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Productivity and profitability of upland rice (*Oryza sativa* L.) under varied crop geometry and soil moisture conservation practices

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Abstract

Rice, a vital staple food, plays a critical role in ensuring food and nutrition security for millions of people. Rice production faces various challenges from both biotic and abiotic stresses, with soil moisture stress being a significant limitation, especially in rainfed upland ecologies. While crop improvement strategies have made progress in addressing abiotic stressors, the complex and diverse nature of these challenges requires a combination of crop improvement and agronomic interventions to stabilize rice productivity and profitability. To explore these factors, an experiment was conducted during the *Kharif* (rainy) season of 2019 at the instructional farm of the College of Agriculture in Kerala. The aim was to investigate how cropping patterns and *in-situ* soil moisture conservation practices impact the growth and yield of upland rice. The research employed a Randomized Complete Block Design (RCBD), incorporating two distinct crop configurations and strategies for conserving soil moisture. The findings showed that paired-row planting in conjunction with live cowpea mulching, hydrogel application, and coir pith compost was superior in terms of crop growth, as evidenced by elevated Leaf Area Index (LAI) at 4.81 and increased dry matter production at 5.5 t/ha. Furthermore, this approach resulted in higher grain yield (3.8 t/ha), straw yield (7.7 t/ha), improved moisture content (29.12% at 60 days after sowing and 18.49% at physiological maturity), and reduced proline content (0.26 µmol/g FW). The maximized net returns of 62887 Rs/ha. and a Benefit-to-Cost (B:C) ratio of 1.8 was recorded for upland rice.

Keywords crop geometry, hydrogel, live mulch, paired row, upland rice

Introduction

Rice is a vital cereal crop in India, occupying 23.3% of cultivated land, playing a key role in food grain supply, and contributing 43% to total food grain and 46% to total cereal production [1]. Rice is grown under both lowland and upland conditions. The traditional puddled transplanted rice under lowland conditions has low water use efficiency and pollutes the environment. For instance, under conditions of continuous flooding, paddy fields are the main source of methane emissions from farms, accounting for roughly 15% to 20% of the total global emissions [2]. Due to the dwindling water supply and rising environmental pollution, the paddy production system has to be moved towards water efficient production practices, especially upland rice systems. Millions of people currently depend on the upland rice as their staple food and the producers of it are among the deprived farmers of the world [3]. With decreasing water availability, suitable modifications in the cropping geometry of upland rice are of great importance.

In the conventional method of planting rice, the scope for intercropping is meagre. Consequently, widening inter row spacing is one of the prerequisites for growing intercrops. It not only gives paddy yield comparable to the conventional planting system in single rows but also facilitates interplanting and management of intercrops without damaging base crops [4]. Many agronomical practices were developed and suggested to increase water use efficiency (WUE) in which live mulching and, the use of super absorbent polymers like hydrogels and coir pith compost are important. These practices increase the period of moisture availability by increasing the available moisture content in the soil. Mulches can improve the performance of seedlings in the field once they emerge from the soil's surface by improving soil water retention and reducing evaporation losses, which also helps to control the growth of weeds [5-6]. Hydrogel, a polymer helps to reduce plant stress and increase growth by releasing moisture near to root surface area. It also helps in reducing leaching losses of fertilizers and is compatible with all soil types [7]. Hydrogel on contacting water swells by 200-600 times of the original volume and helps in trapping rainwater or irrigation water and supplies it slowly based on crop requirements for long periods [8-9]. Utilizing coir pith compost lowers soil bulk density, enhances soil porosity, and augments its water-holding capacity. This compost is nutrient-rich, particularly in potassium and micronutrients, and fosters the growth of native soil microflora [10-11]. There is a prospect for increasing the productivity of upland rice by adopting proper geometry along with moisture conservation practices.

Methodology

The experiment was conducted during the *Kharif* (rainy) season of 2019 at the Instructional farm, College of Agriculture, Kerala. The texture of the soil is sandy clay loam with acidic pH (4.8) and non-saline EC (1.34). The initial nutrient status of the soil is low in nitrogen (190.2 kg/ha), high in phosphorus (35.5 kg/ha) and medium in potassium (248.12 kg/ha) with a carbon content of 0.67% (medium). The experiment focused on two distinct cropping geometries: normal planting and paired-row planting. These planting methods were combined with in-situ soil moisture conservation practices. In total, nine treatments (Table 1), each with three replications were tested in a randomized complete block design (RCBD).

Table 1. Treatment details

Treatment	Short form
Normal planting of upland rice (20 cm x 10 cm) (NP)	T_1
NP + live mulching of cowpea (LMC)	T_2
NP + LMC + hydrogel (H)	T_3
NP + LMC+ coir pith compost (CPC)	T_4
NP + LMC+ H + CPC	T_5
Paired row planting (PR) + LMC	T_6
PR + LMC + H	T_7
PR +LMC + CPC	T_8
PR +LMC+ H+ CPC	T_9

The rice variety used in the experiment was Aiswarya (PTB52) and the cowpea was MFCO0814. Seed rate of rice was 60kg/ha, sown by dibbling method with a spacing of 20 cm x 10 cm. Before sowing, uniform application of lime and farm yard manure (FYM) was done in all the plots. Hydrogel (2.5 kg/ha) and coir pith compost (2.5 t/ha) were also applied to the plots of specific treatments. Recommended doses of fertilizer at the rate of 60 kg nitrogen (urea), 30 kg phosphorus (Rajphos), and 30 kg potash (MOP) per ha were applied. Cowpea was grown as a live mulch for a period of 40 days. After harvesting, it was applied on the surface as a mulch and later applied on the surface of the soil. Five randomly chosen plants within the net plot area were identified and marked. The maximum length and width of the third leaf from the top were measured at 60 days after sowing (DAS). The total leaf count for each plant was then calculated and multiplied by the mean value [12].

$$LAI=\frac{K(L \times W) \times \text{Number of leaves per plant}}{\text{Land area occupied by the plant}}$$

Where, LAI – Leaf area index, K – constant factor (0.75), L – maximum length of 3rd leaf blade from the top (cm), W – maximum width of the leaf blade (cm) [12].

For dry matter production at harvest, the marked plants were uprooted, washed, sun dried, and oven dried at 70 + 5°C to constant weight and expressed in t ha^{-1}. Grains were harvested from each plot and dried to achieve a moisture content of 14%. The straw yield was determined by subtracting the grain yield from the total biological yield. Proline content in the leaves was assessed using the method outlined by Bates et al., [13] and expressed as µmol per gram of fresh weight (FW). The soil moisture content was estimated by using a standard moisture meter which was inserted at 15 cm soil depth in individual plots at particular intervals and the moisture content was recorded in percentage. Gross return was calculated on the basis of grain, straw yield, and their existing market prices. Gross returns and net returns were computed using the formula.

Net returns = Gross returns – Cost of cultivation (in ₹ ha^{-1})
Gross return (₹ ha^{-1}) = Grain yield (t ha^{-1}) x Market price (₹ t^{-1}) + Straw yield (t ha^{-1}) x Market price (₹ t^{-1})

The benefit cost ratio (BCR) was worked out as follows

$$BCR=\frac{\text{Gross return (₹ } ha^{-1})}{\text{Cost of cultivation (₹ } ha^{-1})}$$

The data obtained from the field experiment were compiled, processed and analyzed using OPSTAT software. The treatment means were compared using critical difference (CD) values at 5% probability.

Results

The experimental findings underscore the significant impact of paired row planting, combined with live cowpea mulching, and the application of hydrogel and coir pith compost on both the growth and yield of upland rice. The overall dry matter production relies on photosynthetic capacity, which is influenced by factors like leaf area as depicted in Figure 1. In treatment T_9, the application of hydrogel boosted the overall growth rate of the crop by increased dry matter production. The treatment PR +LMC+ H+ CPC (T_9) led to the maximum grain yield (3.8 t ha^{-1}), straw yield (7.7 t ha^{-1}) followed by the treatment (T_5) with grain and straw yields of 3.5 and 7.6 t ha^{-1} respectively (Table 2 and Figure 2). An additional grain yield of 1.45 t ha^{-1} was obtained with treatment T_9 over T_1 (Normal planting of upland rice). The highest soil moisture content up to 15 cm depth was recorded under the T_9 treatment at 60 DAS (29.1%) and at physiological maturity (PM) (18.5%), followed by treatments T_5 (28.4% at 60 DAS and 18.2% at PM), T_7 (28.2% at 60 DAS and 18.0% at PM) and T_3 (27.8% at 60 DAS and 18.0% at PM) (Table 3). The highest proline concentration of 0.71 (µmol/g FW) in the leaves at the flowering stage was recorded by the treatment T_1 (normal planting of upland rice) which was significantly higher than the rest of the treatments. The rice crop faces maximum moisture stress under treatment T_1 which enhanced the proline content. The lowest proline content of 0.26 (µmol/g FW) was recorded under treatment T_9 which was on par with the other treatments, *viz*. T_5, T_7 and T_3. The net income was significantly influenced by the treatments and the treatment T_9 recorded the maximum net income of 62,887 ₹ ha^{-1} whereas the highest BC ratio of 1.84 was obtained with treatment T_7 and was on par with the treatment T_9. The BC ratio under the treatment T_9 is less compared to the treatment T_7 which is mainly due to the additional cost of coir pith compost included in the treatment T_9.

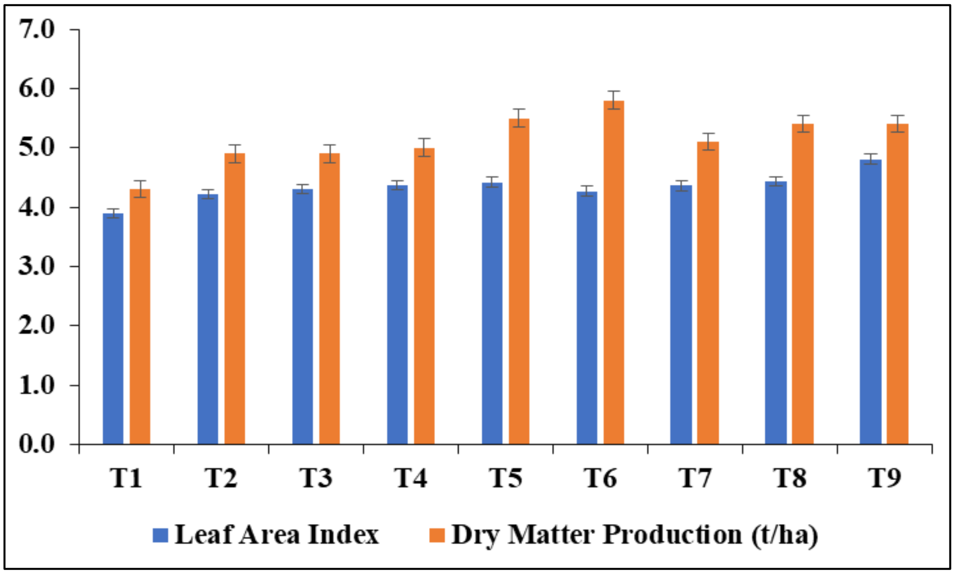

Figure 1. Impact of different cropping geometry and soil moisture conservation techniques on dry matter production and leaf area index in upland rice

Table 2. Impact of different cropping geometry and soil moisture conservation techniques on crop yield, net returns and BCR

Treatments	Grain yield (t ha-^{1})	Straw yield (t ha^{-1})	Net returns (₹ ha^{-1})	Benefit-cost ratio (BCR)
NP	2.37	5.80	36803	1.63
NP + LMC	2.87	6.52	45288	1.65
NP + LMC + H	2.95	6.48	47172	1.66
NP + LMC+ CPC	3.09	6.38	38528	1.45
NP + LMC + H + CPC	3.58	7.66	53109	1.59
PR + LMC	2.73	6.10	39805	1.57
PR + LMC + H	3.27	6.94	59913	1.84
PR + LMC + CPC	3.29	6.86	43676	1.50
PR + LMC + H + CPC	3.82	7.70	62887	1.80
SEm±	**0.58**	**1.15**	**2301**	**0.03**
CD (p =0.05)	1.7	3.4	6958.2	0.1

Discussion

Paired row planting outperformed conventional planting in terms of LAI and dry matter production, likely due to improved access to essential resources like water, nutrients, and sunlight. This enhancement in plant growth, including leaf area/LAI, ultimately led to increased dry matter production. These findings align with the results of Mehta et al., [14]. Utilizing live cowpea mulching contributed to an increase in dry matter production. This boost was attributed to the consistent supply and gradual release of nutrients through the decomposition of organic matter, which supported the production of assimilates. Moreover, live cowpea mulching helped in soil moisture conservation and improved growth attributes, facilitating the enhanced translocation of photosynthates from source to sink, resulting in higher dry matter production [15]. Improved moisture retention and the addition of nitrogen from the mulched biomass likely enhanced nutrient availability, ultimately leading to improved growth and increased dry matter production [16]. Yield is a multifaceted characteristic influenced by various internal and external factors. While a crop's genetic makeup primarily determines its yield potential, the actual productivity, particularly under conditions of moisture stress, depends on the interplay of morphological, physiological, and biochemical factors. In the conventional planting method for upland rice with a spacing of 20 cm x 10 cm, a single row of cowpea is interplanted after each row of rice. This arrangement created increased competition for essential resources such as nutrients, light, and moisture.

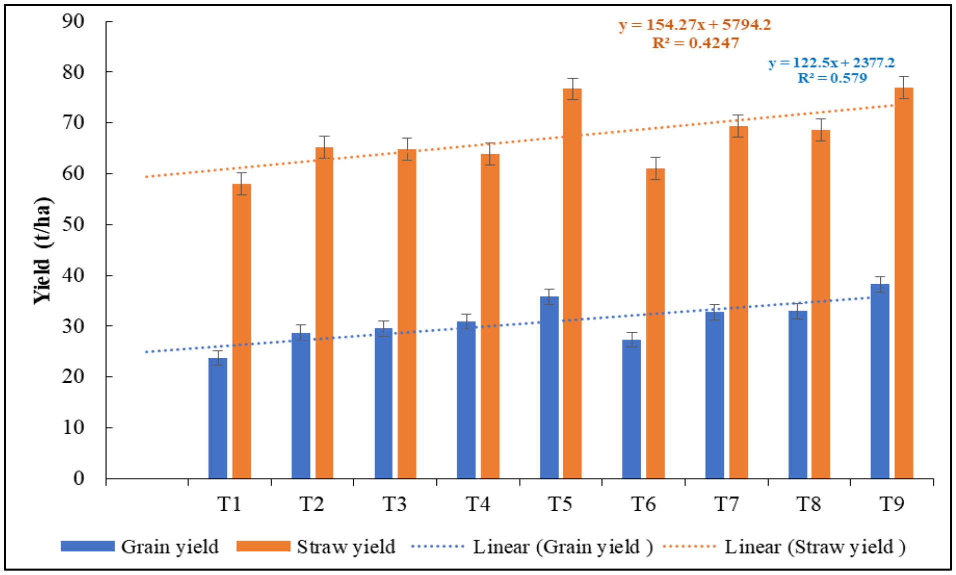

Figure 2. Impact of different cropping geometry and soil moisture conservation practices on grain and straw yields in upland rice

Table 3. Influence of different cropping geometry and soil moisture conservation techniques on soil moisture content (SMC) and proline content in upland rice

Treatments	Proline content (µmol/g FW)	SMC (%) at 15 cm depth at 60 DAS	SMC (%) at 15 cm depth at physiological maturity
NP	0.71	19.22	13.32
NP + LMC	0.49	23.8	14.68
NP + LMC + H	0.32	27.84	17.99
NP + LMC+ CPC	0.42	26.88	15.65
NP + LMC + H + CPC	0.28	28.47	18.22
PR + LMC	0.51	24.14	15.09
PR + LMC + H	0.31	28.19	18.03
PR + LMC + CPC	0.42	27.0	15.95
PR + LMC + H + CPC	0.26	29.12	18.49
SEm±	**0.03**	**0.08**	**0.04**
CD (p =0.05)	0.1	0.2	0.1

Additionally, the cowpea growth became excessive and overshadowed the upland rice plants, impeding their further growth and ultimately resulting in the lowest grain yield. The elevated grain and straw yields seen in treatment T_9 could be ascribed to improved photosynthetic efficiency and enhanced transport of photosynthates from leaves to grains, ultimately leading to increased dry matter production. Additionally, more efficient resource utilization, including moisture, nutrients, and light, as well as improvements in soil physical, chemical, and biological properties, along with heightened activity of soil microbial flora facilitating faster organic matter decomposition, likely contributed to an enriched nutrient and organic matter status of the soil. This, in turn, favored the crop's nutrient absorption, as reflected in the higher grain and straw yields.

Comparable findings were reported by Kumar et al., [17] in maize and Langangmeilu [18] in upland rice. The highest recorded moisture content primarily resulted from the combined effects of hydrogel application, which enhanced the soil's water-holding capacity, the utilization of coir pith compost, known for its capacity to absorb moisture at a rate 400 times its weight, and the practice of cowpea mulching. Cowpea mulching effectively covered and shielded the soil from evaporation, contributing to the improvement in soil moisture content. These outcomes align with the findings of Rehman et al., [19] in aerobic rice and in upland rice cultivation [20]. There isn't a noteworthy variation in proline content across treatments that involved hydrogel application, even when different *in-situ* soil moisture conservation techniques were employed. This uniformity in proline content can be attributed to the minimal stress experienced in the hydrogel-treated plots, followed by those with live cowpea mulching and coir pith compost application. The reduced proline content in the hydrogel-treated plots can be credited to the effective performance of hydrogel in enhancing various soil hydro-physical properties such as porosity, bulk density, mean weight diameter, aggregate stability, and hydraulic conductivity. Hydrogel's ability to absorb 300–400 times its weight in pure water, gradually releasing it to support seed germination, seedling emergence, root growth, and density has contributed to this outcome. Moreover, the decrease in proline content is associated with increased moisture availability, as proline levels tend to decrease when moisture is more abundant. These results are in line with previous studies conducted by different researchers [20-21] in wheat. Paired row planting with live mulching of cowpea, hydrogel and coir pith compost application resulted in improved growth, yield attributes and yield and thereby recorded the highest net income. The highest net income was recorded by the treatment T_9 treatment and was in conformity with the findings of Mehta et al., in dill (*Anethum graveolens*) [14], in sugarcane [2], in maize [22].

Conclusion

The experimental results of the trial conducted during *Kharif* (rainy) 2019 demonstrated that treatment T_9, involving paired row planting with live cowpea mulching and the application of hydrogel + coir pith compost, outperformed all other treatments in terms of growth through higher dry matter production and LAI, yield attributes, grain and straw yield, and net income. Moreover, the highest soil moisture content and lowest proline content recorded by the treatment T_9 reveal it as a better option to conserve soil moisture and also to obtain higher growth and yield. Apart from the *in-situ* soil moisture conservation practices, cropping geometry also had a profound impact on the yield of upland rice. In paired row planting without compromising the plant population, modifying the cropping geometry of upland rice for live mulching will have a complementary effect on growth by way of reducing evaporation, conserving moisture, improving soil physical properties, fertility status, and suppressing weeds. Hence, adopting the approach of paired row planting with live cowpea mulching and the application of hydrogel + coir pith compost becomes highly significant. This technique plays a pivotal role in moisture conservation and enhancing rice productivity, especially in rainfed upland conditions.

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