



Optimization of N dose in rice under conservation agriculture with sub-surface drip fertigation

BISWAJIT RANA¹, C M PARIHAR^{1*}, H S NAYAK¹, KIRANMOY PATRA¹, V K SINGH¹,
P KRISHNAN¹, RENU PANDEY¹, N RATHI¹, B R MEENA¹, ANUP KUMAR², N GUPTA³,
H S SIDHU³ and M L JAT⁴

ICAR-Indian Agricultural Research Institute, New Delhi 110 012, India

Received: 04 November 2020; Accepted: 01 December 2020

ABSTRACT

A field study was framed in rice crop under conservation agriculture (CA) based rice-wheat system at experimental farm of Borlaug Institute for South Asia (BISA)-CIMMYT, Ludhiana, Punjab, India during *kharif* 2019. In the present study, nine treatments were imposed out of which four are CA-based treatments (ZT-N0, ZT-N50, ZT-N75 and ZT-N100), four are CA coupled with subsurface drip fertigation (CA+) based treatments (SSD-N0, SSD-N50, SSD-N75 and SSD-N100) and puddled transplanted rice (PTR) treatment as farmer's practice. The findings of the study showed that PTR treatment out yielded in terms of yield attributing characters and biological yield than other treatments. CA+ treatment (SSD-N100) resulted higher biological yield (2.8%) than CA-based treatments (ZT-N100). SSD-N100 dominated ZT-N100 and PTR treatment in terms of plant N content (both grain and straw), total N uptake and N harvest index. PTR treatment resulted 22-33% higher ANUE than ZT-N100 and SSD-N100 treatments.

Keywords: Biological yield, Economic N dose, Yield attributes, Zero-tilled direct-seeded rice

Rice-wheat (RW) is the dominant cropping system in the Indo-Gangetic plains (IGP) of South Asia. India has about 10 Mha under RW system (Ladha *et al.* 2009). Age old conventional tillage and crop establishment methods of rice are laborious and time consuming, resulting in higher cost of cultivation thus making RW system unsustainable. Due to decline in the groundwater table level in RW area of north-west India, water scarcity has become the major concern for the future sustainability of this cropping system. Now, efficient use of water has become imperative in agriculture in the regions where water is scarce. Further, this issue calls for diversification of RW system and shift in rice based production systems. Conservation agriculture (CA) based on the principles of reduced tillage, crop residue management and diversified crop rotation offers vast potential in this aspect. Surface drip irrigation system can also tackle the issue of water scarcity and can enhance the water and nutrient use efficiency (Sharda *et al.* 2017). But

lateral anchorage is the major hindrance for the adoption of surface drip irrigation system in rice. Contrary to this, sub-surface drip fertigation (SSDF) system resolves the lateral anchorage issue and enables smooth inter-cultural operations throughout the cropping period (Sidhu *et al.* 2019). CA with subsurface drip irrigation has immense advantages over CA alone and conventional tillage-based flood irrigated (PTR/ farmer's practice) rice in terms of water use and saving (Ayars *et al.* 1999). SSDF system facilitates synchronization of water and nutrient availability with the crop demand enabling uniform delivery of water and nutrient through single delivery system. Thus, this system eliminates the gaseous loss of applied N due to high temperature, labour requirement for broadcasting and application of water after broadcasting (Jat *et al.* 2014). Further, sub-surface drip irrigation system with inline/online emitters has greater potential to cut off total water requirement by wetting only rhizosphere area and curtailing evaporation (Evet *et al.* 1995). Smouldering of harvested crop residues can also be resolved by the adoption of CA+ system. Although alternative tillage and crop establishment options have previously been evaluated in RW in the IGP, these are mainly focussed on yield and water productivity. Only a few studies have examined the combined effects of contrasting crop establishment, irrigation methods and N doses on plant growth, crop physiology, grain yield and economics of RW system. Therefore, the present investigation deals with impact of different crop establishment techniques i.e.

¹ICAR-Indian Agricultural Research Institute (IARI), New Delhi; ²ICAR-Indian Institute of Maize Research (IIMR), New Delhi; ³Borlaug Institute for South Asia (BISA)-CIMMYT, Ludhiana; ⁴International Maize and Wheat Improvement Center (CIMMYT), New Delhi. *Corresponding authors e-mail: pariharc@gmail.com.

PTR, CA alone and CA+, irrigation methods and N rates on biological yield, yield components and nutrient use efficiency of rice under conservation agriculture-based rice-wheat system.

Site characteristics

The field experiment was conducted at experimental farm of Borlaug Institute for South Asia (BISA)-CIMMYT, Ladhawal (30.99 °N latitude, 75.44 °E longitude, 229 m amsl), Punjab, India. The region is characterized by a sub-tropical and semi-arid climate with annual rainfall of 734 mm. The experimental site has flat and well drained sandy loam soil texture (Typic Haplustept). Before laying out the current experiment, the field was under conservation agriculture + sub-surface drip fertigation (CA+) based rice-wheat system for last five years.

Installation of sub-surface drip fertigation system

In sub-surface drip fertigation plots, the laterals of polyethylene with an inner diameter of 16mm were buried at 15cm depth parallel to crop rows. The in-line emitters with a discharge of 2.0 l/hr were fitted at 30 cm apart in the laterals. The spacing between two lateral lines was 67.5cm which will supply water for 3-rows of rice. Nitrogen was fertigated through venturi meter with desired injection rate.

Detail of crop establishment and imposed treatments

A short-duration rice variety (123-125 days maturity period) PR 126 was sown during *khariif* 2019. The experiment was framed in a randomized complete block design with nine treatments combinations with three replications. The size of each plot was 135 m² (25 m × 5.4 m) and a 2.5 m wide irrigation channel was provided in between two plots. The treatments under CA+ system were zero-tilled direct-seeded rice (ZTDSR) + sub-surface drip fertigation: without N (SSD-N0), 50% of recommended dose of N (RDN) (SSD-N50), 75% of RDN (SSD-N75) and 100% of RDN (SSD-N100); CA treatments were ZTDSR + flood irrigation system: without N (ZT-N0), 50% of RDN (ZT-N50), 75% of RDN (ZT-N75) and 100% of RDN (ZT-N100); Puddled transplanted rice system + flood irrigation system @ 120 kg N/ha (PTR). Nitrogen as urea was applied treatment-wise in 3-equal splits to PTR treatment at transplanting, at 3rd and 6th weeks after transplanting. In flood irrigated zero-tilled direct-seeded rice (ZTDSR) plots, N was applied in 4-equal splits at 10, 21, 42 and 56 days after sowing (DAS). Similarly, to sub-surface drip (SSD) fertigated ZTDSR plots N was fertigated/applied at 10 days intervals up to panicle initiation stage. A common dose of 60 kg P₂O₅ + 40 kg K₂O + 25 kg ZnSO₄/ha was applied as basal in all the ZTDSR plots.

Yields attributes and yield of rice

Number of tillers and panicles were counted at harvest and were expressed as tillers/m² and panicles/m², respectively. Number of grains in each panicle were counted from randomly selected five plants in each net plot, averaged

and expressed as number of grains per panicle. After drying and cleaning, a representative grain sample was taken from the final produce of each net plot and weight of 1000-grain was recorded and expressed in grams (g).

Two border rows of both directions and also 0.5m in opposite direction (length wise) were left and then the remaining area of each plot was harvested. The weight of total harvested produce (total grain + straw) from each net plot was recorded after sun/air drying and expressed as biological yield in kg/ha. The harvest index was computed by dividing economic yield (grain yield) by the respective biological yield (total produce) and expressed in percentage.

$$\text{Harvest Index (HI)} = \frac{\text{Economic yield}}{\text{Biological yield}} \times 100$$

Plant chemical analysis

Nitrogen (N) content in grain and straw was determined by CHNS analyser. N uptake was computed as:

N uptake (kg/ha) in grain/straw = [% N in grain/straw × grain/straw yield (kg/ha)];

Total uptake of N (kg/ha) = N uptake in grain + N uptake in straw

Nitrogen use efficiency (AE) was calculated as:

Agronomic efficiency (AE) (kg grain yield increase/kg N applied) =

(Grain yield (kg) in fertilized plot - Grain yield (kg) in control plot) / kg of N applied

Optimum N rates

Quadratic relationship between fertilizer N rates and grain yield was developed for two different application methods of ZTDSR plots. Optimum N dose (N_{op}) and economic optimum N dose (N_{eop}) were calculated using quadratic regression equations, market price of rice grain (₹ 15/kg) and cost of fertilizer N (₹ 12/kg of N). The N_{eop} was defined as the rate of N application where ₹ 1 of additional fertilizer N returned ₹ 1 in grain yield, and was based on the assumption that fertilizer N was the only variable cost and all other costs were fixed. The ratio of the cost of fertilizer N to the price of rice grain was referred to as cost: price ratio (CPr).

The N_{op}/N_{eop} doses were calculated as:

$$Y = Ax^2 + bx + a,$$

where, Y is grain yield (kg/ha), x is fertilizer N rate (kg/ha), and a, b, c are regression parameters.

$$N_{op} = -b/2c; N_{eop} = (CPr-b)/2c$$

Statistical analysis

The data were subjected to analysis of variance (ANOVA) using the general linear model procedures of the statistical analysis system (SAS Institute, Cary, NC) for randomized block design. The differences between treatment means were compared using a LSD test at P<0.05 (Gomez and Gomez 1984).

Table 1 Yield attributes and biological yield of rice as affected by different crop establishment techniques, N doses and irrigation methods

Treatment	Tillers/m ² at harvest	Panicles/m ²	Grains/panicle	Test weight (g)	Biological yield (t/ha)	Harvest Index (%)
ZT-N0	297	232	72.3	17.7	7.9	38.6
ZT-N50	370	308	89.8	19.3	11.8	40.0
ZT-N75	399	338	92.4	20.1	13.1	40.8
ZT-N100	420	373	95.9	20.8	15.4	41.0
SSD-N0	279	214	70.6	17.5	7.2	37.9
SSD-N50	386	317	90.8	19.5	11.8	40.1
SSD-N75	403	345	93.0	19.9	13.5	40.1
SSD-N100	424	380	96.9	20.9	15.9	41.3
PTR/FP	434	394	99.6	22.4	17.3	41.3
SEm±	23.7	15.6	3.09	0.65	0.61	1.13
LSD (P=0.05)	71.0	46.8	9.3	2.0	1.83	NS

Yield attributes and biological yield of rice

Total number of tillers, panicles per square meter, total number of grains/panicle and test weight of rice was significantly varied with different crop establishment techniques, N doses and irrigation methods. Total number of tillers, effective tillers/m², grains/panicle and test weight was significantly higher in puddled transplanted rice than other treatments (Table 1). These findings are in line with the findings of Jat *et al.* (2019). The total number of tillers in ZT-N50 and ZT-N75 was at par with ZT-N100. Among ZT and SSD treatments, application of 100% RDN recorded significantly higher numbers of tillers, panicles/m² than unfertilized treatments (SSD-N0 and ZT-N0), 50% of RDN treatments (SSD-N50 and ZT-N50) and at par with 75% of RDN treatments (SSD-N75 and ZT-N75). Different crop establishment techniques and N doses and irrigation methods had significant effect on biological yield (Table 1).

Among the treatments, PTR plots out yielded than all other imposed treatments due to increase in source strength, i.e. yield attributes (Jat *et al.* 2019). Under SSD treatments, fertigation of 100% RDN had 54.9% more biological yield than SSD-N0. SSD-N50 and SSD-N75 plots produced higher biological yield (39.52-47%) than SSD-N0, respectively. Similarly, under CA-based zero-tilled flood irrigated treatments biological yield increased with increase in N doses. Across the treatments, non-significant difference was observed in harvest index. Among the crop establishment techniques, N doses and irrigation management treatments, harvest index (HI) ranged from 37.9 to 41.3 (Table 1). Higher yield in SSD-N100 than ZT-N100 treatment can be ascribed by direct root feeding with water and N through fertigation resulted in less loss of N and unceased availability throughout the crop period (Sidhu *et al.* 2019). This establish better source in terms of LAI, plasticity, net photosynthesis and biomass production and finally biological yield in SSD-N100 than ZT-N100 treatment (Bhatt and Kukal 2016).

Across the treatments, a significant correlation between total tillers/m², panicles/m² and rice grain yield was also observed from Pearson correlation plot. In ZTDSR flood and ZTDSR with SSDF plots, yield attributing characters were total number of tillers and number of panicles per square meter (Fig 1A). Application of 100% RDN increased the panicle density and showed significant correlation with grain yield (Fig 1B). Direct root feeding of water and nutrient in SSD treatments favoured to produce more tiller and panicles than CA-based treatments (Sidhu *et al.* 2019). Evett *et al.* (1995) also hypothesized that yield increase instead of water cut-off in sub-surface drip irrigation may be due to more water available for plants for effective use within the effective rhizosphere zone. SSD-N100 and ZT-N100 plots produced significantly higher grains per panicle than their respective control treatments (ZT-N0 and SSD-N0) and were at par with all other treatments. The test weight of rice variety PR 126 ranged between 17.5-22.4 g across the treatments (Table 1). Similar findings are also reported by Singh *et al.* (2019).

Nitrogen content and uptake pattern of rice

Among the imposed treatments of crop establishment techniques, irrigation methods and differential N doses, significant difference were observed in term of grain and straw N content and total N uptake in rice (Table 2). Application of 75% and 50% RDN through broadcasting under ZT and through SSDF recorded higher grain N and straw N content. In terms of total N uptake (grain+straw) and N harvest index (NHI), SSD-N100 plots dominated PTR and CA-based plots. Synchronization of balanced N supply with plant demand through SSDF system remobilized more mineral N to plant and then organic N from plant parts to grain during grain filling (Zhang *et al.* 2017). As a consequence, an increased N content in grain, straw, total N uptake (6.9%) and NHI (3.82%) were obtained in SSD-N100 plots than PTR treatment.



Fig 1 Pearson correlation between yield attributing characters and grain yield of rice as affected by crop establishment techniques, N doses and irrigation methods.

Table 2 Nitrogen content, uptake, N harvest index and N-use efficiency of rice as affected by different crop establishment techniques, N doses and irrigation methods

Treatment	Grain N (%)	Straw N (%)	Total N uptake (kg/ha)	N-Harvest index	Agronomic efficiency (kg grain increase/kg N applied)
ZT-N0	0.868	0.395	45.8	58.0	—
ZT-N50	1.075	0.498	85.7	59.0	27.8
ZT-N75	1.136	0.482	97.9	61.9	23.9
ZT-N100	1.085	0.432	107.7	63.6	24.5
SSD-N0	0.866	0.379	40.7	58.1	—
SSD-N50	1.111	0.481	86.9	60.8	18.3
SSD-N75	1.150	0.463	99.6	62.3	18.1
SSD-N100	1.132	0.445	115.4	64.1	21.1
PTR	0.923	0.396	107.4	61.6	31.6
SEm±	0.038	0.013	3.812	1.398	—
LSD(P=0.05)	0.113	0.038	11.430	4.193	—

These findings are in conformity with the findings of Rajwade *et al.* (2013) and Veeraputhiran (2000). Alam *et al.* (2020) and Parihar *et al.* (2020) also reported increased soil N storage and availability in CA-based practices due to sequestration of N through decomposition of surface retained residue, more aggregation, better soil physical properties and biochemical properties. So, applied nutrients are locked up in the intra-particulate organic matter and soil microbial biomass which upsurges the soil mineral N pool and remobilization of mineral N to organic N. Hence, an increased grain N content straw N content, total N uptake (0.27%) and NHI (3.13%) were obtained in ZT-N100 than PTR plots.

Nitrogen use-efficiency

Among all the treatments, the agronomic NUE (ANUE) of puddled transplanted rice was recorded highest (31.6 kg grain increase/kg N applied) (Table 2). The ZT treatments had higher ANUE than SSD treatments. Among the ZT treatments, ANUE of ZT-N50 was higher followed by ZT-N100 and ZT-N75. The data indicated that broadcasting of N decreased ANUE with increased N dose. In accordance

with the findings of the present study, other researchers across the globe also confirmed low ANUE in low-land rice cultivation (Fageria and Filho 2001) and puddled sown condition (Cassman *et al.* 1993, Fageria *et al.* 2003). However, in SSD treatments, ANUE increased with increase in N dose due to single rate and 10 days fixed fertigation schedule (frequent but precise) of N through sub-surface drip fertigation system (Sharda *et al.* 2017 and Sidhu *et al.* 2019).

Optimum N rates in rice: A quadratic relationship between differential N doses and grain yield of rice under different N fertilization methods in ZTDSR plots is depicted in Fig 2. The model adequately ascribed the quadratic relationship between grain yield and N application with proportion of variability close to 1 ($P=0.01$). This model is the most appropriate model for determining N doses for economic yield (Fig 2) (Fageria and Baligar 2001). The optimum N dose and economic optimum dose under broadcasting of fertilizer was 250.6 and 243.6 kg/ha whereas in case of fertigation it was 221.3 and 216.3 kg/ha, respectively (Table 3).

A sub-optimal application of 80-100 kg N/ha to

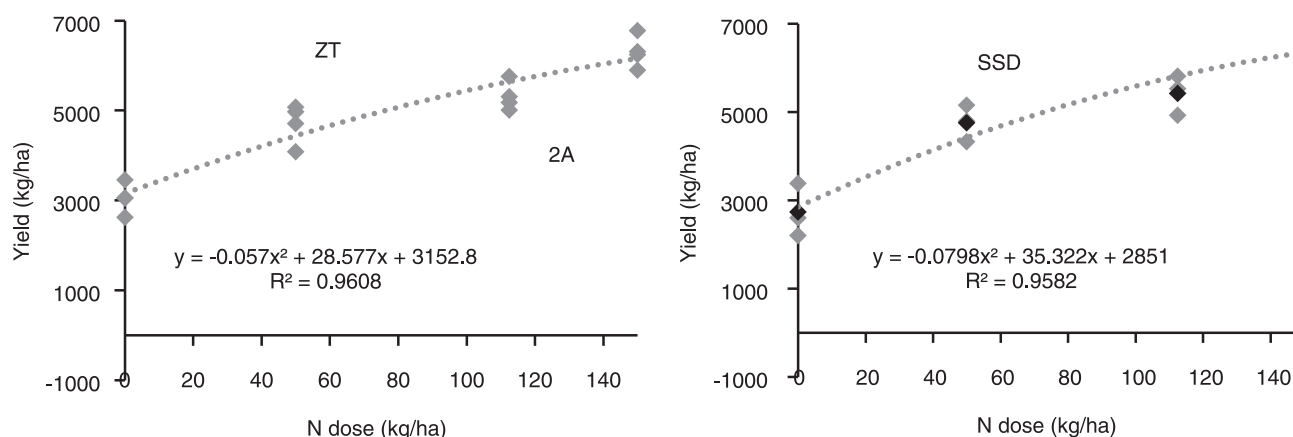


Fig 2 Quadratic relationship between grain yield and differential N doses of rice across ZT and SSD treatments.

Table 3 Optimum and economic optimum N dose under different N management options in direct-seeded rice.

Methods of N application	Optimum N dose for maximum yield (kg/ha)	Economic optimum dose (kg/ha)
Broadcasting in ZT-DSR	250.6	243.6
Fertigation in ZT-DSR through SSDF	221.3	216.3

highly responsive direct-seeded rice was found in ZT-DSR and SSD-DSR treatment for which adoption of different establishment methods become less-economical due to lower yield (Norman *et al.* 1997). Higher N requirement in direct-seeded rice (up to 180-200 kg/ha) than PTR was also reported by Ahmed *et al.* (2016). Sharmiladevi and Ravikumar (2019) also fertigated rice with 240 kg N under sub-surface drip fertigation for optimization of N schedule. Based on the findings of the present study, it can be concluded that DSR plots could not express its full potential due to limited N application. Therefore, a higher N dose may be recommended for DSR plots (both in CA and CA+ system) for achieving higher economic yield and making it more profitable among the farmers.

ACKNOWLEDGEMENTS

The first author acknowledges ICAR–Indian Agricultural Research Institute, New Delhi for financial support. The acknowledgement is due for CCAFS and CIMMYT Academy for providing the all kinds of support and facilities to conduct this research work at CIMMYT-BISA Farm, Ludhiana, India.

REFERENCES

- Alam K M, Bella W R M E, Islamc M A H and Kadera M A. 2020. Soil nitrogen storage and availability to crops are increased by conservation agriculture practices in rice-based cropping systems in the eastern Gangetic Plains. *Field Crops Research* **250**: 107764.
- Ahmed S, Humphreys E, Salim M and Chauhan B S. 2016. Growth, yield and nitrogen use efficiency of dry-seeded rice as influenced by nitrogen and seed rates in Bangladesh. *Field Crops Research* **186**: 18-31.
- Ayars J E, Phene C J, Hutmacher R B, Davis K R, Schoneman R A, Vail S S and Mead R M. 1999. Subsurface drip irrigation of row crops: A review of 15 years of research at the Water Management Research Laboratory. *Agricultural Water Management* **42**: 1-27.
- Bhatt R and Kukal S S. 2016. Tillage and establishment method impact on land and irrigation water productivity of rice-wheat system in North-West India. *Experimental Agriculture* **1**(2):1-24.
- Cassman K G, Kropff M J, Gaunt J and Peng S. 1993. Nitrogen use efficiency of rice reconsidered: What are the key constraints?. *Plant and Soil* **155**: 359-62.
- Evelt S R, Howell T A and Schneider A D. 1995. Energy and water balances for surface and subsurface drip irrigated corn. (In) Proceedings of the Fifth International Micro-Irrigation Congress, April 2-6, Orlando, FL, USA, Pp. 135-140.
- Fageria N K and Filho M P B. 2001. Nitrogen use efficiency in lowland rice genotypes. *Communications in Soil Science and Plant Analysis* **32**(13-14): 2079-89.
- Fageria N K, Slaton N A and Baligar V C. 2003. Nutrient management for improving lowland rice productivity and sustainability. *Advances in Agronomy* **80**: 63-152.
- Gomez K A and Gomez A A. 1984. *Statistical Procedures for Agricultural Research*, 2nd Edition, pp 188-233. John Wiley & Sons, New York.
- Jat M L, Gathala M K, Saharawat Y S, Ladha J K and Yadvinder-Singh. 2019. Conservation agriculture in intensive rice-wheat rotation of western Indo-Gangetic Plains: Effect on crop physiology, yield, water productivity and economic profitability. *International Journal of Environmental Science and Natural Resources* **18**(3): 231-43.
- Jat R K, Sapkota T B, Singh R G, Jat M L, Kumar M and Gupta R K. 2014. Seven years of conservation agriculture in a rice-wheat rotation of eastern Gangetic Plains of South Asia: Yield trends and economic profitability. *Field Crops Research* **164**: 199-213.
- Ladha J K, Kumar V, Alam M M, Sharma S and Gathala M. 2009. Integrating crop and resource management technologies for enhanced productivity, profitability, and sustainability of the rice-wheat system in South Asia. Ladha J K, Yadvinder-Singh and Hardy D (Eds.). Integrated crop and resource management in rice-wheat system of South Asia. Los Banos, Philippines, pp. 69-108.
- Norman R J, Bollich P K, Wilson Jr C E and Slaton N A. 1997. Influence of nitrogen fertilizer rate, application timing and tillage on grain yields of water-seeded rice. *Arkansas Experimental Station Research Series* **460**: 299-302.
- Parihar C M, Singh A K, Jat S L, Dey A, Nayak H S, Mandal B N, Saharawat Y S, Jat M L and Yadav O P. 2020. Soil quality and carbon sequestration under conservation agriculture with balanced nutrition in intensive cereal-based system. *Soil and Tillage Research* **202**: 1046-53.
- Rajwade Y A, Swain D K and Tiwari K N. 2013. Agriculture: Towards a new paradigm of sustainability, pp 293-300.
- Sharda R, Mahajan G, Siag M, Singh A and Chauhan B S. 2017. Performance of drip irrigated dry-seeded rice (*Oryza sativa* L.) in South Asia. *Paddy Water Environment* **15**: 93-100.
- Sharmiladevi R and Ravikumar V. 2019. Simulation of nitrogen schedule for paddy under sub-surface drip irrigation. *Pollution Research Paper* **38** (2): 368-79.
- Sidhu H S, Jat M L, Yadvinder-Singh, Sidhu R K, Gupta N, Singh P, Jat H S and Gerard B. 2019. Sub-surface drip fertigation with conservation agriculture in a rice-wheat system: A breakthrough for addressing water and nitrogen use efficiency. *Agricultural Water Management* **216**: 273-83.
- Singh S, Dhillon B S and Dhillon S S. 2019. Response of rice (*Oryza sativa* L.) varieties to different planting dates. *Journal of Pharmacognosy and Phytochemistry* **8**(3): 600-6.
- Veeraputhiran R. 2000. "Drip fertigation studies in hybrid cotton". Ph D (Ag.) thesis, Tamil Nadu Agricultural University, Coimbatore, Tamil Nadu.
- Zhang X C, Lei J C, Zheng D Y, Liu Z H, Li G H, Wang S H and Ding Y F. 2017. Amino acid composition of leaf, grain and bracts of japonica rice (*Oryza Sativa* ssp. japonica) and its response to nitrogen fertilization. *Plant Growth Regulators* **82**: 1-9.