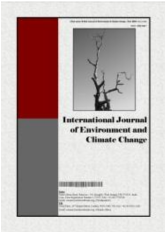

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# Energy Dynamics of Aerobic Rice Cultivation in India

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***Authors' contributions***

*This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.*

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## ABSTRACT

Aerobic rice needs 30% less total water for land preparation, 50% saving on labour requirement and 50% less GHG emission compared to transplanted rice. Energy use efficiency of aerobic rice cultivation also varies due to varieties. However, a detailed study on various energy inputs components of aerobic rice cultivation (variety, water management, spacing, fertilizer dose and weed management) is lacking. To confirm the energy dynamics of aerobic rice cultivation, a combined study was taken up to find out the energy input, output and energy use efficiency of aerobic rice cultivation consisting of various trials conducted at research farm of ICAR-Indian Institute of Rice Research and few other trials conducted at other places. Gayatri variety performed well in terms of higher energy use efficiency at eastern part of India. Further higher energy use efficiency (output/input ratio) was recorded at 100% RFD. Crop spacing also affects the total energy output of aerobic rice. It was seen that the total output energy is highest at optimum spacing of 20 x 10 cm compared to 25 x 10 and 30 x 10 cm. Apart from need based hand weeding, Pendimethalin 1.0 kg /ha + Bispyribac sodium 35 g/ha resulted higher energy use efficiency (2.75) compared to those of other chemical weed management practices. It was observed that aerobic rice based systems maintained higher productivity and profitability in comparison to transplanting based rice cropping systems. The study revealed that varieties, fertilizer dose and spacing played crucial role in enhancing the energy use efficiency of aerobic rice cultivation. So, farmers have to strike a balance among the input resources specially variety, water, fertilizer to achieve higher energy use efficiency in aerobic rice based cropping systems.

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*Keywords:* *Crop establishment methods; energy use efficiency; integrated weed management; spacing.*

## 1. INTRODUCTION

“Aerobic system of rice cultivation is growing as an economically feasible, water-labor-energy saving, mechanized, and climate smart agricultural practice to ensure food security. Seven to ten days early maturity of the aerobic rice crop compared to transplanted rice allows timely planting of the succeeding crop in addition to the improvement in nutrient availability and soil conditions” [1]. “Earlier aerobic rice varieties were developed with the aim to replace the low yielding rice varieties of upland ecosystem” [2]. “In the last decade, aerobic rice has not become popular among farmers due to high weed infestation and high cost to control weeds under aerobic situation as compared to transplanted rice. With the availability of appropriate weed control measures, mechanization reducing labour requirements from 11 to 66% compared to transplanted rice [3] and improved agronomic management practices; aerobic rice cultivation is being successfully implemented in rainfed shallow lowland ecosystem.” “In recent years, aerobic cultivation has gained momentum in irrigated lowlands where rainfall is not sufficient and pumping water from deep well is expensive, delta regions with delayed water supplies and upland system with supplemental irrigation. Aerobic rice needs 30–51% less total water for land preparation depending upon the soil types providing 32–88% higher crop productivity, 50% saving on labour” [4] and can have 50% reduced GHG emission [5] compared to transplanted rice [6].

“Agricultural food production is the process of converting the energy of solar radiation into metabolisable forms of energy and nutrients through photosynthetic pathways, aided by agronomic inputs in the form of seeds, nutrients, tillage, water, weed, pest control and other practices aimed at improving the growing environment for the crop. Energy efficiency has been crucial for sustainable development in agriculture systems” [7]. Quantification of the total energy of external inputs expended on crop production and the energy yield in the form of human appropriated yield is required for the energy balance approach to determine agronomic efficiency. The direct energy used from fossil fuels consumed during mechanical operations, the energy expended in human labour, and the energy incorporated in agronomic inputs such as fertilisers, crop protection products, and seed are all examples of external agronomic energy inputs (AEI) to agricultural fields. The overall energy cost incurred in the production, across the supply chain, and in the storage of all manufactured or refined products, inputs, and fossil fuels used in crop production is referred to as embedded energy in agronomic inputs. The AEI of a product might alter over time if efficiency advancements in the product's manufacturing or distribution process occur. Changes in the AEI, on the other hand, are evenly dispersed among all users of the product. Although transportation costs vary by agricultural region, resulting in variations in the embodied energy of agronomic inputs, eliminating this variation from energy efficiency studies allows comparison of farming systems both spatially and temporally. Energy is a crucial component of a country's development. It is used in agricultural operations such as food processing and transportation, as well as fertiliser, insecticide, and farm equipment manufacturing. It is required for industrial processes that generate employment. It is essential for cooking, domestic lighting, heating, and the development and operation of educational, health-care, and water-supply facilities. It is necessary to convert energy quickly to a common equivalent in order to gain a better grasp of energy issues.

### 1.1 Energy Sources

Commercial and non-commercial energy sources can be categorised in a variety of ways depending on the nature of their transactions. All energy resources, especially commercial energy resources, are natural. Commercial sources include coal, oil, and nuclear power, while non-commercial sources include firewood, biomass, and animal manure. The energy sources are also divided into animate and inanimate categories. Exhaustible / non-renewable or non-depletable / renewable resources are two types of energy sources. The distinguishing feature of an exhaustible resource is that, it gets exhausted when used as an input of a production process, and at the same time, its undisturbed role of growth is nil. That is, the temporal services provided by a given stock of an exhaustible resource are finite. Further, based on conventionality in deriving energy, energy sources could be classified as conventional (coal, oil, hydro, nuclear, etc.) and non-conventional (solar, wind, tidal, geothermal, biogas, etc.) sources. They are also classified as primary types (coal, firewood) or secondary types (electricity). Energy in its primary form can be of different kinds. The main types are chemical (fossil fuels, coal, oil, natural gas, peat; biomass - wood, agricultural residues, etc.), potential (water at a certain height), kinetic (wind, waves), radiation (sun), heat (geothermal reservoirs, ocean thermal reservoirs) and nuclear (uranium). The primary form of energy must generally be converted into secondary or final forms of energy before it can be used. For instance, the potential energy of a waterfall (primary energy) is converted into electricity (secondary energy), which is transmitted and transformed to supply (final) energy to a factory, where it is converted into mechanical energy (useful energy) for productive operations. Important types of secondary energy are electricity and mechanical energy. But chemical energy is also important as a secondary energy, for instance, refined oil products. Final energy is the energy that reaches the consumer. This can be electricity at a suitable voltage or chemical energy in kerosene or batteries. Most of the energy sources are substitutable to each other due to the fact that some form of energy can be converted to other - such as coal to electricity, use of photo-electricity to drive a chemical reaction, wind energy to pump and store water that could be used to produce electricity when required, or solid biomass to produce liquid or gaseous fuels of higher calorific value. All forms are ultimately converted into heat. This gives rise to the inter-fuel substitution process with which an economy can substitute its abundantly available resources to the scarcely endowed one.

#### 1.1.1 Classification of energy

On the basis of source, the energy can be classified as direct and indirect energy.

#### 1.1.2 Direct source of energy

Direct sources of energy include manpower, bullocks, stationary and mobile mechanical or electric power units, such as diesel engines, electric motors, power tillers, and tractors, which all release energy directly. Depending on how easily they can be replenished, direct energy can be categorised as renewable or non-renewable. The energy sources that are direct in nature but can be renewed are classed as renewable direct sources of energy. Humans, animals, solar and wind energy, fuel wood, agricultural wastes, and other energies may fall into this category. Non-renewable direct energy sources are defined as direct energy sources that are not renewable (at least in the next 100 years). Coal and fossil fuels are examples of nonrenewable direct energy sources.

#### 1.1.3 Indirect source of energy

The indirect sources of energy are those that release energy indirectly through a conversion process rather than directly. Some effort is expended in the development of indirect energy sources. Indirect sources of energy include seeds, manures (farmyard and poultry), chemicals, fertilisers, and machines. These can be further categorised into renewable and non-renewable indirect sources of energy based on their replenishment. Indirect renewable energy source: Seeds and manures are examples of renewable indirect energy sources since they may be regenerated over time. Non-renewable indirect sources of energy are energy sources that are not regenerated. Nonrenewable indirect energy sources include chemicals, fertilisers, and machinery manufacturing. On the basis of comparative economic value the energy may be classified as commercial and non-commercial.

#### 1.1.4 Commercial energy

Commercial sources of energy include petroleum products (diesel, petrol, and kerosene oil) and electricity, both of which are capital expensive. Given that the majority of commercial energy sources are non-renewable and, to some part, imported into India, attempts are made to conserve such energy sources.

#### 1.1.5 Non-commercial energy

Each and every source of energy has a monetary worth. Some energy sources are quite inexpensive, while others need a significant investment. Non-commercial energy sources are those that are available for a low cost, whereas commercial energy sources are those that require a large investment. The category of non-commercial source of energy is exemplified by human labour and bullocks. Human and animal labour are easily available and can be exploited as a direct source of energy. Non-commercial sources of energy include materials that are readily available and less expensive, such as fuel wood, twigs, leaves, agro-waste, and animal manure, among others.

### 1.1.6 Energy input from various sources

*1.1.6.1 Direct sources*

The energy input of human labour and a pair of large bullocks (having a body weight of 450 kg) may be assumed to be 1.96 MJ / man-hr and 14.05 MJ / pair-hr, respectively. The specific fuel consumption of the mechanical power source (obtained from the test report) can be used to find energy inputs.

*1.1.6.2 Indirect sources*

The energy requirement in producing seeds, fertilizers, pesticides, weedicides, etc.

### 1.1.7 Calculation of energy requirements for a field operation

The energy requirements for a particular field operation may be calculated as the summation of human, bullock and mechanical and / or electric energy consumed.

*1.1.7.1 Operational costs for various power sources*

Manual power: In case of human labour, the wages of an unskilled labour on the basis of hour or day (as prevailing in a particular locality) are charged.

*1.1.7.2 Animal power*

The charges for operating a pair of bullocks are calculated on the basis of the cost of a pair of bullocks, wages of an operator and cost of the feed for bullocks along with any other expenses (as enforced in a particular locality) in research farms. However, for the farmers' fields, the actual hiring charges are taken as the basis. By considering all these factors multiple trials were conducted at ICAR-IIRR, Hyderabad and data from other trials conducted elsewhere were reported here to come out with complete understanding of energy dynamics of aerobic rice cultivation. The objective of the study was to find out the energy input, output and energy use efficiency of aerobic rice cultivation from various trials conducted at research farm of ICAR-Indian Institute of Rice Research and few other trials conducted at other places.

## 2. MATERIALS AND METHODS

Total four trials on aerobic rice were conducted at Rajendranagar farm of ICAR-Indian Institute of Rice Research, Hyderabad. The first trial laid out in randomised block design with 5 replications. It was consisted of four level of fertilizer dose {(0, 50% recommended fertilizer dose (RFD), 100% RFD and 150% RFD)}. The second trial was also laid out in randomized block design and replicated thrice. Seven varieties (Sampada, MTU 1010, IR 64, IET 20653, GK 5003, PA 6444 and DRRH 3) consisting of HYV and hybrid taken as treatments. The third trial was taken up with 3 different spacing (20 x 10, 25 x 10 and 30 x 10 cm), laid out in randomized block design with 5 replications. The fourth trial consisted of 11 weed management treatments, laid out in randomized block design and replicated thrice. Recommended package and practices were followed except the imposed treatments. Similarly, data were collected from other studies conducted at different places to make it a comprehensive analysis and to come out with a valid energy dynamics status of aerobic rice cultivation.

## 3. RESULTS AND DISCUSSION

Transplanted rice resulted total energy output ranged from 1, 04, 163 to 1, 74, 953 MJ/ha (Table 1). The energy use efficiency varied from 5.43 to 12.85. The lower energy use efficiency recorded in transplanted rice was due to high energy input. Similarly, trials conducted at various placed under rainfed conditions revealed that among rice varieties, Gayatri variety performed well in terms of higher energy use efficiency (13.97) at eastern part of India (Table 1). It was confirmed that variety and water management played crucial role in enhancing the energy use efficiency of aerobic rice cultivation.

Similarly, a trial conducted at ICAR-IIRR research farm (Rajendranagar) revealed that total output energy increases with increased application of recommended fertilizer dose (Fig. 1). However, the increase was not significant beyond 100% of RFD. It indicates higher energy use efficiency (output/input ratio) at 100% of RFD.

Another trial at same experimental farm showed hybrids are better performer interms of energy use efficiency than high yielding varieties under aerobic system (Fig. 2). This was due to higher grain yield recorded under hybrids. Similarly, energy use efficiency also varies among the varieties.

**Table 1. Energy use and energy productivity of differentrice production system in India**

| Rice establishment methods | Total energy input (MJ/ha) | Total energy output (MJ/ha) | References |
|---|---|---|---|
| **Irrigated rice** | | | |
| transplanting | 19,170 | 1,04,163 | Soni and Soe [8] |
| | 13,616 | 1,74,953 | Pradhan et al. [9] |
| | 18,718 | 1,68,266 | Tuti et al. [10] |
| Rainfed rice | 11,031 | 65,033 | Soni and Soe [8] |
| Naveen variety | 11,261 | 1,41,375 | Lal et al. [11] |
| Gayatri variety | 11,521 | 1,60,916 | |
| Swarna variety | 11,484 | 1,43,502 | |
| Annada variety | 8,396 | 52,204 | |

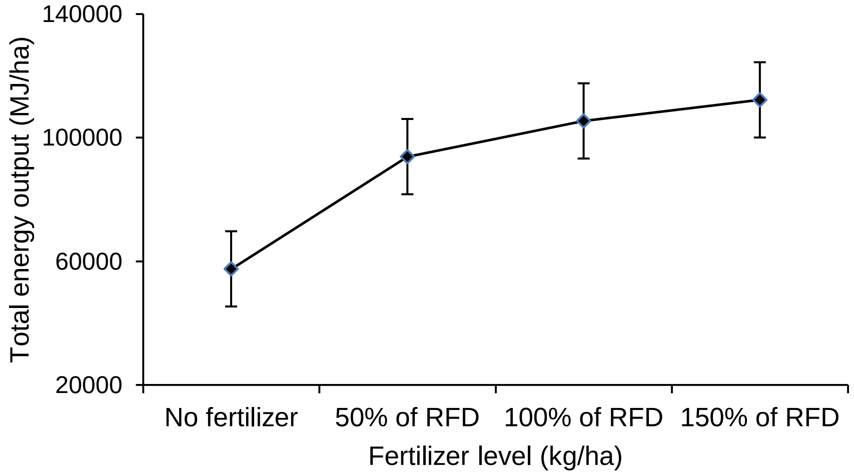


**Fig. 1. Total energy output (MJ/ha) of aerobic rice system under different level of RFD**

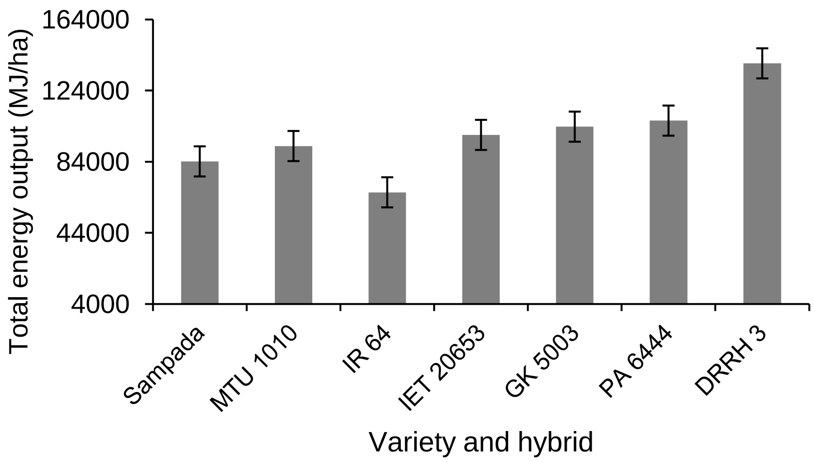


**Fig. 2. Total energy output (MJ/ha) of different varieties and hybrid under aerobic rice system**

Crop spacing also affected the total energy output of aerobic rice. It was seen that the total output energy is highest at optimum spacing of 20 x 10 cm compared to 25 x 10 and 30 x 10 cm (Fig. 3). The highest grain yield was recorded under 20 x 10 cm spacing compared to those under other spacing. Optimum spacing directly impacted grain yield which ultimately resulted the higher energy use efficiency.

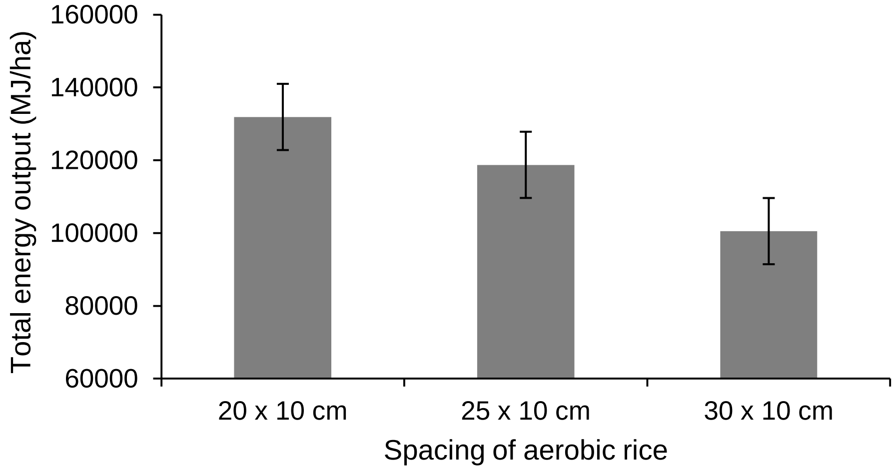


**Fig. 3. Effect of crop spacing on total energy output of aerobic rice cultivation**

Weed management also played a major role for enhancing the energy use efficiency of aerobic system. Apart from need based hand weeding, Pendimethalin 1.0 kg/ha + Bispyribac sodium 35 g/ha resulted the higher energy use efficiency (2.75) compared to those of other chemical weed management practices. So resource inputs such as variety, fertilizer, seed rate, spacing, weed management (Table 2), etc. influence the energy efficiency of aerobic rice cultivation.

**Table 2. Energy use efficiency of weed control management in aerobic rice**

| Treatment | Grain Yield (t/ha) | Weed control efficiency | Energy input (MJ/ha)) | Energy output (MJ/ha) | Energy ratio |
|---|---|---|---|---|---|
| Pendimethalin 1.0 kg /ha+ Bispyribacsodium 35 g/ha | 4.88 | 72.80 | 20714.4 | 57036 | 2.75 |
| Pendimethalin1.0 kg/ha+2,4 D,Na salt 0.06 kg/ha | 4.51 | 65.33 | 20786.1 | 51597 | 2.48 |
| Pendimethalin 1.0 kg/ha + Ethoxysulfuron 15 g/ha | 4.41 | 64.78 | 20845.6 | 50127 | 2.40 |
| Pendimethelin 1.0 kg/ha + (Chorimuron + Metsulfuronmethyl) 40 g/ha | 4.38 | 69.94 | 20647.36 | 49686 | 2.41 |
| Butachlor1.5 kg/ha + Bispyribacsodium 35 g/ha | 4.76 | 70.55 | 20714.4 | 55270 | 2.67 |
| Butachlor1.5 kg/ha + 2,4-D,Na salt 0.06 kg/ha | 4.35 | 56.15 | 20786.1 | 49245 | 2.37 |
| Pretilachlor 1.0 kg/ha + Ethoxysulfuron 15 g/ha | 4.33 | 55.89 | 20845.6 | 48951 | 2.35 |
| Pretilachlor 1.0 kg/ha + (Chorimuron + Metsulfuronmethyl) 40 g/ha | 4.37 | 65.75 | 20647.36 | 49539 | 2.40 |
| Mechanical weeding/weeders at 20 and 45 DAS | 4.48 | 75.19 | 19943.78 | 51156 | 2.57 |
| Need based hand weeding (4 at 15 days interval) | 5.03 | 81.22 | 20866.22 | 59241 | 2.84 |
| Unweeded | 1.92 | 0 | 19770.18 | 28224 | 1.43 |
| CD (p=0.05) | 0.28 | NA | NA | NA | NA |

*(Source: Sreedevi et al. [12])*

## 4. CONCLUSION

The study evaluated energy dynamics of aerobic rice production in different aerobic rice based cropping system. It was observed that aerobic rice based systems maintained higher energy use efficiency in comparison to transplanting based rice cropping systems provided suitable variety, water management practices, spacing and weed management practices are followed. Therefore, farmers have to strike a balance among these resource inputs to achieve higher energy efficiency in aerobic rice based cropping systems.

## COMPETING INTERESTS

Authors have declared that no competing interests exist.

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