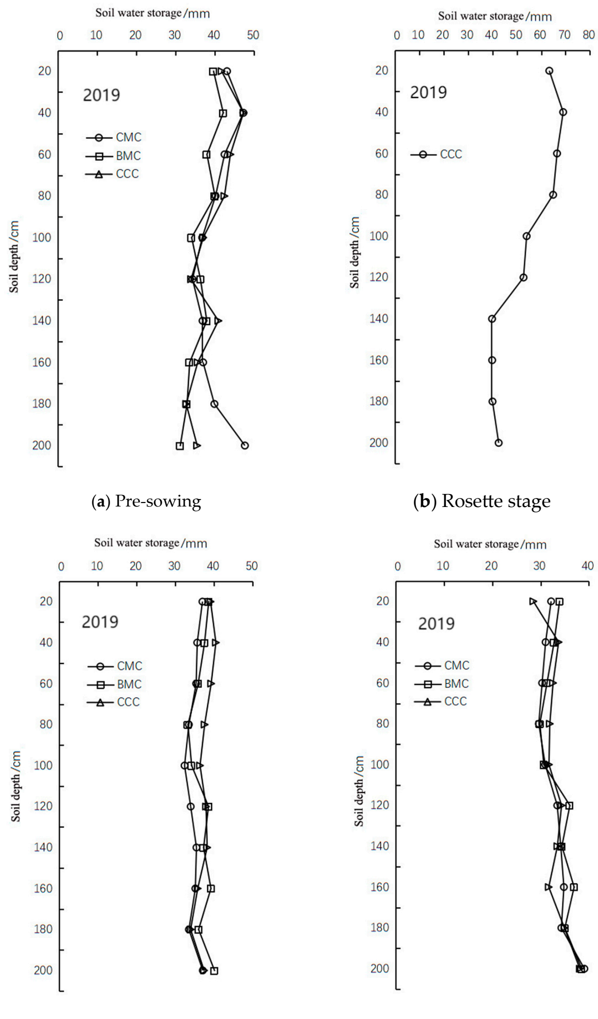


(**a**) Pre-sowing (**b**) Rosette stage

(**c**) Nodulation stage (**d**) Maturation stage

Figure 5. Changes in soil water storage in 0–200 cm soil layers in different growth periods of crops in 2018.

Figure 6 shows the soil water storage in the 0–200 cm soil layer in 2019, which differed between treatments at different growth periods of crops. Before sowing (Figure 6a), soil water storage in each soil layer 0–100 cm of CMC and CCC treatments was higher than that of BMC treatment, and within the 0–80 cm soil layer, soil water storage in each soil layer showed CCC > CMC > BMC treatments, and the average water storage was increased by 8.16%, 6.67%, and 6.45%, respectively, compared with that of the 2018 maturation period, indicating that planting cabbage was favorable for replenishing shallow soil moisture during the recovery period compared with the previous crop planted with beans. In the CCC treatment, soil water storage in the cabbage rosette stage (Figure 6b) was lower than that in the 120–140 cm soil layer before sowing, and water storage in the remaining soil layers was higher; in the CCC treatment, soil water storage in the cabbage nodule stage (Figure 6c) was lower than that in the rosette stage in all soil layers and lower than that in the 0–100 cm and 120–140 cm soil layers before planting; in the maize stolon stage, which coincided with the nodule stage, soil water storage in the 60–100 cm layer was lower in the CMC and BMC treatments than in the planting stage. In the maize stubble stage, which coincided with the cabbage balling stage, soil water storage in all soil layers decreased in the CMC treatment compared with that before sowing, and the changes in soil layers in the BMC treatment were the same as those in the CCC treatment, and water storage in the 60–100 cm soil layer was lower in the CMC and BMC treatments. From cabbage nodulation to cabbage maturation (Figure 6d), soil water storage in the 0–160 cm soil layer decreased in all treatments, and soil water storage in the 160–200 cm soil layer increased in the CMC and CCC treatments, replenishing deeper soil moisture.



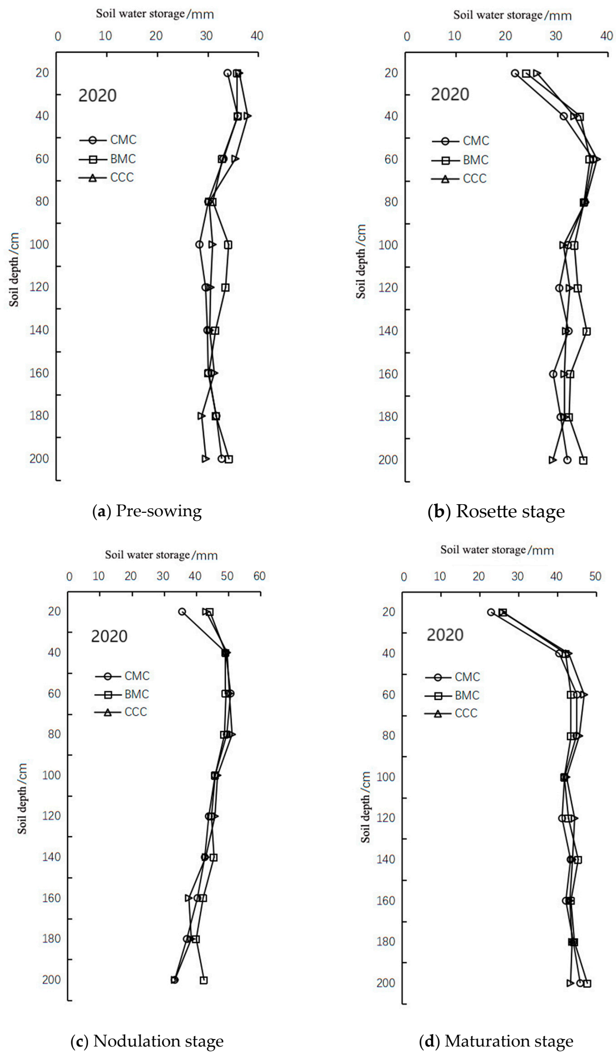
(**a**) Pre-sowing (**b**) Rosette stage

(**c**) Nodulation stage (**d**) Maturation stage

Figure 6. Changes in soil water storage in 0–200 cm soil layers in different growth periods of crops in 2019.

Figure 7 shows the soil water storage in the 0–200 cm soil layer in 2020. Before sowing (Figure 7a), BMC and CCC treatments 0–160 cm soil water storage in each soil layer was higher than the CMC treatment, CMC and BMC treatments 0–60 cm soil water storage in each soil layer was lower than the control CCC treatment, and the average change in water storage in 0–80 cm of CMC, BMC, and CCC treatments was small, and it was increased by 8.15% compared to the 2019 cabbage maturation stage, 6.29% and 10.50%, shallow-rooted crops planted two years in a row were favorable for replenishing shallow soil moisture during the recovery period, deep-rooted and shallow-rooted crop rotations differed in soil moisture changes during the recovery period due to different rotational crops, and the beans–maize rotation was more favorable for replenishing and accumulating soil moisture in the tillage layer during the recovery period than the cabbage-maize rotation. Relative to pre-sowing, soil water storage decreased at 0–40 cm and increased at 40–140 cm in all cabbage rosette treatments (Figure 7b); soil water storage at 40–80 cm was lower than the other treatments in the BMC treatment at the rosette stage and higher than the other treatments at 80–200 cm. Soil water storage in all layers of cabbage increased in all treatments at the nodulation stage (Figure 7c) compared to the rosette stage, with higher storage at 40–80 cm, lower storage at 160–200 cm, higher soil water storage at 60–120 cm in the CCC treatment than the rest of the treatments, and higher soil water storage at 120–200 cm in the BMC treatment than the rest of the treatments. At the maturation stage of cabbage (Figure 7d), the soil water storage capacity of each soil layer from 0–120 cm in the

CCC treatment was higher than the other treatments, and the highest water storage capacity of the soil layers in the CMC, BMC, and CCC treatments were 180–200 cm, 180–200 cm, and 40–60 cm, respectively.



(**a**) Pre-sowing (**b**) Rosette stage (**c**) Nodulation stage (**d**) Maturation stage

Figure 7. Changes in soil water storage in 0–200 cm soil layers in different growth periods of crops in 2020.

3.3. Effect of Different Crop Rotation Combinations on ET

Table 2 shows the stage ET during the 3 years when the planted crop was cabbage. Different crop rotation combinations and stage rainfall all affected the stage ET of cabbage, and the stage rainfall varied greatly during the 3 years. In 2020, the ET of cabbage treatments from sowing to rosette stage was ranked from high to low as CMC > CCC > BMC treatments, with no significant difference. The CMC and CCC treatments consumed slightly more water than rainfall, and the ET of all treatments increased compared to that of cabbage at the same fertility stage in 2018 and 2019, and was significantly higher than that of cabbage treatments planted in 2018, which may be related to the fact that there was less rainfall at this stage of the 2018 season and the drought early in the year delayed growth, which could only absorb less water from the shallower tillage layer. In 2019, the rainfall from the cabbage rosette stage to the bulb stage was very small, only 2.2 mm, which was ineffective rainfall, and the cabbage growth could only consume the pre-storage water in the soil, and the ET within the same growth period of cabbage in 2018 and 2019 was significantly higher than that in 2020, and the ET within the same growth period of cabbage in 2020 was much lower than the rainfall. There was no significant difference in ET from the nodulation stage to the maturation stage of cabbage in three years, and all of them were higher than the rainfall. Natural rainfall was difficult to meet the crop growth demand, and soil moisture was absorbed to ensure the accumulation of substances. In 2020, there was no significant difference in ET between treatments at different fertility stages, with the CMC treatment consuming 24.45% more water than the CCC treatment from rosette to nodule stage of cabbage and the BMC treatment consuming 13.88% more water than the CCC treatment from nodule stage to maturation.

Table 2. Effects of different rotation combinations on phased evapotranspiration of cabbage.

Year	Treatment	Seeding Stage—Rosette Stage		Rosette Stage—Nodulation Stage		Nodulation Stage—Maturation Stage	
		Evapotranspiration/mm	Rainfall/mm	Evapotranspiration/mm	Rainfall/mm	Evapotranspiration/mm	Rainfall/mm
2018	CMC and CCC	31.3 b	46.2	155.4 a	178.5	115.3 a	37.1
2019	CCC	107.5 a	248.3	158.0 a	2.2	72.9 a	28.3
2020	CMC	133.8 a	130.3	13.3 b	128.6	105.8 a	89.5
	BMC	127.8 a	130.3	10.9 b	128.6	120.9 a	89.5
	CCC	131.6 a	130.3	10.7 b	128.6	106.2 a	89.5

Notes: CMC, BMC, and CCC mean cabbage–maize–cabbage, beans–maize–cabbage, and cabbage–cabbage–cabbage, respectively. Different letters show significant differences within treatment at $p < 0.05$ in the same column.

3.4. Effects of Different Crop Rotation Combinations on Crop Economics and Water Use Efficiency

The ultimate impact of crop rotation on crops and soils is manifested in changes in crop ET, economic efficiency, and WUE. As shown in Table 3, the economic benefits of different crops during the three years were cabbage > beans > maize, and the economic benefits and WUE changed more consistently in the third year of the rotation, and the order from high to low was CMC > CCC > BMC; the highest total ET during the reproductive period was in the second year of the rotation, and the sum of total ET during the reproductive period of CMC, BMC, and CCC increased by 27%, 40%, and 51.96% compared with the first year of the rotation and the third year of the rotation, respectively, and a significant difference was found between maize and cabbage among all rotation treatments. Forty percent and 51.96% compared to the first year of rotation and the third year of rotation, respectively, and there was a significant difference between maize and cabbage among all rotation treatments; 27.40% and 51.96%, the total ET during the reproductive period from high to low was maize > beans > cabbage. There was a significant difference in ET between maize and cabbage in all rotation treatments, and there was no significant difference among the three treatments of CMC, BMC and CCC in the first and third year of rotation. WUE was highest in the third year of rotation compared with other years, but the differences between its three treatments of CMC, BMC, and CCC were not significant, and the WUE of the crop showed cabbage > maize > beans, and there were significant differences between beans, maize, and cabbage, and compared with the CMC and CCC treatments in the first year of rotation, the WUE of cabbage in the other years of rotation was significantly higher, and the CCC control group in the third year of rotation was 23.92% higher than it.

Table 3. Effects of different rotation combinations on economic benefits and water use efficiency of crops.

Year	Treatment	Yield (kg/ha)	Cultivation Costs (Yuan)	Corp Prices (Yuan/kg)	Economic Benefit (Yuan/ha)	Evapotranspiration during the Growth Periods of Crops (mm)	Water Use Efficiency (kg·(ha·mm)$^{-1}$)
2018	CMC and CCC	67,944.4	661.25	1.3	87,666.48	302.1 d	225.39 b
	BMC	10,222.2	1164.31	6.3	63,235.55	303.5 d	33.72 c
2019	CMC	20,600.0	1112.80	2.0	40,087.20	433.6 a	47.54 c
	BMC	18,450.0	1112.80	2.0	35,787.20	384.4 b	47.96 c
	CCC	83,055.6	626.37	1.0	82,429.23	338.4 c	247.74 ab
2020	CMC	69,916.0	506.67	1.6	111,358.93	252.9 e	276.75 a
	BMC	64,554.9	506.67	1.6	102,781.17	259.6 e	248.83 ab
	CCC	69,388.2	506.67	1.6	110,514.45	248.5 e	279.31 a

Notes: CMC, BMC, and CCC mean cabbage–maize–cabbage, beans–maize–cabbage, and cabbage–cabbage–cabbage, respectively. Different letters show significant differences within treatment at $p < 0.05$ in the same column.

4. Discussion

In this study, the trend of total soil water storage at the 0–200 cm soil layer in various treatments was similar in different years, and the overall performance was that soil water storage first increased and then decreased with crop growth, which was consistent with the research of Li et al. on the law of change in soil water storage in farmland in the typical hilly area of the Eastern Loess Plateau [15]. This is due to the rainfall being mainly concentrated in June–August; crop planting pre-growth is slow; there is less absorption of water; high rainfall and low ground cover increase soil moisture evaporation and percolation; and soil water storage capacity increases. Crop growth in the middle and late stages is a critical period of biomass accumulation, water demand, rain, and heat. At the same time, the rainfall makes it difficult to meet the crop growth of water demand and the consumption of soil water storage, so the water storage capacity decreased. From 2018 to 2020, the total soil water storage at the 0–200 cm soil layer before sowing showed a decreasing trend, which was due to the lack of rainfall under non-irrigation conditions, which caused crop growth to continuously consume soil water. This is the same as the part of the research results of Han et al. [16], where 6-year-old alfalfa land was not ploughed and then cultivated with rapeseed and wheat.

Different crop types have different growth characteristics, such as differences in the degree of root development, critical water demand periods, and productivity levels, all of which can lead to differences in vertical changes in soil moisture between treatments. The maize root system is mainly distributed in the soil layer of 40–60 cm; cabbage is mainly distributed in the soil layer of 50–60 cm, with a distribution diameter of up to 1 m, with strong fertilizer-absorbing capacity and weak drought resistance; and beans are primarily found in the soil layer of 15–40 cm, with a distribution diameter of up to 60–80 cm. With strong fertilizer absorption capacity and highly drought resistant. The rooting capacity of beans is much greater than that of maize, and the rooting densities and root pore numbers of all crops gradually decrease with an increase in the depth of the soil layer [17]. In this study, the highest soil water storage capacity was in the 20–40 cm soil layer before planting crops, and the shallow 0–80 cm soil layer on the surface met the water demand of crops and evaporation and transpiration. The change in soil water storage capacity was more obvious, and there was a significant law of increasing and then decreasing. The 140–200 cm deep soil water storage was the unutilized infiltrated moisture of the crop, and the BMC treatments had higher water storage per layer than before sowing at maturation during the three-year planting period (except 180–200 cm in 2018), and the deep water storage was higher in all BMC rotation treatments than in the CCC continuous cropping treatments after the crop matured, while there was a fluctuation in the CMC treatments, indicating that the BMC treatments stabilized the increase in the depth of infiltration of rainfall into the soil and the increase in the capacity of the deep soil to recharge water [18]. Tan et al., who studied the effect of compound crop rotation patterns on potatoes, found that, compared with continuous cropping, the soil water storage capacity of potatoes increased at all fertility stages under different crop rotation patterns, and the depth of infiltration of soil precipitation increased, which was partially similar to the results of the present experiment [19]. The differences in regional soil types, crop rotation patterns, and types of crops grown may lead to this difference [20]. In this study, the highest water storage capacity in the CMC, BMC, and CCC treatments was 180–200 cm, 180–200 cm, and 40–60 cm, respectively, at the maturation stage of cabbage, which indicated that crop rotation and continuous cropping would increase the depth of infiltration of rainfall into the soil, and that shallow-rooted crops would reasonably cooperate with deep-rooted crops in crop rotation to be more conducive to replenishing the deep soil water storage capacity.

From the analysis of crop rotation and continuous crop after the effect on cabbage water consumption and economic efficiency, cabbage stage water consumption is related to the rainfall of this stage, the rainfall of the previous stage, and the period of fertility, and the appropriate amount of rainfall can improve the crop WUE [21]. With the increase in planting years, the rainfall during the reproductive period of cabbage increased year by year, the water use efficiency increased, the evapotranspiration during the reproductive period had a significant trend of increasing and then decreasing, and the evapotranspiration during the reproductive period was the highest in the second year of continuous cropping. This is the same as the change rule of water consumption of alfalfa backcrop studied by Tucker [22], but unlike the results of Mao et al., meteorological conditions may be one of the influencing factors [23]. In this study, the ET within the same growth period of cabbage was much lower than the rainfall in 2020, which was probably due to the over-absorption of water during the pre-storage period, resulting in the inhibition of bulb binding. The magnitude of differences between treatments in terms of economic benefits and water use efficiency, in addition to being associated with different treatments, was strongly correlated with the level of soil water storage (Bai et al., 2014 [24]), which decreased from year to year before planting. Soil water storage was lower in the third year of crop rotation. It showed that the mean value of water storage during the whole reproductive period BMC > CCC > CMC, total ET of cabbage BMC > CMC > CC, economic efficiency of cabbage crop CMC > CCC > BMC, and water use efficiency of cabbage CCC > CMC > BMC, and there was no significant difference in all of these.

5. Conclusions

The soil water storage capacity of the 20–40 cm soil layer was the largest before sowing. The soil water storage capacity of the 140–200 cm soil layer of the beans–maize–cabbage rotation was mostly higher at the maturation stage than before sowing, which helped to improve the deep soil environment. Except for the cabbage bulb stage and the ripening stage, the natural precipitation can satisfy the water demand of the crop. From an economic perspective, considering the supply and demand of water, the cabbage-maize-cabbage rotation is the most suitable cropping system for the region. Beans–maize–cabbage rotation is not suitable to replace the continuous cropping of cabbage in terms of WUE.

In the future, it will also be possible to study the effects of different crop rotations on soil microorganisms in the region and further investigate the factors that influence them to improve yield and economic efficiency.

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