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Enhancing productivity of hybrid rice (*Oryza sativa* L.) CoRH2 through nitrogen management practices under transplanted and direct-seeding methods

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Abstract

Field experiments were conducted at Wetland Research Farm, Tamil Nadu Agricultural University, Coimbatore, India, during *Rabi* 2001 and 2002 with a view to formulate a suitable crop establishment method and to optimize the nitrogen management practices for hybrid rice CoRH2. The experiments were laid out in split plot design replicated thrice with four crop establishment techniques in the main plot and seven N management practices were assigned in the sub-plot. The results revealed that different crop establishment methods exerted a significant variation on the seed rate requirement and caused significant influence on growth and yield of hybrid rice. Seeding through one out of two holes (M_3) recorded optimum seed rate of 29.14 and 28.69 kg ha^{-1} during 2001 and 2002 respectively. Except at the early stages of 60 DAS, there was no significant difference in plant height as influenced by establishment methods. Seeding through all the holes (M_1) with higher seed rate recorded significantly higher values of growth characters *viz.,* LAI, tillers m^{-2}, DMP, productive tillers m^{-2} and grain yield which was comparable with transplanting (M_1) and seeding through one out of two holes (M_3). The yield attributes like panicle length and 1000 grain weight were not influenced by the crop establishment methods. The seeding through one out of three holes (M_4) registered significantly higher total number of grains, filled grains panicle^{-1} and lower sterility percentage as compared to rest of the establishment methods. Application of N based on Soil Test Crop Response (STCR) (N_7) enhanced significantly the growth and yield attributing characters viz., plant height, LAI, DMP, total tillers m^{-2}, panicle length, productive tillers m^{-2}, total number of grains panicle^{-1} over the other N management practices and was on par with N application in four splits combined with green manure *Sesbania aculeata* @ 6.25 t ha^{-1} application (N_4). STCR based N application recorded highest sterility percentage whereas LCC based N application noticed lowest sterility percentage. The treatment combination of seeding through all the holes and N application based on STCR (M_2N_7) recorded significantly higher grain yield (8150 and 7905 kg ha^{-1}) and it was on par with M_1N_7, M_2N_3, M_3N_7 and M_1N_3 during both the years respectively.

***Key words**:* Crop establishment methods, nitrogen management, hybrid rice, yield.

Introduction

The evolution of hybrid rice technology has generated high hopes in rice growing regions for meeting the food demands of the ever growing population. It is generally felt that a yield plateau has been reached in conventional rice varieties and any further increase in the productivity of rice from current level of 2817 kg ha^{-1} warrants the breaking of the yield barrier. Hybrid rice cultivation is a technology option available for meeting this challenge. India is yet to fully exploit the technology which offers a 10-15 per cent yield advantage over the best conventional inbred varieties [23, 56]. Establishment technique, plant density, nutrient requirement and management, water management etc., need to be standardized to achieve the reported yield potential of rice hybrids of different duration in various environments. In recent years many factors such as scarcity and raising cost of labour, uncertainty in water release in canal etc., have encouraged many farmers to switch over from transplanting to wet seeding [15]. However, wet seeding in hybrid rice has not been contemplated so far due to increased seed requirement for direct seeding and consequent increase in the cost of production since the hybrid rice seed is a costly input. Yet wet seeding of hybrid rice may become a reality due to the same reasons as in conventional inbred varieties. The grain yield in wet seeding is also comparable to transplanting method and even higher under good management [14]. Economy in seed rate of wet seeded rice had been made possible through the intervention of drum seeder. Studies on optimization of seed rate for wet seeded medium duration hybrid rice CoRH2 using drum seeder have not so far been taken up. When wet seeding of hybrid rice becomes popular a recommendation on seed rate has to be made available.

Hybrid rice shows excellent response to N application, but the recovery of applied N is quite low. Hybrid rice requires different strategies for nitrogen management than inbred to maximize expression of their yield advantage. Leaf colour chart (LCC) is a non-destructive tool for farmers to assess the leaf N status and to determine the time of top dressing to rice crop. Organic nutrition to rice is assuming significance in the context of an increasing concern about sustaining soil health with increasing use of inorganic nutrition on the one hand and expected shortage in N fertilizer for rice cultivation on the other hand. An integrated approach involving organic manures and chemical fertilizers will go a long way in building up of soil fertility on a permanent basis and the system will supply most of the nutrients in a judicious way. Optimization of fertilizer N to hybrid rice has been an important topic for quite long and still continues to attract scientists leading to new concepts and approaches. Hence with the objective of exploiting the full heterotic potential of hybrids and to develop suitable optimal nitrogen management practices to match crop demand with fertilizer N supply thus reducing losses and maximizing crop N utilization, the present study was undertaken to study the effect of different crop establishment methods and nitrogen management practices on the seed rate optimization, growth and yield of rice hybrid CoRH2 under the Coimbatore region of Tamil Nadu, India.

Materials and Methods

Field experiments were conducted during *Rabi* season of 2001 and 2002 in wetland research farm of Tamil Nadu Agricultural University, Coimbatore, to evaluate the effect of crop establishment methods with various N management practices on the optimization of seed rate and yield of rice hybrid CoRH2. The soil of the experimental field was moderately drained, deep clay loam in texture and taxonomically classified as *Typic Haplustalf* with pH (7.7 and 7.6) and organic carbon content (0.73 and 0.68%) during both the seasons respectively. The soil was low in available N (240, 230 kg ha^{-1}), medium in available P (16.5, 17.0 kg ha^{-1}) and high in available K (528, 508 kg ha^{-1}) during 2001 and 2002 respectively. The experiment was laid out in a split plot design replicated thrice. The main plot consisted of four establishment methods and sub-plots were assigned with seven N management practices. The hybrid CoRH2 is a medium duration (125-130 days) suitable for *Rabi* season (September-January) with slender and white grain.

The details of the treatments and the notations used are as follows.

Main plots: Crop establishment techniques

M_1- Transplanting (20 cm x 10 cm)
M_2- Drum seeding through all holes
M_3- Drum seeding through one out of every two holes
M_4- Drum seeding through one out of every three holes

Sub-plots: N managements

N_1- Control (without N)
N_2- 150 kg ha^{-1} in four splits (1/6th N at 7DAT, 1/3rd at active tillering, 1/3rd at panicle initiation, 1/6th at first flowering)
N_3- Green manure application @ 6.25 t ha^{-1} + N 150 kg ha^{-1} in four splits
N_4- 30 kg ha^{-1} + N as per LCC cv.4
N_5 -N application as per LCC cv.4
N_6- 100 per cent N through organic manures (50% N as green manure + 15% N as poultry manure + 20% N as FYM + 15% N as neem cake)
N_7- Soil Test Crop Response (STCR) based N application for a yield target of 8 t ha^{-1}

The drum seeder holes were plugged with cellophane tape to impose the different seeding methods as described in M_3 and M_4 methods. Above ground biomass of *Sesbania aculeata* at the age of 40 days was harvested, weighed and applied to the respective plots as per treatment schedule. The green manure was spread uniformly and incorporated a week prior to transplanting. Seeds of hybrid CoRH2 were treated with carbendazim at 2 g kg^{-1} of seeds against seed-borne pathogens. After 24 hours, the seeds were inoculated with Azospirillum @ 600g ha^{-1}. Then the seeds were soaked in water for 24 hours and incubated in dark for 12 hours to induce sprouting. The drum seeder developed by the Department of Agricultural Engineering, TNAU, Coimbatore, for row seeding of pre-germinated paddy seeds on puddle soil was used for direct seeding. This machine permits uniform seeding at fairly low seed rates of 50-100 kg ha^{-1}. The eight row drum seeder was used for this purpose and it requires 9 kg of pulling force to operate. The machine weighs 11 kg with seed capacity of 8 kg (2 kg/hopper). Seeding output per day is about 1.0 ha with labour requirement of 14 man hours ha^{-1}. The seed rate was optimized by seeding through one out of every two holes and seeding through one out of three holes. The CoRH2 seeds of 20 kg were sown in the wet nursery for raising seeding on the same day of direct seeding in the main field. The seedlings raised were transplanted at 24 days after sowing. The seedlings were transplanted at one seedling hill^{-1} adopting a spacing of 15 cm x 10 cm.The recommended dose of N 150 kg ha^{-1} for *Rabi* as per treatment was applied in equal splits on 30, 45, 70 and 95 DAS. Phosphorus at 50 kg ha^{-1} was applied basally to all the treatments. Potash @ 50 kg ha^{-1} was applied in three equal splits on 30, 45 and 70 DAS along with the first three splits of fertilizer N. In LCC based N management treatments, the LCC values were recorded as per the standard procedure [19] at weekly interval starting from 14 DAT to flowering for transplanted crop. In case of drum seeding the LCC values were recorded at weekly interval from 21 DAS and whenever the LCC values were found to be below the critical level of four, recommended quantity of fertilizer N was applied.

Manure application: Nutrient contents of different organic manures were analysed and based on the nitrogen content of manures. The quantities required for the recommended dose were calculated on dry weight basis and applied to the respective plots one week before transplanting and incorporated well into the field. The *quantities of organic manures added (t ha^{-1}) to substitute the recommended N are presented below:

Sesbania aculeata (50 % N)	Poultry manure (15% N)	Farmyard manure (20% N)	Neem cake (15% N)
4.22	0.90	7.62	0.63

*Quantity applied on dry weight basis

STCR based N application: Based on the soil available N, the required quantity of fertilizer to attain the targeted yield of 8 t ha^{-1} was calculated (Table 1). The fertilizer prescription to attain specific yield targets based on soil available nutrient levels for the experimental field was as follows: *Rabi* season- FN = 46.3T – 0.56 SN, where FN fertilizer nitrogen (kg ha^{-1}), T targeted yield (t ha^{-1}), SN soil available nitrogen (kg ha^{-1}).

Table 1. Fertilizer N applied to attain yield target.

Season	Soil available N (kg ha^{-1})	Targeted yield t ha^{-1}	Required fertiliser N
Rabi 2001	240	8	236.00
Rabi 2002	230	8	242.00

Leaf colour chart (LCC) measurements: The colour of the single leaf was measured by holding the leaf colour chart vertically and placing the middle part of leaf 1 cm in front of colour strip for comparison [19]. During measurement, the leaf being measured was shaded with the body to avoid interference by sunlight intensity. Ten readings were taken for each plot and average was computed by rounding off to the nearest 0-5 to determine the need for N top dressing. The amount of N to be applied at different growth stages was as per the schedule given in Table 2 [19].

Table 2. The amount of N to be applied at different growth stages.

Crop growth stage	N to be applied kg ha^{-1}
Transplanted crop	
Early growth sage (14-21 DAT)	30
Rapid growth stage (28-42 DAT)	45
Late growth stage (45 DAT-Flowering)	30
Direct seeded rice	
Early growth sage (21-35 DAS)	30
Rapid growth stage (35-56 DAS)	45
Late growth stage (56 DAS-Flowering)	30

High dose of 45 kg ha^{-1} was applied only once or twice during rapid growth stage. The N applied kg ha^{-1} in different management practices are given in Tables 3-5.

Seed rate calibration: The drum seeder hopper was filled with a known weight of sprouted seeds and allowed to operate over the plot on a saturated soil condition. After sowing, the weight of the remaining seeds was recorded and difference in weight divided by the area sown gave the seed rate for the covered plot area. The moisture content of the seed used was calculated and the seed rate required was calculated at 14 per cent moisture content basis. From the above data, seed rate required for one hectare was calculated.

Results and Discussion

Seed rate calibration: In general, direct seeded rice requires more quantity of seed rate than transplanted rice. In hybrid rice, where seed cost is relatively higher, optimization of seed rate is crucial. The quantity of seeds required for one hectare was calibrated by manipulating the seed holes in the drum seeder. The seeding through all the holes (M_1) registered the highest seed rate of 70.64 and 68.87 kg ha^{-1} during 2001 and 2003 which was 253.20 and 244 per cent higher than the seed rate adopted for transplanted crop (Tables 6 and 7). Seeding through one out of every two holes registered seed rate of 29.14 and 28.69 kg ha^{-1} and the increase was 45.70 and 43.45 per cent higher than transplanting. Seeding through one out of three holes recorded seed rate requirement of 18.10 and 17.66 kg ha^{-1} and it was 9.50 and 11.70 per cent lower than in transplanted crop. Similar trend of seed rate usage under wet seeding by manipulating the seed holes in the drum seeder were earlier reported [21]. Growth of wet seeded hybrid rice CoRH2 varied distinctly due to different seed rates adopted by manipulating the seed holes in terms of tiller production, dry matter production and leaf area index. Yield attributes like productive tillers and number of grains $panicle^{-1}$ were also affected by seed rate leading to significant effect on grain yield.

Table 3. N applied (kg ha^{-1}) in different N management for transplanting *Rabi* 2001 and 2002.

Time of fertilizer application (DAT)		*Rabi* 2001					*Rabi* 2002				
		M_1N_1	M_1N_3	M_1N_4	M_1N_5	M_1N_7	M_1N_2	M_1N_3	M_1N_4	M_1N_5	M_1N_7
Basal (0)		37.50	-	30.00	-	59.00	37.50	-	30.00	-	60.50
7 DAT		-	25.00	-	-	-	-	25.00	-	-	-
Early growth	14	-	-	-	20.00	-	-	-	-	20.00	-
stages(EGS)	21	37.50	-	-	-	59.00	37.50	-	-	-	60.50
	28	-	50.00	30.00	30.00	-	-	50.00	30.00	30.00	-
Rapid growth	35	-	-	-	-	-	-	-	-	-	-
stages(RGS)	42	37.50	50.00	30.00	30.00	59.00	37.50	50.00	30.00	30.00	60.50
	49	-	-	-	-	-	-	-	-	-	-
Late growth	56	-	-	20.00	20.00	-	-	-	20.00	20.00	-
stages (LGS)	63	37.50	-	-	-	59.00	37.50	-	-	-	60.50
	70	-	25.00	20.00	20.00	-	-	25.00	20.00	20.00	-
Total (kg N ha^{-1})		150.00	150.00	130.00	120.00	236.00	150.00	150.00	130.00	120.00	242.00

Table 4. N applied (kg ha^{-1}) in different N management – Wet seeding – *Rabi* 2001.

Time of fertilizer application (DAS)		M_2N_2	M_2N_3	M_2N_4	M_2N_5	M_2N_7	M_3N_2	M_3N_3	M_3N_4	M_3N_5	M_3N_7	M_4N_2	M_4N_3	M_4N_4	M_4N_5	M_4N_7
B (0)		-	-	30	-	-	-	-	30.00	-	-	-	-	30.00	-	-
EGS	21	37.50	25.00	20.00	20.00	59.00	37.50	25.00	-	20.00	59.00	37.50	25.00	-	20.00	59.00
	28	-	-	-	-	-	-	-	-	-	-	-	-	20.00	-	-
RGS	35	-	-	30.00	30.00	-	-	-	30.00	30.00	-	-	-	-	30.00	-
	42	37.50	50.00	-	-	59.00	37.50	50.00	-	-	59.00	37.50	50.00	30.00	-	59.00
	49	-	-	-	30.00	-	-	-	30.00	30.00	-	-	-	-	30.00	-
	56	-	-	20.00	-	-	-	-	-	-	-	-	-	20.00	-	-
LGS	63	37.50	50.00	-	20.00	59.00	37.50	50.00	20.00	20.00	59.00	37.50	50.00	-	-	59.00
	70	-	-	20.00	-	-	-	-	-	-	-	-	-	-	20.00	-
	77	-	-	-	20.00	-	-	-	-	-	-	-	-	20.00	-	-
	84	37.50	25.00	20.00	-	59.00	37.50	25.00	20.00	20.00	59.00	37.50	25.00	-	20.00	59.00
		150.00	150.00	140.00	120.00	236.00	150.00	150.00	130.00	120.00	236.00	150.00	150.00	120.00	120.00	236.00

B- Basal EGS- Early growth stages RGS- Rapid growth stages LGS- Late growth stages

Table 5. N applied (kg ha^{-1}) in different N management – Wet seeding – *Rabi* 2002.

Time of fertilizer application (DAS)		M_2N_2	M_2N_3	M_2N_4	M_2N_5	M_2N_7	M_3N_2	M_3N_3	M_3N_4	M_3N_5	M_4N_7	M_4N_2	M_4N_3	M_4N_4	M_4N_5	M_4N_7
B (0)		-	-	30	-	-	-	-	30.00	-	-	-	-	30.00	-	-
EGS	21	37.50	25.00	20.00	20.00	60.50	37.50	25.00	-	20.00	60.50	37.50	25.00	-	20.00	60.50
	28	-	-	-	-	-	-	-	-	-	-	-	-	20.00	-	-
RGS	35	-	-	30.00	30.00	-	-	-	30.00	30.00	-	-	-	-	30.00	-
	42	37.50	50.00	-	-	60.50	37.50	50.00	-	-	60.50	37.50	50.00	30.00	-	60.50
	49	-	-	-	30.00	-	-	-	30.00	30.00	-	-	-	-	30.00	-
	56	-	-	20.00	-	-	-	-	-	-	-	-	-	20.00	-	-
LGS	63	37.50	50.00	-	20.00	60.50	37.50	50.00	20.00	20.00	60.50	37.50	50.00	-	-	60.50
	70	-	-	20.00	-	-	-	-	-	-	-	-	-	-	20.00	-
	77	-	-	-	20.00	-	-	-	-	-	-	-	-	20.00	-	-
	84	37.50	25.00	20.00	-	60.50	37.50	25.00	20.00	20.00	60.50	37.50	25.00	-	20.00	60.50
		150.00	150.00	140.00	120.00	242.00	150.00	150.00	130.00	120.00	242.00	150.00	150.00	120.00	120.00	242.00

B- Basal EGS- Early growth stages RGS- Rapid growth stages LGS- Late growth stages

Table 6. Calibration of seed rate for CoRH2 (2001).

Treatment	Area (ha)	Initial weight of seeds (kg)	Weight of seeds after sowing (kg)	Difference in weight (kg)	Seed rate (kg ha^{-1})	% increase over M_1
M_1	-	-	-	-	20.00	-
M_2	0.0453	5.40	2.20	3.20	70.64	253.20
M_3	0.0453	5.40	4.08	1.32	29.14	45.70
M_4	0.0453	5.40	4.58	0.82	18.10	-9.50

Table 7. Calibration of seed rate for CoRH2 (2002).

Treatment	Area (ha)	Initial weight of seeds (kg)	Weight of seeds after sowing (kg)	Differen ce in weight (kg)	Seed rate (kg ha^{-1})	% increase over M_1
M_1	-	-	-	-	20.00	-
M_2	0.0453	5.10	1.98	3.12	68.87	244.40
M_3	0.0453	5.10	3.80	1.30	28.69	43.45
M_4	0.0453	5.10	4.30	0.80	17.66	-11.70

Growth components: Tiller number per unit area registered a progressive increase from seeding through one out of three holes (M_4) to the seeding through all the holes (M_2). At all the stages of growth, seeding through all the holes (M_2) with a seed rate of 70 and 68.87 kg ha^{-1} resulted in significantly higher tillers m^{-2} which was comparable with transplanting (M_1) and seeding through one out of two holes (M_3) (Table 8). Lowest number of tillers was noticed with seeding through one out of three holes (M_4). Plant density is the most important factor affecting tillering in any crop [13]. Similar trend of increasing tiller count with increasing plant densities was earlier noticed [26]. In wet seeding plant density is decided principally by seed rate and hence higher seed rate in the treatment M_2 led to higher plant density resulting in more tiller production. This result is in conformity with the findings that seeding emergence and tiller numbers increased proportionately with increasing seed rate [35]. Joseph [21] also reported that adoption of seed rate of 24 kg ha^{-1} in wet seeding of CoRH2 hybrid rice resulted in higher number of tillers m^{-2} than 20, 16 and 12 kg ha^{-1} [21]. Wet seeded crop produced tillers per unit are comparable to transplanted crop [33]. Nitrogen management practices exerted significant influence on number of tillers at various crop stages across seasons. Application of N based on Soil Test Crop Response (STCR) at all stages of crop in both the years recorded significantly higher tiller numbers and it was on par with the application of N 150 kg ha^{-1} plus green manure @ 6.25 t ha^{-1}(N_2) during both the years. Promotion of tillering with high nutrient availability is an established process [24]. Hence higher nutrient availability in the STCR based N application and green manure plus nitrogen supply favoured higher tiller density as has been reported by earlier workers [12]. To maximize the productivity of hybrid rice, the maximum potential vegetative growth should be ensured with high rate of N fertilizer at early growth stages. In case of STCR based N application, higher dose of N applied in each split might have positively influenced the tiller production. Timely availability of N in right proportion at the critical stages of the growth will help in profuse tillering as seen in various N management practices compared to control.

Table 8. Total tillers m^{-2} of rice hybrid CoRH2 as influenced by crop establishment methods and N management practices.

Treatment	*Rabi* 2001				*Rabi* 2001			
	60 DAS	90 DAS	105 DAS	125 DAS	60 DAS	90 DAS	105 DAS	125 DAS
Establishment methods								
M_1	497	511	542	558	480	497	525	535
M_2	510	524	555	569	491	508	536	548
M_3	490	505	534	550	474	491	519	531
M_4	389	402	428	439	376	390	413	427
SEd	9	10	9	10	8	9	8	9
CD(0.05)	22	24	23	25	19	21	21	23
N Management								
N_1	269	278	302	310	264	272	288	296
N_2	497	513	544	558	477	492	520	533
N_3	576	593	621	637	557	575	606	621
N_4	488	499	529	543	469	484	512	524
N_5	483	492	524	539	463	477	503	515
N_6	405	425	457	471	394	421	447	456
N_7	584	599	626	646	564	582	613	628
SEd	11	13	12	14	10	11	11	12
CD(0.05)	23	26	25	28	20	23	23	25
M at N								
SEd	24	22	22	29	20	21	16	26
CD(0.05)	49	46	46	60	42	43	34	53
N at M								
SEd	26	23	25	30	20	21	16	25
CD(0.05)	47	46	50	60	41	43	33	50

The ammonia N content in the soil solution was positively correlated with the tillering ability in rice [20]. Steady supply of N through four splits of the recommended dose combined with green manure synchronizing with peak requirement of N to the crop might have resulted in considerable increase in tiller compared to other N management practices [31]. Interaction effect of crop establishment methods and N management practices on tiller production of hybrid rice was significant at all the four stages of crop growth in both the seasons.

Dry matter production varied significantly with the different establishment methods and N management practices. A positive and linear response was observed with dry matter production to the seed rate. Seeding through all the holes (M_2) registered maximum DMP of 4121 and 3921 kg ha^{-1} at 60 DAS, 8754 and 8395 kg ha^{-1} at 90 DAS, 13,290 and 12,826 kg ha^{-1}at 105 DAS and 16,230 and 15,552 kg ha^{-1} at harvest and it was on par with transplanting (M_1) and seeding through one out of two holes (M_3) during respective stages of the crop (Table 9). Results on the positive and linear effect of seed rate on DMP by rice were reported [32]. No significant difference in DMP at all the growth stages due to the drum seeding and transplanting methods was reported[33].The application of N based on STCR (N_7) registered higher DMP at all the crop stages and it was comparable with application of N 150 kg ha^{-1} plus green manure (N_3). These results are in line with earlier findings [44]. Highest LAI in STCR based N application might have increased the amount of solar radiation intercepted and utilized by the plant which resulted in higher quantity of photosynthate production ultimately resulting in higher DMP. Similar results of higher plant height and DMP with STCR based N application in CoRH1 rice hybrid was reported [5]. Improvement in DMP with the application of N in four splits along with green manure could be attributed to optimum availability of N at the time when the crop is most responsive as reflected in increased LAI and number of tillers. The continuous release of N from the green manure into the soil solution matching the required absorption rate of the crop enhanced the DMP [53]. Though the total quantity of N was less through green manure plus N applied in four splits, it produced biomass similar to that of STCR based N probably due to steady supply of N for a prolonged period of crop growth [16] and addition of other nutrients through green manure [11]. As a result of higher LAI and increased CO_2 exchange and due to synergistic influence of integrated use of green manure along with fertilizer N, the plant have become photosynthetically more active and contributed to greater biomass production [43].

Table 9. Influence of crop establishment and nitrogen management practices on dry matter production (DMP) (kg ha^{-1}) of CoRH2.

Treatment	*Rabi* 2001				*Rabi* 2002			
	60 DAS	90 DAS	105 DAS	125 DAS	60 DAS	90 DAS	105 DAS	125 DAS
Establishment methods								
M_1	4055	8580	13037	15945	3875	8231	12634	15260
M_2	4121	8754	13291	16231	3921	8375	12826	15552
M_3	3990	8474	12938	15770	3785	8137	12501	15115
M_4	3370	7109	10668	12265	3124	6615	10213	11873
SEd	62	127	175	212	58	115	182	200
CD(0.05)	151	310	429	519	143	280	444	490
N Management								
N_1	3063	5933	7727	9563	2818	5349	7443	9190
N_2	4003	8519	13301	15912	3770	8220	12824	15106
N_3	4516	9297	14437	17485	4279	8948	13864	17039
N_4	3919	8362	13192	15674	3700	8133	12657	14875
N_5	3819	8191	12993	15444	3645	8092	12551	14666
N_6	3191	7809	11199	13430	3094	6996	10913	13129
N_7	4677	9496	14534	17862	4430	9140	14055	17292
SEd	85	175	233	306	81	156	241	289
CD(0.05)	172	351	469	615	163	313	485	581
M at N								
SEd	170	387	405	489	162	311	482	462
CD(0.05)	350	797	834	1008	334	640	993	952
N at M								
SEd	171	349	466	611	162	311	482	577
CD(0.05)	344	702	938	1229	325	626	970	1161

Plant height is a direct index to measure the growth and vigour of the plant. During both the years, the method of crop establishment showed significant influence on plant height at early stages of crop growth. At 60 DAS, the seeding through one out of every three holes (M_4) registered maximum plant height (40.30 and 37.20 cm) which was comparable with the seeding through one out of two holes (M_3) and seeding through all the holes (M_2) but was significantly higher than transplanting (M_1). At 90, 105 and 135 DAS, the method of establishment did not cause any significant difference in plant height. At all the stages of the crop significantly higher plant height was recorded with the N application based on STCR (N_7) and it was comparable with application of N 150 kg ha^{-1} plus green manure @ 6.25 t ha^{-1}(N_3). Plant height generally tends to decrease with higher plant densities due to interplant competition for life [29]. In the present study, however, adoption of seeding through different holes with different seed rate did not cause any significant difference in plant height of wet seeded CoRH2 hybrid rice. Seed rate adopted in the study ranged from 16 to 70 kg ha^{-1} only unlike in the conventional inbred varieties where higher seed rates of 120-150 kg ha^{-1} were used. Perhaps, this lower seed rate coupled with the fairly wide 20 cm inter-row space accomplished by the use of drum seeder holes manipulation reduced the interplant competition and consequently with no adverse effect on plant height. However, at the early stages of crop, plant height in different wet seeding treatments is higher than transplanting whereas in the later stages there is no significant difference in plant height between the establishment methods. The higher plant growth in early stages in wet seeding might be due to early establishment of direct seeded crop in the absence of transplantation shock [37].There is no significant difference in plant height between direct seeding and transplanting due to adoption of different seed rates was earlier reported [21].

Greater availability of nutrients and higher uptake were the causes for the beneficial effect on the growth due to different N management practices. Nitrogen is well recognized as a promoter of vegetative growth and apart from being a substrate for protein synthesis, it also stimulates meristematic growth through protoplasmic synthesis [7].Thus, increased availability of N through different N management practices resulted in higher values of plant height during both the years. Application of higher dose of N based on STCR to a tune of 236 to 242 kg ha^{-1} results in higher availability of N which in turn results in stimulation of meristematic growth leading to increase in plant height. Similar result of enhancement in height of rice plant with increased level of applied N has been documented by several researchers [28].The mineralization during the decomposition of green manure due to integrated use of inorganic fertilizers have enhanced the N availability in the rhizosphere resulting in increased N uptake by rice hybrids which in turn promoted the increase in plant height and consequent favourable effect of growth characters at higher levels of fertilizer N at early stages [38]. In general addition of green manure in rice soil has a positive correlation with plant height [18].

Leaf area index (LAI) in the two seasons was significantly influenced by the crop establishment methods and N management at all crop growth stages. Seeding through all the holes (M_2) recorded the highest LAI of 4.14 and 3.97 at 60 DAS, 5.82 and 5.65 at 90 DAS and 6.86 and 6.64 at 105 DAS which was on par with transplanting (M_1) and seeding through one out of two holes (M_3). Seeding through one out of three holes registered the lower LAI at all the stages of the crop growth. Nitrogen management practices had significant positive influence in enhancing LAI at all the stages irrespective of the seasons. The maximum LAI of 4.84 and 4.68 at 60 DAS, 6.82 and 6.62 at 90DAS, 7.92 and 7.55 at 105 DAS was registered with N application based on STCR (N_7) and it was on par with N 150 kg ha^{-1} plus green manure (N_3) but significantly higher than the rest of the treatments. The interaction between crop establishment methods and N management throughout the crop growth was insignificant during both the years. Higher tiller production in seeding through all the holes due to higher seed rate enabled the production of more leaves per unit area and consequently higher leaf area index. LAI increased with higher population due to more leaves produced per unit area [4]. Adoption of seed rate of 24 kg ha^{-1} produced higher leaf area index [21]. Similar finding of LAI not being significantly influenced between drum seeding and transplanted crop was reported [33]. The total leaf area per unit ground area is an important indicator of total source available to the plant for the production of photosynthates, which accumulate in the developing sink (grain). All the N management treatments recorded substantially higher LAI compared to control in both seasons of investigation. Such increase in LAI is quite obvious due to higher availability of N. At all the stages of growth the LAI was highest in STCR based N applied plots and was on par with the N application in four splits plus green manure applied treatment. The highest plant height coupled with higher number of leaves, number of tillers might have led to significant positive influence on the leaf area index of the STCR based N applied plots. Similar results of increased N supply resulting in taller plants and higher LAI was reported [28]. The increase in LAI of rice in the plot applied with fertilizer application plus green manure is attributed to adequate availability of N during the initial stages of the crop by the split application. The contribution of N from the mineralization of the green manure incorporation might have benefited the expansion of leaf area. The lower response in LCC cv.4 based N application as expressed in LAI is the result of poor N nutrition due to inadequate supply of N to meet the physiological need of the hybrid.

Yield components: The production of panicles both per plant and per unit area is one of the important yield contributing characters. During both the years, the hybrid exhibited significant variation in productive tiller formation due to different crop establishment methods and N management practices. Significantly higher number of productive tillers (496 and 477 m^{-2}) was registered in seeding through all the holes (M_2) and it was on par with transplanting (M_1) and seeding through one out of every two holes (M_3) during the two years respectively (Tables 10 and 11). The number of panicles m^{-2} was significantly enhanced by N management practices over control in all the seasons of cropping. Application of N based on STCR (N_7) registered significantly higher number of productive tillers (563 and 545 m^{-2}) and it was on par with application of N 150 kg ha^{-1} plus green manure @ 6.25 t ha^{-1}(N_3). Interaction effect between crop establishment methods and N management practices was significant. Seeding through all the holes and application of N based on STCR (M_2N_7) resulted in maximum number of productive tillers. The values of yield attributes of most of grain crops including rice would generally be in accordance with that of vegetative growth parameters, since the size of source most often determines the size of sink. In terms of yield attributes, a positive linear relationship with seed rate due to different seeding method was observed only in productive tillers per unit area. Possibly an increase in total tiller production might have led to the promotion of more panicle bearing tillers per unit area under the seeding through all the holes with higher seed rate [47]. Similarly the increased effective tillers per unit area under higher seed rate in wheat as compared to lower seed rate was reported [50]. Tillering ability exerted a significant influence on future production of panicle [26]. Higher number of panicle bearing tillers per unit area with seed rate of 24 kg ha^{-1} in wet-seeded hybrid rice than at 20, 16 and 12 kg ha^{-1} seed rate levels were recorded [21]. The seeding method *viz.*, drum seeding and transplanting did not have significant influence on the number of panicles as was reported [33]. Enhancement of vegetative growth favourably influenced the yield attributes and higher N application levels, i.e. more than 200 kg ha^{-1}, increases the productive tiller density [3]. High N responsive genotypes were found to produce more productive tillers [45]. Hybrid rice responds to higher N application as it has unique physiological pattern of N requirement [55]. The obvious reason for the higher effective tiller production might be due to high N responsiveness of the hybrid to higher N levels, i.e., 236 and 242 kg ha^{-1}. Higher number of panicles with STCR based N application (256.70 kg ha^{-1}) was also reported [5]. Similar results of higher productive tillers were recorded by CoRH2 with application of 175 and 200 kg N ha^{-1} [42]. The application of N fertilizer in four splits along with green manure (N_3) recorded higher number of productive tillers and it was comparable with STCR based N application. Higher N both through organic source as well as fertilizer N resulted in higher nutrient uptake which might have delayed senescence and increased photosynthetic efficiency which ultimately led to increased number of productive tillers [58].

Among the yield attributes, panicle length and thousand grain weight were not significantly influenced by the crop establishment methods, but the numbers of filled and ill-filled grains $panicle^{-1}$ were significantly influenced by the seeding methods due to variation in seed rate adopted. Seeding through one out of three holes (M_4) recorded significantly higher number of total grains $panicle^{-1}$ (140.20 and 138.20) and was on par with transplanting but differed significantly to that of M_3 and M_2. Significantly higher number of filled grains (121.90 and 120.00) during 2001 and 2002 and less number of ill-filled grains per panicle (19.80) were recorded with seeding through one out of three holes (M_4) with lower seed rate as compared to transplanting and other treatments.

Table 10. Influence of crop establishment methods and N management on yield attributes and yield of CoRH2 during 2001.

Treatment	Productive tillers m^{-2}	Panicle length (cm)	Total number of grains panicle^{-1}	Number of filled grains panicle^{-1}	Number of ill-filled grains panicle^{-1}	Sterility %	1000 grain weight (g)	Grain yield (kg ha^{-1})	Straw yield (kg ha^{-1})
Establishment methods									
M_1	487	23.23	135.20	115.28	19.97	14.77	23.98	6511	8018
M_2	496	22.44	130.80	109.79	21.06	16.10	23.67	6646	8209
M_3	481	22.70	133.30	113.33	20.02	15.00	23.86	6417	7906
M_4	383	23.42	140.20	121.90	18.34	13.10	24.08	4907	6299
SEd	8.0	0.47	2.78	2.37	0.40	0.30	0.18	99	144
CD(0.05)	21.0	NS	6.80	5.79	0.98	0.73	NS	243	353
N Management									
N_1	281	20.10	111.10	94.32	16.77	15.10	23.10	3742	4948
N_2	487	23.40	139.10	119.54	19.56	14.06	24.00	6493	8109
N_3	555	24.58	148.20	126.64	21.56	14.50	24.90	7366	8715
N_4	471	23.00	136.48	118.10	18.42	13.50	23.70	6271	7815
N_5	467	22.80	133.40	116.40	17.00	12.70	23.80	6209	7749
N_6	410	21.90	125.78	107.80	18.00	14.30	23.50	5275	6841
N_7	563	24.80	150.53	124.70	25.80	17.10	24.30	7486	9082
SEd	11	0.64	3.82	3.23	0.54	0.41	0.59	147	194
CD(0.05)	23	1.29	7.69	6.50	1.09	0.82	1.18	295	390
M at N									
SEd								297	400
CD(0.05)	NS		NS	NS	NS	NS	NS	612	824
N at M									
SEd								293	387
CD(0.05)	NS		NS	NS	NS	NS	NS	590	779

Table 11. Influence of crop establishment methods and N management on yield attributes and yield of CoRH2 during 2002.

Treatment	Productive tillers m^{-2}	Panicle length (cm)	Total number of grains panicle^{-1}	Number of filled grains panicle^{-1}	Number of ill-filled grains panicle^{-1}	Sterility (%)	1000 grain weight (g)	Grain yield (kg ha^{-1})	Straw yield (kg ha^{-1})
Establishment methods									
M_1	466	23.00	133.40	114.60	18.80	14.10	24.00	6218	7719
M_2	477	22.28	129.00	109.20	19.80	15.40	23.67	6379	7910
M_3	462	22.54	131.50	111.70	19.80	15.10	23.82	6161	7620
M_4	371	23.26	138.20	120.00	18.20	13.15	24.00	4751	5927
SEd	8	0.46	2.66	2.29	0.39	0.33	0.16	120	131
CD(0.05)	20	NS	6.50	5.60	0.95	0.82	NS	294	320
N Management									
N_1	268	20.30	109.50	82.50	17.00	15.52	23.50	2563	4761
N_2	462	23.50	137.40	116.40	21.00	15.28	24.00	6129	7618
N_3	539	24.40	145.30	125.30	20.00	13.76	24.80	7137	8489
N_4	454	22.80	133.70	115.50	18.20	13.61	23.60	6017	7448
N_5	446	22.60	131.80	114.80	17.00	12.89	23.80	5898	7348
N_6	395	21.30	127.00	108.00	19.00	14.96	23.60	5145	6672
N_7	545	24.60	148.20	124.20	24.00	16.30	24.20	7253	8721
SEd	11	0.65	3.58	3.13	0.53	0.46	0.53	155	169
CD(0.05)	22	1.31	7.21	6.29	1.07	0.92	NS	312	340
M at N									
SEd								311	348
CD(0.05)	NS	NS	NS	NS	NS	NS	NS	660	718
N at M									
SEd								310	338
CD(0.05)	NS	NS	NS	NS	NS	NS	NS	623	679

The productive tillers per unit area increased with seed rates but panicle weight is a function of grains per panicle and grain weight decreased with increasing seed rate [35]. When plants per unit area are less, individual plant performance (e.g., grains per panicle, panicle length) are likely to be better due to less competition for resources. However, plant growth measured in terms of yield attributes per unit area, like productive tillers m^{-2}, is found to be higher with increasing plant density per unit area under high seed rate. The adoption of seed rate of 12 kg ha^{-1} produced least ill-filled grains and more grains per panicle than 24, 20 and 16 kg ha^{-1} seed rate but with lesser productive tillers [21]. Panicle m^{-2} was more or less the same in both the wet seeded and transplanted crops was reported [47].

Panicle length and total number of grains per panicle were significantly improved with N application based on STCR (N_7) and it was on par with four splits of fertilizer N plus green manure application (N_3). Higher availability of N at various stages of growth in STCR based N application treatment favourably influenced the yield attributes [5]. Number of filled grains was significantly higher with N application in four splits along with green manure @ 6.25 t ha^{-1} application (N_3). This might be due to better availability of N from organic and inorganic sources at different critical physiological stages which favoured better growth of rice as evidenced by increased tiller number, LAI, leaf N content and consequently higher DMP. The increased number of spikelets with higher accumulation of dry matter in hybrid rice was observed earlier [52]. Availability of adequate N promotes the supply of assimilates to sink thus increasing the number of spikelets and filled grains. About 15-20 per cent of total N uptake by hybrid rice is reported to take place after heading and therefore hybrid rice responds well to N application at flowering [57]. Nutrients available from decomposing green manure to the rice crop during the reproductive stage were utilized for grain formation and grain filling leading to higher number of filled grains per panicle. Generally there is an inverse relationship between sterility percentage and N levels. To fall in line with the above fact, the sterility percentage recorded in the study was least in LCC cv.4 based N application and highest in STCR based N application treatment. This is due to higher N regime in the STCR based N application which results in more tiller production and increased the possibility of unfilled panicles in the later produced tillers. However, LCC based N management reduces the sterility percentage compared to the conventional N application [8]. Thousand grain weights remain unaltered by nitrogen management practices because it is mostly governed by the genetic make up of the plant.

Grain and straw yield: The grain yield of CoRH2 under different establishment methods varied widely from 2950 to 8150 kg ha^{-1}. The main cause for this variation in the different establishment method was due to variation in the seed rate caused by different seeding methods which is reflected in the tillers and productive tillers production and consequently in the yield. Seeding through all the holes (M_2) produced significantly higher grain yield of 6646 kg ha^{-1} which was on par with transplanting (M_1) and seeding through one out of two holes (M_3) (Table 10). In case of seeding through one out of three holes (M_4) with seed rate of 18.10 and 17.66 kg ha^{-1} during both the years, there is a drastic yield reduction compared to other method of establishment. Higher grain yield with increasing seed rates in the wet seeded rice has earlier been reported in conventional inbred varieties [41]. Wet seeding of rice has produced grain yield as that of transplanted rice was earlier reported[41]. Higher grain yield with adoption of higher seed rate of 24 kg ha^{-1} in wet seeded CoRH2 rice hybrid was reported earlier [21]. Productive tillers per unit area are strongly correlated with grain yield in any rice variety [13]. Production of more panicles per unit area at higher plant density associated with higher seed rate led to significant increase in grain yield with seeding through all the holes (M_2) and seeding through one out of two holes (M_3) compared to seeding through one out of three holes (M_4). This was due to increase in economic sink strength. The higher plant population resulted in more utilization of natural resources particularly soil nutrients, moisture, carbon dioxide and radiant energy. The ability to accept and to transform the solar energy by a crop stand has increased the yield [50]. Though the grains $panicle^{-1}$ was higher and sterility percentage was lower with the seeding through one out of three holes (M_4) with lower seed rate of 16-18 kg ha^{-1}, it could not compensate the reduction in panicles per unit area at lower plant density [30]. A distinct enhancement in straw yield with increase in seed rate was evident in both the years. Straw yield is directly proportional to tiller formation and dry matter accumulation in rice. Hence, seeding at higher seed rate by seeding through all the holes (68-70 kg ha^{-1}), seeding through one out of two holes (26-28 kg ha^{-1}) and transplanted rice produced more tillers m^{-2} and recorded higher DMP resulting in higher straw yield [41]. Higher straw yield production through the adoption of higher seed rate of 24 kg ha^{-1} in wet seeded CoRH2 hybrid seed was reported [21].

Ensuring adequate availability of N during the crop growth period is a prerequisite for higher grain yield. Generally the increase in grain yield due to N fertilization was attributed directly by significant improvement in yield attributes like number of panicles m^{-2} and number of grains $panicle^{-1}$. Consequent to the improvement in yield attributes, grain yield was markedly increased in N application based on STCR (N_7) in both the seasons and it was on par with four split application of N along with green manure application. ASD 20 recorded 90 per cent of targeted grain yield through STCR based N application at the highest N application rate of 234 kg ha^{-1} [3]. Similarly the application of N based on STCR (256.7 kg ha^{-1}) for CoRH1 in four splits resulted in higher grain yield [5]. Because of the higher N responsiveness of hybrids, STCR based N application recorded higher grain yield as the total N applied through this regime was higher as compared to other N management practices. Highest grain yield of hybrid rice due to enhanced N rate application of N 200 kg ha^{-1} was noticed due to increased N availability in soil, plant growth parameters and yield attributes [1]. A positive correlation between dry matter production and grain yield was observed [49, 54]. STCR based N application registered significantly higher grain yield of 8150 and 7905 kg ha^{-1} during 2001 and 2002 as against the targeted yield of 8 t ha^{-1} with a deviation of +1.87 per cent and -1.19 per cent respectively. Similar results of deviation of +10 per cent to the targeted yield was reported in wheat crop [36]. The strategy of applying the fertilizer N in four splits plus green manure (N_3) appears to match the crop demand at different physiological stages and reduces the losses through denitrification and volatilization as reflected in recording higher grain yield comparable to STCR based N application (N_7). Thus the increased availability of nutrients at critical physiological phases would have supported for better assimilation of photosynthates towards grain. Increase in grain yield can also be attributed to favourable effect in accelerating the growth and yield parameters [44]. The marked increase in grain yield by the application of fertilizer N in four splits plus green manure might be due to the role played by green manures in dissolving the native and added nutrients and charging the soil solution with adequate essential elements by the production of various organic acids during the decomposition [27]. The enrichment of soil fertility through green manure addition into the soil [17] and improved soil physical condition might have promoted the yield attributes contributing to the increased grain yield [48]. The slow and steady release of nutrients from green manures have helped the rice plant to meet the nutrient requirement at all the stages and thereby favourably influenced the various yield parameters and ultimately resulted in higher yield [10].

The response of hybrid to N application based on STCR (N_7) was in the higher magnitude as evident from significant variation in straw yield from the various treatments but was on par with the application of fertilizer N in four split plus green manure @ 6.25 t ha^{-1} (N_3). Application of higher dose of N in STCR based N application promoted higher biomass and this resulted in significant enhancement in straw yield. It might be due to higher number of tillers and enhanced N uptake at all growth stages of crop [38]. The highest straw yield in CoRH1 was recorded with N application based on STCR methods [6]. The demonstrated effect of green manure as well as N on grain yield has been repeated once again with straw production. It is a known fact that the grain yield is a function of straw yield as adequate straw production is obligatory for effective photosynthesis and steady transport of nutrients and metabolites required for grain production.

Interaction between crop establishment and N management: In the preceding discussion, the effects of two production variables on the growth of hybrid rice have been discussed individually. Each one of them viz., establishment method and N management practices exerted a significant influence on the growth and yield of both the seasons. The interaction effect of these production factors was also significant in respect of most of growth parameters, important yield attributes and yield of grain and straw from the hybrids. The interaction effect was found to be additive. Thus the combination of the best level of each of the two variables invariably resulted in better growth and higher yield. The benefits of the larger plant density with seeding through all the holes with higher seed rate were complemented by increased nutrient contribution from N application based on STCR and the application of N in four splits along with green manure. The highest grain yield of 8150 and 7905 kg ha^{-1} was recorded when the seeding through all the holes using the drum seeder combined with N application based on STCR (M_2N_7) which was comparable with M_2N_3, M_1N_7, M_1N_3 and M_2N_3. The nutrient requirement for this stand establishment was adequately met by the N application based on STCR approaches and the green manure incorporation plus N application in four split.

The present study concludes that wet seeding of hybrid rice could be accomplished as a economically viable technology by the use of eight row drum seeder with some modifications in the seed holes of the seeder. The rice hybrid CoRH2 has the potential to yield 7905 to 8150 kg ha^{-1} under wet-seeded condition during *Rabi* season. Seeding through one out of two holes using eight row seeder with a optimum seed rate of 29 kg ha^{-1} in combination with N application based on Soil Test Crop Response (STCR) (M_2N_7) approach resulted in highest grain yield of 8150 kg ha^{-1} with a maximum of + 1.87 per cent deviation of targeted yield under Tamil Nadu condition. Green manure @ 6.25 t ha^{-1} plus N application @ 150 kg ha^{-1} application registered yield comparable with STCR based N application confirms the philosophy with which this N management approach was developed.

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