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Effect of Terracing on Soil Moisture of Slope Farmland in Northeast China's Black Soil Region

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Abstract: The impact of terracing construction on the soil moisture content of slope farmland was analyzed at three sites in northeast China's black soil region, across a range of latitudes and hydrological, temperature and soil quality conditions. At each research site, slope farmland with terracing was compared to unterraced slope farmland with a similar shape and gradient. During the wet crop growth period (July) and dry postharvest period (October) of 2022, the TRIME-PICO64TDR soil moisture measuring instrument was used to measure the soil moisture content at depths of 0–60 cm. Terracing increased soil moisture content by up to 2.83 percentage points during the crop growth period and by up to 1.69 percentage points during the postharvest period. Terracing had a significant impact on the volumetric soil moisture content of the shallower soil layer (0–30 cm) during the growing period, and on the volumetric soil moisture content of the deeper soil layer (30–60 cm) during the postharvest period. Terracing weakens the effect of slope position on volumetric soil moisture, reducing differences in volumetric soil moisture content among different slope positions. The difference in the water conservation benefit of terracing among the sites is mainly related to soil quality: the lower the soil bulk density and the higher the silt clay content is, the greater the benefit of terracing for retaining moisture. The findings of this study can be beneficial for guiding management measures for slope arable soil in black soil regions around the world.

Keywords: black soil region; terracing; soil moisture; growing season; harvest season; slope

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1. Introduction

Black soils are a globally important natural resource supporting agriculture, forestry, and prairie ecosystems. The black soil region of Northeast China is a major grain-producing area [1]. This region falls into the northern temperate semi-humid and semi-arid climate zones where soil moisture mainly comes from precipitation. Slope farmland accounts for 60% of the total agricultural land in the region, including moderate slopes of around 10% to extreme slopes of over 25%.

In recent years, heavy precipitation and freeze–thaw effects have led to severe soil and moisture loss on sloping farmland in the region, resulting in a decrease in land productivity [2]. As an important aspect of soil conditions, soil moisture drives plant evaportranspiration and soil evaporation [3]. It is a key influencing factor for soil moisture content and energy exchange in the soil–plant–atmosphere continuum [4]. Soil moisture content is affected by a wide range of hydrological factors, such as surface runoff, subsurface runoff, and groundwater recharge [5]. Soil moisture is also a key factor limiting plant growth [6], which largely determines land productivity. Research studies indicate that terracing can effectively improve soil texture, conserve water sources, and prevent soil erosion in central China's Loess Plateau area, with good water retention capacity [7–10]. However, the impact

of terracing measures on soil moisture is influenced by multiple factors [11]. Research has shown terraces may improve the soil moisture balance and increase soil moisture content by increasing surface water infiltration into deeper soil [12], but the impact on shallow and deep soil moisture needs further investigation.

At present, most studies in the Northeast China black soil region focus on the erosion processes of different land uses and types of slopes, as well as the impacts of various agricultural practices and vegetation covers on slope farmland erosion [13,14]. Nevertheless, the effect of soil and moisture conservation engineering measures—and specifically, terracing—On the soil moisture of slope farmland in black soil regions is poorly understood. Previous research on the moisture conservation benefits of terracing has mainly focused on central China's Loess Plateau area and southern China's red soil areas, where the soil type, topographic, and geomorphic characteristics are quite different from those of the black soil region. Accordingly, it is particularly important to study the impact of terracing construction on soil moisture of slope farmland in the black soil region and the role that terraces can play in moisture storage and moisture conservation for the development of black soil agriculture.

Prior studies have examined the spatial heterogeneity of soil moisture in the Northeast China black soil region at different time periods, concluding that the dominant factors affecting soil moisture vary by location [15] and by season due to differences in precipitation, land use and management practices [16,17]. For example, in semi-arid grassland areas, the soil texture, bulk density, and vegetation cover significantly affect the spatial and temporal stability of soil moisture in the dry season [18]. However, research on the temporal and spatial variability of dry season surface soil moisture on typical Karst Plateau slope lands found a strong spatial dependence, mainly affected by geological conditions and slope, indicating that the factors controlling soil moisture distribution are characterized by high temporal and spatial differences [19].

To date, most research on soil moisture in China has been conducted in the Loess Plateau region [20,21] and in areas subject to desertification [22,23]. By comparison, the Northeast China black soil region shows a relatively complex terrain and significant differences in the characteristics of soil and moisture loss from slope farmland. The suitability of soil and moisture conservation measures also greatly differs from that of those in loess and red soil areas. This article focuses on the prominent issue of intensified soil and moisture loss in slope farmland in the Northeast China black soil region. It explores the impact of agriculture terraces under different water, temperature and soil quality conditions, and the effects on the soil moisture of slope farmland during the crop growth period (with crops on the field, rainy season) and the postharvest period (with no crops on the field, dry season). It clarifies the regulatory effect of terracing construction on soil moisture in slope farmland in the black soil region and provides a scientific basis for the moisture storage and conservation work of slope farmland in the region.

2. Materials and Methods

2.1. Research Sites

For this study, three sites in the black soil region with typical terracing construction on slope farmland were selected (Figure 1). The sites represent different water, temperature and soil quality conditions. The first site, in Dongliao County of Liaoyuan Municipality, Jilin Province (43°01′ N, 125°24′ E), sits in a typical low mountain and hilly area, with an annual average temperature of 5.2 °C and an annual precipitation of 662 mm. The second site, in Bin County of Harbin Municipality, Heilongjiang Province (45°37′ N, 127°31′ E), consists of a mostly hilly landscape, with an annual average temperature of 4.4 °C and an annual average precipitation of 570 mm. The third site, in Keshan County of Qiqihar Municipality, Heilongjiang Province (48°30′ N, 125°49′ E), is located in the hilly transition zone between the Lesser Khingan Mountains and the Songnen Plain, with an annual average temperature of 2.4 °C and an annual average precipitation of 488.2 mm.

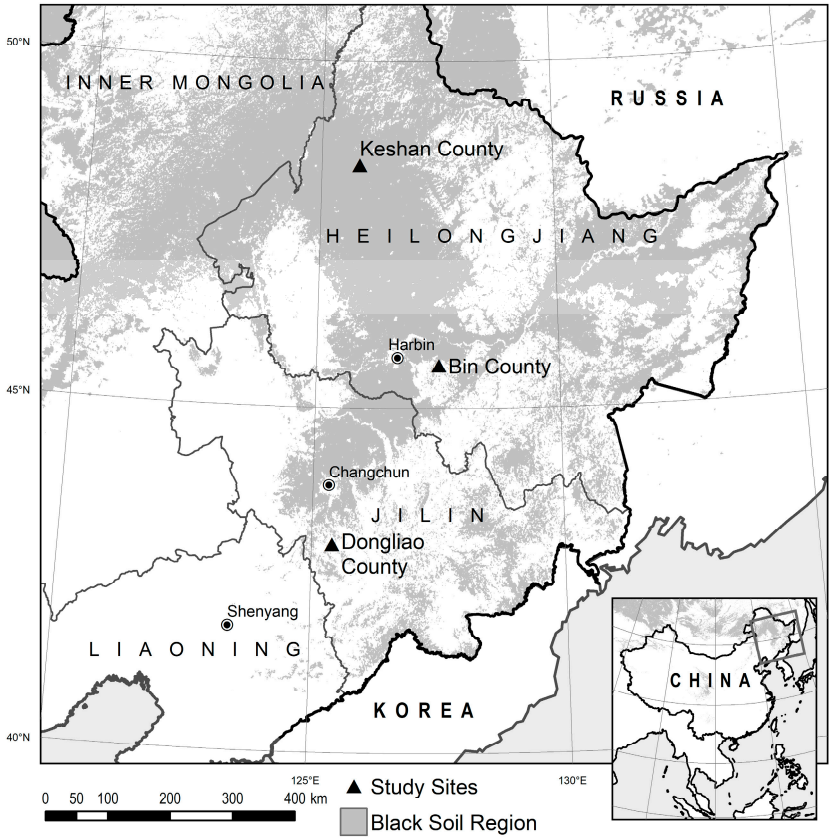


Figure 1. Locations of the study sites in the black soil region of Northeast China. (black soil distribution from United Nations Food & Agriculture Organization, GBS map 1.0).

2.2. Research Methods

2.2.1. Site Types and Sample Site Settings

Figure 2 shows the relative positions of the selected fields on the landscape. The selected terraced and sloping (control) fields in Dongliao County both range in elevation from 326 to 334 m. The selected terraced and sloping fields in Bin County have elevations of 286 to 294 m. The selected terraced and sloping fields in Keshan County have an elevation of 293 to 307 m. The terraces at three locations were excavated and filled on the basis of the original sloping farmland, which was transformed into a wide shaped terrace at the bottom. All of the plots are planted with corn (maize). In addition, the measurement points are all far away from roads, water sources, forests, etc.

At each site, we established three measurement transects corresponding to the elevation contours of three terraces midway up the hillside in the terraced fields (see Table 1). We designated these three levels as the upper, middle, and lower slope positions (but note that the upper slope position is not at the very top of the hillside, nor is the lower slope position at the very bottom, to avoid the effects of those extremes on soil moisture). To test the spatial variability of soil moisture within terraces [24], we further subdivided the terraced fields into inner, middle, and outer zones by distance from the previous higher terrace, resulting in 27 measurement points on the terraced fields. For comparison, we similarly subdivided the control fields, resulting in nine measurement points there.

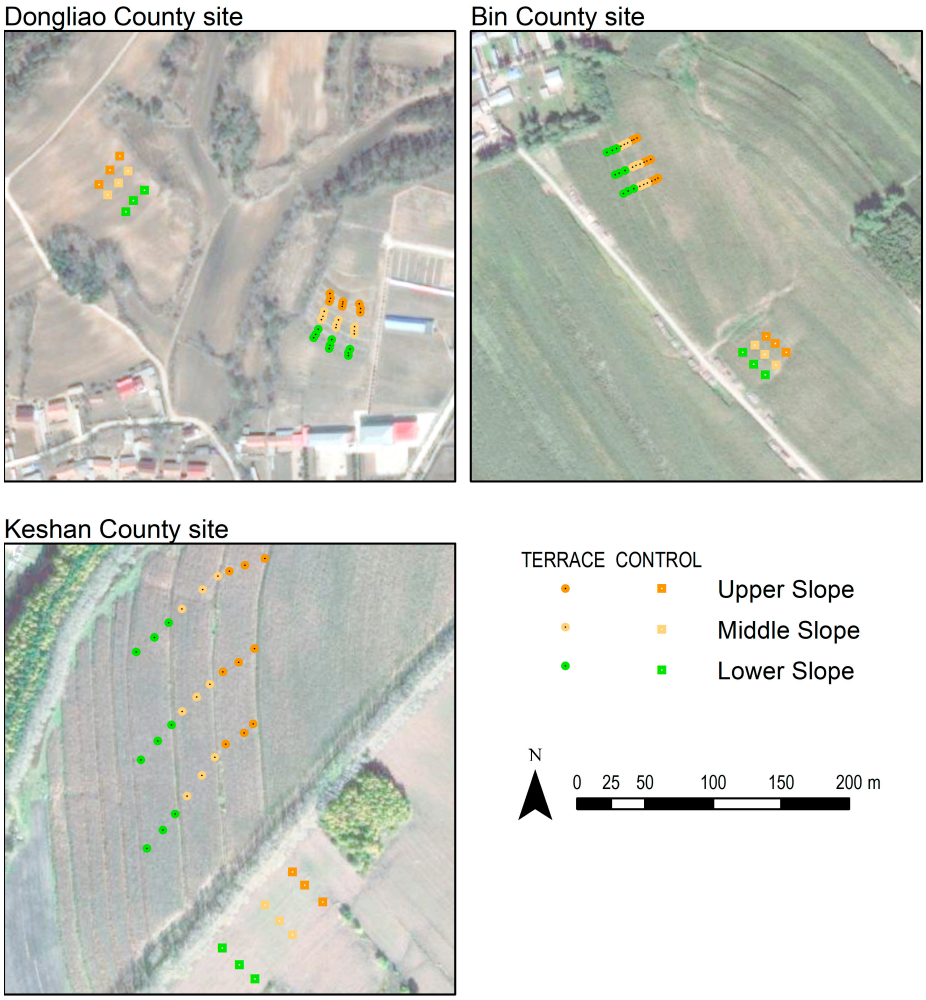


Figure 2. Landscape settings of the soil moisture measurement points on the terrace and control slopes. Imagery from Esri, Maxar, and Earthstar Geographics (Imagery from Esri ArcGIS 10.8.1 software).

Table 1. Elevations of measurement points and slopes of terraced and control fields.

	Terraced Plots			Control Plots		
	Minimum Elevation (m)	**Maximum Elevation (m)**	**Average Slope (%) from Upper to Lower**	**Minimum Elevation (m)**	**Maximum Elevation (m)**	**Average Slope (%) from Upper to Lower**
			Dongliao County			
upper	334.26	334.56		334.65	335.26	
middle	329.65	330.26	10.3	329.54	329.65	10.6
lower	325.98	326.26		325.11	325.65	
			Bin County			
upper	293.75	294.12		293.98	294.45	
middle	290.56	290.88	10.2	290.32	290.65	10.3
lower	286.01	286.98		286.32	286.54	
			Keshan County			
upper	305.65	306.88		306.95	307.65	
middle	299.58	300.22	9.6	300.56	301.25	10.1
lower	293.65	294.87		293.11	293.35	

2.2.2. Soil Property Measurement, Methods, and Meteorological Factors

We measured volumetric soil moisture in each of the terraced and control slope fields using the TRIME-PICO64TDR® soil moisture measuring instrument. TRIME-PICO64® is based on TDR (time domain reflection) technology, which calculates and displays soil

moisture content through the analog voltage output by the reading system, with high accuracy (The instrument is from Beijing Aozuo Ecological Instrument Co., Ltd., produced in Germany). Measurements were taken at all of the measurement points at each site on three dates during the crop growth period (July, panicle stage) and the postharvest period (October) of 2022 (Table 2). Measurements were made at every 10 cm of soil depth from 0 cm to 60 cm, repeated three times and averaged.

Table 2. Measurement dates at three sites in the crop growing and postharvest periods.

	Dongliao County	**Bin County**	**Keshan County**
Crop growth period	12 July 16 July 20 July	5 July 7 July 9 July	22 July 24 July 26 July
Postharvest period	12 October 15 October 18 October	22 October 24 October 26 October	6 October 8 Octobe 10 October

At the same time, a soil plane was excavated at each soil moisture measurement point, with a depth of 60 cm. At each moisture measurement location, aluminum boxes and a 100 cm^3 ring knife were used to take undisturbed soil samples. The samples were taken back to the laboratory for processing, and the ring knife method was used to measure soil bulk density, porosity, field water capacity, and capillary water capacity. The determination of the soil mechanical composition was performed using the pipette method, and the double ring knife method was used for measuring the soil infiltration rate. The soil pH value was measured using the potential method. The measurement of the distribution range of corn roots was completed through excavation and measurement at the experimental site. In addition, the calculation methods for some indicators are as follows:

$$SWS = \theta \times h \times 10^{-1}$$

where SWS is the soil moisture storage capacity in mm, θ is the volumetric soil moisture content expressed as a percentage, and h is the thickness of soil in cm [25]. We calculated δ Sw, representing the contribution to ecological services from soil moisture, as:

$$\delta\ Sw = SMt/SMs$$

where SMt is the soil water of terraced slopes and SMs is the soil moisture of the unterraced (control) slopes [26].

The precipitation and temperature conditions at the three sites have similar seasonal characteristics. July is the month with the highest precipitation and temperature, making that an important month for crop growth, while October has much less precipitation and is cooler (Figure 3).

2.2.3. Data Processing

For this study we used Excel 2010® and IBM SPSS Statistics26® software for data organization and statistical analysis; Canoco 5.0® software for redundancy analysis to analyze the relationship between soil moisture and influencing factors; and ArcMap10.8® and Origin2021® software for mapping. We applied one−way ANOVA and independent sample *t*-tests to evaluate the significance of differences and used the Pearson correlation method to analyze the correlation between soil properties (soil bulk density, total porosity, capillary water capacity, field capacity, clay, silt, sand, and pH) and water content. Significance levels were all set at 0.05.

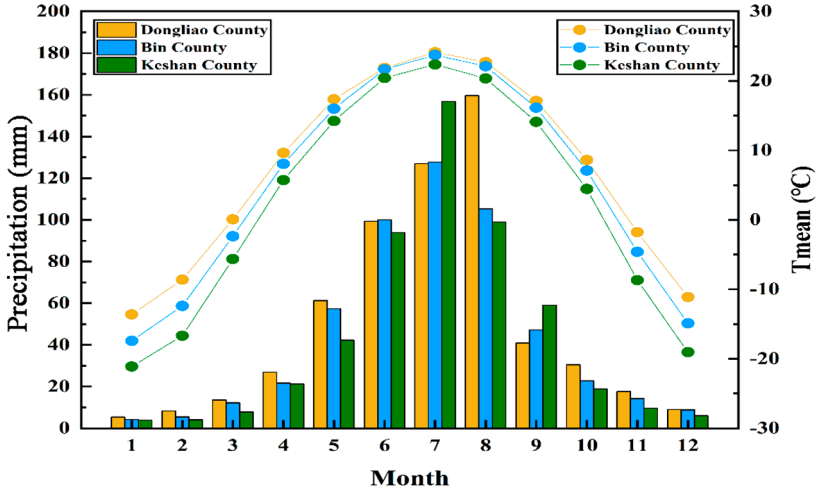


Figure 3. Monthly precipitation and air temperature (Tmean) at three sites.

3. Results and Analysis

3.1. Impact of Terracing on Soil Moisture during the Crop Growth Period

3.1.1. Characteristics at Different Depths

In order to analyze the changes in volumetric soil moisture after the construction of terracing on slope farmland, we calculated the spatial distribution of volumetric soil moisture at different soil depths on the three terraced slopes and three control slopes. As seen in Figure 4, there is strong consistency in the changes in volumetric soil moisture content with soil depth and along the slope at the three sites. The vertical variation of volumetric soil moisture content in both the terraced and control slopes shows a pattern of first increasing and then decreasing, with the maximum volumetric soil moisture detected at a depth between 10 and 30 cm depending on the site.

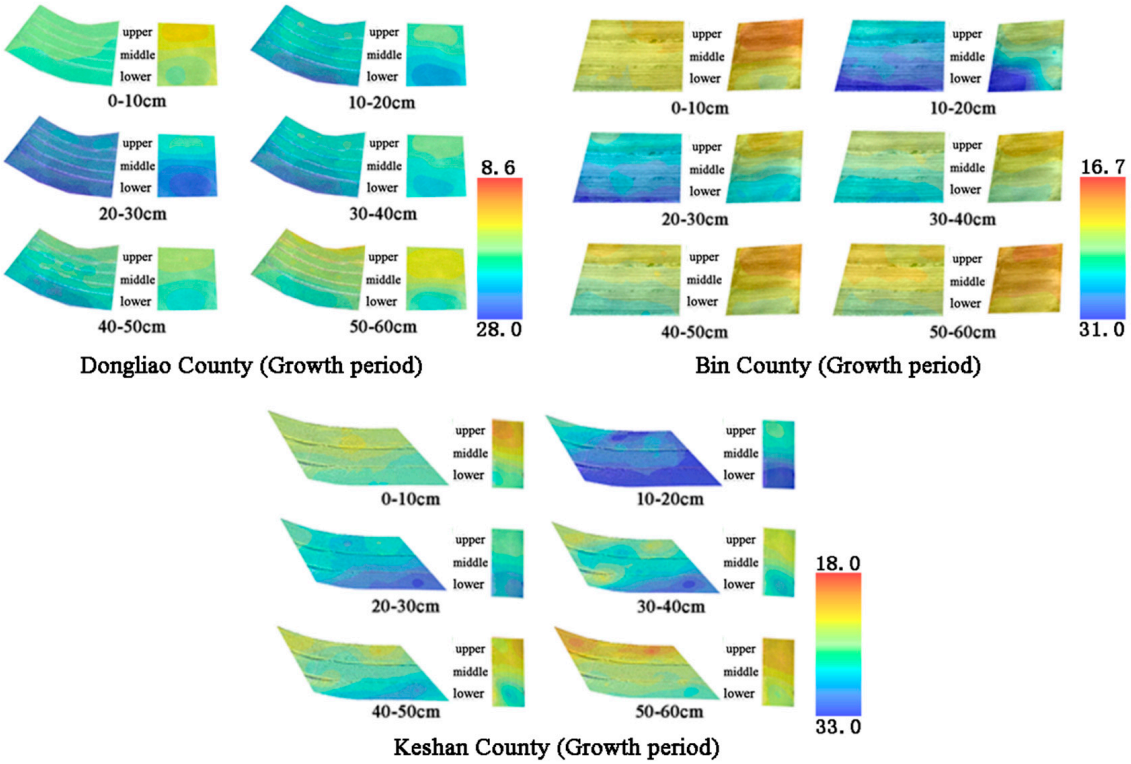


Figure 4. Soil moisture content (volumetric percent) at depths of 0–60 cm in terraced and control slope fields at three locations during the crop growing period.

After the construction of terracing, the soil moisture contents of six soil layers between 0 to 60 cm in three locations increased compared with the control slope (Table 3). The Dongliao and Keshan sites showed the greatest improvement in soil moisture content in terracing at the depth of 0–10 cm, while the Bin County site showed the greatest improvement at the 20–30 cm depth.

Table 3. Percentage-point increases in volumetric soil moisture in terraced fields compared with control fields during crop growth period.

Soil Depth	Dongliao County	Bin County	Keshan County
0–10 cm	2.56	1.61	3.29
10–20 cm	1.30	2.37	3.12
20–30 cm	1.48	3.38	2.05
30–40 cm	1.97	2.04	2.84
40–50 cm	1.72	2.11	3.10
50–60 cm	0.98	2.12	2.60

At two sites, the moisture contents reach their maximum values in the 10–20 cm soil layer of both terraced and control slopes, at 27.66% and 25.29% (Bin County) and 31.49% and 28.37% (Keshan County). In Dongliao County, the moisture content reaches its maximum value at the 20–30 cm soil layers of both the terraced and control slopes, at 24.90% and 23.42%, respectively. The soil in Dongliao County is loose and sandy, allowing for the greater downward infiltration of water, resulting in maximum soil moisture at relatively low depths.

The moisture content of the surface layer (0–10 cm) of the terraced and control slopes in the three locations is significantly lower than that of deeper soil layers ($p < 0.05$). This is because the surface volumetric soil moisture is strongly controlled by climatic conditions, especially the influence of rainfall and evaporation. This layer is the first to receive rainwater and also the first to be affected by evaporation.

3.1.2. Characteristics at Different Slope Positions

From Figure 4, it can be seen that volumetric soil moisture content consistently increases from the upper slope to the middle slope to the lower slope. Precipitation generally moves downslope through surface and subsurface runoff caused by gravity after reaching the ground surface, so it is not surprising that volumetric soil moisture should be greater in the lower slope.

As illustrated in Figure 5, the moisture contents at the upper, middle and lower slope positions in Dongliao County are 20.39%, 21.26% and 23.56% in the terraced slopes and 18.35%, 19.81% and 22.21% in the control slopes, respectively. In Bin County, the moisture contents at the upper, middle and lower slope positions are 22.87%, 23.77%, and 25.46% in the terraced slopes and 20.11%, 21.53%, and 23.65% in the control slopes. The comparable figures for Keshan County are 25.53%, 26.94% and 29.23% in the terraced slopes and 22.51%, 23.37% and 27.32% in the control slopes. The moisture content of the three locations decreases with elevation from the lower slope to the middle and upper slope positions.

The differences in moisture content between the upper and lower slopes are 3.17 percentage points for the terraced slope and 3.86 for the control slope in Dongliao County, 2.59 and 3.54 in Bin County, and 3.70 and 4.81 in Keshan County. At all three sites, the terraced slope saw a smaller change in moisture content compared that of the control slope, indicating that terracing construction reduces the transport of water along the slope (surface runoff and subsurface runoff), making the soil moisture content more uniform along the slope.

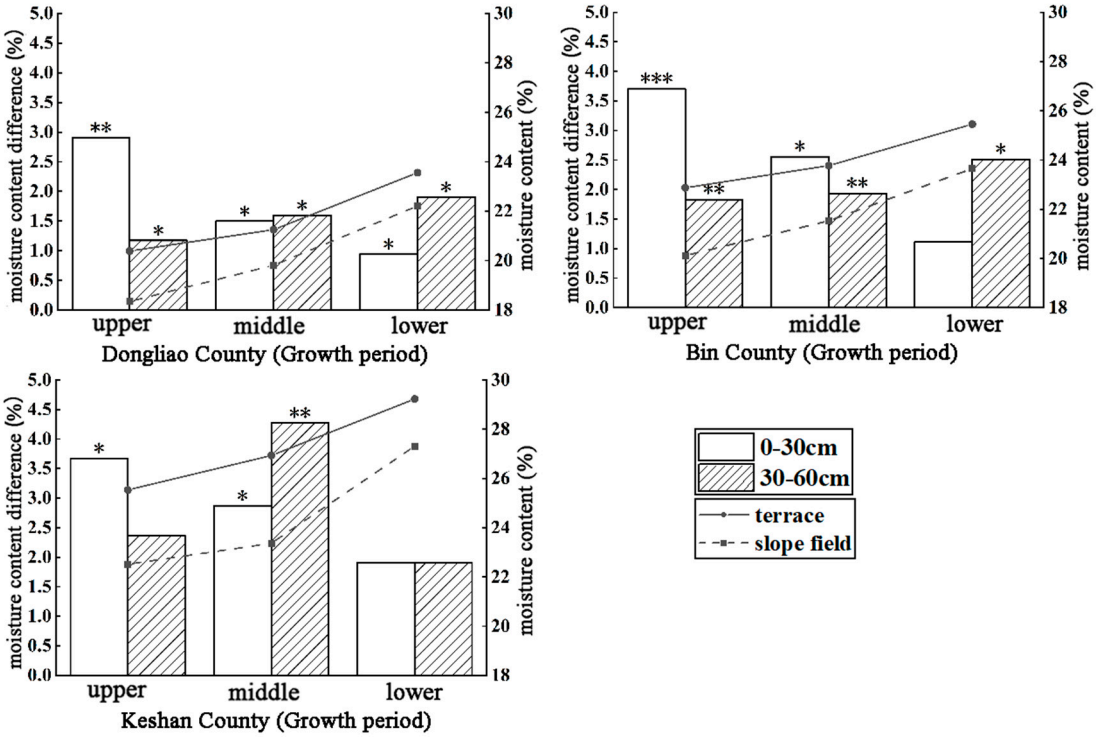


Figure 5. Volumetric soil moisture content of terraced and sloping fields during the crop growth period, and differences between shallow and deep soil layers at different slope positions. Asterisks indicate slope positions. Significance: * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$. The x-axis represents the slope position. The bar chart represents the difference in moisture content, while the line chart represents the moisture content.

In our field investigation, we found that over 90% of the corn roots in the study area are distributed within the 0–30 cm soil layer. There are also significant differences in volumetric soil moisture content and changes along the slope between the 0–30 cm and 30–60 cm soil layers. Therefore, we further examined the shallower soil layers (0–30 cm) and deeper soil layers (30–60 cm) separately. From Figure 5, it can be seen that the volumetric soil moisture content of the shallower and deeper soil layers of terraced slopes is greater than that of the control slopes. In the shallow soil layer, the difference is greatest in the upper slope and declines to the lower slope. In the deeper soil layer, the pattern reverses at the Dongliao County and Bin County sites, while in Keshan County the greatest difference is found at the middle slope, followed by the upper slope and then the lower slope.

Terracing in Dongliao County significantly increases moisture content at all three slope positions, especially in the shallower soil layer. Terracing in Bin County causes a more significant increase in the moisture content of the shallower soil layer on the upper slope, and a more significant increase in the moisture content of the deep soil layer in the middle and lower slopes. Terracing in Keshan County has little impact on the moisture content of the lower slope, mainly increasing the moisture content of the shallower layer on the upper and middle slopes.

In general, the terracing effect on the moisture content of the shallower soil layer is more obvious on the upper slope, and the terracing effect on the deep soil layer is more obvious on the lower slope. From the upper to the lower slope, the higher impact of terracing in Dongliao County and Bin County on soil moisture content also changes from the surface to deeper layers. For Keshan County, sticky soil with good water retention leads to insignificant differences in soil moisture content between the control and the terraced slopes at most slope positions. Overall, during the crop growth period, terracing leads to a greater improvement in soil moisture conditions in the shallower soil layer in the upper

slope, and a greater improvement in soil moisture condition in the deeper soil layer in the lower slope.

3.2. Impact of Terracing on Volumetric Soil Moisture Content during Postharvest Period

3.2.1. Characteristics at Different Depths

From Figure 6, it can be seen that the changes in volumetric soil moisture with depth during the postharvest period are similar to those in the crop growth period. From 0 cm to 60 cm soil depth, the volumetric soil moisture shows a change trend of first increasing and then decreasing with soil depth.

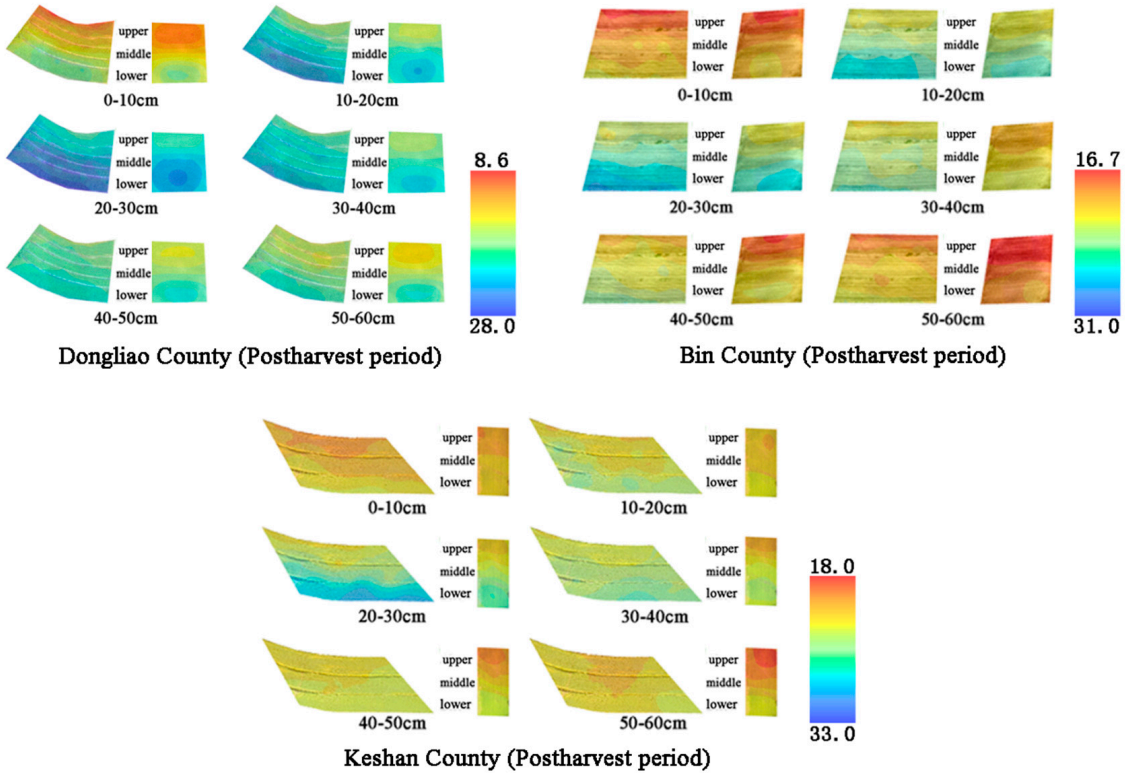


Figure 6. Volumetric soil moisture content at 0–60 cm in terraced and sloping fields at three locations at the end of crop season.

After the construction of terraces, the moisture content of the six soil layers increased on the terraced slopes compared with the control slopes (Table 4). However, the vertical variation in volumetric soil moisture content in both the terraced and control slopes remained unchanged. The volumetric soil moisture content at all three sites reached the maximum at the 20–30 cm depth. In the postharvest period, the moisture contents of terraced and control slopes were 23.79% and 22.49%, respectively, in Dongliao County, 24.25% and 23.30% in Bin County, and 25.68% and 23.95% in Keshan County.

Table 4. Percentage point increases in volumetric soil moisture in terraced fields compared with control fields during postharvest period.

Soil Depth	Dongliao County	Bin County	Keshan County
0–10 cm	0.72	0.23	0.72
10–20 cm	1.44	0.67	2.09
20–30 cm	1.30	0.95	1.72
30–40 cm	1.49	2.27	1.86
40–50 cm	1.59	2.00	1.70
50–60 cm	1.34	2.45	2.02

The moisture content of the surface layer (0–10 cm) of the terraced and control slopes at all three sites was significantly lower than that of other soil layers ($p < 0.05$), as was the case in the growing season. However, the differences in moisture content between the terraced and control slopes were generally found at deeper levels in the postharvest period, at 40–50 cm in Dongliao, at 50–60 cm in Bin County, and at 10–20 cm in Keshan—mostly falling into the deeper soil layer (30–60 cm). This is mainly because the environmental conditions during the postharvest period differ from those of the crop growing period, with less rainfall and insufficient water replenishment on the slope surface. With no crop roots to promote water absorption in the shallow soil layer, the postharvest period sees an increase in soil moisture infiltration downward, resulting in a significant difference in moisture content in the deep soil layer between the terraced and control slopes.

3.2.2. Characteristics at Different Slope Positions

Comparing Figures 4 and 6, we see that the 0–60 cm volumetric soil moisture content of the terraced and control slopes is greatest in the lower slopes, declining toward the upper slopes in both time periods and all three locations. As illustrated in Figure 7, the moisture contents at the upper, middle and lower slope positions in Dongliao County are 18.25%, 20.41% and 22.65% in the terraced slopes and 16.74%, 18.92% and 21.72% in the control slopes, respectively. In Bin County, the moisture contents at the upper, middle and lower slope positions are 20.16%, 22.00%, and 23.07% in the terraced slopes and 18.63%, 20.53%, and 21.78% in the control slopes. The comparable figures for Keshan County are 22.20%, 23.32%, 24.97% in the terraced slopes and 20.24%, 21.65%, 23.54% in the control slopes.

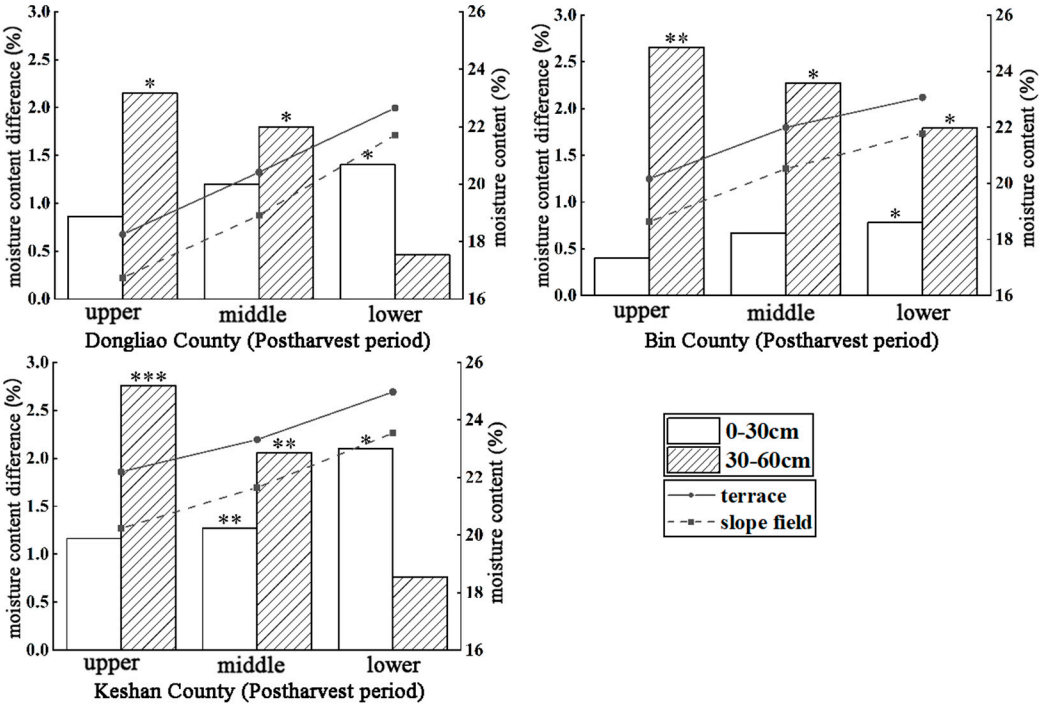


Figure 7. Volumetric soil moisture content of terraced and sloping fields during the postharvest period, and differences between shallow and deep soil layers at different slope positions. Asterisks indicate significance: * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$. The bar chart represents the difference in water content; the line chart represents the water content.

Consistent with the pattern seen in the crop growth period, the range of change in moisture content of the terraced slopes from the upper to the lower slope is smaller than that of the control slopes. The range of change in the moisture content of the terraced and control slopes, respectively, is 4.40 and 4.98 percentage points in Dongliao County, 2.91 and 3.15 in Bin County, and 2.77 and 3.30 in Keshan County. This indicates that terracing plays

a positive role in regulating moisture content along the slope in both the crop growth and postharvest periods.

Figure 7 shows that the volumetric soil moisture content of the shallower layer (0–30 cm) and deeper layer (30–60 cm) is higher on the terraced slopes than on the control slopes across the different slope positions in the postharvest period. However, unlike in the crop growth period, the differences are almost all greater in the deeper soil layer. In the shallower soil layer, the difference in moisture content decreases from the lower slope to the upper slope, but the situation is reversed for the deeper soil layer.

Terracing in Dongliao County significantly increased the moisture content of the deeper soil layer at the upper and middle slope positions, and the shallower soil layer in the lower slope position. The terracing in Bin County significantly increased the moisture content of the deeper soil layer at all three slope positions, most notably the upper slope position, with a significant impact on the shallower soil layer only at the lower slope position. Terracing in Keshan County significantly increased the moisture content of the deeper soil layer in upper slope positions and both the deeper and shallower layers in the middle slope position, but only the shallower layer in the lower slope position. Thus, we find that the impact of terracing on volumetric soil moisture content shifts from deep to shallow as we progress downslope. Overall, the pattern for the postharvest period is the opposite of that of the crop growth period: terracing has a greater impact on the deeper soil layer in the upper slope position and on the shallower soil layer in the lower slope position.

3.3. Soil Moisture Storage and Moisture Content Benefits of Terracing at Different Locations

To further examine the impact of terracing on the volumetric soil moisture content under different site conditions, we calculated soil moisture storage capacity using the equation proposed by Bai Yiru et al. in their study of soil moisture storage stability [25].

It can be seen from Figure 8 that terracing is associated with improved soil moisture storage capacity in both the crop growth period and the postharvest period at all three sites. In the growing season, the moisture storage capacities of the terraced slopes in Dongliao County, Bin County and Keshan County were 9.66 mm, 13.62 mm and 16.98 mm higher than those of the control slopes at the depth of 0–60 cm. During the postharvest period, they were 7.92 mm, 8.58 mm, and 10.14 mm higher than those of the control slope.

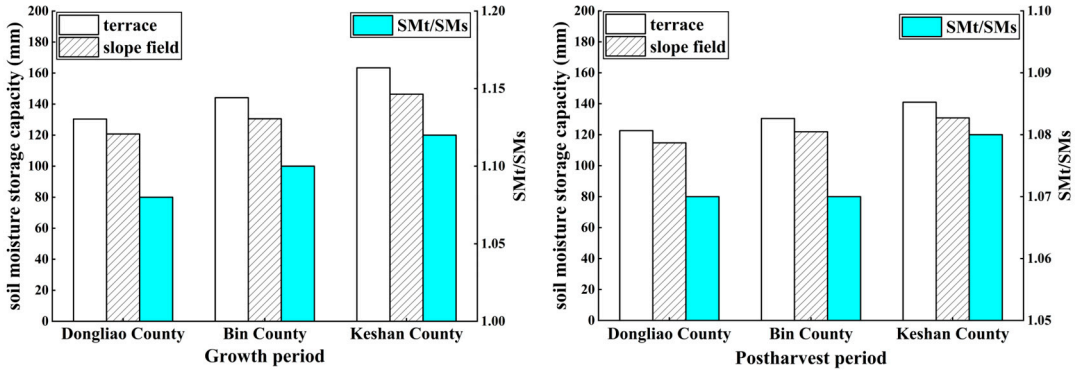


Figure 8. Moisture storage capacity of terraced and sloping fields and SMt/SMs at three locations during the growth and postharvest stages.

In order to quantify the benefits of terracing for slope farmland, Wei et al. proposed a key indicator (δ) defined as the ratio of the ecological services between terraced and unterraced slopes [26]. At δ = 1, terracing makes no difference; if δ > 1, it has a positive effect, while if δ < 1, it has a negative impact.

From Figure 8, it can be seen that δ Sw > 1 in both the crop growth and postharvest periods at all three sites, where δ Sw represents the contribution to ecological services of soil moisture (δ Sw = SMt/SMs). In the growing season, Dongliao County, Bin County, and Keshan County, respectively, saw δ Sw values of 1.08, 1.10, and 1.12; the postharvest

period δ Sw values were 1.07, 1.07, and 1.08. According to the results, terracing in the three locations has moisture storage benefits for slope farmland, with the greatest benefits occurring in Keshan County.

3.4. Soil Property at Different Locations

From Table 5, it can be seen that, of the three locations, the soil bulk density is greatest in Dongliao County, followed by Bin County, then Keshan County. The opposite ranking of sites holds for capillary water capacity, field capacity, and soil porosity. The soil in Dongliao County and Bin County is mainly composed of sand, followed by silt and clay, while the soil in Keshan County has more silt and clay particles, with the least sand particles. In general, the soil in Keshan County is the most viscous, followed by Bin County, and the soil in Dongliao County has the lowest clay content. Overall, the construction of terraces in the three locations reduced soil bulk density and increased soil clay content. In addition, on the slope of sloping farmland, due to the tendency of sand to move downward under the influence of rainwater and gravity, the content of clay particles in the upper slope was relatively high.

Table 5. Soil properties of terraced and control slopes at three sites.

Site	Slope Type	Slope Position	Soil Bulk Density ($g \cdot cm^{-3}$)	Total Porosity (%)	Capillary Water Capacity (%)	Field Capacity (%)	Clay (%)	Silt (%)	Sand (%)	pH
Dongliao County	terraced	upper	1.45	39.37	23.04	21.38	17.07	31.67	51.26	6.85
		middle	1.48	40.80	22.68	21.50	16.57	31.17	52.26	6.59
		lower	1.49	41.15	22.33	20.33	16.55	30.69	52.76	6.36
	control	upper	1.46	39.71	19.42	18.88	18.27	31.92	49.81	6.26
		middle	1.51	39.09	19.45	18.60	16.78	25.92	57.30	6.39
		lower	1.52	38.22	18.92	17.81	14.27	27.90	57.83	6.28
Bin County	terraced	upper	1.30	47.56	30.18	22.79	21.85	30.90	47.25	5.16
		middle	1.33	44.95	31.19	24.04	20.33	26.41	53.26	5.67
		lower	1.35	44.93	34.21	25.32	20.28	27.89	51.83	6.09
	control	upper	1.35	46.15	30.33	22.32	21.80	28.55	49.65	6.10
		middle	1.38	43.98	30.99	23.71	17.33	29.06	53.61	6.10
		lower	1.39	43.18	28.12	20.90	17.80	28.07	54.13	6.29
Keshan County	terraced	upper	1.12	53.16	38.50	29.42	35.41	40.96	23.63	6.05
		middle	1.14	51.97	38.03	27.92	34.72	43.43	21.85	6.07
		lower	1.15	48.15	36.33	27.00	34.94	42.93	23.13	5.91
	control	upper	1.12	51.61	38.58	28.59	36.45	37.88	25.67	5.86
		middle	1.17	50.10	37.92	26.13	33.51	40.85	25.64	5.91
		lower	1.18	48.14	35.45	27.95	31.14	40.72	28.14	6.22

The Pearson correlation analysis results in Table 6 show that the soil moisture content across the three sites is extremely significantly negatively correlated with soil bulk density, but extremely significantly positively correlated with capillary water capacity and field capacity. It is significantly positively correlated with porosity, clay content, and silt content, and significantly negatively correlated with sand content. The smaller the soil bulk density, the higher the content of clay and silt in the soil; the lower the sand content, the greater the soil moisture content.

Table 6. Pearson correlation analysis of soil moisture and physicochemical properties. Asterisks indicate significance: * $p < 0.05$, ** $p < 0.01$.

Index	Water Content	Soil Bulk Density	Total Porosity	Capillary Water Capacity	Field Capacity	Clay	Silt	Sand	pH
Water content	1								
Soil bulk density	−0.617 **	1							
Total porosity	0.563 *	−0.966 **	1						
Capillary water capacity	0.646 **	−0.951 **	0.953 **	1					
Field capacity	0.656 **	−0.949 **	0.928 **	0.958 **	1				
Clay	0.577 *	−0.968 **	0.917 **	0.871 **	0.901 **	1			
Silt	0.579 *	−0.837 **	0.752 **	0.695 **	0.777 **	0.906 **	1		
Sand	−0.586 *	0.934 **	−0.869 **	−0.816 **	−0.869 **	−0.983 **	−0.969 **	1	
pH	−0.287	0.517 *	−0.581 *	−0.525 *	−0.395	−0.395	−0.161	0.301	1

Table 7 shows that terrace construction had the largest effect on soil capillary water capacity, field capacity and soil porosity content in Dongliao County; Bin County saw the most significant impact on soil clay content and soil bulk density, and in Keshan County, the sand content of the soil was mainly reduced and the silt content was increased. The construction of terracing in these three locations improved the local soil quality.

Table 7. Soil properties of terraced and slope farmland in three regions; δ value, defined as the ratio between terraced and sloping fields.

Index	Bulk Density	Capillary Water Capacity	Field Capacity	Total Porosity	Clay	Silt	Sand
Dongliao County	0.99	1.18	1.14	1.04	1.04	1.05	0.96
Bin County	0.97	1.07	1.08	1.03	1.10	1.01	0.96
Keshan County	0.98	1.01	1.02	1.02	1.04	1.07	0.86

4. Discussion

4.1. Relationship between Volumetric Soil Moisture (SMC) and Influencing Factors

We performed a redundancy analysis (RDA) based on a linear simulation of the relationship between volumetric soil moisture and influencing factors on both the terraced slopes and the control slopes. RDA assesses how much of the variation in one set of variables can be explained by the variation in another set of variables. Influencing factors for this study include slope position, soil bulk density, porosity, soil mechanical composition, and soil acidity or alkalinity. The first two RDA axes for the terraced and control slopes can cumulatively explain more than 98% of the total variance between sampling points and influencing factors. Therefore, the first two axes were selected to analyze the relationship between soil moisture and influencing factors, and used to create a two-dimensional sorting diagram (Figure 9).

The length of the connecting line of each influencing factor represents the correlation between that factor and volumetric soil moisture; the longer the arrow, the greater the correlation. By calculating the relative contribution rates of various factors influencing volumetric soil moisture content, it was found that, on the control slopes, slope position made the greatest relative contribution to volumetric soil moisture, reaching 52.5%, followed by soil bulk density, with a contribution of 44.0%. On the terraced slope, soil clay content made the greatest relative contribution to volumetric soil moisture, reaching 57.5%, followed by slope position, with a contribution of 37.9%. Apparently, terrace construction weakens the impact of slope position on volumetric soil moisture and increases the impact of soil texture on volumetric soil moisture. These results are relatively consistent with those of Tian Zhuo and others regarding the factors influencing the spatial variation in volumetric soil moisture in the Longji rice terraces of southwestern China's Guangxi Province [27].

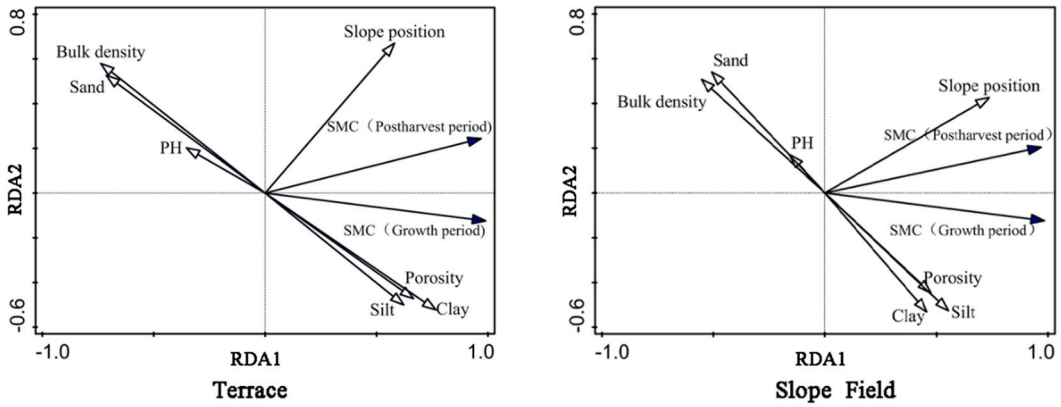


Figure 9. RDA ranking of volumetric soil moisture content (SMC) and influencing factors affecting terraced and control slope farmland.

The angle between the influencing factors and the soil moisture vectors for the crop growth and postharvest periods indicates that the impact of slope position on soil moisture is greater during the postharvest period. The other influencing factors have a greater impact on soil moisture during the crop growth period. Slope position, porosity, clay and silt particles are all positively correlated with soil moisture, while soil bulk density, sand and pH are all negatively correlated with volumetric soil moisture. That is, volumetric soil moisture content gradually decreases as we move upslope. In addition, the more soil silt or clay particles there are, the greater the soil porosity, thus increasing volumetric soil moisture.

4.2. Temporal Differences

Physiologically active soil water is important for plants during both the crop growth period and the postharvest period, but the factors that affect volumetric soil moisture in those two periods are not the same. During different seasons, there are significant differences in climate and environmental conditions, such as precipitation and temperature, which affect the replenishment and consumption of volumetric soil moisture. Changes in biological factors, such as vegetation cover and root distribution, affect the flow and distribution of soil moisture [28]. With much more rain at these study sites during the crop growth period, the average soil moisture content of terraced fields is higher than that in the control fields by 1.66, 2.27, and 2.83 percentage points in Dongliao County, Bin County and Keshan County, respectively. This equates to soil water storage at the 60 cm depth that is 9.66 mm, 13.62 mm, and 16.98 mm higher than that in the control slopes at those three sites. The differences are lower for the postharvest period, when there was less precipitation: the average volumetric soil moisture content of terraced fields was 1.32, 1.43, and 1.69 percentage points higher than that of control slopes at those sites, equating to soil moisture storage capacities at the 60 cm depth that are 7.92 mm, 8.58 mm, and 10.14 mm higher. The terracing in the three sites thus increased the soil moisture content and slope moisture storage capacity during both wet and dry seasons. The construction of terracing did not change the vertical pattern of soil moisture, which is consistent with prior research on the vertical changes of soil moisture in newly constructed terracing in the Loess Plateau hilly region in central Gansu Province [29].

From Table 5, we can see that the construction of terracing has significantly affected the surface morphology, which also increases the residence time of precipitation on the slope, allowing more rainwater to enter the soil, to replenish soil moisture and provide water for plant growth [9,12]. This is consistent with Gong Yunlong's research on volumetric soil moisture changes after slope modification in southern China's hilly areas [30]. RDA analysis shows that after the construction of terracing, the impact of slope position on volumetric soil moisture was weakened in both seasons, and the impact of soil texture on soil moisture was increased. Table 5 shows that the construction of terracing reduced soil

bulk density and increased soil porosity, capillary water capacity and field water capacity. In addition, the soil texture increased in viscosity, increasing the soil moisture storage capacity. The results indicate that the effects of terracing on volumetric soil moisture content and moisture retention are mainly affected by precipitation during both seasons, even though the temperature (and thus evaporation) is greater during the wet season. This is generally consistent with the research results of Wang Yanping et al. on the dynamic changes of volumetric soil moisture in the Loess Plateau area [28]. Furthermore, the construction of terracing significantly improves soil quality at the lower slope position, while the regulation of volumetric soil moisture during the growing season is more significant at the upper slope position. This indicates that the impact of terracing construction on volumetric soil moisture in slope farmland is mainly related to changes in surface morphology.

During the crop growing season, there is plenty of precipitation and, compared with deeper soil layers, the soil surface is more sensitive to precipitation [19]. Niu Yun and others also found that the variation in volumetric soil moisture in the 0–10 cm soil layer is the greatest in the wet season in the Qilian Mountains of central China [31]. Terrace construction turns the slope into several flat surfaces, cutting off the runoff on the slope [8,11,24], and weakening the impact of slope position on volumetric soil moisture. Each slope position on the terrace can receive more water, while the control slopes tend to shed surface runoff with faster flow rates. The difference in moisture content between the upper and lower positions on the terrace is smallest at the surface layer (0–10 cm). More importantly, transpiration by plants causes the roots to absorb water, leading to more water accumulation around the crop roots, thus reducing the soil permeability coefficient and reducing precipitation infiltration downwards, resulting in more water being fixed in the surface [32]. This explains the significant difference in moisture content between the terraced slopes and the control slope in the shallow soil layer (0–30 cm), and the small difference in the deep soil layer (30–60 cm).

During the postharvest season, the situation is reversed, mainly because there is less precipitation, but also because there is no crop root system to absorb water in the shallow soil layer, so more soil moisture is able to infiltrate to the deeper soil layer. With less precipitation, dry air, and strong surface evaporation, the shallow soil layer sees lower levels of volumetric soil moisture in the postharvest season, while the deeper layer is less affected by environmental disturbances, resulting in a significantly higher moisture content in the deeper soil layers of the terraced fields compared with the control slopes. In the crop growth period, the increased moisture content of the shallower soil layer in the terraced fields compared with the control slopes generally decreases from the upper to the lower position on the slope, while the opposite pattern holds for the deeper soil layer. In the Keshan County site, due to the long slope and gentle gradient at the lower position, as well as the sticky soil, water accumulated at the lower slope; as a result, terracing made less of a difference on moisture content there, but the general finding applies to the upper and middle positions on the slope.

Runoff and erosion control is an important feature of terraced slopes compared with control slopes. The control slopes tend to produce surface runoff and soil erosion during the rainy crop growth period. Volumetric soil moisture therefore accumulates more on the lower slope, and moisture content on the lower slope position is significantly higher than that on the upper slope position. As terrace construction reduces runoff along the slope, it allows more rainwater to infiltrate the soil [33]. This results in a greater impact of terracing on the water content on the upper slope position in shallower soil layers and a smaller impact on the lower slope position. The opposite is true for deeper soil layers during the crop growth period, when crops absorb and utilize water for growth. The water in the upper slope position of the terraced fields is absorbed by the root system and concentrated in the shallower soil layer, resulting in less water infiltration into the deeper soil layer. When the water in the lower slope position exceeds the plants' water requirements, there is still yet more water that can penetrate the deeper soil layer.

During the postharvest period, terracing has a greater impact on the shallower soil layer at the lower slope position, while the impact is greater on the deeper soil layer at the upper slope position. This is because there is less precipitation in this period, so direct precipitation has a smaller impact on volumetric soil moisture content. Table 5 shows the variation in the soil texture of different slope positions, resulting in different soil moisture retention and infiltration abilities. These results are similar to those found by Bai Yiru et al. [25], which show that the upper slope has a higher clay content and a better water retention capacity, with less downward infiltration of water and lower water content in the lower soil layer. However, due to the high content of sand particles and poor water retention in the below-slope position of the control slopes, soil moisture infiltration is more significant in the shallower soil layer, while the moisture content in the deeper soil layer is higher. In addition, during the postharvest period, with less precipitation and no crop coverage on the soil, the shallow soil layers of both the terraced and control slopes are affected by evaporation, resulting in a greater impact of terracing on the shallow soil layer in the below-slope position and a greater impact on the deep soil layer in the above-slope position.

4.3. Differences among Locations

Previous studies have shown that the heterogeneity of volumetric soil moisture in slopes is influenced by multiple factors [34], and the magnitude of volumetric soil moisture content in different sites is related to local climate, soil quality, cultivation measures, and so forth. Dongliao County, Bin County and Keshan County are located in different latitudes, with Dongliao at the southern extreme and Keshan furthest north. During the crop growth period (July), the precipitation in Keshan is the highest, and that in Dongliao is the lowest; in the postharvest period (October), the precipitation in Keshan is the lowest and that in Dongliao is the highest. However, in both periods, the volumetric soil moisture in Dongliao is the lowest and that in Keshan is the highest.

In the crop growth period, the soil moisture content of Keshan County is significantly greater than that of Bin County and Dongliao County, and in the postharvest season, the soil moisture content of Keshan County is significantly greater than that of Dongliao County. In order to further analyze the reasons for the difference in soil moisture content in the three locations, Table 5 shows in detail the soil property indicators of three locations, and Table 6 presents a Pearson analysis of these soil properties and volumetric soil moisture. These results are consistent with the research of Li Yuan et al. [35] on the Hani terrace and Tian Zhuo [27] on the Longji rice terraces. The correlation between soil moisture content and soil pH is not significant, which is similar to the research results of Jin Zhenjiang et al. [36] regarding the Longji rice terraces. According to the analysis results in Table 6, precipitation affects the soil moisture content in the crop growth and postharvest periods, and the difference in moisture content between the different sites is mainly due to different soil textures.

The benefits of terracing for the moisture storage and retention capacity of slopes also show the same results in the three locations. From Table 7, it can be seen that the improvement effect of terraces on soil properties in the three locations is not significantly related to the soil's moisture storage and retention capacity. From this, it can be concluded that the difference in the benefits of terracing for storing and retaining moisture in slopes in different locations are mainly related to differences in soil quality—the more clay particles in the soil, the better the soil's moisture storage and retention ability. Slopes with these soil characteristics are likely to derive greater benefits from terrace construction.

5. Conclusions

This study measured and analyzed the soil moisture of terraced and control slope farmland under three different conditions in the black soil region of Northeast China. The research results have elucidated the impact characteristics of terrace construction on soil moisture and clarified the regulatory mechanism of terracing on soil moisture, providing a

scientific basis for preventing and controlling soil erosion in slope farmland and protecting the productivity of black soil.

(1) For both the wet and dry seasons, terracing improved the volumetric soil moisture content of slope farmland in Dongliao County, Bin County and Keshan County, respectively, increasing them by 1.67, 2.27 and 2.83 percentage points in the wet growing season, and by 1.31, 1.43 and 1.69 percentage points in the dry postharvest season. However, terracing did not alter the pattern of change in soil moisture content from shallower to deeper soil layers or along the slope. There are significant seasonal differences in soil moisture content that are basically consistent with precipitation amount;

(2) The impact of terracing on volumetric soil moisture in the shallow and deep soil layers varies by season. Soil texture plays a crucial role. During the crop growth period, terracing has a significant impact on volumetric soil moisture in the shallow layer (0–30 cm), while during the postharvest period, it has a significant impact on soil moisture in the deep layer (30–60 cm). In both periods, the most significant effect on volumetric soil moisture is seen in the upper slope. Terracing reduces the magnitude of the difference in moisture content between different slope positions, making the distribution of moisture content on the slope more uniform;

(3) Terracing increased the moisture storage and retention capacity of the slope during both seasons, especially during the crop growth period. Of the three sites, the terracing in Keshan County showed the highest moisture storage and moisture conservation benefit. Dongliao County showed the lowest benefit, mainly as a result of the local soil quality. The lower the soil bulk density and the higher the silt clay content, the better the soil moisture conservation, and the greater the benefit of terracing. In addition, the relative contribution rate of clay content to the impact of terracing on volumetric soil moisture is 57.5%, providing an avenue for further reducing soil erosion in slope farmland in black soil regions after the construction of terracing.

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References

1. Liu, X.; Yan, B. Water and soil loss and food security in northeast black soil region. *China Water Soil Conserv.* **2009**, *30*, 17–19.
2. Liu, B.; Zhang, G.; Xie, Y.; Shen, B.; Gu, Z.; Ding, Y. The Scope and Delimitation of Northeast Black soil region and Typical Black soil region in Northeast China. *Sci. Bull.* **2021**, *66*, 96–106.
3. Chang, X.; Chang, G. Research progress on soil moisture in arid and semi-arid regions. *Desert China* **2021**, *41*, 156–163.
4. Bogena, H.R.; Huisman, J.A.; Baatz, R.; Hendricks Franssen, H.J.; Vereecken, H. Accuracy of the cosmic-ray soil water content probe in humid forest ecosystems: The worst case scenario. *Water Resour. Res.* **2013**, *49*, 5778–5791. [CrossRef]
5. Heathman, G.C.; Cosh, M.H.; Merwade, V.; Han, E. Multi-scale temporal stability analysis of surface and subsurface soil moisture within the Upper Cedar Creek Watershed, Indiana. *Catena* **2012**, *95*, 91–103. [CrossRef]
6. Berndtsson, R.; Nodomi, K.; Yasuda, H.; Persson, T.; Chen, H.; Jinno, K. Soil water and temperature patterns in an arid desert dune sand. *J. Hydrol.* **1996**, *185*, 221–240. [CrossRef]
7. Li, Z.; Yang, L.; Wang, G.; Hou, J.; Xin, Z.; Liu, G.; Fu, B. Current Situation, Problems and Countermeasures of Soil and Water Loss Control in the Loess Plateau. *J. Ecol.* **2019**, *39*, 7398–7409.
8. Liu, C.; Jiao, Y.; Gao, X.; Liu, X.; Shen, E. Infiltration characteristics and influencing factors of soil moisture in different landscape types of Hani terrace water source area. *Soil Water Conserv. Bull.* **2018**, *38*, 99–105.

9. Chen, D.; Wei, W.; Chen, L. Effects of terracing practices on water erosion control in China: A meta-analysis. *Earth-Sci. Rev.* **2017**, *173*, 109–121. [CrossRef]
10. Tang, M.; Zhao, X.N.; Gao, X.D.; Zhang, C.; Wu, P.T. Characteristics of soil moisture changes in different land use types in loess hilly areas. *J. Appl. Ecol.* **2018**, *29*, 765–774.
11. Wei, W.; Feng, X.; Yang, L.; Chen, L.; Feng, T.; Chen, D. The effects of terracing and vegetation on soil moisture retention in a dry hilly catchment in China. *Sci. Total Environ.* **2019**, *647*, 1323–1332. [CrossRef] [PubMed]
12. Widomski, M.K. Terracing as a Measure of Soil Erosion Control and Its Effect on Improvement of Infiltration in Eroded Environment. In *Soil Erosion Issues in Agriculture*; Books on Demand: Norderstedt, Germany, 2011; pp. 315–334.
13. Zou, W.; Han, X.; Li, L.; Wang, F. Study on the dynamic changes of soil moisture under different land use methods in black soil regions. *J. Soil Water Conserv.* **2009**, *23*, 236–239.
14. Su, Z.; Zhang, G.; Yu, Y. Dynamic changes in soil moisture under different land use patterns in typical black soil regions of Northeast China. *Geogr. Sci.* **2013**, *33*, 1104–1110.
15. Feng, Q.; Zhao, W.; Qiu, Y.; Zhao, M.; Zhong, L. Spatial Heterogeneity of Soil Moisture and the Scale Variability of Its Influencing Factors: A Case Study in the Loess Plateau of China. *Water* **2013**, *5*, 1226–1242. [CrossRef]
16. He, X.; Tian, L.; Wang, H.; Jin, Y.; Li, Y. Temporal and spatial variation characteristics of soil moisture in seabuckthorn communities in alpine sandy areas. *Bull. Soil Water Conserv.* **2023**, *43*, 23–33.
17. Penna, D.; Brocca, L.; Borga, M.; Dalla Fontana, G. Soil moisture temporal stability at different depths on two alpine hillslopes during wet and dry periods. *J. Hydrol.* **2013**, *477*, 55–71.
18. Zhao, Y.; Peth, S.; Wang, X.Y.; Lin, H.; Horn, R. Controls of surface soil moisture spatial patterns and their temporal stability in a semi-arid steppe. *Hydrol. Process.* **2010**, *24*, 2507–2519. [CrossRef]
19. Zhang, C.; Zhang, W.; Chen, H.; Nie, Y.; Ye, Y.; Wang, K. Temporal and spatial variability of surface soil moisture in dry season on typical Karst Plateau slope land. *J. Ecol.* **2015**, *35*, 6326–6334.
20. Liu, B.; Shao, M. Estimation of soil water storage using temporal stability in four land uses over 10 years on the Loess Plateau, China. *J. Hydrol.* **2014**, *517*, 974–984. [CrossRef]
21. Li, X.; Jia, X.; Wei, X. Profile distribution of soil–water content and its temporal stability along a 1340-m long transect on the Loess Plateau, China. *Catena* **2016**, *137*, 77–86. [CrossRef]
22. Zhang, P.; Shao, M.; Zhang, X. Scale-dependence of temporal stability of surface-soil moisture in a desert area in northwestern China. *J. Hydrol.* **2015**, *527*, 1034–1044. [CrossRef]
23. Chen, X.; Chen, L.; Song, N.; Li, M.; Wu, T.; Yang, X.; Wang, L.; Wang, X. Comparison of Water Dynamics of Two Types of Soil in Desert Grassland. *J. Appl. Ecol.* **2020**, *31*, 1560–1570.
24. Xu, Y.; Wang, J.; Cai, S.; Zhou, M. Spatial variability of soil moisture in gentle slope horizontal terraces. *J. Agric. Eng.* **2008**, *24*, 16–19.
25. Bai, Y.; Shao, M. Temporal stability of slope soil water storage in rain fed areas of the Loess Plateau. *J. Agric. Eng.* **2011**, *27*, 45–50.
26. Wei, W.; Chen, D.; Wang, L.; Daryanto, S.; Chen, L.; Yu, Y.; Lu, Y.; Sun, G.; Feng, T. Global synthesis of the classifications, distributions, benefits and issues of terracing. *Earth-Sci. Rev.* **2016**, *159*, 388–403. [CrossRef]
27. Tian, Z.; He, J.; Zhang, S.; Fang, R.; Li, Z.; Zou, C. Spatial variability of soil moisture on typical slope surface of Longji Rice Terraces. *J. Southwest Agric.* **2021**, *34*, 2197–2203.
28. Wang, Y.; Wang, L.; Han, X.; Yang, W. Characteristics of soil water consumption and supply changes under different land use modes in the Loess Plateau region. *J. Ecol.* **2015**, *35*, 7571–7579.
29. Wang, Y.; Ouyang, X.; Zhang, F. Temporal and spatial variability of soil moisture in newly constructed terraced fields in the loess hilly area of central Gansu. *China Soil Water Conserv.* **2015**, *403*, 56–58.
30. Gong, Y. Analysis of Soil Moisture after Slope Modification in Southern Red Soil Hilly Areas. *Subtrop. Soil Water Conserv.* **2018**, *30*, 17–21.
31. Niu, Y.; Liu, X.; Ma, L.; Zhang, H.; Zhang, X. Study on rainfall distribution of soil under main vegetation in Qilian Mountains. *Gansu For. Sci. Technol.* **2003**, *4*, 1–4.
32. Zhang, P.; Xu, Y.; Wu, X. The effect of plant root water absorption on slope stability. *J. Yangtze River Acad. Sci.* **2020**, *37*, 120–125.
33. Tenge, A.J.; Graaff, J.D.; Hella, J.P. Financial efficiency of major soil and water conservation measures in West Usambara highlands, Tanzania. *Appl. Geogr.* **2005**, *25*, 348–366. [CrossRef]
34. Guo, X.; Fu, Q.; Lu, H.; Gao, F.; Hang, Y. Spatial heterogeneity and main control factors of soil moisture on slopes of mixed use of agriculture and forestry in the northeast black soil region. *J. Agric. Eng.* **2018**, *34*, 123–130.
35. Li, Y.; Song, W.; Ma, J. Study on Soil Water Characteristics of Water Terraced Fields in Southwest China—Taking Hani Terraced Fields as an Example. *J. Soil Water Conserv.* **2021**, *35*, 160–169.
36. Jin, Z.; Yan, Q.; Wu, M.; Wang, J.; Zhang, J.; Gu, Z.; Wang, X. Characteristics of soil moisture, nutrients and enzyme activities in the leisure period of Longji rice terraces. *J. Guilin Univ. Technol.* **2022**, *42*, 177–182.

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