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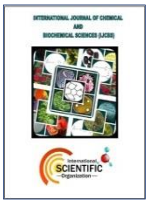

Recognizing Influence on the Environment and Eco-Efficiency Variations at the Agricultural Level

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Abstract

Eco-efficiency, or financial gain per metric ton of environmental damage, may vary widely across farms that harvest the same crop. Identifying viable strategies for improving the environmental performance of products is made easier when one has a firm grasp of the factors that contribute to the observed variations in eco-efficiency (E-E). In this study, we looked at how eco-efficiency varied among 210 rice paddy (RP) fields in India. We used multiple linear regression modeling (MLP) to analyze the effects of agriculture systems (standard, restricted input (RI), natural) and yield, as well as their possible interactions, on financial profit per unit of effect on ecosystems (terrestrial, freshwater, coastal) and human health (HH). Our research demonstrated that natural agriculture systems had better eco-efficiency than standard and RI agriculture systems and a positive correlation between eco-efficiency and production. Also, we found that production for impacts on ecological systems is positively correlated with eco-efficiency of standard and RI systems, yet not for impacts on aquatic and freshwater ecosystems or human health. Based on our findings, natural RP farms not only have reduced environmental effects per unit of rice production but also generate greater financial gains.

Keywords: Eco-efficiency (E-E), rice paddy, Environmental impact, multiple linear regression modeling (MLP)

Full length article **Corresponding Author*, e-mail:*g.subbulakshmi@jainuniversity.ac.in*

1. Introduction

Agriculture has been more intensive during the last 10 decades as a result of a number of reasons, such as government subsidies and technological advancements. Farmers were particularly efficient at improving agriculture production and output as a consequence of new advancements in agricultural production management, which led to decreased food costs. However, the increasing environmental deterioration has been a price to pay for these successes [1].Throughout the last several decades, there has been a rising awareness among the general public of the environmental issues related to food manufacturing. In 2018, the globe generated over 783M tons of RP. A number of environmental effects are also brought on by the RP industry. Global warming is caused by emissions of methane (CH_4) from rice agriculture [2]. Also, the use of chemical fertilizers and pesticides to improve RP output results in widespread soil and water contamination as well as possible health problems for people. From seed to plate, standard and natural agriculture methods were included in a number of life cycle assessment (LCA) studies that measured the environmental effects of RP yield. Since natural agriculture practices utilize fewer fertilizers and pesticides, there may be fewer negative effects on toxic effects and eutrophication in addition to fewer effects on global warming per unit of produce [3]. Others, however, discovered that natural rice agriculture does not always result in less environmental damage per unit of production than standard agriculture. This is mainly because natural rice agriculture harvests are less, but additionally because natural manure contains higher levels of metal and CH_4 emissions. Yet, as technology and fertilizer management have advanced over time, productivity has increased, resulting in fewer negative environmental effects. Since it enables examination into how more products and services may be produced while using fewer resources and producing less environmental harm, the idea of E-E has grown in favor among scholars in recent years [4]. E-E may be more readily measured by comparing the financial value-added of a corporation to the environmental harm caused during the manufacturing process, in comparison to the idea of sustainability, whose description is still ambiguous. To progress towards a more comprehensive life cycle sustainability assessment, the socioeconomic efficiency of agricultural production is deemed vital in addition to environmental implications [5]. Eco-efficiency, here defined as the financial value generated per unit of environmental impact, is one of the metrics that may be used to combine the financial and environmental elements in life cycle analyses. Just a few researches examined the E-E of RP systems [6]. Wet-season rain-fed systems were determined to be the most eco-efficient between 44 RP farms in Bangladesh when variations in E-E between them were examined with a concentration on various seasons and irrigation options. Research findings on the environmental effects or E-E of RP production to date have generally concentrated on a small number of farms, a small number of inputs or a small number of midpoint environmental effects [7,8].

The characteristics of innovation systems and their impact on improved agricultural E-E are investigated in the paper [9]. E-E was calculated for 79 nations using aggregate data and econometric methodologies, which allowed researchers to analyze a wide variety of parameters related to research, extension, business, and policy.Research [10] examines agricultural E-E and the factors affecting it in Jilin Province's agricultural production zone using a super SBM-DEA technique that takes into account carbon emissions from fields using panel data regression.Research [11] uses data envelopment analysis to calculate the E-E of producing high-yielding variety (HYV) rice by integrating an on-farm environmental damage index (OFEDI) as an undesired outcome. This index measures the amount of harm done to the environment on the farm.In order to improve the sustainable growth of local agriculture, research [12] developed a data-driven methodology to assess and enhance agricultural eco-efficiency (AEE). In order to create an AEE assessment index system, agricultural non-point source pollution (NPSP) pollutants were regarded as the undesirable output. In addition, a model for data envelopment analysis (DEA) was developed to analyze AEE from both static and dynamic angles. Analysis was also done on the geographical development as well as the temporal and spatial aspects of AEE. In addition, we used a random effect (RE) panel Tobit model to quantitatively analyze AEE's input elements and provide realistic recommendations for regional agriculture's sustainable growth.The impact of European agri-environmental initiatives on E-E on farms is analyzed in study [13]. To examine the scheme contributions affected E-E initiatives, they combined data envelopment analysis with effect evaluation. Based on their findings, the E-E of both dairy and agricultural production had considerable potential for enhancement.Article [14] summarizes findings from an environmental and financial analysis of a number of different crops. Life cycle assessment (LCA) and life cycle costing (LCC) techniques were used to evaluate the production of corn and rapeseed. The research was conducted on farms that raised both plants and animals.In study [15], agricultural E-E was assessed utilizing window data envelopment analysis, showing that financial and environmental goals may be achieved utilizing the region's best practices. To reduce E-E indices outliers, we used the multivariate data cloud approach. The bootstrap scale-return significance test occurred. To our knowledge, there hasn't been any research that thoroughly and methodically describes how different RP agriculture methods and farms may have different environmental consequences and eco-efficiency.

2. Materials and methods

2.1Farms for rice paddy

The largest producer of RP in Burdwan, which is located in West Bengal in India as seen in Figure 1. The province produced “1425,000 tons of rice from 205,000 hectares (ha)” of planted RP fields in 2019, accounting for 45% of “India total rice output”. In the province of Burdwan, our investigation examines RP yield in three different agricultural systems: traditional agriculture, natural agriculture, and agriculture with little external inputs. Standard agriculture uses pesticides and artificial fertilizers, whereas natural agriculture does not. As a result, synthetic fertilizers and pesticides are utilized in fewer quantities in limited-input agricultural systems than they are in traditional ones. Using surveys given to rice farmers in west Bengal, India in 2019, we gathered data from a farm-specific life cycle inventory. The same questionnaires were used to collect financial data, such as productivity and production expenses per farm. 210RP farms made up the sample, comprising 137 standard system farms, 47 farms with fewer inputs, and 16 farmers using natural systems. The financial and environmental foreground data gathered from the farms are summarized in Tables 1, 2, and 3. Additional information is provided, including specifics on each of the 210 farms.

2.2Eco-efficiency research

In contrast to LCA's measure of impact per dollar made, E-E is a percentage that shows how much financial gain is produced for each unit of effect. For each of the four effect categories terrestrial, pure water, coastal, and HHas well as for every RP farm, as shown in equation (1), we estimated the eco-efficiency:

$$Eco-efficiency=\frac{Net\ economic\ fit}{Environmental\ imapct} \quad (1)$$

The net profit in relation to the environmental load or effect is greater the higher the eco-efficiency. For example, cost-effective ways to lessen environmental consequences may be found using the E-E indicator

2.3 Financial gains

The net financial profit was computed by deducting production expenses from production income. All fixed and variable expenses for the duration of the product life cycle were included in farm-specific expenses. Depreciation, equipment upkeep and service, land rent, and agricultural insurance were all fixed expenditures, while labor and material inputs were expenditures. All farm management system's production revenues in 2019 were unique. The selling price for each kg of RP produced using the other two technologies was 90,000 Rial, compared to 133,000 Rial for natural RP. Using the 2019 exchange rate of 113,000 Rials to the US dollar, we translated selling values to dollars.

2.4 Effects on the environment

2.4.1 Stock information

We calculated the farm gate environmental impacts. We obtained baseline information on emissions corresponding for burning diesel fuel according to energy consumption per unit from the eco-Invent database 3.2 and estimated farmyard manure and inorganic fertilizers from inputs. We calculated rice farm-level CH_4 emissions using IPCC-recommended manure application modifications.

Moreover, we calculated the emissions of farm yard manure (FYM), residue burning emissions, and heavy metal emissions from chemical fertilizers applied to soil, and we made the assumption into agricultural soil. Our research did not include soil natural carbon changes due to a lack of experimental data on Indian rice production techniques. Yet, among other effects, the cultivation of rice may worsen soil erosion, accelerating climate change.

2.4.2 Life cycle impact assessment (LCIA)

The LCIA was conducted using the ReCiPe2016 endpoint technique. The ReCiPe2016 endpoint technique divides the environmental effects into three key harm classifications: ecosystem quality, human health, and resource depletion.

Here, we concentrated on harm to the quality of the terrestrial, pure water, and coastal ecosystems as well as harm to human health. As stated in ReCiPe2016, we used three different sets of impact factors. The independent viewpoint offers impact factors with a 2 decades time horizon and somewhat solid scientific support. At a time range of 10decades, the repercussions are shown from a hierarchical viewpoint. The egalitarian viewpoint considers all influence paths with measurable effects across the broadest time horizon.

Three pesticides that were being used at some of the 210farms included in ReCiPe2016 but not at others required us to compute new environmental destruction factors. In order to do this, we collected information on the fate and effects of these three pesticides and used USESLCA to determine impact variables.

2.5 Statistical analysis

The relationship between an environmental effect or E-E and the agricultural system and yield was examined for each damage category and each viewpoint by using a multiple linear regression model. We added an interaction between the agricultural system and yield since there may be differences in correlations with yield across agriculture systems. For net profit, we created a regression model similar to the one above. At the final stage of the research, we assessed the midpoint impact categories' respective contributions to farm impacts. We used the program 'visreg' in R, version 4.0.0, to display the regression models throughout all of the statistical analysis.

3. Results and Discussions

3.1Financial Gains

Figure 1 shows that for all three production methods, net profit rises as productivity does. Because of the increased selling price per unit of RP produced, we also found that natural production systems outperform standard and RI for RP production systems in net profit.

3.2 Effects on the environment

The hierarchical approach states that for all agriculture methods, terrestrial environmental impacts per tonne of rice produced decrease with productivity. With yields of more over “3 tons per ha per year” in figure 2a, the natural agriculture approaches have the lowest impacts. Standard and low-input agricultural yields harm humans and aquatic environments. Contrarily, effects on clean water and coastal habitats are stable in natural agricultural systems, or they worsen as yields rise. Also, we discovered that when compared to the other two agriculture systems in figure 2b-d, traditional agriculture systems consistently had greater effects. Both the egalitarian and the individualist viewpoints showed comparable trends.

3.3 Eco-efficiency

The E-E of natural agriculture systems is consistently greater than that of standard and low-input agriculture systems, according to the hierarchist viewpoint, and it is positively correlated with yield in figure 3. Each of the four damage categories produced the same outcome. For traditional and low-input agriculture systems, the E-E based on causing harm to terrestrial ecosystems is highly associated with production, whereas E-E relies on fresh water and coastal habitats and HH does not change with production. The egalitarian and individualist points of view revealed the same patterns.

3.4 Contributions with a relative effect

The hierarchist approach shows that land usage, followed by global warming, has a major impact on the destruction of terrestrial ecosystems for all three agricultural systems. Eutrophication is a significant factor in all three agriculture systems when it comes to harm to freshwater environments, but eco toxicity is more significant in traditional agriculture systems. Fipronil use in traditional agricultural systems was the primary source of toxicity, which caused an average of 50% of the harm to freshwater ecosystems. Failure of marine ecosystems is mostly caused by harmful effects from background systems' releases of heavy metals. All three agricultural strategies produced the same outcome. For all three agricultural methods, fine particle matter generation, global warming, and non-carcinogenic toxicity are the key factors affecting HH harm.Identical findings were made for the individualist viewpoint, albeit given the shorter time horizon than the hierarchist perspective, the effects of global warming on terrestrial ecosystems and HH are less significant. Findings from an egalitarian standpoint were similarly comparable, with two major deviations. For HH harm, non-carcinogenic toxicity becomes significant, especially for standard and low-input agricultural systems. This is a reflection of the egalitarian viewpoint's wider temporal horizon than the hierarchist perspective, which has a specific impact on the significance of mental levels of exposure. The next exception is global warming's rising impact on terrestrial ecosystems throughout all agriculture methods, which is offset by the egalitarian perspective's long-term repercussions.

3.5 Effects on the environment

In comparison to standard and RI agriculture systems, our research indicated that natural agriculture systems consistently had fewer environmental consequences per ton of rice produced. A comparison of various rice growing techniques using an LCA analysis According to their findings, the reduced grain production in natural agriculture as compared to standard agriculture totally offsets the decrease in environmental effects caused by the avoidance of the use of fertilizers and pesticides. Studies have shown that scale expansion and better technology for applying natural fertilizer or manure have led to an increase in productivity in natural rice cultivations, which may be very variable.

In contrast to prior studies, our research demonstrates that natural agriculture may result in excellent incomes and increased yields. Natural agriculture systems with yields greater than “3 tons/ha/year” cause less damage to terrestrial ecosystems of rice produced than standard agriculture systems and this can be attributed to the fact that the land use effects are lower for natural agriculture systems than for standard agriculture systems. Since less land is required to produce the same quantity of RP due to the dominance of land use effects, the effects on terrestrial ecosystems consistently decline with yields in all agriculture systems. Some other crops, such as durum wheat and tomato cultivation, have been claimed to have a less environmental impact as yields have increased. Pesticide usage, especially fipronil and diazinon, and synthetic fertiliser use are reduced in natural agriculture systems, resulting in less harm to freshwater ecosystems as compared to standard and RI agriculture systems. Reduced reliance on agrochemicals is one benefit of integrating chemical and biological control strategies in the battle against pests and fungus. One effective approach of integrated pest management is the release of the parasitoid wasp Trichogrammabrassicae into RP fields to combat the striped rice stem-borer Chilosuppressalis. Both high-yield standard agriculture and low-yield, low-input agriculture does the same amount of harm to freshwater ecosystems every ton of rice produced. Some agricultural methods overcompensate for the increase in yields by requiring excessive quantities of fertilizers and pesticides. The effects of pollution from nutrient runoff and pesticides might be mitigated and practice for rice cultivation. Lastly, compared to standard and RI agriculture methods, the HH consequences per ton of rice produced are lower in natural agriculture systems i. We further observed that CH_4 field emissions were significant for HH consequences through global warming, despite the fact that these effects varied from system to system. Nevertheless, our estimates for CH_4 field emission are not final. With the exception of a manure application scaling factor unique to farms, we used the IPCC's Tier 1 emission factor methodology, which involves using essentially general emission scaling factors. Taking measurements of farm-level methane emissions in the field might greatly enhance our ability to predict environmental impacts. Notwithstanding these caveats, a number of additional researches have shown the significance of CH_4 field emissions in calculating rice's greenhouse gas footprint.

3.6 Eco-efficiency

By comparing natural agriculture systems to RI agriculture systems and standard agriculture systems, we discovered that natural agriculture resulted in a much higher E-E of RP production. This result holds true throughout four failure classifications that are symbolic of ecosystem quality and HH, and the consistently greater net financial profit of natural rice. Figures 1 and 2 show that positive relationship between net profit and output, as well as a "negative to neutral association" between environmental effect and yield, which helps explain our finding of a substantially positive relationship among E-E and yield for natural agriculture methods. Both “environmental effect and financial profit” are positively associated to yield in these systems, however, the E-E of RI and traditional agriculture systems did not alter with production for pure water and coastal ecosystems and for HH consequences.

An increase in fertilizer and pesticide applications may boost crop yields. This was also suggested as a means to boost ecoefficiency by optimizing the use of available resources. For terrestrial ecosystems, the greatest gain in E-E over yield occurs as yields grow since less land is required per unit of rice produced. Increases in farm size are also linked to more productive use of land and other resources. Because of economies of scale, less agricultural labor is outsourced, and fewer chemical fertilizers and pesticides are used, all of which contribute to better ecological efficiency.

The chemical and physical qualities of the soil may be improved by bio-fertilizers and compost, leading to higher crop yields. In addition to minimizing the loss of ammonia and nitrate by the use of bio-fertilizers, these two forms of N are also kept in the soil through this practice, which helps to reduce N_2o emissions. From a production standpoint, our research shows that natural rice cultivation is more eco-efficient than both standard and low-input agriculture methods. Competition among agricultural methods that prioritize sustainability depends heavily on consumer demand for natural rice and improved crop yields. The low market penetration of natural rice may be linked to customers' reluctance to pay the higher costs associated with buying organic food. Several researchers propose that including environmental externalities in rice market pricing might encourage natural rice growing.

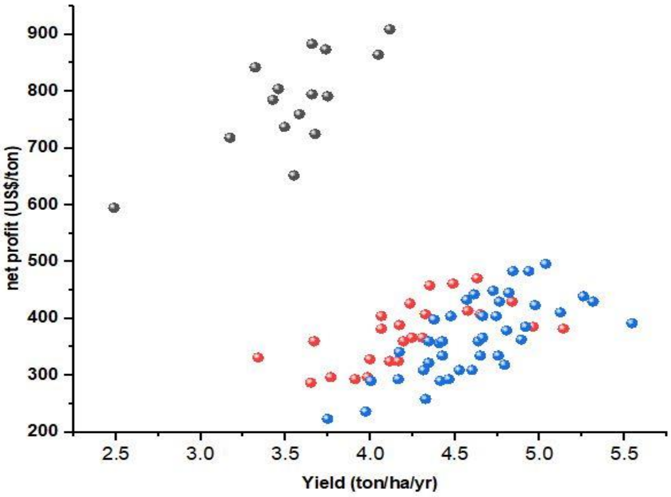
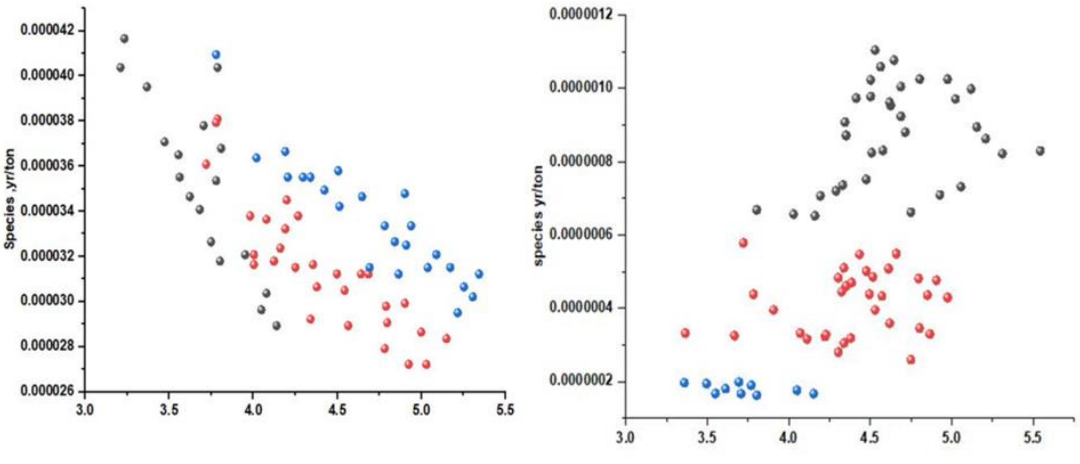
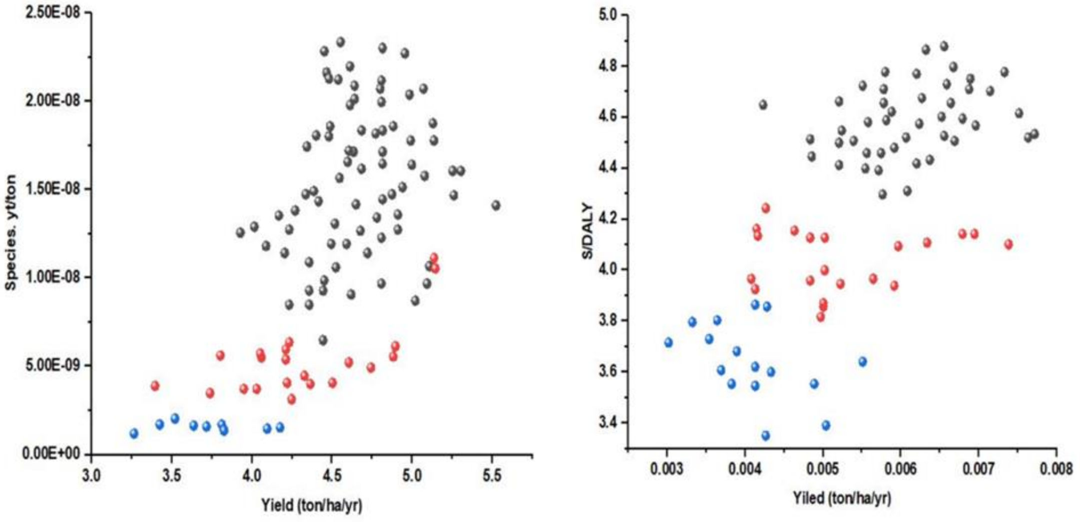


Figure 1: Relationship between net income ($/t paddy produced) and yield (ton/ha/year) for all agriculture system (standard = blue, RI = red, and natural = black)



(a) Terrestrial

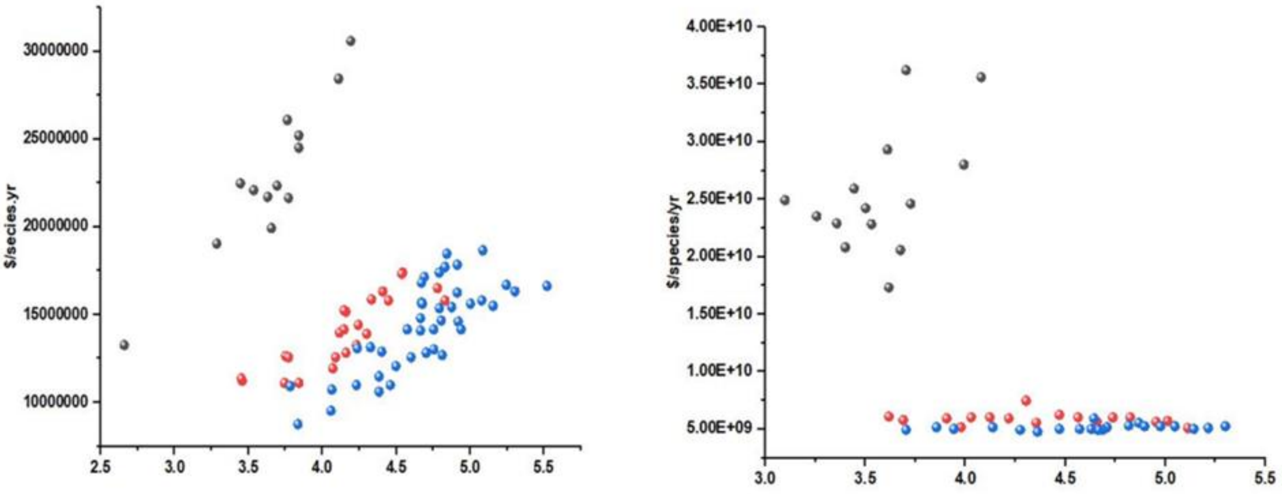
(b) Freshwater



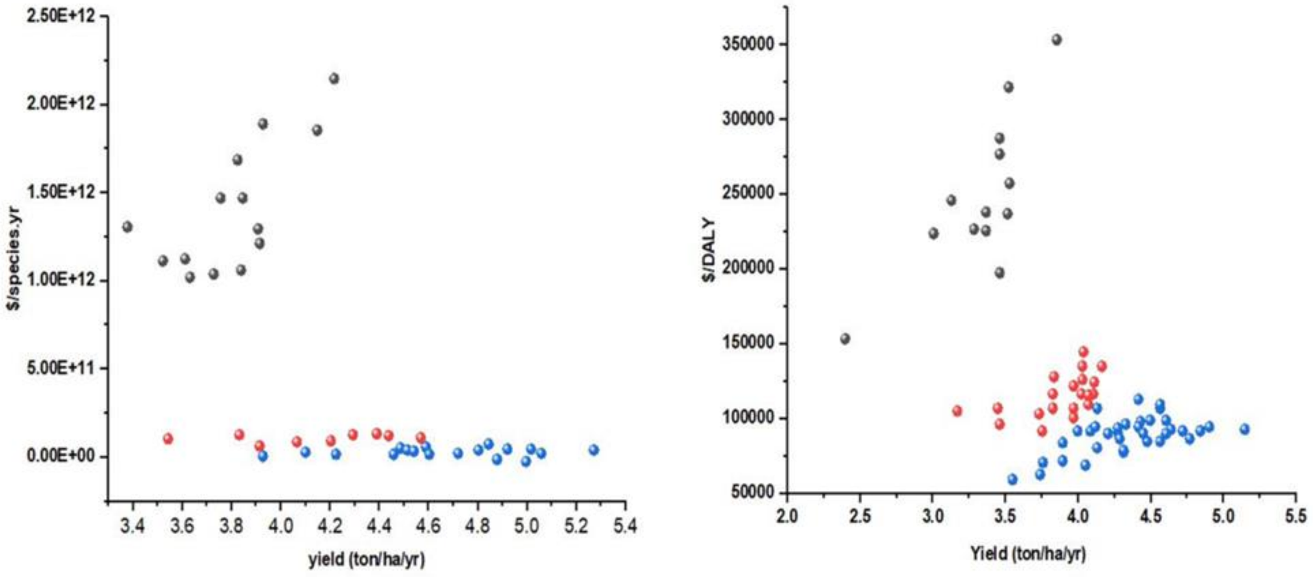
(c) Coastal

(d) Human health

Figure 2: Comparison of environmental impact with agricultural system yield



(a) Terrestrial **(b) Freshwater**



(c) Coastal **(d) Human health**

Figure 3: RP production eco-efficiency for damages as a function of yield (ton/ha/year) for each agriculture style.

Table 1: Financial and ecological data from 210 sampled farms (standard)

	Standard (n =140) Min	1st quartile	Median	3rd quartile	Max
Foreground environmental data (unit/hectare/year)					
Manure(kg)	0	0	0	800	1005
Nylon(kg)	4.4	7.5	8.2	9.1	14
Diesel fuel(kg)	17.2	258	335	421	688
Seed(kg)	25	38	45	50	83
Potassium(kgk_2o)	0	50	70	100	200
Nitrogen(kg)	70	200	230	280	357
Phosphate(kg p_2o_5)	0	116	180	220	325
Oil(kg)	1.1	1.6	1.8	2.3	4.1
Electricity(kwh)	0	85	200	394	720
Pesticide(kg)	8.0	13.0	14.8	17.4	20.3
Yield(ton/hectare/year)					
Yield	3.50	4.32	4.66	4.80	5.69
cH_4Field Foreground environmental data (unit/hectare/year)					
cH_4	135	135.6	135.6	135.6	151
Economic data ranges ($/ton paddy produced)					
Total revenue	2787	3442	3710	3823	4531
Variable cost	980	1230	1380	1484	1700
Fixed cost	30	400	460	548	660
Net profit	230	365	400	430	514
Total life cost	1440	1700	1820	1971	2267

Table 2: Financial and ecological data from 210 sampled farms (RI)

	RI (n = 50)	1st quartile	Median	3rd quartile	Max
Foreground environmental data (unit/hectare/year)					
Manure(kg)	0	200	350	650	900
Nylon(kg)	5	7	8	9	13.4
Diesel fuel(kg)	688	162	194	237	267
Seed(kg)	5	7	8	9	13.4
Potassium(kgk_2o)	0	15	50	75	100
Nitrogen(kg)	55	80	100	120	210
Phosphate(kg p_2o_5)	0	80	100	110	195
Oil(kg)	0.8	1.1	1.2	1.4	1.7
Electricity(kwh)	0	187	231	311	470
Pesticide(kg)	6.2	8.0	8.7		
Yield(ton/hectare/year)					
Yield	5.69	3.00	3.90	4.10	4.25
cH_4Field Foreground environmental data (unit/hectare/year)					
cH_4	135	138.9	141.4	146.1	150.2
Economic data ranges ($/ton paddy produced)					
Total revenue	2389	3106	3265	3384	4149
Variable cost	870	1065	1200	1320	1490
Fixed cost	345	407	480	407	680
Net profit	299	355	395	424	471
Total life cost	1380	1544	1672	1790	2090

Table 3: Financial and ecological data from 210 sampled farms (natural)

	Natural (n = 20)	1st quartile	Median	3rd quartile	Max
Foreground environmental data (unit/hectare/year)					
Manure(kg)	300	473	625	745	800
Nylon(kg)	6	7.3	8	9	9.8
Diesel fuel(kg)	77	132	146	160	190
Seed(kg)	35	39	45	50	60
Potassium(kgk_2o)	0	0	0	0	0
Nitrogen(kg)	0	0	0	0	0
Phosphate(kg p_2o_5)	0	0	0	0	0
Oil(kg)	0.8	1.1	1.2	1.3	1.5
Electricity(kwh)	81	154	191	259	289
Pesticide(kg)	0	0	0	0	0
Yield(ton/hectare/year)					
Yield	1.98	3.11	3.35	3.49	3.95
cH_4Field Foreground environmental data (unit/hectare/year)					
cH_4	140	143.5	145.8	147.8	148
Economic data ranges ($/ton paddy produced)					
Total revenue	2330	3663	3942	4116	4649
Variable cost	500	657.5	794	888	1000
Fixed cost	390	400	463	490	700
Net profit	608	729	797	862	906
Total life cost	988	1091	1229	1371	1700

4. Conclusions

On the basis of widespread on RP production in "India", we discovered that natural agriculture systems consistently had a greater E-E than restricted and standard agriculture systems. Moreover, we discovered that there is a favorable correlation between natural agriculture's E-E and its output. When looking at the effects on terrestrial ecosystems, solely, better yields in RI and traditional agriculture systems result in a greater eco-efficiency, but not for coastal and freshwater ecosystems and HH. This means that the environmental costs of utilizing additional external inputs like fertilizers and pesticides cancel out the financial benefit of increased yields in low-input and traditional systems. The transition to natural agriculture system has been widely praised for its positive effects on both the financial success of rice producers and the protection of HH and natural environments. The share of the market of natural rice growing might grow with better farmer knowledge and the incorporation of environmental externalities into rice pricing.

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