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# Water use, energy use efficiency and carbon footprint of transplanted rice (*Oryza sativa*) in response to surface drainage

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## ABSTRACT

A field study was undertaken to determine the productivity, water use, energy efficiency, and carbon footprint under enforced surface drainage for 15 days at various growth stages of rice (*Oryza sativa* L.) during *kharif* 2011 and 2012. The continuous submergence improved the rice grain yield (3.41 t/ha) and straw yield (4.68 tonnes/ha) over the continuous drainage. The water-use was higher with continuous submergence (15350 $m^3$) followed by alternate wetting and drying, whereas, the lowest water was used with continuous drainage (5400 $m^3$). The continuous submergence consumed the highest total input energy ($84.97 \times 10^3$ MJ/ha) and produced 1.23 fold higher output energy, 452.6 of human energy profitability and 0.04 kg/MJ of energy productivity than the continuous drainage. Alternate wetting and drying was the most energy efficient which produced the highest energy ratio (1.53) and energy productivity (0.53). However, the lowest energy intensiveness was noticed with continuous drainage. Similarly, alternate wetting and drying followed by continuous drainage had the lowest carbon footprint and carbon dioxide emission. Thus, submergence of 5–7 cm may be followed as per the availability of water, while, submergence may be avoided for 15 days at tillering under limited water to obtain optimum yield with better energy efficiency.

**Key words:** Carbon footprint, Energy efficiency, Rice productivity, Surface drainage, Water use

In the last few decades, the levels of green house gasses, viz. carbon dioxide ($CO_2$), nitrous oxide ($N_2O$) and methane ($CH_4$) in the atmosphere have increased immensely. Consequently, the precipitation pattern and temperature altered (Khanal 2009). Change in precipitation pattern has alarmed the uncertainty of water availability in agriculture, which uses 70–80% of the total utility in arid and semi arid areas. The precipitation pattern has deviated more than the others weather parameters, and it is well documented that there are not much changes in total rainfall but the number of rainy days has reduced (de Witt *et al.* 2007). In the recent past, occurrence of drought and floods has increased, whereas the available runoff for storing in ponds and tanks has decreased significantly in India (Kulkarni 2003). Among various abiotic constraints, limitation of water or drought is one the most important in rice. About 23 million ha of rice area in South and Southeast Asia is affected by drought (Chauhan and Abugho 2013). It is experienced that the drought prone area is gradually increasing in India. Under this situation, continuous submergence is least energy efficient and also increases the carbon footprint (Singh and Ahlawat 2015).

It was visualized that, in modern farming, the use of commercial energy increased sharply. In the Eastern Himalayan region, efficient use of energy resources is vital in terms of increasing production, productivity, competitiveness of agriculture, as well as sustainability of rice (*Oryza sativa* L.) production system. Energy auditing is one of the most common approaches to examine energy use efficiency and environmental impact of a production system. Agriculture is an important sector using energy and supplying energy in various forms (Lal 2013), enhancing food security (Karimi *et al.* 2008) and contributing to development of rural economy. The contribution of component energy on production system has been reported, however, under limited water or prolonged dry spell conditions, water may be the important component in production system. Therefore, water may be precisely utilized and efficient utilization of available energy is a prerequisite that needs to be tested with various energy indices, viz. energy ratio, human energy profitability and energy intensiveness. Changeover of traditional to modern agricultural practices leads to combustion of fossil fuel and use of alternate energy sources leading to emission of $CO_2$ into the atmosphere. Thus, an understanding of the emission expressed in kilogram of carbon equivalent [kg $CO_2$ eq. (CE)/ha] is required for various inputs and management options. The data on energy budgeting and carbon emission under limited water availability was

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lacking. Therefore, the study was aimed to know the effect of applying surface drainage for 15 days at various growth stages of rice on productivity, water-use, energy parameters, and carbon foot-print.

## MATERIALS AND METHODS

The field study was conducted in clay loam soil at the Research Farm of ICAR Research Complex for NEH Region, Basar, Arunachal Pradesh, India (27° 95'N latitude and 94° 76'E longitude, 664 m above MSL) during rainy seasons (May–October) of 2011 and 2012. Soil of the experimental field was acidic in reaction (pH 5.3), contained 13.2 g/kg of organic carbon, 96.9 mg/kg of available nitrogen, 5.2 mg/kg of available phosphorus and 105.3 mg/kg of available potassium. Plough soil layer (0–15 cm) had bulk density 1.32 g/cm$^3$, particle density 2.44 g/cm$^3$ and 42.9% porosity. The study site was under humid sub–tropical type of climate. The mean minimum and maximum daily temperatures, and seasonal rainfall ranged from 17.3–22.7°C, 24.9–30.4°C, and 1433.8 and 2440.4 mm, respectively during cropping seasons of 2011 and 2012.

An experiment was laid–out in a randomized complete block design and replicated thrice. Rice variety used in the study was RCM-11 which had a medium stature and matures in 135 days. The treatments included surface drainage (SD) for 15 days, viz. SD at tillering, SD at panicle initiation, SD at booting, SD at flowering, SD at milking; 15 days alternate wetting and drying, continuous drainage (opened drainage gate throughout the season; no impounding of water in the season), and continuous submergence. Maximum care was taken that during SD water did not accumulate in the plots. Outlets were opened during imposition of SD and rests were closed as per treatment requirements. The water level was maintained in individual plots by providing irrigation from the nearest water sources and bunds were lined with polythene sheets of 60 µm gauge to avoid seepage loss. Remaining management practices were done as per recommendation for the area. Plot size was 4 m × 5 m. Submergence plots were puddled and kept continuously submerged from transplanting to till two weeks before harvest.

Twenty one days old seedlings were transplanted at a spacing of 20 cm × 10 cm with two seedlings per hill. Water layer of 7 cm was maintained for continuous submergence, whereas remaining treatments had water levels as per treatment details. Surface water was drained two weeks prior to harvest for all the treatments. The crop was supplied with 80 kg N in the form of urea (46% N) that was applied in three equal splits, i.e. 1/3 as basal, 1/3 at tillering, and remaining 1/3 at panicle initiation stage. Entire dose of phosphorus [60 kg $P_2O_5$/ha as single super phosphate (16% P)] and potassium [40 kg $K_2O$/ha as muriate of potash (60% K)] were applied before transplanting. To avoid any pest incidence, crops were uniformly sprayed with fungicide (Hexaconazole 5% EC at 500 g/ha) and insecticide (one spray, Buprofezin 25% SC at 500 ml/ha).

Rice crop was harvested from net plot area of 5.0 m$^2$ at physiological maturity stage from each plot and grain yield was adjusted to a moisture content of 14%. Similarly, straw yield was recorded from the same area of each plot. The water parameters such as effective rainfall, contribution from soil profile were measured as per the formula suggested and modified by Patel *et al*. (2008).

The equation for determining effective rainfall is given below:

Surface run-off of close gate plots (m$^3$) = [(Volume of water in the plot + total rainfall) - levee height (7 cm)]

Effective rainfall (m$^3$) = Total rainfall - surface runoff

Contribution from soil profile (45 cm depth; m$^3$) = Soil water content at transplanting - soil water content at harvest

Total water use (m$^3$) = (Effective rainfall + irrigation + contribution from soil profile).

Deep percolation was not considered during the study. Energy analyses and carbon footprint were taken into account considering all the forms of energy and carbon balance (input and output) during the cultivation process, and established energy relationship for understanding the energy conversion process. Water requirement was estimated separately as per actual volume of water required for individual treatments and on the basis energy input in MJ/ha was estimated. The formulae used in the study to calculate energy analysis are shown in Table 1.

Analysis of variance (ANOVA) was carried out to test for differences between the treatments using a statistical computer package SAS version 9.2 (SAS Institute Inc., Carry NC, USA). The significant difference between treatment means were compared with the standard error of means (SEm±) and least significant differences (LSD) at a 5% level of probability (P<0.05).

## RESULTS AND DISCUSSION

### *Grain and straw yield*

The results indicated that rice grain and straw yields and harvest index were influenced significantly by imposition of surface drainage (Table 2). The highest rice grain and straw yields was recorded under continuous submergence

Table 1 Calculations of various energy indices and carbon footprint

| Particular | Calculations |
|---|---|
| Energy ratio (ER) | Output energy (MJ/ha)/Input energy (MJ/ha) |
| Energy profitability (EP) | Net energy return (MJ/ha)/Input energy (MJ/ha) |
| Human energy profitability (HEP) | Output energy (MJ/ha)/Labour energy (MJ/ha) |
| Energy productivity (EPr) | Economic yield (kg/ha)/Energy input (MJ/ha) |
| Energy intensiveness (EI) | Energy input (MJ/ha)/ Cost of cultivation (₹/ha) |
| Carbon footprint | Total carbon emission or input (kg CE/ha)/Economic yield (kg/ha) |

Table 2 Rice yield and water parameters of rice as influenced by surface drainage (two years pooled data)

| Treatment | Grain yield (tonnes/ ha) | Straw yield (tonnes/ ha) | Harvest index | Rainfall ($m^3$) | Effective rainfall ($m^3$) | Irrigation ($m^3$) | Surface runoff ($m^3$) | Contribution from soil profile ($m^3$) | Total water use ($m^3$) |
|---|---|---|---|---|---|---|---|---|---|
| Continuous drainage | 1.22 | 2.45 | 0.33 | 18300 | 4800 | 0 | 13500 | 600 | 5400 |
| Surface drainage at tillering | 3.08 | 4.38 | 0.41 | 18300 | 8220 | 1500 | 10080 | 230 | 9950 |
| Surface drainage at panicle initiation | 2.60 | 3.80 | 0.41 | 18300 | 8220 | 1500 | 10080 | 250 | 9970 |
| Surface drainage at booting | 2.44 | 4.31 | 0.36 | 18300 | 7800 | 1500 | 10500 | 230 | 9530 |
| Surface drainage at flowering | 2.34 | 4.29 | 0.35 | 18300 | 7800 | 1500 | 10500 | 240 | 9540 |
| Surface drainage at milking | 2.33 | 4.28 | 0.35 | 18300 | 7800 | 1500 | 10500 | 220 | 9520 |
| Alternate wetting and drying | 1.55 | 2.95 | 0.34 | 18300 | 6200 | 5800 | 12100 | 460 | 12460 |
| Continuous submergence | 3.41 | 4.68 | 0.42 | 18300 | 12100 | 3200 | 6200 | 50 | 15350 |
| SEm± | 0.10 | 0.10 | 0.015 | | | | | | 442.5 |
| LSD (P=0.05) | 0.29 | 0.29 | 0.04 | | | | | | 1305.7 |

(3.41 and 4.68 tonnes/ha, respectively). This was due to the better availability of water, which suppressed the weeds and provided the congenial conditions for growth and development of crop (Table 2). Continuous drainage recorded rice grain and straw yields of 1.22 and 2.45 tonnes/ha, respectively. The lower yields in continuous drainage resulted from moisture stress, which restricted the supply of assimilates (source limitation) led to inferior growth and yield attributes. Similar findings were also reported by other researches (Bouman *et al.* 2005, Peng *et al.* 2006, Dass *et al.* 2012). Alternate wetting and drying registered 1.19 times reduction of grain yield over continuous submergence. Surface drainage at tillering had the lowest influence on rice grain yield and the yield reduction by 10.5% only. It was noticed that overall imposition of surface drainage had negative impact on rice grain yield, with the progress of rice growth stages, grain yield reduction up to 30.9% at panicle initiation, 39.8% at booting, 45.6% at flowering and 46.0% at milking over the continuous submergence. The highest straw yield reduction (90.9%) was observed in continuous drainage followed by alternate wetting and drying (58.8%) over the continuous submergence. Similar finding was also reported earlier (Pirdashti *et al.* 2004). The highest harvest index was noticed with the continuous submergence, which was statistically comparable to surface drainage at tillering and panicle initiation. However, the lowest harvest index was noticed with continuous drainage (Table 2).

### *Water parameters*

Total water use largely depended on rainfall received during growing season and water drained at particular growth stages, however, it was significantly ($P<0.05$) influenced by surface drainage at various growth and development stages of rice (Table 2). The average seasonal rainfall during the study was 18300 $m^3$, but effective rainfall varied as per the distribution of rainfall during the imposition of SD and the lowest effective rainfall was obtained with continuous drainage followed by alternate wetting and drying. In contrast to these, irrigation requirement was the highest with alternate wetting and drying followed by continuous flooding, whereas, higher surface runoff noticed with continuous drainage followed by alternate wetting and drying. This was due to formation of soil cracks percolated the more water, thus required more water to reach the optimum depth. The contribution of water from soil profile was highest with continuous drainage followed by alternate wetting and drying. The highest quantum of water was used under continuous flooding (15350 $m^3$) followed by alternate wetting and drying (12460 $m^3$). It was noticed that surface drainage at various growth and developmental stages of rice reduced the water use by 18.8–64.8%. However, the lowest water was used with continuous drainage (5400 $m^3$). During the rice growing period, the total water use ranged from 5400–15350 $m^3$. Continuous flooding utilized 64.8% excessive water than the continuous drainage and 18.8% more over alternate wetting and drying. Under water deficit conditions, water was judiciously utilized for growth and development than submerged conditions. This was mainly resulted in higher rate of reduction in transpiration than photosynthetic assimilation of carbohydrates (Centritto *et al.* 2009).

### *Energy requirement and output*

Imposition of surface drainage at various growth stages influenced significantly the input and output of energy (Tables 3-5). The total energy requirement was significantly higher with continuous submergence ($85 \times 10^3$ MJ/ha), whereas the lowest input energy was obtained in continuous drainage ($35 \times 10^3$ MJ/ha). Water consumed the highest share of energy and it ranged from 40.9–66.2%, although the largest volume was met out by the rain (Table 3). Fertilizers viz. N, $P_2O_5$ and $K_2O$ were the second largest

Table 3 Component energy inputs (MJ/ha) for raising rice during study period (two years pooled data)

| Treatment | Diesel | Machinery | Seeds | Nitrogen | $P_2O_5$ | $K_2O$ | Water | Pesticides | Labour |
|---|---|---|---|---|---|---|---|---|---|
| Continuous drainage | 1014 (7.5) | 251 (1.9) | 588 (3.5) | 4848 (36.0) | 666 (4.9) | 268 (2.0) | 5508 (40.9) | 120 (0.9) | 220 (1.6) |
| Surface drainage at tillering | 1014 (5.6) | 251 (1.4) | 588 (3.2) | 4848 (26.7) | 666 (3.7) | 268 (1.5) | 10149 (55.9) | 120 (0.7) | 236 (1.3) |
| Surface drainage at panicle initiation | 1014 (5.6) | 251 (1.4) | 588 (3.2) | 4848 (26.7) | 666 (3.7) | 268 (1.5) | 10169 (56.0) | 120 (0.7) | 236 (1.3) |
| Surface drainage at booting | 1014 (5.7) | 251 (1.4) | 588 (3.3) | 4848 (27.4) | 666 (3.8) | 268 (1.5) | 9721 (54.9) | 120 (0.7) | 236 (1.3) |
| Surface drainage at flowering | 1014 (5.7) | 251 (1.4) | 588 (3.3) | 4848 (27.4) | 666 (3.8) | 268 (1.5) | 9731 (54.9) | 120 (0.7) | 236 (1.3) |
| Surface drainage at milking | 1014 (5.7) | 251 (1.4) | 588 (3.3) | 4848 (27.4) | 666 (3.8) | 268 (1.5) | 9710 (54.9) | 120 (0.7) | 236 (1.3) |
| Alternate wetting and drying | 1014 (4.9) | 251 (1.2) | 588 (2.8) | 4848 (23.4) | 666 (3.2) | 268 (1.3) | 12709 (61.4) | 120 (0.6) | 250 (1.2) |
| Continuous submergence | 1014 (4.3) | 251 (1.1) | 588 (2.5) | 4848 (20.5) | 666 (2.8) | 268 (1.1) | 15657 (66.2) | 120 (0.5) | 240 (1.0) |

Figures in the parenthesis are % contribution

Table 4 Component energy inputs (MJ/ha) used by rice during study period with various treatments (two years pooled data)

| Particular | Continuous drainage | SD at tillering | SD at panicle initiation | SD at booting | SD at flowering | SD at milking | Alternate wetting and drying | Continuous submergence |
|---|---|---|---|---|---|---|---|---|
| *Non-renewable energy* | | | | | | | | |
| Diesel (C) | 1014 (7.5) | 1014 (5.6) | 1014 (5.6) | 1014 (5.7) | 1014 (5.7) | 1014 (5.7) | 1014 (4.9) | 1014 (4.3) |
| Machinery (C) | 251 (1.9) | 251 (1.4) | 251 (1.4) | 251 (1.4) | 251 (1.4) | 251 (1.4) | 251 (1.2) | 251 (1.1) |
| Fertilizer (C) | 5782 (42.9) | 5782 (31.9) | 5782 (31.8) | 5782 (32.6) | 5782 (31.6) | 5782 (32.7) | 5782 (27.9) | 5782 (24.5) |
| Pesticide (C) | 120 (0.9) | 120 (0.7) | 120 (0.7) | 120 (0.7) | 120 (0.7) | 120 (0.7) | 120 (0.6) | 120 (0.5) |
| *Renewable energy* | | | | | | | | |
| Seed (C) | 588 (4.4) | 588 (3.2) | 588 (3.2) | 588 (3.3) | 588 (3.3) | 588 (3.3) | 588 (2.8) | 588 (2.5) |
| Water (NC) | 8996 (40.9) | 10149 (56.0) | 10169 (56.0) | 9721 (54.9) | 9731 (54.9) | 9710 (54.9) | 9445 (61.4) | 11699 (66.2) |
| Labour (NC) | 220 (1.6) | 236 (1.3) | 236 (1.3) | 236 (1.3) | 236 (1.3) | 236 (1.3) | 250 (1.2) | 240 (1.0) |

C: Commercial energy input; NC: Non-commercial energy input; SD: Surface drainage; Figures in parenthesis are percentage of total contribution of energy input.

Table 5 Energy input-output relationship of rice as influenced by surface drainage (two years pooled data)

| Treatment | Energy input ($\times 10^3$ MJ/ha) | Energy output ($\times 10^3$ MJ/ha) | Net energy ($\times 10^3$ MJ/ha) | Energy ratio | Energy profitability | Human energy profitability | Energy productivity (kg/MJ) | Energy intensiveness (MJ/₹) |
|---|---|---|---|---|---|---|---|---|
| Continuous drainage | 35.07 | 48.55 | 13.48 | 1.39 | 0.39 | 220.3 | 0.034 | 1.58 |
| Surface drainage at tillering | 81.89 | 100.03 | 18.14 | 1.22 | 0.22 | 423.7 | 0.038 | 3.49 |
| Surface drainage at panicle initiation | 67.65 | 85.81 | 18.16 | 1.27 | 0.27 | 363.5 | 0.039 | 2.89 |
| Surface drainage at booting | 72.03 | 89.74 | 17.71 | 1.25 | 0.25 | 380.1 | 0.034 | 3.07 |
| Surface drainage at flowering | 70.30 | 88.02 | 17.72 | 1.25 | 0.25 | 372.9 | 0.033 | 3.00 |
| Surface drainage at milking | 70.14 | 87.84 | 17.70 | 1.25 | 0.25 | 372.1 | 0.033 | 2.99 |
| Alternate wetting and drying | 39.00 | 59.71 | 20.71 | 1.53 | 0.53 | 239.0 | 0.040 | 1.62 |
| Continuous submergence | 84.97 | 108.62 | 23.65 | 1.28 | 0.28 | 452.6 | 0.040 | 3.56 |
| SEm± | | 2.54 | 2.54 | 0.05 | 0.05 | 10.84 | 0.002 | |
| LSD (P=0.05) | | 7.30 | 7.30 | 0.12 | 0.12 | 30.81 | 0.005 | |

contributors (24.5–42.9%). Among fertilizers, nitrogen was the largest energy contributor, which contributed 20.5-36% and least with $K_2O$ (1.1–2%). Mandal *et al.* (2002) explained that higher bio-energy consumption was due to application of mineral fertilizers (non-renewable source), therefore suggested for supplementation of plant nutrients through renewable sources. Many researchers suggested that the energy used by fertilizers represented the major part of total input energy as compared to other input requirements. It had also been reported that diesel and machinery, and irrigation for land preparation were the second key factors for energy requirement followed by seed requirement (Choudhary and Kumar 2013). The results confirmed these findings, however, water consumption was the principal energy necessity ranging from $5.5 \times 10^3$ MJ/ha (continuous drainage) to $15.7 \times 10^3$ MJ/ha (continuous submergence). Pesticide was the least energy input among others. It was noticed that continuous submergence utilized 69.7% of renewable energy and water was the major contributor (Table 4). The energy output was also dependent on yield harvested and it was noticed 1.24 times higher in continuous submergence ($108.6 \times 10^3$ MJ/ha) followed by surface drainage at tillering (Table 5). However, the lowest energy was produced with continuous drainage due to inferior growth and lowered yield attributes. Imposition of surface drainage at other growth stages had lower energy output than the continuous submergence and surface drainage at tillering, but yet their effect was more pertinent to continuous drainage and alternate wetting and drying.

*Energy relationship*

The net energy was obtained with continuous submergence, mainly due to the fact that energy requirement was less but energy output in terms of biological yield was considerably higher. Imposition of alternate wetting and drying was statistically comparable to the continuous submergence, but was significant higher to continuous drainage (Table 5). Alternate wetting and drying was most energy efficient and recorded 1.53 of energy ratio and energy profitability (0.53) followed by continuous drainage. These might be due to higher net energy production with unit expenses of energy. Human energy profitability ranged from 220.3 (continuous drainage) to 452.6 (continuous submergence), depending upon energy production and energy consumption in terms of human labour. The highest energy productivity was obtained under continuous submergence (0.04 kg/MJ), but was comparable to alternate wetting and drying, surface drainage at tillering and panicle initiation. This was mainly due to significantly higher economic yield of the rice and respective lower cost involved in the production. It was also noticed that continuous submergence was the most energy intensive treatment over the others. However, it was noticed that continuous drainage and alternate wetting and drying were the least energy intensive treatments.

*Carbon budgeting*

Among the various inputs used, the highest total carbon input was consumed by labour (40.7–45.1%) followed by seeds (34.9–38.6%), and water (5.8–15.0%) (Table 6). The comparison of various surface drainage indicated that the highest carbon emission was recorded with continuous flooding (2524 kg/CE/ha), whereas, the lowest carbon emission was noticed with continuous drainage (2278 kg/CE/ha). It was also noticed that continuous submergence registered 10.8% higher carbon emission than the continuous drainage. Alternate wetting and drying had the lowest carbon footprint (0.075) followed by continuous drainage (0.09), whereas, surface drainage at tillering noticed with 88.4% higher carbon footprint followed by continuous submergence (59.6%) and SD at panicle initiation (58.9%) than the continuous drainage (Fig 1). The highest carbon footprint was observed in surface drainage at tillering followed by continuous submergence. This suggested that while the carbon footprint of crop production largely relies on labour, seeds and water, it also depended on the ability of the crop to convert these into economic yields (Ma *et al.* 2012). Irrigation consumed a considerable amount of energy and carbon inputs, which enables the rain water harvesting and *in-situ* moisture conservation measures. That avoids use of diesel engines and electricity consumption for water pumping (West and Marland 2002).

The results of this study confirmed that the highest grain yield of rice was harvested with continuous submergence followed by surface drainage for 15 days at tillering with saving of 5400 m$^3$/ha of water use. Continuous submergence

Table 6 Component carbon inputs (kg/CE/ha) for raising rice during study period (two years pooled data)

| Treatment | Diesel | Machinery | Seeds | Nitrogen | $P_2O_5$ | $K_2O$ | Water | Pesticides | Labour |
|---|---|---|---|---|---|---|---|---|---|
| Continuous drainage | 17 (0.7) | 95 (4.2) | 880 (38.6) | 104 (4.6) | 12 (0.5) | 6 (0.3) | 217 (5.8) | 4 (0.2) | 1028 (45.1) |
| Surface drainage at tillering | 17 (0.7) | 95 (4.0) | 880 (36.8) | 104 (4.4) | 12 (0.5) | 6 (0.3) | 245 (10.2) | 4 (0.2) | 1028 (43.0) |
| Surface drainage at panicle initiation | 17 (0.7) | 95 (4.0) | 880 (36.8) | 104 (4.3) | 12 (0.5) | 6 (0.3) | 245 (10.3) | 4 (0.2) | 1028 (43.0) |
| Surface drainage at booting | 17 (0.7) | 95 (4.0) | 880 (37.0) | 104 (4.4) | 12 (0.5) | 6 (0.3) | 234 (9.8) | 4 (0.2) | 1028 (43.2) |
| Surface drainage at flowering | 17 (0.7) | 95 (4.0) | 880 (37.0) | 104 (4.4) | 12 (0.5) | 6 (0.3) | 235 (9.9) | 4 (0.2) | 1028 (43.2) |
| Surface drainage at milking | 17 (0.7) | 95 (4.0) | 880 (37.0) | 104 (4.4) | 12 (0.5) | 6 (0.3) | 234 (9.8) | 4 (0.2) | 1028 (43.2) |
| Alternate wetting and drying | 17 (0.7) | 95 (3.9) | 880 (35.9) | 104 (4.2) | 12 (0.5) | 6 (0.2) | 228 (12.5) | 4 (0.2) | 1028 (41.9) |
| Continuous submergence | 17 (0.7) | 95 (3.8) | 880 (34.9) | 104 (4.1) | 12 (0.5) | 6 (0.2) | 282 (15.0) | 4 (0.2) | 1028 (40.7) |

Figures in the parenthesis are % contribution

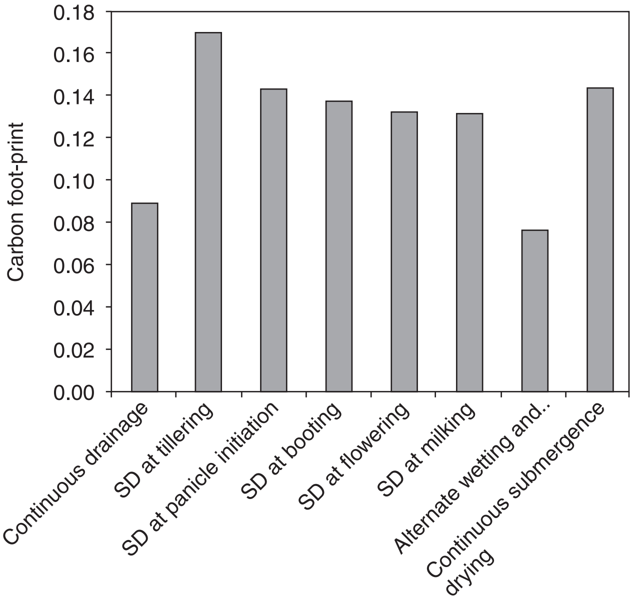

Fig. 1 Carbon foot-print as influenced by enforced surface drainage (SD) at various growth stages of rice (SEm±, 0.006; LSD, $P$=0.016).

was the most energy efficient, but under limited supply of water, imposition of surface drainage at tillering compensated the energy utilization. Water was the principal and fertilizer was secondary contributor in energy inputs. However, imposition of surface drainage at any growth stage reduced the crop yield significantly. The continuous drainage was the lowest energy efficient excluding energy ratio and profitability followed by alternate wetting and drying. Similarly, continuous drainage had the lowest carbon footprint and carbon emission while, continuous submergence had the highest values. Under aberrant weather and limited water availability, irrigation might be skipped for 15 days during tillering to cut the crop water requirement. This may not be the energy efficient, but certainly helpful under dry spell or aberrant weather situations.

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