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Estimation of Carbon Footprint in Direct Seeded Rice (*Oryza sativa*) under Rainfed Medium Land Situation

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ABSTRACT

An experiment was conducted for two consecutive years, 2018 and 2019 during the *kharif* season on direct seeded rice in the experimental farm of the Central Agricultural University, Imphal. The experimental site is located under the eastern Himalayan region (II). The study was conducted to investigate into the carbon footprint of direct seeded rice under rain fed medium land situation. The study was based on factorial randomized block design (FRBD) comprising of two factors, sowing techniques and seed rate. Broadcasting and line sowing were the levels under sowing techniques and seed rate has five levels including 80 kg ha^{-1}, 90 kg ha^{-1}, 100 kg ha^{-1}, 110 kg ha^{-1} and 120 kg ha^{-1}, respectively. The total estimated greenhouse gas emission in line sowing method (11.02% was at par with broadcasting method (11.06%) with 120 kg ha^{-1} of seed rate followed in both the methods. Line sowing with 100 kg ha^{-1} resulted in highest carbon output. Further, line sowing with 80 kg ha^{-1} was superior in terms of parameters like carbon efficiency, carbon sustainability index and carbon efficiency ratio.

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INTRODUCTION

Rice (*Oryza sativa* L.) acts as a staple food crop for more than half of world's population. Nearly 12% of the world's arable land is under rice cultivation (FAO, 2020). Various agricultural operations during rice cultivation has been a major contributor to the greenhouse gas emission in the form of carbon dioxide (CO_2) from fossil fuels, release of methane gas (CH_4) due to submergence in traditional tilled-transplanted rice system, cattle rearing and nitrous oxide (N_2O) from inorganic and organic fertilizer and manure management practices (Pandey and Agrawal, 2014; Tjandra *et al*., 2016; Ashoka *et al*., 2017; Yadav *et al*., 2018). The conventional tilled-transplanted rice production system has been seen to adversely affect the environment and reducing the profitability of rice cultivation. Agriculture alone accounts for 8.8 to 10.2% of total greenhouse gas emission. Globally, rice production systems have purportedly released around 523 million tonnes CO_2-equivalent of greenhouse gas year^{-1}. Rice is cultivated on 43 million ha in India and studies reported an emission of 96.2 million tonnes of CO_2-equivalent year^{-1}, which was 18.4% to the global greenhouse gas emission from rice fields as per 2016-2017 reports (FAO, 2017). The bed planting method (BP), direct-seeded rice (DSR), zero tillage (ZT) are the other alternatives to traditional tilled-transplanted system of rice which escapes the operations like tillage, puddling, transplanting; hence, would reduce the emission from the inputs required for crop production (Wassmann *et al*., 2004; Pathak *et al*., 2011). In India, the direct seeded rice is mostly grown in uplands which cover roughly 4.95 million ha (12%) of total rice area (FAO, 2017).

Till today, majority of the analysis regarding the emission of greenhouse gases from direct-seeded rice has been analyzed by Pathak and Wassmann (2007), Ahmad *et al*. (2009), Pathak (2015), Chaudhary *et al*. (2017) and Yadav *et al*. (2017). Keeping this in view, a field based study has been performed to estimate the carbon footprint in direct-seeded rice cultivation in the rainfed area of Imphal, Manipur.

MATERIALS AND METHODS

Characterization of Experimental Site

The study area comes under the eastern Himalayan region (II) and the sub-tropical zone (NEH-4) of Manipur. In the experimental farm of Central Agricultural University, Imphal, a study was conducted for two consecutive years during the *kharif* season of 2018 and 2019. The field coordinates was 24.45° N and 93.56° E and elevation of 790 m above mean sea level. The land was moderately leveled with clay textured soil. The pH value of 5.5 of the initial soil analyses documented that the soil was slightly acidic with high organic carbon content of 1.15%. The N availability of the soil was medium (322 kg ha^{-1}), the available P_2O_5 and available K_2O in the soil was also medium (17.59 kg ha^{-1} and 287.17 kg ha^{-1}, respectively). The mean temperature during both the years of experiment has recorded a maximum of 27.63 °C and minimum of 18.85 °C. The average annual rainfall of the site was 1730 mm.

Experimental Details

The experiment were laid under factorial randomized block design (FRBD) with two factors: planting methods with two levels- line sowing and broadcasting and another factor was seed rate with five levels, 80 kg ha^{-1}, 90 kg ha^{-1}, 100 kg ha^{-1}, 110 kg ha^{-1}, 120 kg ha^{-1}. The experiment consisted of 10 treatments replicated thrice. Each treatment has 3 m × 4 m plot size.

The treatment were paired as: S_1R_1 = Broadcasting + seed rate (80 kg ha^{-1}), S_1R_2 = Broadcasting + seed rate (90 kg ha^{-1}), S_1R_3 = Broadcasting + seed rate (100 kg ha^{-1}), S_1R_4 = Broadcasting + seed rate (110 kg ha^{-1}), S_1R_5 = Broadcasting + seed rate (120 kg ha^{-1}), S_2R_1 = Line sowing + seed rate (80 kg ha^{-1}), S_2R_2 = Line sowing + seed rate (90 kg ha^{-1}), S_2R_3 = Line sowing + seed rate (100 kg ha^{-1}), S_2R_4 = Line sowing + seed rate (110 kg ha^{-1}), S_2R_5 = Line sowing + seed rate (120 kg ha^{-1}).

The paddy variety Tamphaphou (CAU R1) having duration of 135-140 days was used in this experiment because of its consumable quality. The field was ploughed thoroughly once by tractor followed by power tiller. It was then leveled and formed to have a submergence condition for rice paddy cultivation. The treatments were arranged according to the design. Nitrogen in the form of urea, phosphorus in the form of single super phosphate and potassium in the form of muriate of potash at the rate of 60, 40, 30 kg ha^{-1}, respectively were applied in each treatment in split doses. Nitrogen was applied in three split doses, 50% of the nitrogen was applied as basal and the other 50% was splitted into two equal halves, one at active tillering stage (35 DAS) and the other at flower initiation stage (65 DAS). The entire recommended dose of phosphorus and potash was applied as basal. The pre-sprouted seeds were broadcasted or line sowed as per the proposed seed rate on second fortnight of June during both the years of experiment.

Carbon Footprint Estimation

The environmental impact of direct seeded rice cultivation was estimated by greenhouse gases emission. In this study, spatial and yield-scaled carbon footprint of direct seeded rice cultivation from field up to the farm gate was studied. The sum total of major greenhouse gases like CH_4, N_2O and CO_2 emitted throughout the production of a crop when expressed in terms of CO_2 equivalents is known as spatial carbon footprint (Pratibha *et al.*, 2016). The corresponding emission coefficients have been presented in table 1 (Deng, 1982; Dyer and Desjardins, 2003; Lal, 2004; Tabatabaie *et al.*, 2012; Gathorne-Hardy, 2016; Vetter *et al.*, 2017).

These emissions were calculated as per the standard emission coefficients prescribed by IPCC, 2017; where CO_2, CH_4 and N_2O were converted into equivalence of CO_2 by using the factors of 1, 25 and 298 on volume basis for CO_2, CH_4 and N_2O respectively.

Table 1: List of carbon dioxide equivalence factors used in direct seeded rice cultivation

Item	Units	Kg CO_2-e ha^{-1}	References
Land Preparation			
Human labor	day	0.86	Deng (1982)
Fuel-diesel	kg	2.68	Deng (1982)
Cultivator	hour	3.70	Dyer and Desjardins (2003)
Disk plough	hour	5.90	Dyer and Desjardins (2003)
Tractor	hour	12.27	Gathorne-Hardy (2016)
Power Tiller	hour	12.27	Gathorne-Hardy (2016)
Chemical Fertilizer			
Nitrogen	kg	1.30	Tabatabaie *et al.* (2012)
Phosphorus	kg	0.20	Tabatabaie *et al.* (2012)
Potassium	kg	0.20	Tabatabaie *et al.* (2012)
Plant Protection Chemicals			
Fungicide	litre	3.90	Lal (2004)
Herbicide	litre	6.30	Lal (2004)
Insecticide	litre	5.10	Lal (2004)
Chemical spray	litre	0.70	Lal (2004)
Seeds			
Rice grain	kg	5.65	Vetter *et al.* (2017)

The emission of CH_4 gas from partially submerged paddy field and emissions of N_2O gas from urea fertilizer was represented after some modifications.

Emission of CH_4 = EF × SF × A × D × 10^{-6} (Tubiello *et al.*, 2014) ………… (1)

Where,

EF = Combined methane emission factor emitted per season, 10 g $m^{-2}year^{-1}$ for India (Conrad *et al.*, 1996; Parashar *et al.*, 1996).

SF = 0.8 for without organic amendment and flood prone rainfed condition (IPCC, 1996).

A = Rice paddy area harvested (ha $year^{-1}$).

D = Duration of cultivation (in days).

N_2O emissions = N × EF_1 × 44/28 ………… (2)

Where,

N_2O emissions = N_2O emissions from synthetic nitrogen manure, crop residue additions to the managed soils (kg N_2O $year^{-1}$).

N = Consumption of nitrogen through fertilizers, manure, crop residue, *etc.*, (kg N input $year^{-1}$).

EF_1 = Emission factor 0.01 for N_2O emissions from N inputs (kg N_2O-N kg^{-1} N input).

GWP = (emission of CO_2 × 1 + emission of CH_4 × 25 + emission of N_2O × 298) ………… (3)

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Where,

GWP = Global warming potential (kg CO_2-e ha^{-1}).

The summation of the global warming potential values from all the stages gives us an idea of the spatial carbon footprint and yield scaled carbon footprint.

Spatial carbon footprint (GWP_s) was calculated as,

$$GWP_s = \sum_{i=0}^{n} GWP \quad \text{............ (4)}$$

Where,

n = Number of components that contributed in the values of global warming potential.

i = The index assumes values starting with the value on the right hand side of the equation and ending with the value above the summation sign (n).

Yield scaled carbon footprint (GWP_Y) = Spatial carbon footprint Grain yield .... (5)

Estimation of the yield-scaled global warming potential (GWP_Y) or greenhouse gas intensity helps to measure and identify the efficiency of any production systems by linking grain yield with global warming potential of the system.

Measures of Carbon Input and Output, Carbon Efficiency, Carbon Sustainability Index and Carbon Efficiency Ratio

The carbon (C) input was estimated as the total carbon emission or the spatial carbon footprint multiplied by the factor 12/44 as suggested by Chaudhary *et al*. (2017). The carbon equivalent of different plant parts like grain, straw plus root biomass of the rice crop when summed together gives the carbon output. The total carbon present in the whole crop was measured by multiplying the harvest with 40% carbon (assuming that it is present in the plant biomass).

Carbon efficiency and their related parameters used in the experiment were given by Lal (2004) and Chaudhary *et al*. (2017) as follows:

Carbon input = Total carbon emission (kg CO_2-e) from all inputs × 12/44 .... (6)

Carbon output = (Grain yield × carbon equivalent) + (Straw yield × carbon equivalent) .... (7)

Carbon efficiency (CE) = Carbon output Carbon input .... (8)

Carbon sustainability index (CSI) **= (**Carbon output - Carbon input) C input .... (9)

Carbon efficiency ratio (CER) = Grain yield in terms of carbon equivalent Total carbon input .... (10)

Statistical Analysis

For testing the significance of the overall differences among the treatments, analysis of variance (ANOVA) was applied wherever appropriate. According to Gomez and Gomez (1984) to test the significance of the difference between the two treatment means, the critical difference value at P = 0.05 was computed when 'F' value was found significant.

RESULTS AND DISCUSSION

Carbon Footprint in Direct Seeded Rice Production

The cultivation operations in direct seeded rice with different levels of seed rate under broadcasting and line sowing techniques contributed significantly to the greenhouse gases emissions (represented in Table 2). Sowing of seed at 120 kg ha^{-1} under line sowing technique has resulted in maximum CO_2 emission closely followed by broadcasting of same seed rate. The nitrous oxide and methane emission levels were the same for all the treatment combinations. It was seen in the study that varied seed rate has no significant effect on this two greenhouse gases emission. This was due to same rate of chemical fertilizers applied to all the treatments and drainage facility at frequent interval during different growth stages of rice. The level of nitrous oxide emissions was more compared to methane emission. This was due to methane gas being produced by obligate anaerobic bacteria under continuously submerged rice field, the direct seeded rice being sown in well puddled wet-bed under intermittently flooded condition, methane production was low. This study corroborates with Khalil *et al*. (2004) and Wang *et al*. (2017).

Table 2: Greenhouse gases emission as influenced by varied sowing techniques and seed rates in our study of direct seeded rice cultivation (mean data of two experimental years)

Treatment		(CO_2-e kg ha^{-1})						
ST	SR	Labor	Diesel	Machinery	Fertilizer	Pesticide	Pesticide spray	Seeds
BC	80	102	56	75	92	10	1.72	452
	90	108	56	75	92	10	1.72	509
	100	119	56	75	92	10	1.72	565
	110	124	56	75	92	10	1.72	622
	120	130	56	75	92	10	1.72	678
LS	80	108	56	75	92	10	1.72	452
	90	113	56	75	92	10	1.72	509
	100	124	56	75	92	10	1.72	565
	110	130	56	75	92	10	1.72	622
	120	135	56	75	92	10	1.72	678
Total		-	-	-	-	-	-	-

Table 2 Continues …

Treatment		(CO_2-e kg ha^{-1})			Total GHG emission or CF_s (CO_2-e kg ha^{-1})	CF_y (CO_2-e kg kg^{-1})
ST	SR	Total CO_2 emission	Total N_2O emission	Total CH_4 emission		
BC	80	790	283	9.72	1083	0.21
	90	852	283	9.72	1145	0.20
	100	919	283	9.72	1212	0.21
	110	982	283	9.72	1274	0.23
	120	1044	283	9.72	1336	0.26
LS	80	795	283	9.72	1088	0.20
	90	857	283	9.72	1150	0.20
	100	925	283	9.72	1218	0.20
	110	987	283	9.72	1280	0.22
	120	1049	283	9.72	1342	0.25
Total		9200	2830	97.20	12128	2.19

[* ST = Sowing Techniques, SR = Seed rate, BC = Broadcasting, LS = Line sowing, Pesticide = Fungicide + Herbicide + Fungicide, CFs = Spatial carbon footprint, CFy = Yield scaled carbon footprint]

However, this alternate drying and wetting of soils leads to larger microbial activity thus enhancing nitrous oxide gas emission (Harrison-Kirk *et al*., 2013). The treatment with 120 kg ha^{-1} in line sowing followed by broadcasting with the same seed rate exhibited 11.02% and 11.06% of total greenhouse gas emission or spatial carbon footprint respectively, which was the highest among all the treatments. This variation in emission was because of more human labor required in line sowing and higher quantity of seeds sowed than the optimum through line sowing than in broadcasting. The carbon foot print study indicated that the CO_2-e emissions from seeds contributed the maximum followed by human labor and thirdly by fertilizers more specifically in line sowing method than broadcasting method. The highest carbon footprint in respect of yield (CF_y) was found in broadcasting method with 120 kg ha^{-1} (0.26 kg CO_2-eq kg^{-1} rice) which also followed the same trend as of carbon footprint in respect of space (CF_s). This indicates less efficient rice production system with higher CF_y. But then again it was much lesser than the annual average of 5.65 kg CO_2-e kg^{-1} rice in Indian agriculture (Vetter *et al*., 2017). From the experiment, 9200 kg ha^{-1} (~ 75%) of total carbon dioxide gas, 2830 CO_2-e kg ha^{-1} (~ 24%) of nitrous oxide gas and 97.20 CO_2-e kg ha^{-1} (0.81%) of methane was released (Table 2).

From the average data of two years, the carbon input and carbon output gave varied result with different seed rate and sowing techniques (data presented in Table 3).

Table 3: Evaluation of carbon parameters in direct seeded rice cultivation due to varied sowing techniques and seed rate (mean data of two experimental years)

Treatments		Carbon input (kg ha^{-1})	Carbon output (kg ha^{-1})	Carbon efficiency	Carbon sustainability index	Carbon efficiency ratio (CER)
Sowing Techniques	Seed rate (kg ha^{-1})					
Broadcasting	80	295	5870	20	18.88	7.06
	90	312	6094	20	18.52	7.23
	100	331	6176	19	17.68	6.90
	110	348	6028	17	16.35	6.26
	120	364	5932	16	15.28	5.67
Line sowing	80	297	6084	21	19.50	7.52
	90	314	6162	20	18.65	7.28
	100	332	6382	19	18.22	7.26
	110	349	6223	18	16.83	6.53
	120	366	6118	17	15.72	5.91

Among all the treatments, the carbon input was lowest in broadcasting technique compared to line sowing technique. The treatment in broadcasting method with 80 kg ha^{-1} recorded the lowest carbon input of 295 kg ha^{-1} while line sowing method with 100 kg ha^{-1} was highest in terms of carbon output (6382 kg ha^{-1}). This may be due to higher human labor involvement in line sowing technique for the field operations such as sowing, harvesting and threshing. The treatment in line sowing method with 80 kg ha^{-1} was superior in terms of carbon efficiency and carbon sustainability index. This higher carbon efficiency and carbon sustainability index in line sowing method was owing to the optimum carbon output (grain yield) although with lesser carbon input as any cropping system becomes sustainable with increased efficiency of the inputs. Similar findings were reported by Lal (2004), Chaudhary *et al*. (2017) and Yadav *et al*. (2018). Thus, it can be concluded from the study that line sowing technique with 100 kg ha^{-1} seed rate in direct seeded rice field could be a significant way to cut global warming potential of the conventional rice cultivation system.

CONCLUSION

Based on the findings from this two-year study on the carbon footprint of direct-seeded rice under rain-fed medium land conditions, it can be concluded that the line sowing technique, particularly at a seed rate of 100 kg ha^{-1}, offers a substantial reduction in greenhouse gas emissions compared to traditional broadcasting methods. The line sowing method demonstrated superior performance in terms of carbon efficiency, carbon sustainability index and carbon efficiency ratio, highlighting its potential as a sustainable agricultural practice. While both broadcasting and line sowing at a seed rate of 120 kg ha^{-1} resulted in the highest greenhouse gas emissions, the overall carbon output was significantly higher with line sowing. The findings emphasize the importance of optimizing seed rates and sowing techniques to enhance the sustainability

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of rice production. Future research should focus on refining these practices to further mitigate the environmental impact and enhance the efficiency of rice cultivation systems. This study provides a crucial step towards developing sustainable agricultural practices that can contribute to global efforts in reducing the carbon footprint of crop production.

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Conflict of Interest

The authors declare no conflict of interest.

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