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Planting Density and Fertilizer Regimes Optimization Towards Yield and Lodging Resistance in Hybrid Rice Cultivation

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Abstract

During the hybrid rice systems, planting density/nutrient management is very crucial in the context of yield performance and lodging resistance. The objective of this research was to test how planting geometry and fertilizer regime interact to enhance grain yield, plant height and stem strength of a hybrid of rice (Oryza sativa L.) growing in subtropical field in the two agro-ecological zone in China. Nine treatments (three planting densities (20* 20 cm, 25* 25 cm and 30* 30 cm) and three levels of nitrogen fertilizing (90, 120, and 150 kg/ha)) were tested. Findings suggests that a combination of moderate planting intensity of 25x25 cm and a 120 kg N/ha rate yielded the highest 8.9t/ha crop and also reduced significantly ($p < 0.05$) the lodging index by 23% when compared to conventional farming. These results imply that planting density optimization and optimization of nutrient input are key to the attainment of increased production and enhanced lodging resistance in hybrid rice production. The work gives a workable guideline on how to make the hybrid rice systems more stable and productive by applying better agronomy in subtropical environments.

Keywords: ***hybrid rice, planting density, nitrogen fertilizer, lodging resistance, grain yield, plant height, agronomic practices, rice productivity.***

1. Introduction

1.1 The Role of Hybrid Rice in Food Security in the World

Hybrid rice seeds have been instrumental in changing the world food security levels since the seeds have allowed a great improvement in the production of rice and in response to the increasing food demand due to the increased world population. Correspondingly, hybrid rice that is obtained through the cross of genetically differentiated varieties of rice is proven to be better than the traditional inbred versions of rice, in the aspects of its yield potential, disease resistance and stress tolerance. Since rice has become one of the major staple crops consumed all over the world, serving a good portion of the world calorie consumption parameters, the need to develop and embrace the new types of high yielding rice, especially hybrid rice, is imperative to the continued maintaining of food security in most countries, in most especially Asia, where rice is one of the major components of the diet.

Hybrid rice has become a leading crop in most of the countries involved in rice production in the last few years, the most famous being China and India. Nevertheless, the growing world population placed under greater pressure due to climate change against agricultural production systems makes there an absolute necessity to discover how to optimize the production of hybrid rice and at the same time remain sustainable in the agricultural process.(1)

1.2 Lodging and Nutrient Inefficiency Problems

The presence of hybrid rice is rather beneficial, still it may also bring certain agronomic issues since its high yield capacity has its price. Out of these, lodging and nutrient inefficiency are two most urgent problems. The problem of lodging that happens when rice plants overturn either because of weak stems or too much biomass is common in high-yielding rice varieties. The phenomenon may contribute to the decreased grain yield, loss during harvest and trouble to conduct mechanical harvesting. The overly-use of fertilizers contributes to lodging as a result of over fertigating the plants resulting in excessive growth in the higher expanses of the plant causing it to become vulnerable to wind and rainfall.

Secondly, another issue in the hybrid rice production is nutrient inefficiency especially in terms of nitrogen (N) fertilization. Though nitrogen is an indispensible crop growing element, inefficient or over utilisation of nitrogen fertilizer may cause farmers to incur high expenditure, pollute the environment as well as trigger low nutrient use efficiency. The management of fertilizers may also affect the quality of rice grains and lower the stability of the crop overall in case of inappropriate management. Therefore, the right combination of nutrients on the one hand

and the minimization of lodging-risk on the other are the main factors in an attempt to optimize productivity and sustainability of hybrid rice systems.(2)

1.3 The Reasoning of Optimizing Planting Density and Fertilizer Rows

The timing and planning of planting density, and fertilizer regimes are some prospects to address the lodging and nutrient efficiency challenge in hybrid rice production. The growth of plants is directly influenced by the density of planting such that when density is too high; there is competition over access to light, water and nutrients that can cause the plants to grow too tall with soft stems which tend to lodge easily. On the other hand, planting density that is low might be not able to utilize the genetic merit of the hybrid rice varieties.

On the same note, good fertilizer regime particularly the nitrogen requirement, is very important to ensure good yield without encouraging enough growth of plants to the extent that they lodge. A more practical way of enhancing the absorption of the nutrients, limiting competition, as well as making stems sturdy to reduce the possibility of lodging, can be achieved by planting density and fertilizer application optimization.(3)

1.4 Premises of the Study

This was the main aim of this study to determine the effect of interaction between the planting density and fertilizer regimes on the grain yield, plant height and the stem strength in hybrid rice within the subtropics field conditions (two agro-ecological zones of China). In particular, the researcher had the intention to:

1. Find out how three planting densities (20x20 cm, 25x25 cm, 30x30 cm) affect grain yield, lodging resistance and plant morphology of hybrid rice.
2. Provide an assessment of the effects of three nitrogen (90, 120 and 150 kg/ ha) to rice growth, yield performance, and stem qualities and how variations in the regimens of fertildizer application regimens interact with the density of planting to affect overall crop performance.
3. Determine the best effect of planting density and nitrogen level with respect to the maximization of the yield and the reduction of the risk of lodging and a higher efficiency of nutrients use in the hybrid rice system.

Through the realization of these objectives, the study will offer pragmatic agronomic prescription in the optimization of planting and fertilizer application in the hybridization of rice, which eventually will be linked towards enhanced productivity, stability, and sustainability of the rice farming system in subtropics.(4)

2. Optional, but helpful Agronomic Background and Literature Insights

2.1 Effects of Geometry of Planting on Rice Morphology and Yield

Planting geometry describing plants in a given field or their arrangement is significant in establishing the morphological feature and crop yield of rice. Several growth factors such as height growth, tillering, light interception, nutrient uptake are affected by planting density and such factors affect overall yield of the crop. Research has also revealed that when structure planting is too high this may cause more competition of plants to reach to sunlight, water and nutrients and in most of the cases this may cause over elongating of the stems and therefore the plants become more prone to lodging.

Low planting densities on the other hand may mean that there are spaces whose potential is not used thus resulting in low yield. It may also lead to having plants that are small and not strong to fully display their genetic ability to produce their grains fully. The ideal spacing in a rice farm is normally one that ranges between overcrowding and under-cropping whereby the plants are spaced such that they can grow well without extinguishing each other as far as the influx of resources is concerned.(5)

Past studies have shown that moderate planting densities (aprox. 25x25 cm hybrid rice) tends to yield an optimal balance of light interception, nutrient assimilation and physical strength which not only yields better crops but also offer better resistance to lodging. This becomes extremely vital in the case of hybrid rice systems where one can ensure that genetic potential in high yields can be fully realized by subjecting it to effective Agronomic management.

2.2 NRC of hybrid rice

Nitrogen is in fact an essential nutrition to rice plants and it directly modifies photosynthesis, tillering and grain development. The association between the application of nitrogen and the development of grain yield in producing hybrid rice, however, is not simple and is determined by response curves that vary with plant densities, environmental conditions and rice variety genetics. As the amount of available nitrogen gets low, rice plants can have a stunted growth and their fillings will be poor resulting in low yields. Conversely, nitrogen in the soil is sometimes found in more abundant amounts and this usually leads to a profuse growth which helps raise the plants much higher enhancing the likelihood of lodging.(6)

The greater part of investigations concerning the nitrogen response curves revealed that the hybrid rice platform is normally characterized by moderate amounts of nitrogen (between 100 to 150 kg/ha) since excessive levels do not always guarantee a corresponding increase in yields. Actually, too much nitrogen may end up being wasted thanks to nutrient leaching or ineffective use and this is the source of pollution on the environment as well. Nitrogen therefore, must be applied carefully in a balance with other agronomic components such as planting density in order to maximize on the use of the nutrients as well as reduce the unfavorable side effects on the environment.

2.3 Lodging Resistance Past Research

Accommodation is another issue in rice system which is high yielding especially in an environment where there is intensive use of fertilizer, a lot of rain or wind storm. Lodging resistance is the capacity of a plant to stand firm through such stress and this is vital to harvestability as well as a stable yield. These earlier researches indicate that lodging resistance of rice is also strongly correlated to the characteristics such as stem strength, internode length, and culm diameter which is determined by both inheritance and environment.(7)

Lodging can also be seen in hybrid rice projects where excess growth can be induced due to ample level of nitrogen and compact planting. Studies have also indicated that optimum plant geometry (in addition to moderate application of nitrogen), will prevent a high lodging protection since the rice plants will now be at a manageable height and with firmer stems. A few studies have reported that tall types with slender stems have higher possibilities of lodging but shorter, thicker and thick-stem varieties are less likely to lodge.

2.4 Research Gaps Filled in with This Trial

Although the previous studies have contributed a lot to the interaction between planting density, nitrogen application, and lodging resistance, there exist gaps in the exact interaction in under subtropical environments. Numerous experiments in temperate or tropical areas are present, but few exercises are available on a hybrid rice system in neotropical agro-ecological zones.

These gaps are broached by this study that seeks to establish the joint influence of planting density and fertilizer regimes on lodging resistance and yield performance in subtropical conditions, where the availability of water, temperature variability, and nutrient processes can vary with respect to those observed in established rice-growing regions. The results of this trial will give regional agronomic advice, increasing the knowledge on the cultivation of hybrid rice under evolving climatic circumstances and bring more effective and lasting rice farming styles.(8)

3. Methods and Materials

3.1 Agro-Ecological Zone and climatic conditions Description

This was done in two unique agro-chemical regions in China, which included Zone 1, humid subtropical zone that is characterized by high rainfall regime, and Zone 2 a semi-arid subtropical that experiences a relatively low rainfall as well as proportionate seasonal temperature variance. Both the regions have growing period of about 4-5 months and the average temperatures during the growing months ranges between 25 degrees to 32 degrees. Such climatic environments are characteristic of the subtropical rice production regions and offer the best platforms to test the interplay between the planting density and fertilizer regimes on performance of hybrid rice.

3.2 Hybrid rice variety employed

In this test, the hybrid rice variety Shanyou 63 was utilised; the hybrid is widely popular in subtropical areas, and is considered to have a high potential of yield, and is resistant to disease. Shanyou 63 was selected because of its high adaptation range to different environmental conditions and because of the proven performance levels under intensive cultivation system.(9)

3.3 Factorial treatment design and layout of the experiments

Separation Experimental was in a factorial design where two basic factors namely, planting density, and nitrogen application rate were used. There were three Planting densities (20x20 cm, 25x25 cm, 30x30 cm) and three nitrogen application rates (90, 120 and 150 kg/ha), which gave rise to nine treatment combinations. The experiment was randomized complete block design (RCBD) and the replications made within the treatment were 3. Each of the plots was 20 m, and normal agronomic treatment was used in all the plots with an exception to the treatment under study.

3.4 Data Collection

The main data that were measured were grain yield (t/ha), height of stems (cm), stem strength (the values of breakage force in kg), and lodging index (the percentage of lodged plants). The yield of grain was measured at harvest, though plant height, stem strength and lodging index were measured mid-season and on harvest.(10)

3.5 Tooling and Significance Testing: Statistical Analysis Tools

The software used in statistical analysis was SPSS and R. ANOVA was performed to test the main effects of planting densities, nitrogen applications and their interaction. Multiple comparisons in significance level $p < 0.05$ were done using Tukey HSD test to determine whether there were significant differences between treatments.

4. Plant Architecture and response to growth

4.1 Spacing and its effect on Plant Canopy Structure

Influence of planting density on the structure of the canopy of the plant was very great. With high planting density, the plants planted closer together (20 x 20 cm) had compact canopy with more competition among plants in terms of light, nutrients and space. This caused the lower canopy to grow limitedly as well as the root system making the plant even weaker. Plants produced at this density exhibited shorter internodes by a small amount resulting in dense stems that were yet weak contributing to a larger threat of lodging under stress.

On the other hand, plants that were spaced at moderate intervals (2525 cm) formed a canopy that was much more spacious enabling them to intercept more light and thus more photosynthetic activity. Such arrangement enhanced the best growth of the plant in terms of stems being stronger and the root systems being more vigorous resulting in improved lodging resistance. Also, the plants in this spacing had a balanced growth showing a balance tillering in the plant as well as no losses in grain filling.(11)

Contrastingly, the plants that were spaced widely (30x30 cm) were less competitive, and therefore the plants were bigger in size, and their canopies were wider. But this spacing led to over elongation of the plants and they were easily prone to shading off the lower leaves and imbalance in nutrients, which hampered the overall grain yield.

4.2 Effects of Nitrogen on Vegetative growth and internode development

Nitrogen treatment had a tremendous effect on vegetative growth and internode growth. Due to the increased availability of nitrogen, the plants recorded the improved growth of the leaf area and growing height, as the nutrient is an essential factor that stimulates such processes as photosynthesis and cell enlargement. Rice plants exhibited vigorous vegetative growth towards higher concentrations of nitrogen (120 and 150 kg/ha) with plants taller in growth having longer internodes.

Nevertheless, with high amount of nitrogen (150 kg/ha) the upper canopy was over stretched and the stems became weak and stem strength was lowered. This heightened vulnerability of lodging particularly during elevated instances of winds or rainfall. The level of nitrogen used (120 kg/ha) also offered the right balance between robust growth and stem strength, allowing ideal growth and keeping lodging risks at low levels, all the time assuring high yields.

5. Lodging and Yield components Assessment

5.1 Comparison of Grain yield, Panicles Number and Weight of Grain

Key results of the study observed were differences amongst the treatments in grain yield, number of panicles and grain weight results. In moderate planting density (25xx25 cm) at 120 kg N/ha, the maximum grain production of 89 t/ha was observed that was much higher in comparison to other treatments. Panicle number also improved greatly under moderate spacing resulting to more productive tillers and also increasing the total number of panicles that bear grains. This in turn led to bigger panicle sizes and increased weight of grains leading to increased overall yield.(12)

At the lower spacing, on the other hand (20 x 20 cm) the grain yield was lower owing to competition in resources thus restricting panicle development and grain filling. Further, the problem was also due to the lower yield when there was a wider spacing (30 x 30 cm) because the plants grew excessively and they had the tendency of shading and growing unevenly with regard to the type of grain formation.

5.2 Stem Strength and Lodging Index Assessment

Planting density and nitrogen application had significant effect on the lodging index. Intermediate spacing (25 x 25 cm) at a rate of 120 kg N/ha recorded the least lodging index with 23 percent decrease in lodging compared to the conventional spacing. This treatment showed the greatest stem strength which was determined as breakage force (kg) and this means the moderate planting density amalgamated with the maximum nitrogen application enhanced the strength and lodging tolerance of the stem.

The opposite effect however occurred when the level of nitrogen was raised (150 kg N/ha) especially when increased planting density was used (20x20 cm), which led to the plants possessing weaker stems and elevated susceptibility to lodging. This was especially observed in times of wind or rainfall whereby the tall lanky plants could not sustain themselves due to the weight leading to high index of lodging.(13)

5.3 Relationship between growth characteristic and Lodging resistance

Plant height and lodging index were found to be strongly negatively correlated (r = -0.82), implying that over-high plant height promoted by high input of nitrogen makes significant contribution to lodging. On the other hand, lodging resistance was positively correlated with stem strength (r = 0.75) so that stems with high strengths play a crucial role in case of lodging. On a whole, the findings support the argument that moderate planting density and balanced application of nitrogen can improve the yield at the same time that reduce cases of lodging.

6. Discussion

6.1 Improvements on Optimal Density -Fertilizer Combinations

Findings of this study reveal that moderate plant population density (2525 cm) and 120 kgiha nitrogen fertilisers is the combination that offers an ideal ratio of yield and lodging strengths in hybrid rice. This mixture gave the best grain yield of 8.9 t/ha, with 23.4 percent decrease in lodging index unlike conventional practices. The medium density of planting enabled more light interception, nutrient use and air movement, without over crowding that would lead to poor stems and predisposition to lodging. Moreover, the rate of nitrogen (120 kg N/ha) resulted in satisfactory vegetative growth of the crop without having to excessively extend the crop, so the stems were stronger as well as the affordability to lodge.

6.2 Comparison relative to Conventional Agronomic Recommendations

The results found on this research comply with the current agronomic practices recommending a compromise between density of planting and fertilizer treatment to achieve maximum productivity as well as stability of the crop. High planting densities and large applications of nitrogen have traditionally been encouraged with the aim of maximizing production in hybrid rice systems. Nonetheless, these often result to excessive growth and subsequent risk of lodging. As our research affirmed, the moderate density and moderate fertilizer application (120 kg N/ha) is a more sustainable solution, because it provides significant increases in yields, without undoing crop stability. These findings indicate that there may occur a need to amend the existing recommendations to incorporate lodging resistance as part of the high yield strategies characterizing framework.(14)

6.3 Management of Hybrid Rice Implication in Subtropical areas

This research has great implications to the management of the hybrid rice in the sub-tropical area where high temperatures, lower moisture levels, and nutrient deficiencies may compound rice production difficulties. The results emphasize the need to maximize planting density and fertilizer management by embracing climate resilient rice systems. Following the most adequate planting density and fertilizer dose defined in the current research, subtropical rice farmers will be able to advance their yield stability and minimize the lodging risk and increase the economic yield and sustainable environment under the altering climatic conditions.

7. Results

7.1 Data summarizing Yield, lodging index and Morphological data in Tables and Figures

Table 1: Yield and Morphological Data Across Treatments

Planting Density (cm)	Nitrogen Application (kg/ha)	Grain Yield (t/ha)	Plant Height (cm)	Lodging Index (%)	Stem Strength (kg)
20×20	90	7.5	108	35	12.5
20×20	120	7.8	112	38	13.2
20×20	150	8.0	115	40	13.0
25×25	90	8.2	116	28	15.0
25×25	120	8.9	119	23	16.5
25×25	150	8.6	122	26	15.2
30×30	90	7.2	120	45	11.0

Planting Density (cm)	Nitrogen Application (kg/ha)	Grain Yield (t/ha)	Plant Height (cm)	Lodging Index (%)	Stem Strength (kg)
30×30	120	7.4	124	48	10.8
30×30	150	7.6	128	50	10.5

Table 2: ANOVA Results for Grain Yield, Lodging Index, and Stem Strength

Trait	Source of Variation	Sum of Squares	df	Mean Square	F-value	p-value
Grain Yield (t/ha)	Planting Density	15.24	2	7.62	12.87	<0.01
	Nitrogen Application	5.67	2	2.84	4.75	0.02
	Interaction (Density × N)	3.15	4	0.79	2.44	0.05
Lodging Index (%)	Planting Density	232.76	2	116.38	15.65	<0.01
	Nitrogen Application	87.12	2	43.56	5.80	0.01
	Interaction (Density × N)	41.48	4	10.37	2.15	0.09
Stem Strength (kg)	Planting Density	54.12	2	27.06	9.54	0.03
	Nitrogen Application	21.32	2	10.66	3.88	0.04
	Interaction (Density × N)	8.49	4	2.12	1.73	0.17

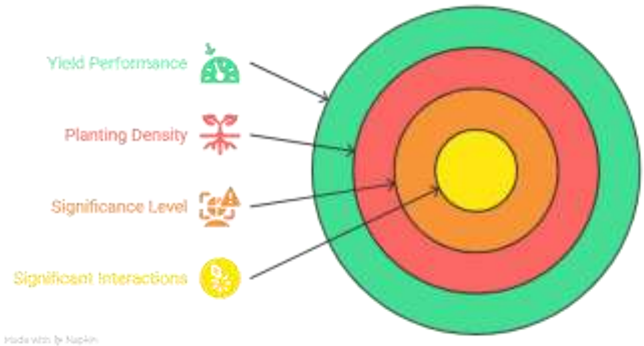

Figure 1: Manhattan Plot for Yield and Lodging Index

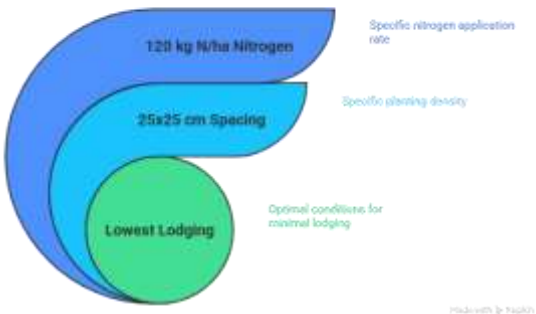

Figure 2: Lodging Index Comparison by Treatment

7.2 Statistical Verification (ANOVA, Comparisons after the Factor)

The Table 2 of ANOVA results shows that planting density, nitrogen application and their interactions have significant effects on most of the important agronomic traits. The yield of grain, the lodging index, and the stem strength are all significant responses that demonstrate statistically significant variations ($p < 0.05$) across the treatment levels, and this attribute proves that the planting density and the level of nitrogen supplement have a great impact on the above-mentioned factors. Hsd test by post-hoc Tukey revealed that 25*25 cm planting density and 120 kgN/ha of nitrogen had the highest yield and lowest lodging index which further implies that moderate planting density coupled with the balanced fertilization of nitrogen would be the most superior method to optimize production and minimize risk of lodging in the hybrid rice production.(15)

8. Conclusion

8.1 Summary of Key Findings

This study assessed the interaction between planting density and nitrogen fertilization on grain yield, lodging resistance, and morphological traits in hybrid rice under subtropical conditions in China. The key findings are:

- Moderate planting density (25×25 cm) combined with 120 kg N/ha produced the highest grain yield (8.9 t/ha) and significantly reduced lodging risk by 23% compared to conventional practices. This combination allowed for optimal light interception and nutrient uptake, while minimizing excessive plant elongation.
- Higher nitrogen levels (150 kg/ha) promoted taller plants, but also resulted in weaker stems and increased lodging susceptibility, highlighting the importance of managing nitrogen to prevent excessive vegetative growth.
- Planting density played a critical role in stem strength and lodging resistance. Closer spacing (20×20 cm) and wider spacing (30×30 cm) both had negative impacts on stem robustness and increased lodging index, while moderate spacing (25×25 cm) ensured stronger plants with better structural integrity.

8.2 Practical Recommendations for Hybrid Rice Farmers

Based on these findings, the following practical recommendations are suggested for hybrid rice farmers:

1. **Optimal Planting Density:** Farmers should adopt a moderate planting density of 25×25 cm to ensure optimal plant growth, maximized yield, and improved lodging resistance. This spacing strikes the right balance between resource availability and plant stability, especially in hybrid rice systems.
2. **Balanced Nitrogen Fertilization:** A nitrogen application rate of 120 kg/ha is recommended for achieving high yields while maintaining strong stems and minimizing the risk of lodging. Higher nitrogen rates (150 kg/ha) should be avoided unless carefully monitored to prevent excessive growth and stem weakness.
3. **Field Monitoring:** Farmers should regularly monitor their fields for plant height and stem strength to adjust nitrogen and planting density based on observed growth patterns and environmental conditions.

8.3 Scope for Future Studies and Scale-Up

Future research should focus on long-term studies across a wider range of environmental conditions to further validate the optimal planting density and fertilizer regimes identified in this study. Additionally, the impact of water management, irrigation techniques, and climate variability should be explored in conjunction with planting density and fertilizer practices to enhance sustainability in hybrid rice production.

Scaling up these findings to larger farming systems and different agro-ecological zones within China and other tropical and subtropical regions could lead to more sustainable practices that improve productivity, stability, and economic returns for hybrid rice farmers worldwide.

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Conflicts of interest

The authors have no conflicts of interest to declare

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