Effects of Micro-sprinkler Irrigation on Soil Water and Nitrogen Dynamics and Banana Yield under Banana-Fertilizer Intercropping (Postprint)

Authors: Hu Junming, Huang Zhonghua, Luo Weigang, Li Tingting, Meng Yancheng, Huang Taiqing, Liao Ting, Yu Yuefeng, Hu Junming

Date: 2018-05-02T00:00:00+00:00

Abstract

To investigate the effects of micro-sprinkler irrigation on soil water and nitrogen dynamics as well as banana yield in a banana-green bean intercropping system (hereinafter referred to as banana-green bean intercropping), the experiment was designed with four different irrigation quota treatments: MSI2 (900 $m^3 \cdot hm^{2}$), MSI3 (1,350 $m^3 \cdot hm^{2}$), MSI4 (1,800 $m^3 \cdot hm^{2}$), and MSI5 (2,250 $m^3 \cdot hm^{2}$), using no irrigation and clean cultivation as controls. The results showed that during the green bean growth period under banana-green bean intercropping, soil evaporation between plants in each irrigation treatment exhibited varying degrees of decline, while soil evaporation between plants in the banana clean cultivation MSI0 treatment showed an upward trend. With increasing irrigation amount, banana inter-plant evaporation gradually increased, with the cumulative inter-plant evaporation in MSI5 reaching as high as 385.6 mm, which was 12.2%, 7.6%, and 4.9% higher than that of MSI2, MSI3, and MSI4, respectively, leading to reduced irrigation water use efficiency. Micro-sprinkler irrigation treatments increased surface soil water content, with the 0-30 cm soil layer water content in MSI2, MSI3, MSI4, and MSI5 treatments being significantly higher than that in MSI0 and MSI1, while below 30 cm, soil water content began to decrease. Micro-sprinkler irrigation also improved soil tilth and increased soil available nitrogen. The MSI2 treatment exhibited a relatively ideal soil solid-liquid-gas phase ratio (2:1:1), while the MSI3 treatment had the highest available nitrogen content in the topsoil. The MSI4 treatment achieved a yield as high as 48,218 $kg \cdot hm^{2}$, and the MSI3 treatment exhibited banana fruit sugar content as high as 25.67%. Therefore, under banana-green bean intercropping, appropriate irrigation through micro-sprinkler irrigation is beneficial for increasing banana yield and improving fruit quality.

Full Text

The Effect of Micro-Sprinkler Irrigation on Soil Water and Nitrogen Dynamics and Banana Yield under Banana-Mung Bean Intercropping

HU Junming[1]*, HUANG Zhonghua[2], LUO Weigang[2], LI Tingting[1], MENG Yancheng[1], HUANG Taiqing[1], LIAO Ting[2], YU Yuefeng[1]

[1]Agricultural Resource and Environment Research Institute, Guangxi Academy of Agricultural Sciences, Nanning 530007, China
[2]Nanning Irrigation Experiment Station, Nanning 530001, China

Abstract

This study investigated the effects of micro-sprinkler irrigation on soil water-nitrogen dynamics and banana yield under a banana-mung bean intercropping system (referred to as "banana-green manure intercropping"). Four irrigation quota treatments were established: MSI2 (900 $m^3 \cdot hm^{2}$), MSI3 (1,350 $m^3 \cdot hm^{2}$), MSI4 (1,800 $m^3 \cdot hm^{2}$), and MSI5 (2,250 $m^3 \cdot hm^{2}$), with no irrigation and clean cultivation as controls.

The results showed that during the mung bean growth period, soil evaporation between plants decreased to varying degrees under all irrigation treatments in the intercropped system, while evaporation under clean cultivation (MSI0) showed an upward trend. As irrigation volume increased, evaporation between banana plants gradually increased, with MSI5 reaching the highest cumulative evaporation of 385.6 mm—12.2%, 7.6%, and 4.9% higher than MSI2, MSI3, and MSI4, respectively—resulting in reduced irrigation water use efficiency. Micro-sprinkler irrigation increased surface soil moisture content, with MSI2, MSI3, MSI4, and MSI5 showing significantly higher water content in the 0–30 cm soil layer compared to MSI0 and MSI1, while moisture began to decrease below 30 cm.

Micro-sprinkler irrigation also improved soil tilth structure and enhanced soil available nitrogen. The MSI2 treatment achieved an ideal soil three-phase ratio (2:1:1), while MSI3 produced the highest available nitrogen content in the topsoil. MSI4 yielded the highest banana production at 48,218 $kg \cdot hm^{2}$, and MSI3 achieved the highest fruit sugar content at 25.67%. Therefore, under banana-green manure intercropping, appropriate micro-sprinkler irrigation is beneficial for increasing banana yield and improving fruit quality.

Keywords: banana-mung bean intercropping, micro-sprinkler irrigation, soil water and nitrogen, yield

Introduction

Banana cultivation typically employs wide row spacing with clean tillage, leaving large gaps between plants and extensive exposed soil surface. Due to intense solar radiation, soil water evaporation is substantial, making drought a critical constraint on banana production (Qiu et al., 2007). As a major subtropical economic fruit crop, bananas have seen increasing market value, leading to widespread over-reliance on chemical fertilizers to boost yields. Intercropping represents the essence of traditional Chinese agriculture (Li, 2013; Liu et al., 2016), and legume-non-legume intercropping systems can enhance biological nitrogen fixation and improve soil fertility (Fastie, 1995; Kamruzzaman & Hasanuzzaman, 2008; Li, 2013). Banana intercropping fully utilizes the light, heat, and spatial resources under banana canopies, increases green ground cover, improves plantation environments, facilitates crop rotation and fallow periods, and creates an efficient planting model that boosts economic returns.

Bananas are tropical herbaceous plants with high water demands, and micro-sprinkler irrigation is an important water-saving technique widely used in modern banana production (Liu et al., 2009; Zhang et al., 2009; Zang et al., 2014). Green manure and straw incorporation are crucial practices that combine soil utilization and conservation, supporting national initiatives to reduce chemical fertilizer use (Zheng et al., 2009; Yuan et al., 2011). Traditional green manure management focuses on plowing under the biomass. However, in banana-green manure intercropping systems, this approach is difficult because banana roots are concentrated in shallow surface layers with extensive distribution. The grain-green manure mung bean variety developed by Guangxi Academy of Agricultural Sciences is an excellent leguminous green manure with strong nitrogen-fixing capacity. After seed harvest, the plants remain green and nutrient-rich, making it an ideal summer green manure for tropical regions. The shading effect of mature banana plants and the integrated water-fertilizer management environment provide favorable conditions for green manure decomposition and nutrient release. Currently, few studies have reported on the ecological effects of micro-sprinkler irrigation on soil environments and its impacts on yield and quality under banana-green manure intercropping. This study established different micro-sprinkler irrigation quotas in a banana-grain/green manure mung bean intercropping system. After harvesting mung bean pods at maturity, the aboveground fresh biomass was cut and directly mulched in situ to investigate the effects of micro-sprinkler irrigation on soil water-nitrogen dynamics, banana yield, and fruit quality, thereby clarifying the effectiveness of micro-sprinkler irrigation under banana-green manure intercropping to provide guidance for water-saving irrigation and chemical fertilizer reduction technologies in banana production.

Materials and Methods

1.1 Study Site

The experiment was conducted from 2014 to 2015 at the Nanning Irrigation Experiment Station. The experimental site had previously grown sugarcane and had no history of water-fertilizer experiments. The terrain was flat with uniform fertility. The soil was red loam developed from Quaternary red clay, with a pH of 5.9, organic matter content of 21.36 g · kg ^{1}, alkali-hydrolyzable nitrogen of 95.82 mg · kg ^{1}, available phosphorus of 62.68 mg · kg ^{1}, available potassium of 278.91 mg · kg ^{1}, total nitrogen of 1.25 g · kg ^{1}, total phosphorus of 0.86 g · kg ^{1}, and total potassium of 3.2 g · kg ^{1}. Field water holding capacity was 26.68%, and bulk density was 1.38 g · cm ^{3}. The experimental area is located at 22°53 7 N, 108°17 48 E in a monsoon climate region, with a multi-year average temperature of 22.9°C and annual rainfall of 1,274.2 mm. New banana plants were established in 2014, and ratoon crops were grown in 2015. Daily rainfall and temperature during the intercropping period are shown in [Figure 1: see original paper], representing normal climatic conditions.

1.2 Experimental Materials

The banana cultivar "Williams B6" was planted in deep furrows with wide rows at 2.4 m row spacing and 2.2 m plant spacing, resulting in a density of 125 plants per 666.7 m^2. Standard banana cultivation management practices were applied. The intercropped green manure was the grain-green manure mung bean variety "Gui Lüdou 5" developed by the Agricultural Resource and Environment Research Institute of Guangxi Academy of Agricultural Sciences. Mung bean was sown at 37.5 kg · hm ^{2} by shallow hoeing and broadcasting in the spaces between banana rows, with a 30 cm border distance from banana plants. No fertilizer was applied to mung bean, which was managed according to conventional field practices. After pod harvest, aboveground plants were cut and directly mulched in situ. Micro-sprinkler irrigation facilities were installed near the banana root zone after transplanting, using micro-sprinkler hoses with a diameter of 63 mm, 3 outlet holes, and a flow rate of 20–30 L · h ^{1}. The hoses provided uniform water distribution during irrigation, and mung bean growth, plant height, and green manure cover had no interactive effects on micro-sprinkler performance.

1.3 Experimental Design

Four micro-sprinkler irrigation quota treatments were established: MSI2 (900 m^3 · hm ^{2}), MSI3 (1,350 m^3 · hm ^{2}), MSI4 (1,800 m^3 · hm ^{2}), and MSI5 (2,250 m^3 · hm ^{2}), with MSI1 (no irrigation, CK) and banana clean cultivation MSI0 (CK) as controls. The experimental design and irrigation quotas during the intercropping period are detailed in . The total experimental area was 2,000 m^2, using deep furrow and wide row planting with three replications arranged randomly. All treatments received the same irrigation amount before mung bean planting and after harvest; intercropping period irrigation quotas are shown in

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1.4 Measurement Items and Methods

Evaporation between plants: Micro-lysimeters were installed in the center of each experimental plot before mung bean planting and weighed daily from 8:00-9:00 AM using a 0.01 g precision balance. The difference between consecutive days' weights represented evaporation between plants (Wang et al., 2012).

Soil water content: Measured at the uniform seedling stage, full-bloom stage, pod-bearing stage, and post-harvest at 10–100 cm depth in 10 cm increments using the oven-drying method.

Soil three-phase ratio: At 0–20 cm tillage layer, soil water content, bulk density, and porosity were measured before mulching after mung bean harvest to calculate the proportions of gas, liquid, and solid phases (Chen, 2005).

Soil available nitrogen: Soil profiles at 10–90 cm depth were sampled at initial flowering, pod-bearing stage, 10 days after mulching, and 20 days after mulching. Samples were air-dried and analyzed using the alkali-hydrolysis diffusion method (Bao, 2000).

Banana yield: Measured in each experimental plot at harvest and converted to per-hectare yield.

Soluble total sugar content in banana fruit: Determined using the anthrone colorimetric method (Zhang, 1992).

1.5 Data Processing

Data processing, statistical analysis, and graphing were performed using Microsoft Excel 2003 and DPS 6.55. Data on soil three-phase ratio, available nitrogen, banana yield, and quality were from the second year of the intercropping experiment. Multiple comparisons were conducted using Tukey' s method.

Results

2.1 Dynamics of Soil Evaporation between Plants under Micro-Sprinkler Irrigation

Evaporation between plants is influenced by rainfall, irrigation, temperature, sunlight, and surface vegetation (Sun et al., 2014). As shown in [Figure 2: see original paper], evaporation under micro-sprinkler irrigation in the banana-mung bean intercropping system exhibited varying degrees of decline, while clean cultivation (MSI0) showed fluctuating increases, reaching cumulative evaporation of 429.7 mm. With increasing irrigation volume, cumulative evaporation between plants increased. MSI1 had the lowest cumulative evaporation at 315.97 mm, while MSI5 reached the highest at 385.6 mm—12.2%, 7.6%, and 4.9% higher than MSI2, MSI3, and MSI4, respectively. Mung bean was planted in early April when temperatures were around 21.5°C and sunlight was not intense, resulting in relatively low evaporation for MSI0 and MSI1. Other treatments had higher evaporation due to irrigation on day 2 after sowing, which increased soil moisture. Irrigation events on days 31, 43, and 63 caused sharp evaporation spikes the following day in MSI2, MSI3, MSI4, and MSI5. During the pod and harvest stages, summer conditions with stronger solar radiation and higher temperatures, combined with incomplete canopy cover during early banana vegetative growth, caused intense evaporation in MSI0. In contrast, mung bean cover significantly reduced evaporation in other treatments compared to MSI0, demonstrating that intercropped mung bean effectively reduced soil water evaporation.

2.2 Soil Water Dynamics under Micro-Sprinkler Irrigation

Under micro-sprinkler irrigation, MSI2, MSI3, MSI4, and MSI5 had significantly higher water content in the 0–30 cm soil layer compared to MSI1 and MSI0 [Figure 3: see original paper]. Below 40 cm, soil water content began to decrease but remained at relatively high levels. Due to water infiltration, water content in the 30–60 cm layer was also higher in MSI2, MSI3, MSI4, and MSI5 than in MSI1 and MSI0. Water content gradually decreased with soil depth across all treatments, converging to similar levels at 100 cm depth. During the mung bean full-bloom stage, MSI1 had higher water content than MSI0 in the 0–30 cm layer due to mung bean shading, with minimal differences below 30 cm. Under intercropping, all irrigated treatments maintained high water content in the 0-20 cm layer, with MSI4 and MSI5 higher than MSI2 and MSI3. During the pod-bearing stage and post-harvest, MSI1 had higher water content than MSI0 across all soil layers. These results indicate that banana-mung bean intercropping improves soil water retention and moisture conservation.

2.3 Soil Three-Phase Ratio in Tillage Layer under Micro-Sprinkler Irrigation

The soil three-phase ratio is a critical parameter for evaluating relationships among soil water, nutrients, air, and heat. As shown in , both liquid and gas phase proportions increased under intercropping with irrigation, but the liquid phase ratio continuously increased with irrigation volume while the gas phase ratio decreased. MSI5 reached the limiting value for the liquid phase, while all treatments showed significantly higher gas phase ratios compared to MSI1 and MSI0. Appropriate irrigation helped increase the gas phase level. MSI1 had higher gas and liquid phase ratios than MSI0, with the gas phase being extremely significantly higher, while MSI0 had an excessively high solid phase with low gas and liquid phases, indicating a compact and heavy soil state likely caused by strong surface water evaporation. This demonstrates that intercropping mung bean in banana plantations effectively loosens soil and enhances soil layer permeability. The ideal soil three-phase ratio is 50% solid, 25% liquid, and 25% gas (Herrmann & Witter, 2002). In this study, MSI2 achieved a solid phase of 49.4%, liquid phase of 26.5%, and gas phase of 23.3%—approximately a 2:1:1 ratio—indicating that 900 $m^3 \cdot hm^{2}$ of micro-sprinkler irrigation under banana-mung bean intercropping approaches the ideal soil structure.

2.4 Changes in Soil Available Nitrogen Content under Micro-Sprinkler Irrigation

From the soil profile perspective [Figure 4: see original paper], available nitrogen content below 40 cm depth showed little variation among treatments, remaining essentially constant at 80–84 $mg \cdot kg^{1}$. However, nitrogen content in the upper 30 cm layer was significantly affected by treatments. In MSI0, available nitrogen in the 10–30 cm layer gradually decreased over time, declining by approximately 5.1% by 20 days post-harvest compared to the initial flowering stage, likely due to root uptake without external nitrogen supplementation. In contrast, MSI1 showed the opposite trend, with low nitrogen at initial flowering that increased by 19.0% 20 days after green manure mulching—attributed to both nitrogen release from mung bean root nodules and nutrient release from decomposing mung bean straw. MSI2, MSI3, MSI4, and MSI5 showed similar trends, with surface soil available nitrogen increasing by 23.4%, 29.8%, 20.4%, and 20.5%, respectively, 20 days post-harvest. In summary, surface soil available nitrogen was highest across treatments, decreasing with profile depth and remaining relatively constant below 40 cm as background levels.

2.5 Effects of Micro-Sprinkler Irrigation on Banana Yield and Quality

Analysis of banana yield and quality in the second year of the intercropping experiment [Figure 5: see original paper] revealed that clean cultivation without irrigation (MSI0) produced the lowest yield. Banana-mung bean intercropping without irrigation (MSI1) increased yield by 5.8% compared to clean cultivation. All irrigated intercropping treatments outperformed clean cultivation, with MSI4 achieving the highest yield—8.4%, 4.0%, and 6.1% higher than MSI2, MSI3, and MSI5, respectively. These results indicate that irrigation at the MSI4 quota produced the best yield increase under intercropping conditions. Using soluble total sugar content as the primary quality indicator, clean cultivation without irrigation produced the lowest sugar content, while MSI1 showed extremely significantly higher sugar content than clean cultivation. Among irrigated treatments, MSI3 produced the highest sugar content, 7.1% higher than MSI2. However, sugar content continuously decreased with increasing irrigation volume, with MSI4 and MSI5 showing 9.0% and 12.3% reductions compared to MSI3, respectively.

Discussion

Banana-mung bean intercropping effectively suppresses evaporation between plants. Evaporation at the soil-plant interface does not contribute to crop growth and development, representing ineffective water loss (Jing et al., 2010).

It constitutes a large proportion of total evapotranspiration in farmland, and suppressing evaporation is an effective measure to improve water use efficiency (Wu et al., 2006). Agricultural practices commonly use crop straw mulching to reduce water loss, as mulching separates soil from atmospheric contact and mitigates solar radiation and wind effects, resulting in significantly lower evaporation than bare soil (Denisov et al., 2002; Diaz et al., 2005; Ji et al., 2010). This study found that banana evaporation between plants showed a fluctuating downward trend during mung bean growth, decreasing by 26.3% compared to monoculture, while surface soil moisture gradually increased to approximately 20.5% at mung bean harvest. Compared to surface mulching, banana-mung bean intercropping utilizes understory space resources, increases green ground cover, reduces solar radiation-induced water evaporation from exposed soil, and demonstrates effective moisture retention.

Micro-sprinkler irrigation increases surface soil water content in banana-mung bean intercropping systems. Soil water serves as a transport carrier for water-soluble components (David, 2014), and micro-sprinkler irrigation uniformly distributes water from the canopy to the root zone, similar to natural rainfall. Water-saving irrigation aims to achieve maximum yield or benefit with minimum water use (Zhou et al., 2002). This study found that different irrigation quotas under intercropping increased soil moisture, but due to the robust stems and tall plants of mung bean shading sunlight, evaporation between plants decreased to varying degrees compared to controls. Surface soil moisture was maintained above 22.0% for extended periods, indicating that micro-sprinkler irrigation increases surface soil moisture. However, water infiltration affects deep soil moisture distribution, and excessive irrigation increases evaporation between plants, reducing water use efficiency. Intercropped mung bean plays a role in water storage and conservation, highlighting the importance of controlling irrigation volume to prevent water waste. These findings are consistent with results from Lü et al. (2007), Li et al. (2016), and Yi et al. (2017).

Banana intercropping improves soil tilth structure. Crop combination selection and appropriate agronomic measures are key factors for successful intercropping systems (Brooker et al., 2015). Kang and Zhang (1997) found that intercropped crops not only enhance soil water storage capacity but also create soil pores through root contraction, increasing the gas phase ratio and achieving soil loosening effects. In this study, banana-mung bean intercropping significantly increased the soil gas phase ratio, improving soil tilth structure. With increasing irrigation volume, the liquid phase ratio continuously increased while the gas phase ratio decreased, possibly because excessive irrigation creates waterlogging effects that are exacerbated by intercropped mung bean, leading to unreasonable soil three-phase ratios.

Appropriate irrigation in banana-mung bean intercropping increases soil nitrogen supply, enhances banana yield, and improves fruit quality. Legume nitrogen fixation and allelopathic effects in intercropping systems help regulate soil habitats and increase available nitrogen content (Suman et al., 2006). This two-year study found that micro-sprinkler irrigation combined with mulching increased soil available nitrogen content, with nitrogen in the upper 30 cm tillage layer increasing over time. Under the banana-mung bean intercropping system with micro-sprinkler irrigation, the 1,350 $m^3 \cdot hm\ ^2$ quota produced the highest yield, while the 1,800 $m^3 \cdot hm\ ^2$ quota achieved the best quality. This may be because irrigation enhanced mung bean growth, producing more root nodules for nitrogen fixation, or because irrigation combined with green manure mulching improved soil physical properties, altered soil tilth structure, promoted mineral nitrogen release, facilitated banana root nutrient uptake and aboveground growth, and increased photosynthate translocation to banana fruits. Whether the improvements in yield and quality result from micro-sprinkler irrigation alone or from the interactive effects of water-fertilizer coupling with green manure mulching requires further verification.

Conclusion

Micro-sprinkler irrigation under banana-mung bean intercropping reduced soil evaporation between plants, while evaporation under monoculture without irrigation showed an upward trend. Micro-sprinkler irrigation increased surface soil water content, improved banana tillage layer structure, and enhanced soil fertility. Specifically, the 900 $m^3 \cdot hm\ ^2$ irrigation quota achieved the optimal soil three-phase ratio, the 1,350 $m^3 \cdot hm\ ^2$ quota produced the highest topsoil available nitrogen content, the 1,800 $m^3 \cdot hm\ ^2$ quota yielded the highest banana production, and the 1,350 $m^3 \cdot hm\ ^2$ quota resulted in the best fruit quality. Appropriate micro-sprinkler irrigation under banana-mung bean intercropping can increase banana yield and improve fruit quality, representing an important green efficiency-enhancing technology that supports chemical fertilizer reduction and water-saving irrigation for sustainable banana industry development.

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