Indian Journal of Agricultural Sciences **89** (11): 1911–5, November 2019/Article

Energy budgeting of aerobic rice (*Oriza sativa*)-wheat (*Triticum aestivum*) cropping system as influenced by potassium fertilization

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Received: 13 March 2019; Accepted: 22 April 2019

ABSTRACT

A field experiment was conducted in 2015–16 and 2016–17 to estimate the energy budget of aerobic rice (*Oriza sativa* L.)-wheat (*Triticum aestivum* L.) cropping system (RWCS) as influenced by K fertilization. Results revealed that in aerobic RWCS the non-renewable energy and renewable energy shares 86% and 14% of the total input energy use respectively. Split application of recommended dose of K (RDK=60 kg K_2O/ha) in both rice and wheat, at 50:50 or 75:25 ratio increased the system productivity by 8.2% over applying entire dose as basal (B). Among the treatments, T_{12} (150% RDK as basal) recorded the highest energy input (37481.5 MJ/ha), whereas T_1 (control) recorded the lowest (35474.5 MJ/ha). Treatments T_{11} [75% RDK as basal + 25% at panicle initiation (PI) or ear initiation (EI)+ 2 foliar spray of 2.5% KNO_3] recorded the highest output energy (340 ×10^3 MJ/ha) which remained at par with T_4 [50% RDK as basal + 50% at panicle initiation (PI) or ear initiation (EI)], whereas the lowest was recorded in control (275.9 ×10^3 MJ/ha). Two split application of 60 kg K_2O/ha at 50:50 ratio increased the system energy output by 5.5% and 13.5% over T_2 (100% RDK as basal) and T_3 (50% RDK as basal) respectively. Similarly, split application of potassium under T_4 treatments increased the system energy use efficiency, energy productivity and energy profitability by 17.9%, 25% and 20.5% respectively over control. Thus in aerobic RWCS, 4R (right time, right dose, right method, right form) stewardship based K application ensure efficient utilization of input energy and maximize the production of biological energy.

Key words: Aerobic rice, Energy, Indo-Gangetic Plains, Potassium, System productivity, Wheat

According to Fertilizer Association of India (FAI) statistics, fertilizer consumption in India increased to the tune of 370 times from 1950–51, whereas food grain production increased only five times (Anonymous 2017). For the same period, the consumption of nitrogen (N) and potassium (K) fertilizer increased by 315 and 400 times respectively, which indicates that the import and use of muriate of potash (MOP) was increased enormously. Globally, India occupies fourth place in K consumption. K is entirely imported from other countries, since K reserve is not there in India. Absence of K reserve in India makes K fertilizer become costlier. Besides, the production of K fertilizer is highly energy consuming process. Though K production is less energy consuming process in comparison to N, still it accounts for a significant amount of energy input in terms of production, transport and application. After N, potassium accounts for highest energy consumption in fertilizer sector (Paramesh *et al.* 2017). Adaption of imbalanced fertilization of NPK (6.7:2.7:1 during 2016-17) for more than 40 years deteriorated the soil health. K is the most neglected nutrient in RWCS followed by phosphorus. Removal of N, P and K from native soil reserve is not matching with amount of nutrient added externally to the soil. In India, unlike N and P, the recommendation of K is made as a maintenance dose. As a result, RWCS is running in negative K balance (Bijay-Singh *et al.* 2004). Further, excess and rapid withdrawal of groundwater leading to a decline in the groundwater table, increased energy cost of pumping water and deterioration of groundwater quality, increasing salinity (Tiwari *et al.* 2009).

In recent years, the production of rice (*Oriza sativa* L.) and wheat (*Triticum aestivum* L.) crops are highly water and fertilizer inputs intensive. Similarly, the consumption

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of electricity in agriculture is increasing constantly over the years (Paramesh *et al.* 2017). Aerobic rice could save up to 50% of irrigation water and its water productivity is 60% higher than that of transplanted rice (Singh and Chinnasamy 2007). But aerobic rice is more prone to K deficiency as it does not receive sufficient irrigation water, which could have otherwise supplied considerable amount of K to plant (Singh and Wanjari 2012). In addition, availability of soil K is decreased under aerobic conditions in comparison to submerged soil. Insufficient supply of K reduces crop productivity even in K rich soils like Vertisols (Srinivasarao *et al.* 2011).

Thus, we designed an experiment with the hypothesis that, aerobic rice cultivation along with efficient K management not only saves irrigation water and reduces GHGs emission, it also reduces total energy input and increase energy output. However, to judge the sustainability of any system, the energy budget of the system must be measured (Choudhary *et al.* 2017). So, we conducted field experiments to study the K fertilization effect on energy indices of aerobic RWCS.

MATERIALS AND METHODS

A two-year field experiment was conducted during *kharif* and *rabi* season of 2015–16 and 2016–17 at research farm of ICAR-Indian Agricultural Research Institute (IARI), New Delhi. The climate of site is semi-arid type with hot and dry summer and cold winter. The total amount of rainfall received during the *kharif* season of 2015 and 2016 was 818 and 1153 mm respectively. Similarly, in *rabi* season it was 19.8 and 92.7 mm during 2015–16 and 2016–17 respectively. The soil of experimental plot (before *kharif* 2015) was sandy clay loam in texture with 7.5 *p*H, EC (0.32 dS/m), OC (0.55%), available N-201 kg/ha (Subbiah and Asija 1956), available P-12.8 kg/ha (Olsen *et al.* 1954) and available K-213.8 kg/ha (1 N NH_4OAc-extractable K) (Hanway and Heidel 1952).

The experiment was conducted in randomized block design with 12 treatments and three replications. The treatment details are presented in Table 1. During both the years of experiment, rice was sown and harvested during second fortnight of June and October, respectively, with the row spacing of 0.25m and seed rate of 40 kg/ha. Similarly, the wheat crop was sown and harvest in the mid of November and April, respectively, with the row spacing of 0.23 m and seed rate of 100 kg/ha. Rice cultivar Pusa Basmati 1509 and wheat cultivar HD 2967 were used in conducting the experimentation. For each crop of the rice and wheat, the recommended dose of N and P is 120 and 60 kg/ha.

The details of energy inputs and their standard conversion factors are given in Table 2. The energy equivalences of inputs are given in Mega Joule (MJ).

$$\text{Energy use efficiency} = \frac{\text{Energy output (MJ/ha)}}{\text{Energy input (MJ/ha)}}$$

$$\text{Net energy} = \text{Energy output (MJ/ha)} - \text{Energy input (MJ/ha)}$$

$$\text{Energy productivity} = \frac{\text{REY (kg/ha)}}{\text{Engery input (MJ/ha)}}$$

$$\text{Energy intensiveness} = \frac{\text{Input energy (MJ/ha)}}{\text{Total cost of cultivation (₹/ha)}}$$

$$\text{Energy profitability} = \frac{\text{Net energy (MJ/ha)}}{\text{Input energy (MJ/ha)}}$$

Table 1 Treatments details

Treatment	Treatment details	K_2O (kg/ha)
T_1 Control	No potassium application in both the crops	0
T_2 100% B	Entire recommended dose of potassium (RDK) was applied at the time of sowing in both the crops through muriate of potash (MOP)	60
T_3 50% B	50% of the RDK was applied at the time of sowing in both the crops through MOP	30
T_4 50% B + 50% PI/EI	50% of the RDK was applied at the time of sowing, remaining 50% applied at panicle/ ear initiation (PI/EI) stage in both the crops through MOP	60
T_5 75% B + 25% PI/EI	75% of the RDK was applied at the time of sowing, remaining 25% applied at PI/EI stage in both the crops through MOP	60
T_6 2 FS	Two foliar spray (FS) of 2.5% KNO_3 [1st FS @ active tillering (AT), 2nd FS @ PI/EI]	8.8
T_7 100% B + 2 FS	Basal application of 100% RDK at the time of sowing + 2 FS of 2.5 % KNO_3 [1st FS @ AT, 2nd FS @ PI/EI]	68.8
T_8 50% B + 2 FS	Basal application of 50% RDK at the time of sowing + 2 FS of 2.5 % KNO_3 [1st FS @ AT, 2nd FS @ PI/EI]	38.8
T_9 75% B + 2 FS	Basal application of 75% RDK at the time of sowing + 2 FS of 2.5 % KNO_3 [1st FS @ AT, 2nd FS @ PI/EI]	53.8
T_{10} 50% B + 25% PI/EI + 2 FS	Basal application of 50% RDK at the time of sowing + 50% RDK at PI/EI + 2 FS of 2.5 % KNO_3 [1st FS @ AT, 2nd FS @ PI/EI]	68.8
T_{11} 75% B + 25% PI/EI + 2 FS	Basal application of 75% RDK at the time of sowing + 25% RDK at PI/EI + 2 FS of 2.5 % KNO_3 [1st FS @ AT, 2nd FS @ PI/EI]	68.8
T_{12} 150% B	150% RDK was applied at the time of sowing in both the crops	90

Table 2 Inputs, outputs and their energy equivalents

Input/Output	Equivalent energy (MJ)	Reference	Quantity/ha/ year	Energy equivalent (MJ/ha)	Percentage from total (%)
Human labour					
Man (h)	1.96	Mohammadi *et al.* (2010)	720	1411.2	3.95
Woman (h)	1.57	Mandal *et al.* (2002)	216	339.1	1
Machinery					
Tractor (h)	62.80	Zangeneh *et al.* (2010)	35.75	2245.1	6.3
Chemical fertilizers					
Nitrogen (kg)	66.14	Mohammadi *et al.* (2010)	240	15873.6	44.7
Phosphorus (kg P_2O_5)	12.44		120	1492.8	4.15
Potash (kg K_2O)	11.15			According to treatments	
Gypsum (kg)	10.0	Devasenapathy *et al.* (2009)	5	104.5	0.3
Herbicide (L)	238.32	Esengun *et al.* 2007	3	1430	4
Seed					
Rice (kg)	14.7	Jackson *et al.* (2010)	40	588	1.7
Wheat (kg)	14.7		100	1470	4.1
Fuel (L)	46.3	Safa and Tabatabaeerfar (2002)	4	370.4	1
Irrigation (m^3)	1.02	Mohammadi *et al.* (2010)	9250	9435	26.55
Total Input				35474	100%

System productivity was calculated in terms of rice equivalent yield (REY). For calculating REY, the yield of wheat including grain and straw first converted to REY, and then it was added with actual rice yield to derive system REY.

$$REY = \frac{Y_w}{P_r} \times P_w + Y_r$$

where, Y_w = Yield of wheat; Y_r = Yield of rice; P_w= Price of wheat grain; P_r = Price of rice grain.

All the data were subjected to one-way analysis of variance (ANOVA) using the general linear model procedures of the Statistical Analysis System version 9.3 (SAS Institute, Cary, NC). The F-test was used to determine significant difference of potassium fertilization and least significant difference (LSD) was used to compare means.

RESULTS AND DISCUSSION

System productivity: The system productivity was found between the range of 8.62 to 11.28 t REY/ha (Table 3). Among the treatments the highest system productivity was recorded in T_{11}(75% B + 25% PI/EI + 2 FS) which remained at par with T_4, T_5, T_7, T_9, T_{10}, whereas the T_1 recorded the lowest. The treatments, viz. T_2(100% B) and T_4(50% B + 50% PI/EI) increased the system productivity by 20.2% and 30% respectively, over T_1. The application of 60 kg K_2O in two splits at 50:50 or 75:25 ratios during sowing and PI/EI stage increased the system productivity (10%) significantly over applying entire dose of K as basal. Similarly, two foliar sprays of potassium nitrate also increased the system productivity by 6.6% over control treatment. Split application of 100% RDK as half at sowing and remaining half at panicle initiation (PI) in rice/ear initiation (EI) in wheat stage increased system productivity by 8.2 and 17.8% over T_2 (100% B) and T_3 (50% B) respectively. It clearly indicated that application of sub optimal dose of K (< 60 kg K_2O/ha) causes severe yield loss in both aerobic rice and wheat. Moreover, splits application of 60 kg K_2O/ha at 50:50 or 75:25 ratios during sowing and PI/EI stages provide the maximum benefit over application of entire recommended dose of potassium as basal. Adequate supply of K helps in better development of yield attributes in rice and wheat especially in the soils were the native K supply is inadequate to the total crop needs (Awan *et al.* 2007). Thus, the system productivity was found higher in T_4, T_5, T_7, T_9, T_{10}, T_{11} treatments compared to all other treatments.

System energy input, energy output and net energy: The share of renewable and non-renewable energy sources in aerobic RWCS was 14 and 86%, respectively (Table 2). Use of external inputs (fertilizers, herbicide) and adaption of mechanization increased the share of non-renewable energy sources. In conventional RWCS, operations like transplanting, harvesting, threshing and cleaning were performed manually, whereas in aerobic RWCS, these operations are replaced by machinery. Similarly, instead of manual weeding, herbicides were used for weed control. Thus non-renewable energy account major share in total energy use. Tomar *et al.* (2006) reported that in RWCS, about 25–30% of energy was consumed for field preparation and crop establishment.

Based on pooled data, the total energy requirement of aerobic RWCS excluding K was 35474.7 MJ ha^{-1}. In total energy input, N and P fertilizers alone account 49% of the total energy input followed by irrigation (26.6%), human labour (5%) and herbicide (4%). The labour requirement of aerobic rice (448 man-hours/ha) was relatively more than

Table 3 Effect of K application on energy indices of aerobic RWCS by taking REY (two year pooled data)

Treatment	System productivity (REY t/ha)	Energy input	Energy output	Net energy	Energy productivity (kg REY/MJ)	Energy profitability	Energy use efficiency
			($\times 10^3$ MJ/ha)				
T_1	8.62^D	35.47	275.9^D	240.5^D	0.24^D	6.78^D	7.8^D
T_2	10.36^B	36.81	320.0^B	283.2^B	0.28^B	7.69^B	8.7^B
T_3	9.51^C	36.14	297.6^C	261.4^C	0.26^C	7.23^C	8.2^C
T_4	11.21^A	36.81	337.4^A	300.6^A	0.30^A	8.17^A	9.2^A
T_5	11.18^A	36.81	336.9^A	300.1^A	0.30^A	8.15^A	9.2^A
T_6	9.19^C	35.67	288.3^C	252.7^C	0.26^C	7.08^{CD}	8.1^{CD}
T_7	11.22^A	37.01	337.6^A	300.5^A	0.30^A	8.12^A	9.1^A
T_8	10.35^B	36.34	318.8^B	282.4^B	0.28^B	7.77^B	8.8^B
T_9	11.21^A	36.67	337.6^A	300.9A	0.31^A	8.20^A	9.2^A
T_{10}	11.26^A	37.01	338.9^A	301.9^A	0.30^A	8.16^A	9.2^A
T_{11}	11.28^A	37.01	339.9^A	302.9^A	0.30^A	8.18^A	9.2^A
T_{12}	10.56^B	37.48	323.2^B	285.7^B	0.28^B	7.62^B	8.6^B
SE(d)	0.202	-	5.61	5.61	0.005	0.15	0.15
LSD (P=0.05)	0.419	-	11.63	11.63	0.010	0.31	0.32

Means followed by a superscripted similar uppercase letter within a column are not significantly different (at $P<0.05$). Duration of aerobic rice & wheat 120 and 150 days respectively.

wheat (344 man-hours/ha) due to more number of irrigations and weeding. Fuel and electricity (irrigation) are direct non-renewable energy sources, which together contributed about 27% total energy input. The total energy input use of aerobic RWCS was found between the range of 35.47 to 37.48 ($\times 10^3$ MJ/ha). Among the treatments, T_{12}(150% B) recorded the highest energy input (37481.5 MJ/ha), whereas T_1(control) recorded the lowest (35474.5 MJ/ha).

The total output energy produced by aerobic RWCS was found between the ranges of 275.9 to 339.9 ($\times 10^3$ MJ/ha) (Table 3). Among the treatments, T_{11}(75% B + 25% PI/EI + 2 FS) recorded the highest energy output (337-340 $\times 10^3$ MJ/ha) which remained at par with T_4, T_5, T_7, T_9 and T_{10}, whereas T_1 recorded the lowest (275.9 $\times 10^3$ MJ/ha). The treatments T_4, T_5, T_7, T_9, T_{10} and T_{11} increased system total energy output by 5-6% and 13-14 % over T_2(100% B) and T_3(50% B) respectively. Similarly, treatments T_4, T_5, T_7, T_9, T_{10} and T_{11} increased the system net energy by 6 and 15% over T_2(100% B) and T_3(50% B) respectively. It is clear from the results that the input energy was efficiently used in aerobic RWCS when the RDK is applied in two splits with or without supplementation of foliar spray. The amount of bio-energy produced through rice is greater than wheat. This is due to higher biological yield production in rice compared to wheat. Similarly, in both the crop, the energy produced through straw was greater than energy produced from grain. This is due to higher straw yield in comparison to grain yield in both the crop.

Energy productivity, energy profitability and energy use efficiency: The highest energy productivity, energy profitability and energy use efficiency was recorded in T_{11}(75% B + 25% PI/EI + 2 FS) which remained at par with T_4, T_5, T_7, T_9 and T_{10} whereas T_1 recorded the lowest (Table 3). The energy productivity, energy profitability and energy use efficiency of aerobic RWCS were found between the ranges of 0.24 to 0.30, 7.8 to 9.2 and 6.78 to 8.20 respectively. The higher energy profitability in treatments, viz. T_4, T_5, T_7, T_9, T_{10} and T_{11} indicates that more energy (net energy) is produced for every one unit of input energy. Similarly, higher energy productivity indicates, that more yield (REY) is produced for every one unit of energy input. Treatments, viz. T_2 and T_4 increased the system energy use efficiency, energy productivity and energy profitability by 11.7:16.7:13.4 % and 17.9:25:20.5 % respectively, over T_1. In control the input energy was inefficiently utilized due to inadequate supply of potassium, whereas adequate supply of K through split application of RDK or foliar spray ensured the efficient utilization of input energy. In aerobic RWCS, the input energy requirement is relatively lower in-comparison to conventional RWCS since field operation like puddling, nursery preparation, transplanting is omitted and it also requires less number of irrigations. Kazemi *et al.* (2015) reported that input energy requirement of RWCS especially for fuel and fertilizer can be reduced by adopting more efficient methods like balanced nutrition, split application, dry direct seeding etc.

Based on two-year study, it is concluded that chemical fertilizers and electricity account the major share of total input energy. Supply of potassium based on 4R (right time, right dose, right method, right form) nutrient stewardship in rice-wheat cropping system could increase the system productivity and energy use efficiency. The improvement of all the energy indices, viz. net energy output, energy use efficiency, energy productivity and energy profitability in treatments T_4 and T_9 indicate split application of RDK or supplementation of K through foliar spray in addition to the basal application is a win-win strategy to reduce input energy requirement and efficient energy utilization.

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