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# Investigation of the Effects of Biodegradable Hydrogel on Paddy Crop Growth

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**Research Article**

**Keywords:** Paddy rice, Biodegradable hydrogel, Cassava peels, Water use efficiency, Grain yield, Leaf area index, Soil amendment

**Posted Date:** August 10th, 2026

**DOI:** https://doi.org/10.21203/rs.3.rs-10144496/v1

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**Additional Declarations:** No competing interests reported.

# Abstract

Water scarcity and climate variability present significant challenges to paddy rice production in sub-Saharan Africa. This study investigated the efficacy of a biodegradable hydrogel derived from cassava peels as a soil conditioner to improve rice growth, water use efficiency (WUE), and grain yield. A field experiment was conducted at the Ruwhiti Irrigation Scheme in Tanzania using a randomized complete block design with four hydrogel application rates (0, 10, 20, and 30 kg/ha) and the rice variety TXD 306. Results demonstrated that the application of hydrogel significantly enhanced morphological and physiological parameters compared to the control. The 30 kg/ha application rate yielded the highest performance, recording 13 panicles per plant, a leaf area index (LAI) of 2.29, and a grain yield of 4,850 kg/ha. Notably, the 30 kg/ha treatment increased WUE to 0.272 kg/m³, representing a 16.2% improvement over the control group (0.234 kg/m³). Statistical analysis (ANOVA and LSD test, $p < 0.05$) confirmed that the 30 kg/ha treatment was superior to the control in grain yield, panicle number, and LAI. These findings suggest that cassava peel-derived hydrogels are an effective, locally sourced soil amendment for optimizing moisture retention and nutrient availability. Consequently, this technology provides a viable, sustainable strategy for maximizing rice productivity and resource-use efficiency in water-limited agricultural regions.


# 1. Introduction

The intensification of paddy rice production is increasingly constrained by erratic rainfall patterns and the inherent inefficiency of traditional irrigation systems, particularly in sub-Saharan Africa (Rosegrant et al., 2002). As water scarcity intensifies due to climate-driven shifts, the adoption of advanced soil conditioning technologies has become a strategic necessity for maintaining regional food security (Tall et al., 2018). Among these innovations, biodegradable superabsorbent hydrogels (SAHs) derived from agricultural residues, such as cassava peels, offer a promising solution by enhancing soil moisture retention and facilitating the sustained release of nutrients within the crop's root zone (Sutha et al., 2020).

Recent studies have demonstrated that the application of bio-based hydrogels significantly alters the physiological and morphological development of rice plants. These polymers act as 'miniature reservoirs' that mitigate water stress during critical growth stages such as panicle initiation and grain filling, which are highly sensitive to moisture deficits (Chaudhary et al., 2020). Furthermore, the integration of hydrogels into soil matrices has been shown to improve leaf area index (LAI) and biomass accumulation by optimizing the plant's photosynthetic capacity and reducing transpiration losses (Sood et al., 2023). Beyond these physiological benefits, the use of cassava-derived hydrogels addresses environmental concerns associated with synthetic, petroleum-based polymers, as these bio-based materials are highly biodegradable, preventing the accumulation of toxic microplastics in agricultural soils (Adjuik et al., 2022).

Despite the established potential of hydrogels in controlled environments, a critical knowledge gap remains regarding their field-level performance under the specific pedoclimatic conditions of Tanzania. Most existing research on starch-based hydrogels has been conducted under standardized laboratory or greenhouse settings, which do not fully replicate the complex soil moisture dynamics, nutrient leaching rates, and variable irrigation water quality found in Tanzanian rice schemes. Consequently, there is limited evidence on the optimal application rates of locally sourced cassava peel hydrogels needed to achieve tangible improvements in grain yield and water-use efficiency under smallholder farming conditions.

This study, therefore, evaluates the performance of locally synthesized hydrogels in improving panicle density, water use efficiency, and overall grain productivity. By comparing various application rates against traditional farming practices, this investigation provides critical evidence for the scalability of sustainable hydrogel technology in rice-based cropping systems.

## 2. Materials and Methods

# 2.1 Experimental Site

The study was conducted from October to March during the 2025/2026 cropping season at the Ruwhiti Irrigation Scheme, Nyakayenzi Village, Kasuga Ward, Kakonko District, Kigoma Region, Tanzania (Fig. 2.1). The site lies at an altitude of 1,100–1,700 m above sea level and experiences a tropical savannah climate (Aw) with bimodal rainfall averaging 850–1,100 mm annually. Mean annual temperature ranges between 18°C and 28°C. The experimental site, characterized by well-drained, ferrallitic, and moderately fertile soil, serves as a crucial test bed for evaluating the performance of hydrogel amendments in rice production.

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# 2.2 Hydrogel Synthesis and Characterization

Biodegradable superabsorbent hydrogel was synthesized using a modified alkaline gelatinization and physical cross-linking method. Cassava peels (Mkombozi variety) were washed, dried, and ground into fine powder. The starch slurry (1:10 w/v ratio) was adjusted to pH 7.0 using 0.1 M NaOH. The slurry was heated to 70°C under continuous stirring for 60 minutes to achieve complete thermal gelatinization, which disrupts native starch crystalline domains and promotes the formation of a physically cross-linked network. The resulting gel was oven-dried at 60°C and processed into uniform granules (approx. 1–2 mm). Laboratory characterization was conducted at the Sokoine University of Agriculture (Chemistry and Physics Department).

# 2.3 Experimental Design and Layout

The experiment followed a randomized complete block design (RCBD) with four treatments and three replications. Treatments included application rates of 0 kg/ha (Control), 10 kg/ha (T1), 20 kg/ha (T2), and 30 kg/ha (T3). Each plot measured 4 m × 5 m (20 m²), separated by 1 m pathways. Hydrogel was uniformly incorporated into the top 0–20 cm soil layer one week before transplanting (Fig. 2.2).

# 2.4 Crop Establishment and Data Collection

Rice variety TXD 306 was transplanted at a 20 cm × 20 cm spacing. Basal NPK (10-18-24) fertilizer was applied at 100 kg/ha. Urea was applied in two splits (21 and 35–40 days after transplanting). Crop parameters including plant height, tiller/panicle number, and biomass were measured at maturity. LAI was calculated as (Leaf length × Leaf width × 0.75 × Number of leaves) / Ground area. WUE (kg/m³) was calculated as grain yield (kg/ha) / total water input (m³/ha), including rainfall and irrigation.

# 2.5 Statistical Analysis

Data were analyzed using R software (version 4.3.2) via the 'Agricolae' package. Analysis of Variance (ANOVA) was performed to evaluate treatment effects, and means were separated using the Least Significant Difference (LSD) test at $p \leq 0.05$.

## 3. Results

The field trial conducted at the Ruwhiti Irrigation Scheme evaluated the efficacy of four biodegradable hydrogel application rates (0,10,20, and 30 kg/ha) on the agronomic performance of the rice variety TXD 306.

# 3.1 Grain Yield

Hydrogel application significantly influenced rice grain yield ($p \leq 0.05$). The 30 kg/ha treatment recorded the highest mean grain yield of 4,850 kg/ha, which was significantly superior to the control (4,300 kg/ha). While treatments at 10 and 20 kg/ha also surpassed the control, no significant difference was observed between these two application rates (Table 3.1).

Table 3.1
Effect of hydrogel application on rice grain yield

| Hydrogel Treatment (kg/ha) | Mean Grain Yield (kg/ha) |
|---|---|
| 0 (Control) | 4,300 b |
| 10 | 4,533 ab |
| 20 | 4,500 ab |
| 30 | 4,850 a |

Note: Means followed by the same letter are not significantly different ($p \leq 0.05$).

## 3.2 Yield Components and Growth Parameters

The number of panicles per plant and spikelets per panicle were significantly enhanced by hydrogel application. The 30 kg/ha rate produced the highest panicle number (13) and spikelets per panicle (126) (Table 3.2). Plant height did not vary significantly among treatments ($p > 0.05$), indicating that hydrogel application influenced reproductive development rather than vegetative stature. Leaf Area Index (LAI) also showed significant variation, peaking at 2.29 for the 30 kg/ha treatment (Table 3. 2).

Table 3.2
Influence of hydrogel rates on yield components and growth parameters

| Hydrogel Treatment (kg/ha) | Panicle /Plant | Spikelets/Panicle | Plant Height (cm) | LAI |
|---|---|---|---|---|
| 0 (Control) | 12 b | 96c | 73.07a | 1.85c |
| 10 | 11 c | 97c | 73.93a | 2.03b |
| 20 | 12 b | 106b | 72.07a | 1.74d |
| 30 | 13 a | 126a | 73.51a | 2.29a |

Note: Means within columns followed by the same letter are not significantly different ($p \leq 0.05$).

## 3.3 Biomass Yield and Water Use

Biomass yield followed a trend similar to grain yield, with the 30 kg/ha application achieving the highest biomass (10.777.78 kg/ha). Furthermore, increasing hydrogel concentrations correlated with decreased water requirements; the 30 kg/ha treatment required the lowest average volume of irrigation water (17,771.7 $m^3$/ha) compared to the control (18.387.0 $m^3$/ha) (Table 3.3).

Table 3.3
Effect of hydrogel application on biomass yield and water use

| Hydrogel Treatment (kg/ha) | Biomass Yield (kg/ha) | Water Use ($m^3$/ha) |
|---|---|---|
| 0 (Control) | 9555.56d | 18,387.0a |
| 10 | 10073.30b | 18,093.7b |
| 20 | 10000.00c | 17,774.3c |
| 30 | 10777.78a | 17,771.7c |

Note: Means within columns followed by the same letter are not significantly different ($p \leq 0.05$).

## 4. Discussion

The present study demonstrates that the application of biodegradable hydrogel significantly influences the agronomic performance of rice variety TXD 306. The observed increase in grain yield and water use efficiency (WUE) with the application of hydrogel at 30 kg/ha confirms the material's efficacy as a soil moisture-retention amendment in paddy environments.

# 4.1 Effect on Growth and Yield Components

The significant increase in panicle number and leaf area index (LAI) at higher application rates suggests that the hydrogel successfully mitigated moisture stress during critical growth stages. Interestingly, while most parameters showed a linear increase with hydrogel dosage, intermediate application rates (10 and 20 kg/ha) occasionally showed non-linear responses compared to the control. This variability may be attributed to heterogeneous soil moisture distribution or site-specific interactions between the biodegradable matrix and soil microbial activity, which may temporarily immobilize nutrient availability before the full benefits of the hydrogel are realized.

# 4.2 Impact on Water Use Efficiency (WUE)

The improvement in WUE achieved with 30 kg/ha treatment underscores the potential of hydrogel to optimize irrigation management. By reducing the frequency of irrigation, the hydrogel effectively minimizes deep percolation and evaporation losses, which are the primary drivers of low water productivity in the Ruwhiti Irrigation Scheme. The synchronization of moisture release with crop demand confirms that hydrogel acts as a 'mini-reservoir' within the root zone.

## 5. Conclusion

This study confirms that the application of biodegradable hydrogel derived from cassava peels is a viable strategy to enhance the productivity and water use efficiency of rice variety TXD 306 in ferrallitic soils. The 30 kg/ha application rate emerged as the optimal treatment for maximizing grain yield (4,850 kg/ha) and optimizing water resource management. These findings provide a sustainable dual solution to the challenges of water scarcity and declining crop yields, supporting the shift toward more climate-resilient irrigation practices.

## 6. Recommendation

Based on the findings of this study, the following recommendations are made Scaling Application:

- It is recommended that smallholder farmers adopt the 30 kg/ha hydrogel application rate to maximize rice yields and ensure stable crop performance during periods of erratic rainfall.
- Long-term Soil Assessment: Future studies should investigate the long-term impact of repeated hydrogel application on soil physical properties and the degradation rate of the cassava-based
- Economic Viability: Further research should conduct a comprehensive cost-benefit analysis to determine the affordability and commercial feasibility of mass-producing cassava-based hydrogel.

- Integration with Irrigation: Agricultural extension services should provide training on the precise incorporation of hydrogel during land preparation.

# Declarations

7.1 Clinical Trial Registration

This study is not a clinical trial; therefore, clinical trial registration is not applicable.

7.2 Ethics, Consent to Participate, and Consent to Publish

This research involved experimental agricultural fieldwork and did not involve human or animal subjects. Therefore, Ethics, Consent to Participate, and Consent to Publish declarations are not applicable.

7.3 Author Contributions

Jenard Mathayo Mlengera: Conceptualization, methodology, formal analysis, investigation, writing – original draft.

Dr. Stanslaus Terengia Materu: Supervision, validation, writing – review and editing.

Dr. Yusto Mugisha Yustas: Supervision, methodology review, writing – review and editing.

7.4 Conflict of Interest

The authors declare no conflict of interest.

7.5 Funding Source

This research received no external funding.

7.6 Data Availability

The data used in this study are available from the corresponding author upon reasonable request.

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# Figures

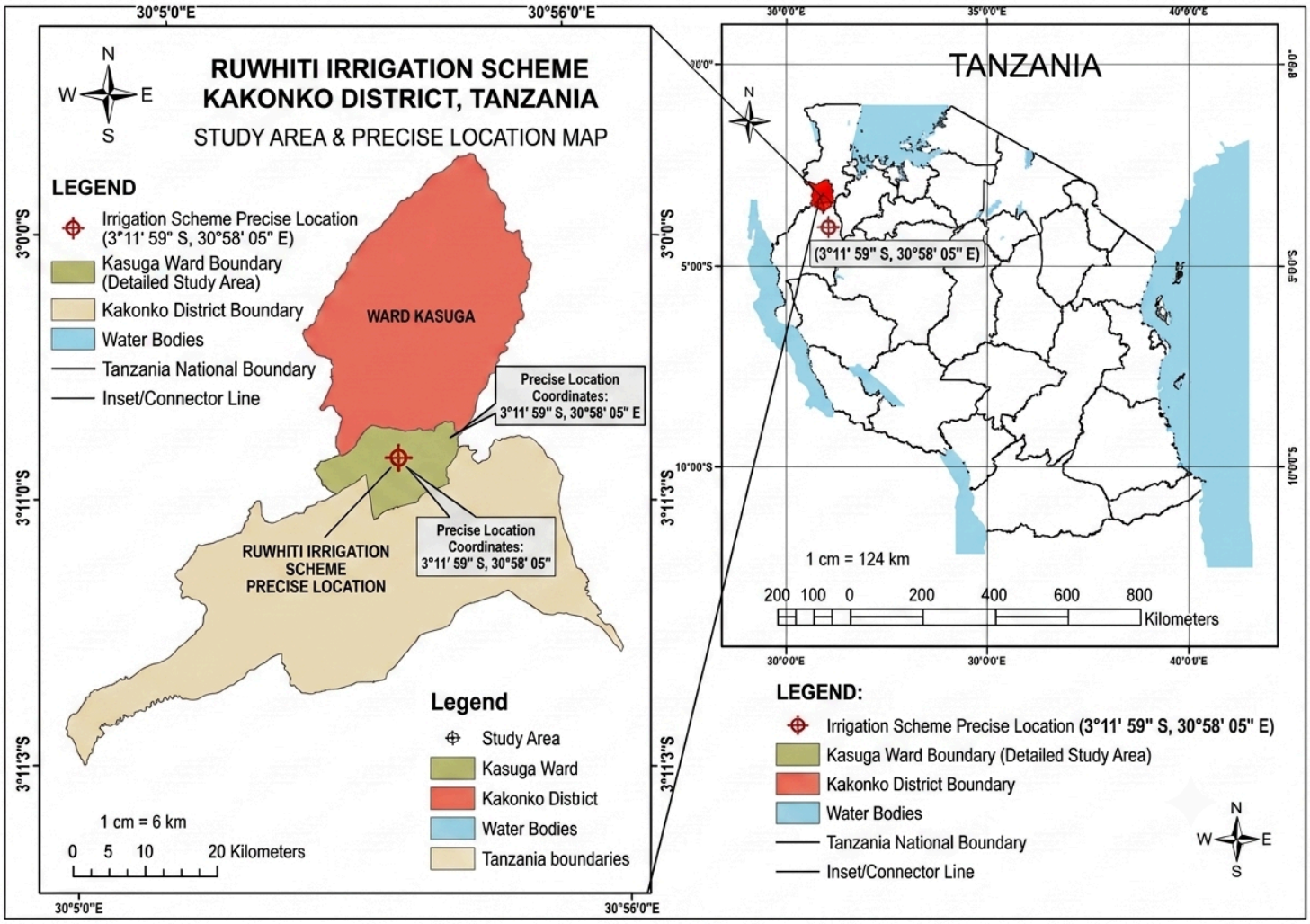



**Figure 1**

**Figure 2.1: Location of the study Area in Tanzania**

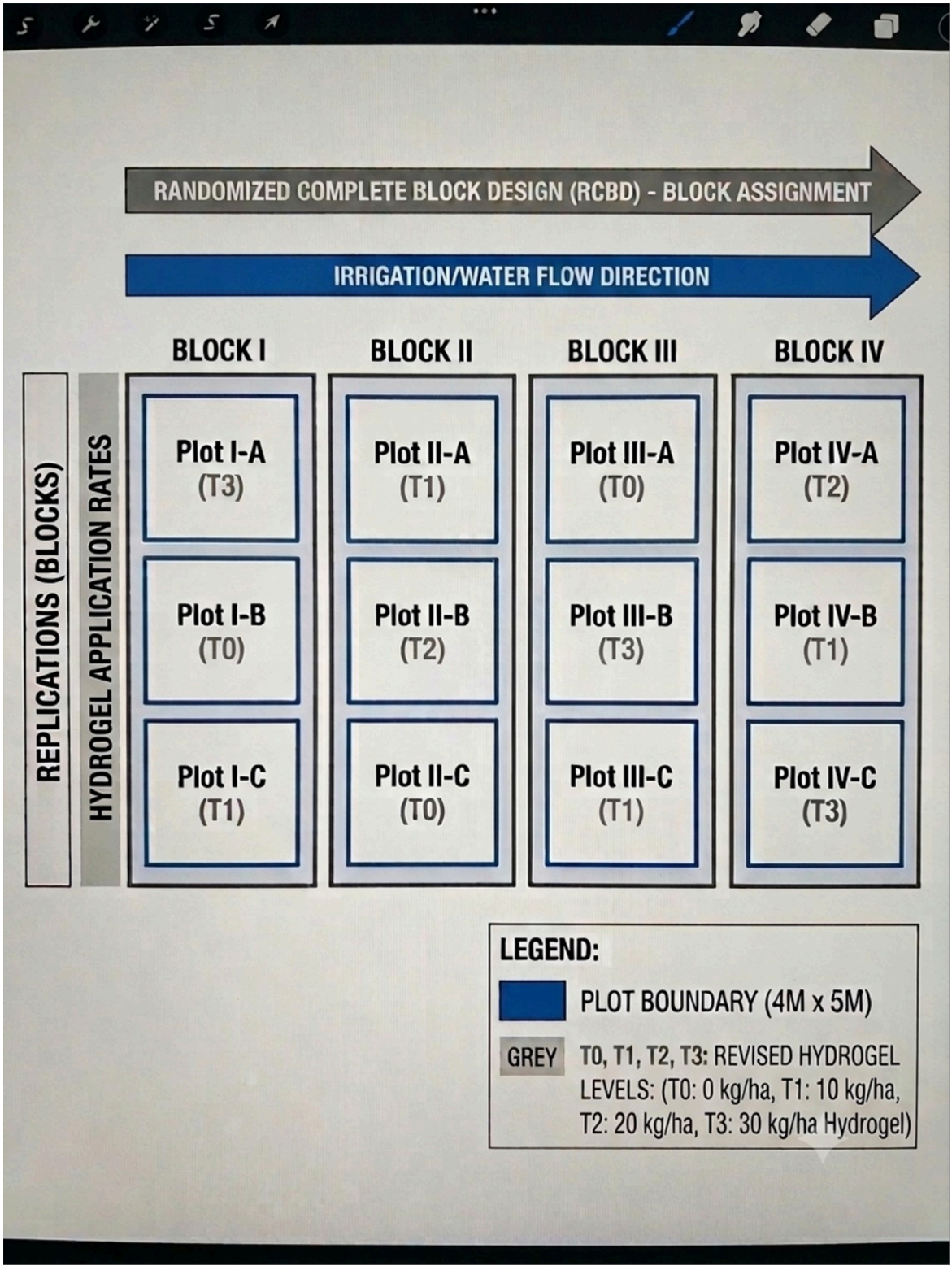



Figure 2

**Figure 2.2: Schematic layout of the experimental design (RCBD).The layout includes four blocks (replications) and four treatment levels, plot dimensions (4mx 5m) and 1m wide pathways are maintained to reduce border effects. The arrow indicates the natural slope and direction of irrigation water flow.**

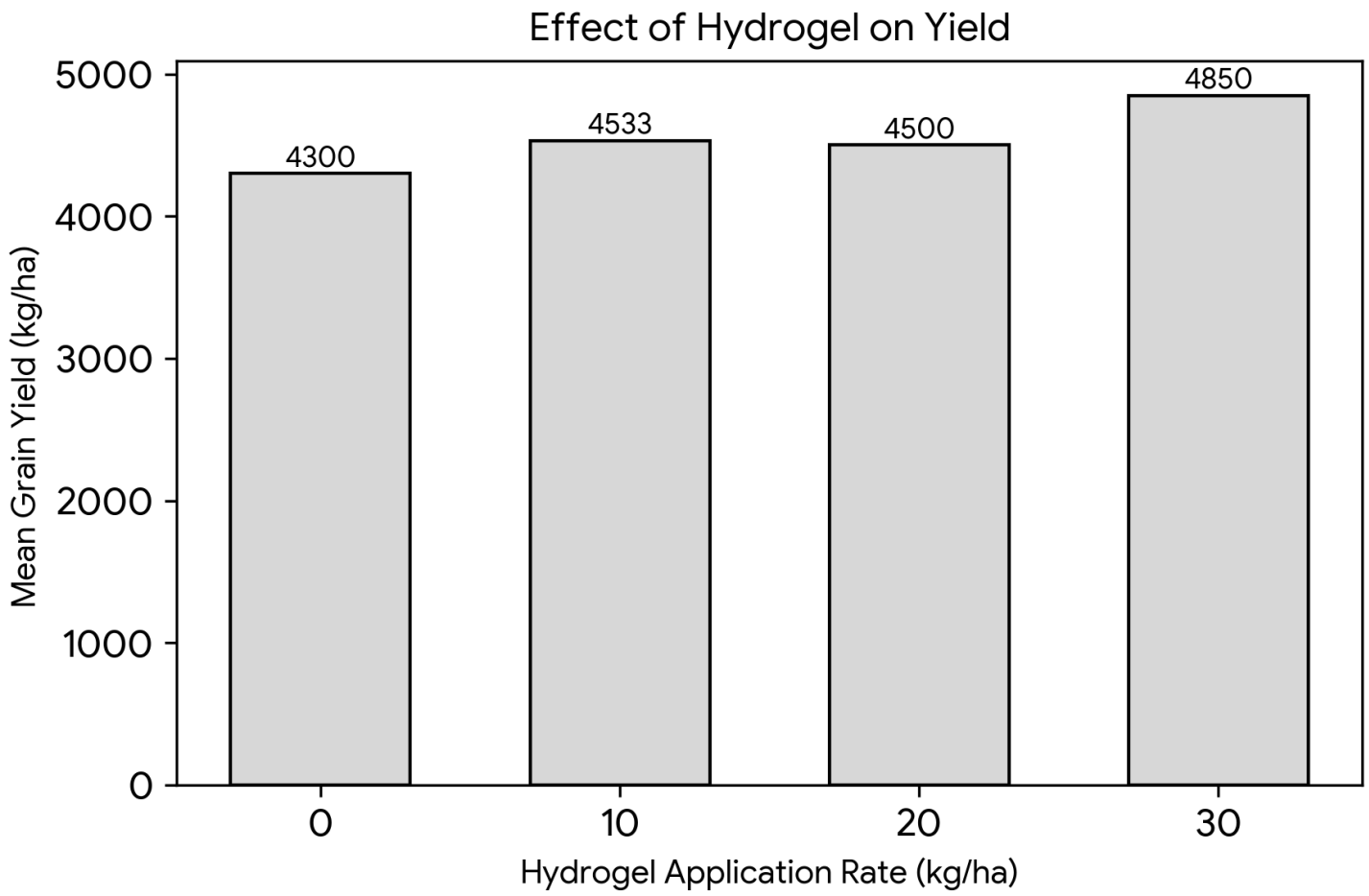



**Figure 3**

**Figure 3.1: Effect of hydrogel on grain yield**

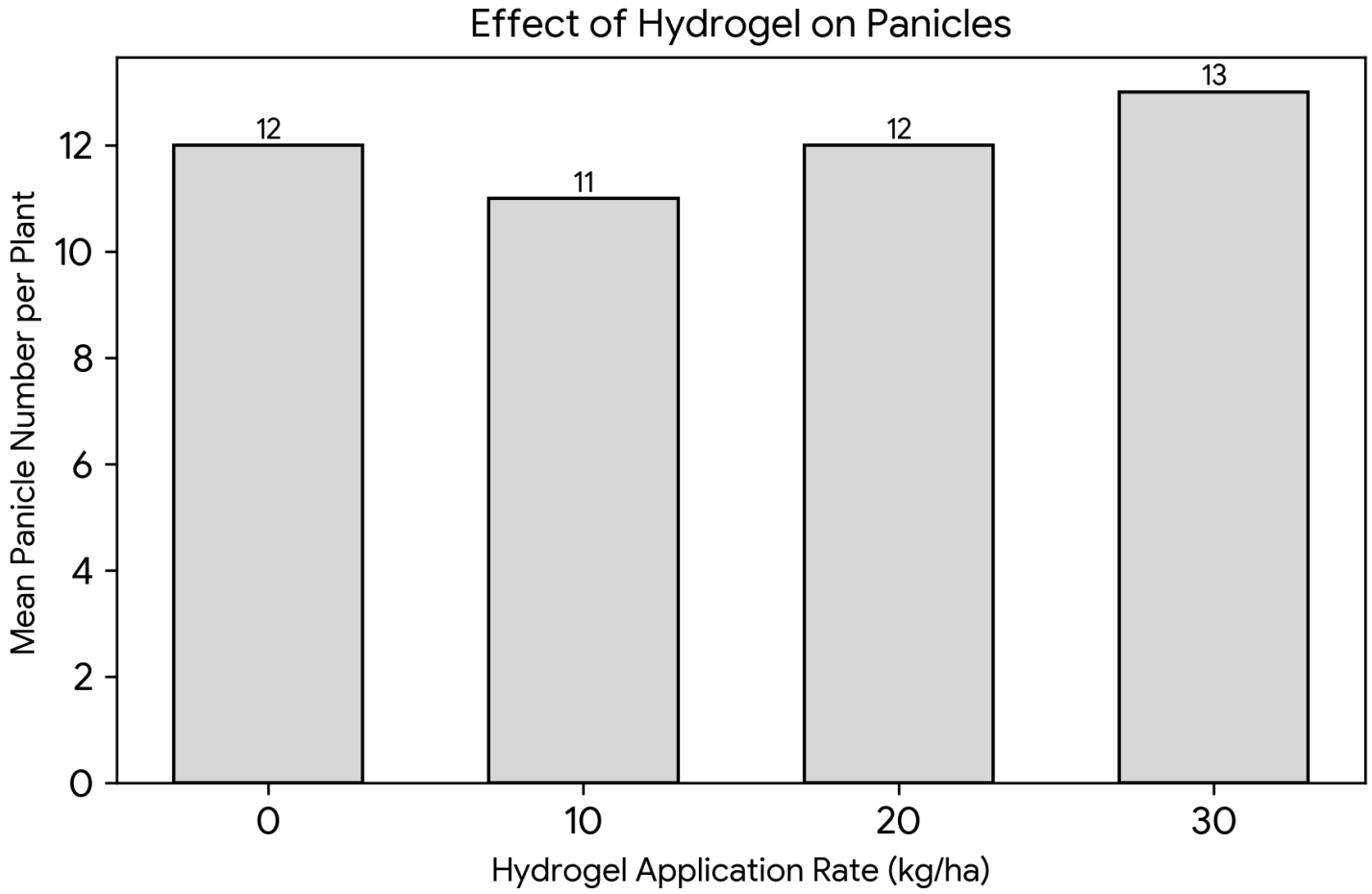



**Figure 4**

**Figure 3.2: Effect of hydrogel on panicle number per plant**

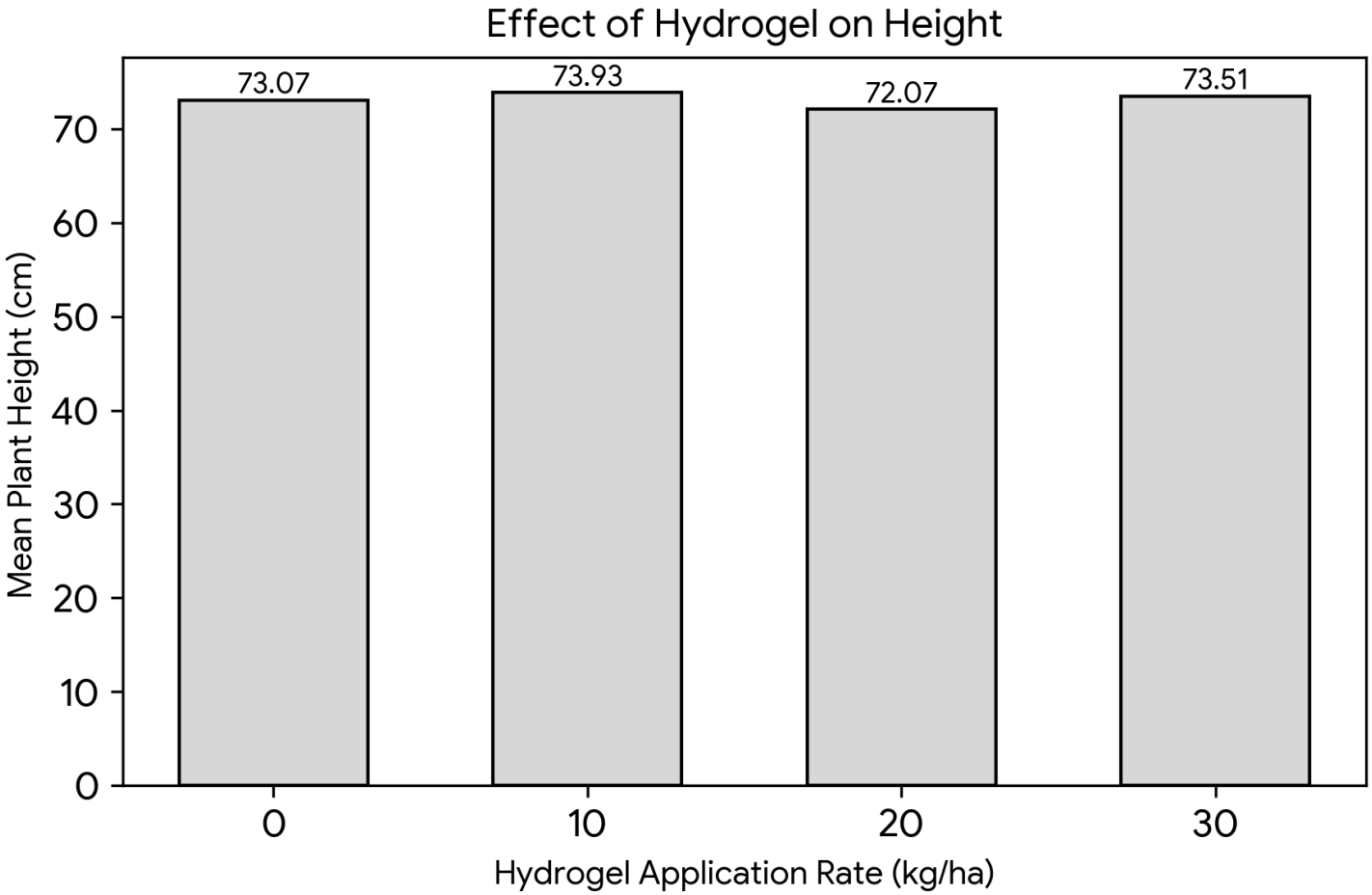



**Figure 5**

**Figure 3.3: Effect of hydrogel on plant height (cm)**

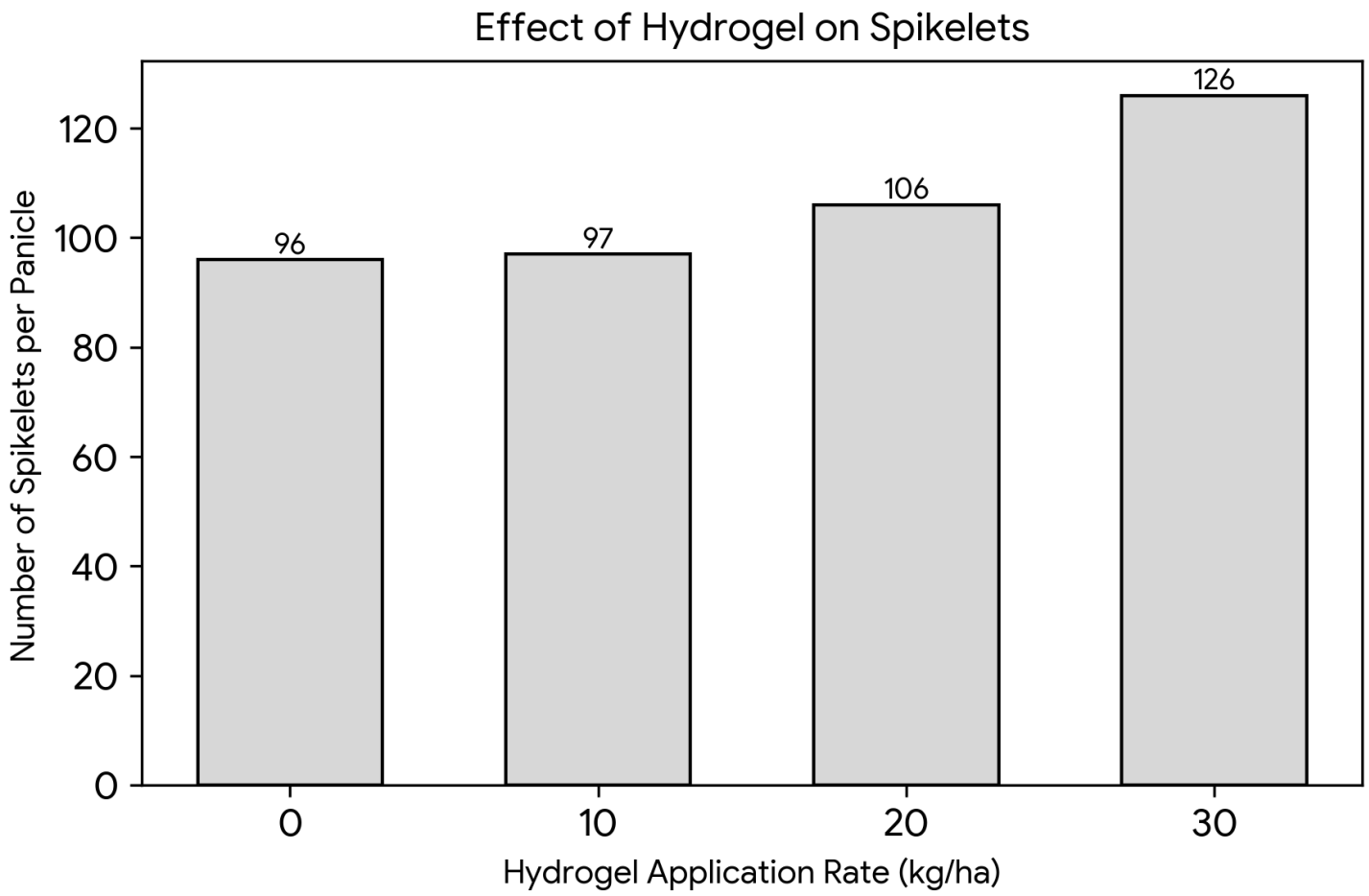



**Figure 6**

**Figure 3.4: Effect of hydrogel on number of spikelet's per panicle**

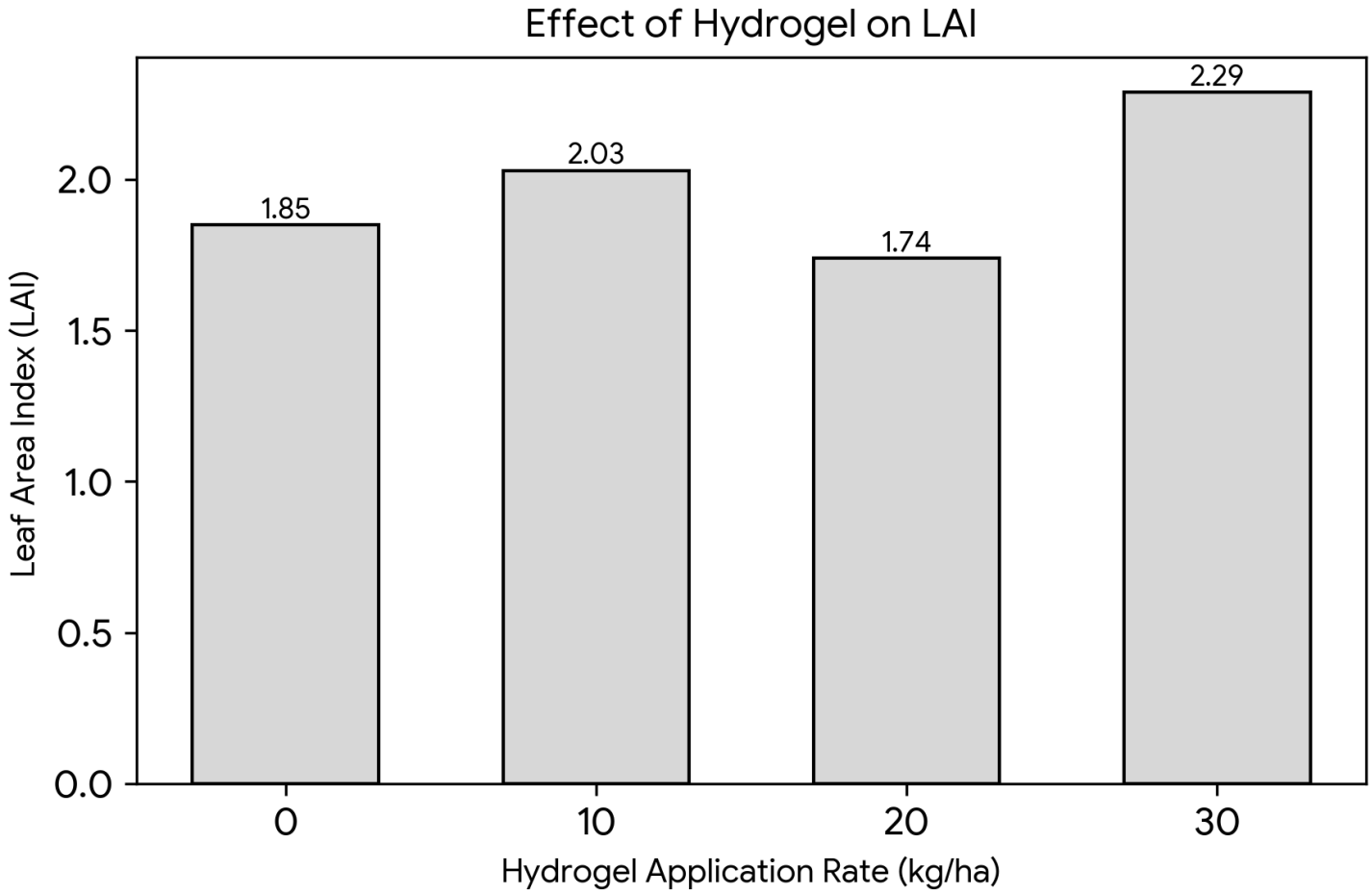



**Figure 7**

**Figure 3.5: Effect of Biodegradable hydrogel on LAI of paddy**

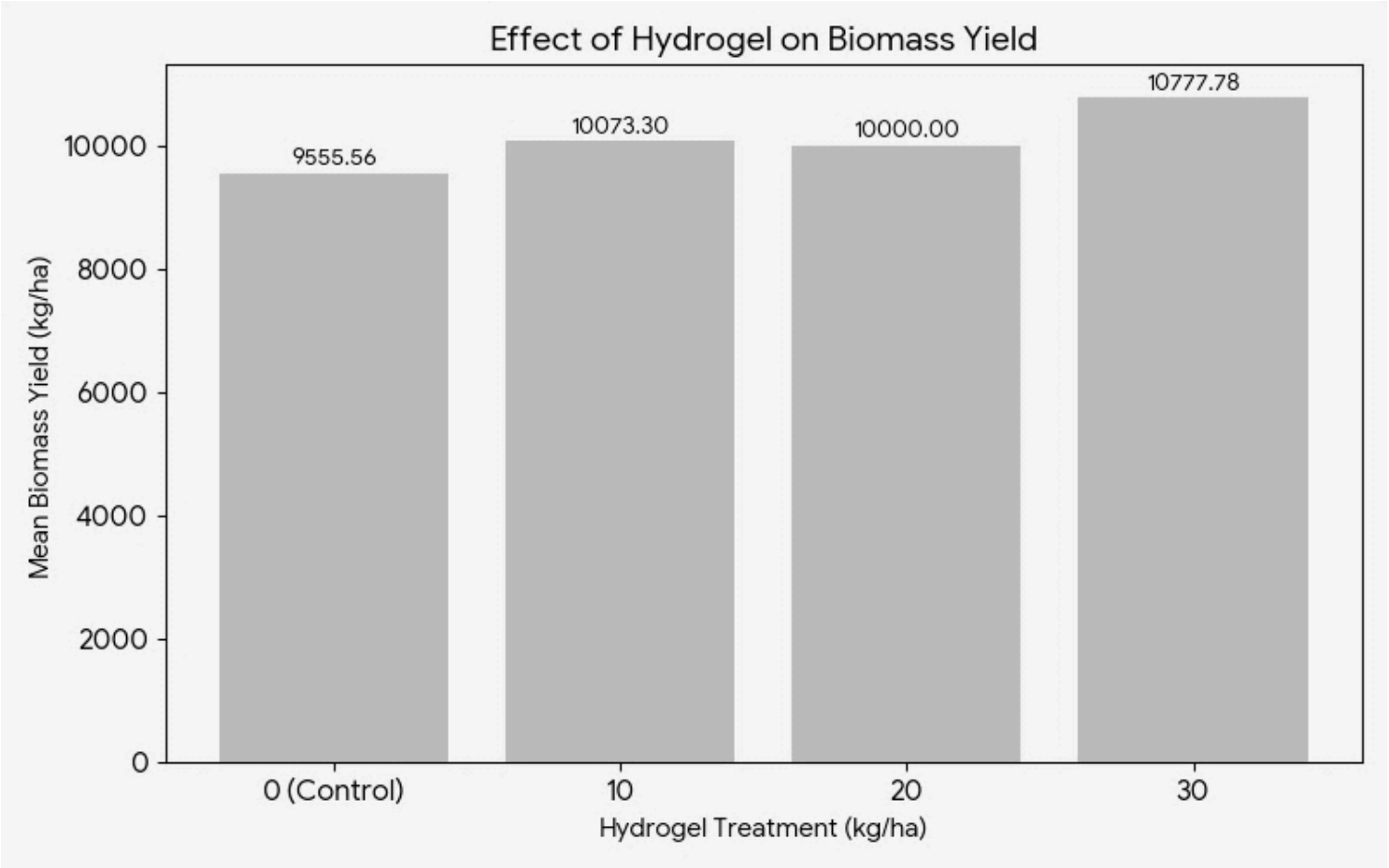



**Figure 8**

**Figure 3.6: Effect of hydrogel on biomass yield.**

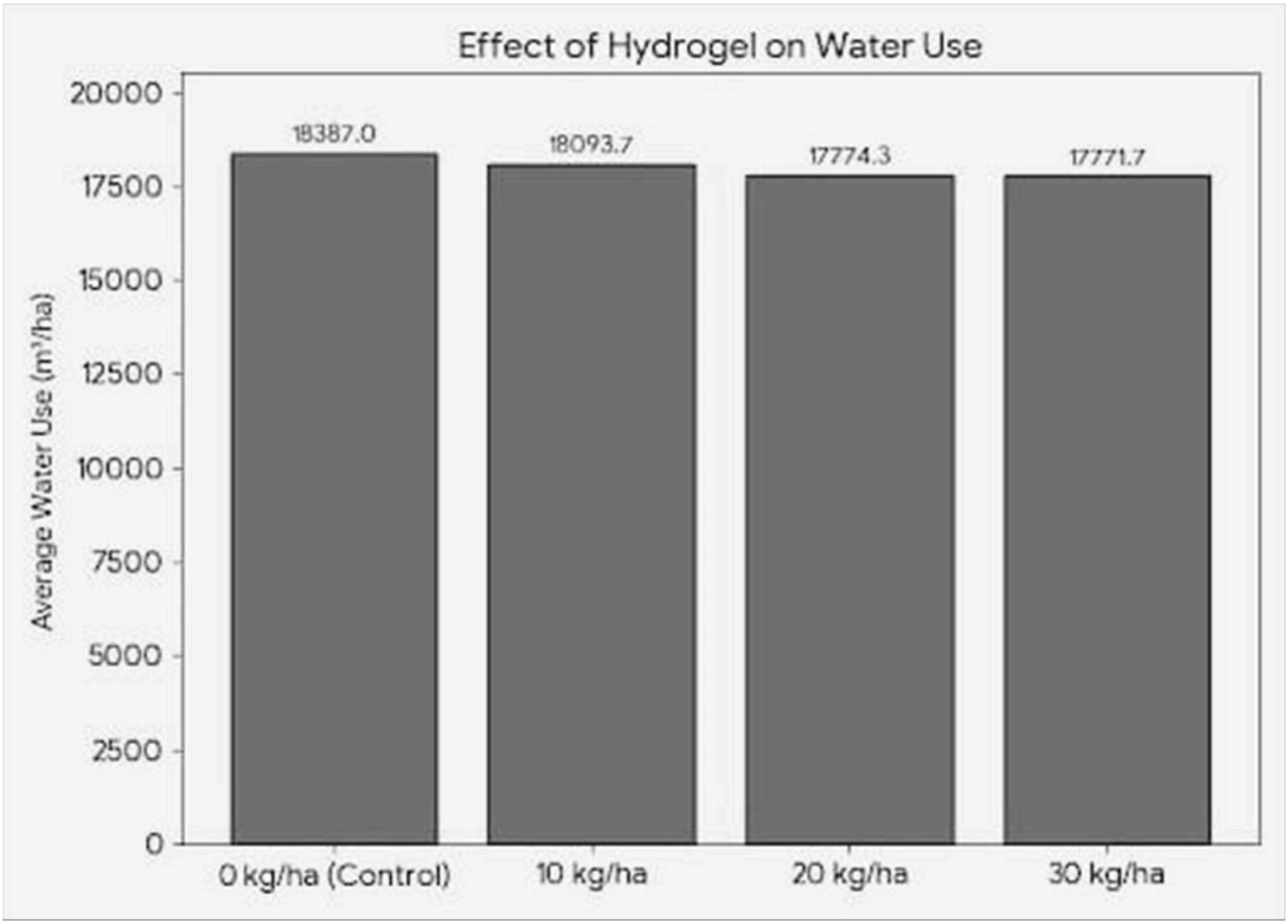



**Figure 9**

**Figure 3.7: Effect of hydrogel on Water use**