Impacts of Chemical Fertilizer Ban and Adoption of Organic Fertilizer for Paddy Farming: Propensity Score Matching and Value Chain Analysis

S S Niwarthana[1]*, M Thibbotuwawa[2] and H S R Rosairo[3]

ABSTRACT

This study was conducted to estimate the socio-economic impact of the chemical fertilizer ban and organic fertilizer adoption on the paddy sector in Sri Lanka. It aimed to find the answers to several questions related to the sudden policy change including the challenges faced by the paddy sector, the impact on farmer income and farm productivity, and food security changes of the country. This study used both primary and secondary data and evaluated the impact of the chemical fertilizer ban using Value Chain Analysis and propensity score matching methods. The study finds a drop in paddy production and yield levels due to the ban on chemical fertilizers. However, there is no significant impact of the organic fertilizer adoption program on farm yield or income based on the matched sample as shown by ATT results primarily due to the quick reversal of the ban. Value chain analysis showed that the farmers have faced severe challenges due to the inorganic fertilizer ban including poor access to necessary fertilizer, the lack of adequate raw materials for producing organic fertilizers, low quality of available organic fertilizer, insufficient training and extension services related to organic fertilizer and lack of incentives for organic farming. Therefore, future organic policies should have a comprehensive action plan to address the aforementioned challenges. The study further suggests going for an integrated plant nutrition management (IPNM) approach with site-specific application techniques to maximize fertilizer use efficiency and harmful effects.

Keywords: *Chemical fertilizer, organic fertilizer, Fertilizer import ban, Fertilizer policy framework, Value chain analysis, Propensity score matching*

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Introduction

The agriculture sector, an important part of the socio-economy of Sri Lanka, contributes significantly to economic growth, exports, and providing livelihoods to a significant proportion of its people. It accounted for 6.9% of the country's Gross Domestic Product (GDP) and generated Rs.1.5 billion in income (CBSL, 2021). Rice is a dietary staple of Sri Lankans, and it is the major source of energy in the Sri Lankan diet contributing to 40 percent of the daily per capita intake of calories (Department of Census and Statistics, 2019). At the time of independence, high dependence on imports for the supply of rice was a major policy challenge faced by the nation. Hence, successive governments have assigned high priority to achieving the goal of 'self-sufficiency' in rice. As a result, domestic paddy production increased steadily, recording over fivefold growth in the total production from 1960 to 2022, reducing the import dependency significantly (Department of Census and Statistics 2023). However, misuse of chemical input is vigorously debated in the agricultural sector and countries have been adopting more sustainable farming practices worldwide in recent times.

The Government of Sri Lanka (GOSL) imposed the ban on the importation of chemical fertilizers, pesticides, and herbicides by the Imports and Exports (Control) Regulation No 07 of 2021 on May 06, 2021. The ban was aimed at shifting conventional farming to entirely organic farming to make Sri Lanka the first country to achieve 100% organic status globally and it has been guided by the government's responsibility to ensure the right of Sri Lankan consumers to access quality, safe and nutritious food. Other than health reasons, there was an urgent need for policymakers to reduce fertilizer imports during this economic crisis to improve the nation's foreign exchange situation by cutting a massive expenditure on subsidies from the pandemic-hit public budget (Ted Nordhaus, 2022). For example, Sri Lanka imported 952,000 Mt of fertilizer in 2020 equivalent to Rs. Million 48,227. With the import ban, the import volume of fertilizer dropped drastically to 412,000 Mt in 2021 and further down to 363,000 Mt in 2022. Despite low import volumes compared to 2021, expenditure on fertilizer imports exhibited a considerable increase in 2022 due to the increase in average import prices.

Moreover, there is a popular belief that excessive and improper use and elevated exposure to fertilizers and agrochemicals are among the causes of chronic kidney diseases (CKD) (Beillard and Galappattige, USDA, 2021). Thus, reducing the country's rising healthcare costs due to the overuse of chemicals in agricultural production has been also indicated as a compelling reason for the ban (Vineet Kumar, 2021). Nevertheless, despite CKD being highly prevalent in agricultural production areas, there is no strong evidence to prove the impact of chemical fertilizers on CKD issues (Wimalawansa, 2014).

Policies that are taken to address one group of stakeholders without proper consultation of all the stakeholders often lead to complaints by others due to adverse impacts on their economic welfare. Similarly, with stiff opposition from the different stakeholders, the import ban on chemical fertilizers was replaced by a license requirement on July 31, 2021. The ban on the importation of chemical fertilizers was removed on November 30, 2021, considering the issues faced by the farmers during the 2021/22 *Maha* Season. Despite the removal of the ban, the country experienced a severe shortage of fertilizer due to various domestic and global issues. Fertilizer markets experienced rising prices and supply disruptions due to the Russia-Ukraine conflict. The impact of this shock has been compounded for Sri Lanka which has been suffering from a severe economic crisis due to a lack of foreign reserves, a debt default, high inflation, import restrictions, and shortages of critical goods and services (Thibbotuwawa *et al.*, 2023).

However, sustainable agriculture including organic farming was at the top of the policy agenda of the agriculture sector, and the government is seriously plagued with a shortage of foreign exchange which is necessary for importing chemical fertilizers. Thus, giving important evidence on the impact of the policy on the chemical fertilizer ban and making crucial recommendations for fertilizer-related policies for use by policymakers is a timely requirement. Against this backdrop, this research primarily focused on estimating the socio-economic impacts of the chemical fertilizer ban on the rice sector in Sri Lanka. To achieve the above objective, the study aimed to identify major challenges faced by paddy farmers along the value chain during the 2021/22 Maha season and to examine the effect of the organic fertilizer adoption on farmer productivity and farm income during the 2021/22 Maha Season due to the chemical fertilizer ban. Further, the impacts of the ban on national food security are evaluated using secondary data. Finally, global experiences of converting from conventional to organic farming are evaluated to identify the challenges, different strategies, and success stories to propose policy recommendations to support an effective fertilizer policy framework for the country.

The rest of the paper is organized as follows. Section 2 undertakes a comprehensive review of the literature on paddy cultivation, usage of chemical fertilizer, and organic farming to set the scene. Section 3 presents the research questions, methodology, and data. Section 4 offers the analytical results of the descriptive and quantitative analysis. Section 5 concludes with recommendations for a better transformation program.

Literature Review

Paddy farmers in Sri Lanka have been applying Urea, Sulphate of Ammonia (SA), Muriate of Potash (MOP), and Triple Super Phosphate (TSP) on paddy since the green revolution. About 92% of synthetic fertilizers applied by local farmers are imported fertilizers into the country. Among them, approximately 70% of imported fertilizers are used for rice. Fertilizer is heavily subsidized for paddy farmers and changes in the level or method of subsidy are often associated with the use of fertilizer. For example, the import of synthetic fertilizers in Sri Lanka dropped approximately by 33% from 816,900 Kg in 2015 to approximately 548,100 Kg in 2017 due to the change in government subsidy policy from material subsidy to a cash grant scheme (Dandeniya and Caucci, 2020). Therefore, chemical fertilizer usage and subsidy are said to be beneficial for paddy farmers for many reasons including increased paddy production, paddy productivity, farmer income, and living status of the farmers.

Empirical evidence shows that fertilizer subsidies have played a significant role in the growth of the paddy extent of cultivation as well as paddy production. According to the study of Abeysinghe, 2014, there is a positive relationship between applied fertilizer quantity and the amount of paddy production in the Matale District. Dulanjani and Shantha (2021) examined the microeconomic impact of fertilizer subsidy in Sri Lanka with special reference to the Murawesihena Block under the Udawalawe irrigation system. The results revealed that there is a positive relationship between fertilizer usage and average paddy yield in the study area. Samarasekara (2015) also indicated that there is a positive impact of the subsidy on the usage of fertilizer, average paddy yield, and paddy harvested extent in the country. Ranathilaka and Imbulana Arachchi, (2019) examined that the government fertilizer subsidy policy is significantly and positively related to paddy productivity, contributing to an increase in paddy production and uplifting farmers' living status in Polonnaruwa District.

On the other hand, scholars have also been widely concerned about its environmental impacts. Environmental pollution, notably soil and water contamination, biodiversity loss, and collateral harm to organisms were identified as negative environmental impacts of the green revolution (Wijesinghe, 2021). The overuse of chemical fertilizers leads to soil acidity, reduced soil fertility, pollution of air, water, and soil, and lessened important nutrients of soil and minerals, by bringing hazards to the environment. Sole utilization of chemical fertilizers led to weak microbial activity in the cropping system. Constant usage of chemical fertilizer and long-term persistence on the soil may result in decreasing organic matter load, humus load, and useful organisms, and it may cause stunting plant growth, and even become responsible for the emission of greenhouse gases (Heena Nisar Pahalvi *et al.,* 2021).

Sri Lanka doesn’t have a separate organic farming policy, but the National Agriculture Policy 2023 focuses on promoting the organic agriculture sector through providing incentives, enforcing regulatory framework, and technological advancement and dissemination. According to the global literature, some countries have adopted strategies to grow organic agriculture, and Sikkim State in India has already declared 100 percent organic status under the national strategy of ‘one state at a time’ (John Paull, 2017). This can be considered a successful case of converting conventional agriculture into a sustainable organic agriculture model. The name is Sikkim has been uplifted worldwide as the only state to become 100 percent organic (Amit Khurana & Vineet Kuma, 2020). Their conversion policy was not just a sudden decision, the Sikkim government had introduced a structured and organized policy framework which was gradually implemented over 13 years. As such, Sikkim was awarded the 2018 Future Policy Award for the world’s best laws and policies promoting agroecology (FAO, 2022).

To discourage the purchasing process, reducing subsidies on chemical fertilizers and pesticides at the rate of 10 percent every year was implemented as one of the initial steps. Apart from that, the Sikkim government interrupted lifting the Government of India quota, placing an order to SIMFED for the supply of synthetic fertilizers, issuing trade licenses for trading fertilizers and pesticides, and even transporting from outside the state. With gradual minimization, the state took the further decision to close down all commercial fertilizer and pesticide outlets in 2009 and then, banned the importation of any chemical pesticides or fertilizers into Sikkim in 2014 (State Policy on Organic Farming, GOS). Among the actions taken by the Sikkim government towards its organic conversion, purchasing and making available certified organic manures for farmers, subsidizing a large number of rural and vermicompost units to encourage farm production, organizing large-scale training and orientation programs, and establishing infrastructures like seed processing units to encourage farmers to produce certified seeds of desired varieties organically can be highlighted. Those actions assisted in avoiding interruptions between transition periods. Further, three Livelihood schools on organic farming were established. This aimed to generate employment opportunities to educate unemployed youths of the state.

As the entire state is being converted into organic, Sikkim focused on including the basic concept of organic farming in the course curriculum for school education for entire state children and the establishment of study centres in every headquarters. These children in turn will help their parents in the organic farming process. Here, they introduced the various integrated systems of government departments, institutions, and civil societies, and their schemes harmoniously duly considering organic farming principles and local situations. These include Government departments such as Agriculture, Animal Husbandry, Forest, Fisheries, Local Bodies, Finance, Revenue, Industries, Agriculture universities, and ICAR institutions in the state (State Policy on Organic Farming, GOS). However, Sikkim farmers faced many obstacles at the beginning of the organic conversion period. Sathish Rao (2017) indicated that low yield production, an infestation of pests and disease, certification, and profitability due to the organic adoption were challengeable in Sikkim. The study found that organic yields are only 19.2% lower than conventional yields with a credible interval of 95% ranging from 15.5 % to 22.9%. Moreover, Lauren (2015) also proved that conventional yields were significantly higher than organic crop types and the yield ratios of most crop types do not vary significantly from one another (Lauren C. *et al*, 2015).

Cuba is also an inspiring example of developing their food system as a more localized and sustainable one (Wright, 2005). After the disintegration of the Soviet Bloc in 1991, the national food crisis circumstance had been developed due to the shortage of industrial chemicals and fuel inputs. It led to deciding whether to step aside their population suffering from hunger or turn to economically and ecologically viable alternatives. Therefore, a more common sense and logical approach emerged in the direction of food and farming (Wright, 2012). Cuban experience noteworthy evidenced that the necessity of implementing such a transition of agriculture production was beyond their policy design. Cuban experience indicated that there are three pillars behind the success of the organic policy transition, namely, Cuban farmers' cooperative movements, the creation of organopónicos, and the hard work of Cubans. Cuban farmers have gone through the cooperative movement which shared their local knowledge. That was guided to find the Organic agriculture practice as a development alternative in response to the crisis of the farming community.

Secondly, to solve the national food problem of Cuba organopónicos were introduced. By adopting this concept, urban ecological gardens were created in the suburbs of Cuban biggest cities. This solution assisted in providing food to the local communities, coping with changing poor eating habits and contributing to the elimination of hunger. The third one is the hard work of Cubans. Cuban farmers were working hard, and the revolutionary people revealed their high degree of interest regard to social problems. For instance, creating a promising education and health care, developing good technologies providing cultural enrichment by educating many scientists and world sportsmen to the entire world, and contributing to agriculture can be investigated (Livia Eliasova, 2016).

Bhuthanese also initiated converting their farming to Organic status in 2003 and expressed their interest in the first 100 %Organic country. Bhutan farmers who operate in small and integrated farming under the mercy of a distantly located highly volatile market system have a major impact on adopting organic agriculture. The policy could choke small farmers between two objectives of substance and commercialization while having plenty of benefits. These were limiting the production without the support of alternative production technologies for the agriculture system, limiting access to organic manure due to the declining FYM/leaf litter of poor shooting management, additional effort on the certification process, and unlearning conventional practices (Mahesh Ghimira, 2008). Apart from these, extensive analyses showed that organic crop yields on average are 24% lower than conventional yields. The organic policy affected Bhutan's GDP, increased welfare losses, lowered food security, and weakened Bhutan's cereal self-sufficiency. There was a significant decline in the Nitrogen (N) availability to crops (Feuebacher, *et al.*, 2018)

Against this backdrop, this study aims to explore the major challenges faced by farmers during the organic conversion period in Sri Lanka to identify the challenges and drawbacks of the organic conversion process relative to global experiences. Also, this study attempts to evaluate the impacts of organic conversion on farmers' yield and income as well as broader food security impacts on the country which is a gap in the literature.

Methodology and Data

Theoretical Framework

The study adopted a mix of quantitative and qualitative methodological approaches in answering the below research questions.

1. What are the major challenges faced by paddy farmers during the 2021/22 Maha season due to the chemical fertilizer ban?
2. What is the effect of the organic fertilizer adoption on farmer productivity and farm income during the 2021/22 Maha Season due to the chemical fertilizer ban?
3. What are the impacts on rice production and food security at the national level due to the chemical fertilizer ban?
4. What were the challenges faced and different strategies and effective policies adopted by other countries when converting from conventional to organic paddy farming?
5. What are the policy recommendations to support an effective fertilizer policy framework for the country?

Various secondary and primary data collection instruments/tools were used in the study. Reviewing literature (desk research) was the instrument used in secondary data collection. A consultative approach was adopted throughout the evaluation process.

Value Chain Analysis

The economic system of food production, distribution, and consumption are organized as interconnected value chains. A value chain consists of all value-generating activities required to bring a product/service from primary producers through different phases of production to distribution of the final product to consumers (Kaplinsky R., 2004). Originally defined by Porter in 1985, the value chain analysis (VCA) has emerged as a powerful analytical tool in development policymaking, and it has been widely adopted by researchers, industry, and development practitioners to understand the different production systems (Kaplinsky R. &., 2001). The standard VCA method developed by the United States Agency for International Development (USAID) was applied in this study (Figure 1). This framework consists of 4 steps: 1) data collection; 2) value chain mapping; 3) analysis of opportunities and constraints and 4) vetting findings and proposing recommendations. Accordingly, both secondary and primary data were collected in the first step. These collected data were analyzed in the mapping exercise in the second step and the constraints and opportunities were identified in the third step. Finally, the findings were vetted through consultation in the final step.

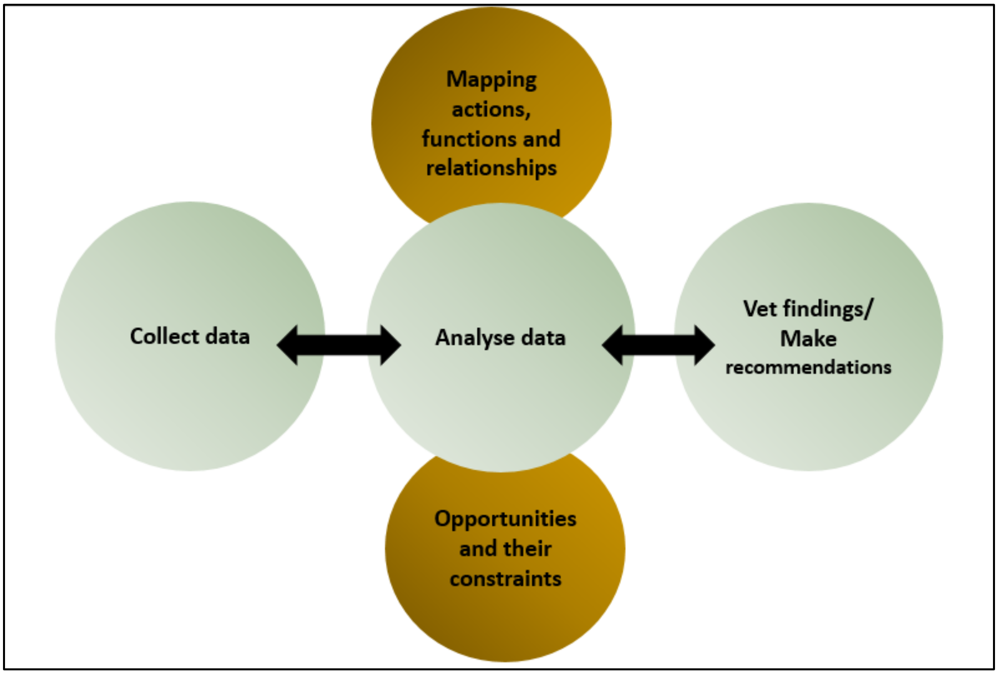

Figure 1. Process for the VCA
Source: Authors’ compilation.

The content analysis method was used for analyzing the qualitative data collected. This includes labelling/ coding all information so that similarities and differences can be recognized for summarization. Here, the aim was to make sense of the data collected and highlight the important messages and features or findings. Value chain mapping was the process of developing a visual depiction of the basic structure of the value chain. A value chain map illustrates the way the product flows from raw material to end markets and presents how the industry functions. Final products and markets, key functions/activities, various market channels, actors, enabling environment, and linkages/relationships will be mapped schematically; these have been explained for a better understanding of the market structure, dynamics, and enabling environment including quality standards and safety regulations, etc.

Since there are no rigid rules on value chain mapping, the following guidelines were adopted in the mapping process. First, the producers were listed at the top of the map, and the functions were listed on the right side of the map. Then, end markets were listed across the bottom of the map and the participants/actors were filled in blocks according to their functions and markets. If participants/actors were involved in more than one function or market, the block was extended to reach the relevant functions/markets. Next, the linkages were drawn between participant blocks with arrows in the direction of the product flow. Finally, additional information related to the value chain such as supporting markets and business enabling environment was placed in the value chain space. This approach was used to summarize data in an organized manner by describing the impact of the ban on chemical fertilizer on farm households, especially focusing on paddy production and yield levels.

Propensity Score Matching

To analyze the impact of the chemical fertilizer, ban on farm yield and farm income during the 2021/22 *Maha* season, the propensity score method was used. Farmers choose either to adopt or not to adopt a given technology based on expectations, objectives, and observable and unobservable characteristics which is referred to as self-selection (Chala and Tilahun, 2014). Especially, during the 2021/22 *Maha* season, some farmers decided to remain as non-adopters applying insufficient amounts available to themselves or buying at higher prices from the available previous stock of chemical fertilizers in the market. Thus, a simple comparison of the adopters with non-adopters tends to overestimate the impact of improved agricultural technology on farmers' productivity and income. Several methods have been used in the literature to correct the sample selection problem occurring in econometric estimations. These methods include the PSM (Amare, et al., 2012; Asfaw et al., 2012; Jena et al., 2012), the Heckman selection model (Beltran et al., 2013; Blundell and Dias, 2002), the endogenous switching regression models (Alene and Manyong, 2007; Amare, et al., 2012; Asfaw, et al., 2012) and instrumental variable models (Heckman, 1997; Nelson and Startz, 1990). No one method dominates over the others and the appropriate choice of evaluation method depends on data availability and the policy parameters of interest (Blundell and Dias, 2002).

Propensity Score Matching has been widely used for program evaluation in many fields since it was first suggested by Rosenbaum and Rubin (1983). It was used to create a matching counterfactual control group that controls all the factors except the treatment and the outcome. The difference in performance between the matched treated and control groups was tested using mean comparison tests. In this study, PSM was used to compare the difference between the outcome variables of treated (organic fertilizer adopters) and control (non-adopters) farmers with similar characteristics. It determines the causal effect of the adoption of organic manures on different outcome variables such as farm yield and farm income. The PSM process was carried out in four steps: first, the probability of adoption was estimated for each unit in the sample by a logit model; second, a matching algorithm was selected and used to match the organic fertilizer adopters with non-adopters to construct a comparison group; third, a balancing test was conducted after matching to ascertain whether the differences in covariates in the two groups in the matched sample have been eliminated; and forth, the program effect was estimated.

In the first step, a logit model was estimated and thereby the propensity scores for each observation would be obtained. The outcome variable Y is either paddy yield or farmer income and the treatment is whether a farmer adopted organic fertilizer or not. The treatment is defined as a binary variable for adopters and for non-adopters. Where Y_j^C is the outcome for the j^{th} control household and Y_i^T is the outcome for the i^{th} treated household, the outcome variable Y can be expressed as:

$$Y = \begin{cases} Y_j^C if \;\; D = 0 \\ Y_i^T if \;\; D = 1 \end{cases}, \qquad (1)$$

Each household has a vector of exogenous characteristics (covariates) denoted by X that includes household characteristics (household total, gender of the respondent, age of the respondent, level of education, employment status, household income, year of farming experience, asset index and Locality (sector, district). Since it is difficult to match units based on a multidimensional vector of characteristics, the PSM summarizes those characteristics using a single index variable called the propensity score which is used in matching (Katchova, 2010). The propensity score measures the conditional probabilities of adopting treatment, given a set of pre-treatment characteristics, which can be expressed below (Rosenbaum and Rubin, 1983; Rubin, 1977). The magnitude of a propensity score is between 0 and 1; the larger the score, the more likely the farmers would adopt.

$$p(X) = \Pr(D = 1|X) = E(D|X). \qquad (2)$$

In the second step, the "nearest neighbour (NN) matching" method, which is one of the most commonly used matching methods to form two balanced groups based on their estimated propensity scores was used. Control units for which there are no treated units with a sufficiently similar score were discarded from the sample. After the matching, households in each group would have similar propensity scores. Where p_i and p_j are propensity scores of the i^{th} treated unit and j^{th} nearest neighbour, the nearest neighbour matching of control units will be given as below.

$$C(i) = \min_j \left\| p_i - p_j \right\|, \qquad (3)$$

In the third step, the balance was tested using a t-test to compare the means of all covariates included in the propensity score to determine if the means were statistically similar in the treated and control groups. Once units were matched, the characteristics of the constructed treated and control groups should not be significantly different; i.e., the matched units in the treated and control groups should be statistically comparable. If the balance was not achieved; i.e., the means of the covariates are statistically different, a different matching option or specification should be used until the sample was sufficiently balanced (Katchova, 2010).

Finally, the impact on farmers would be calculated by comparing the means of outcomes across adopters and their matches of non-adopters. The most common evaluation parameter of interest is the ‘average treatment effect on the treated (ATT)’. It gave the difference between the outcome for the treated group which was observable and the outcome for the treated group had it not been treated which was unobservable (Katchova, 2010). Where n^T is the number of treated units and the weights $w_{ij} = 1$ if $j \in C(i)$ and $w_{ij} = 0$ otherwise, ATT for the NN matching were calculated as follows:

$$ATT^{NN} = \frac{1}{n^T} \sum_{i \in T} \left(Y_i^T - \sum_{j \in C(i)} w_{ij} Y_j^C \right), \qquad (4)$$

This was the difference between the outcome variable (paddy yield and farmer income) for organic fertilizer adopters and the outcome they would have received had they not adopted organic fertilizers.

Empirical Model

This study analyzed the impact of the organic fertilizer adoption program on farm yield and farm income during the 2021/22 *Maha* season. Farm yield and income were used to construct the two models and selected hypothesized covariates were referred to according to the previous papers (Mukuken G. Wordofa *et al.*, 2021 and Md Abdus Salam *et al.*, 2021). The Asset index was calculated by using Principal Component Analysis (PCA) and ranked on a five-point scale where 5 indicates the highest asset value and 1 indicates the least asset value. The asset index value outcomes were measures based on household and living conditions, land assets, farm machinery, and irrigation methods. The propensity score matching method was used to evaluate the impact of organic fertilizer adoption on farm yield and income considering the selection problem. T study group the yield of some separately by taking the receipt of treatments as one indicator variable.

$$Y = \alpha + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 + \beta_4 X_4 + \beta_5 X_5 + \beta_6 X_6 + \beta_7 X_7 + \beta_8 X_8 + \beta_9 X_9 + \beta_{10} X_{10} + \beta_{11} X_{11} + \beta_{12} X_{12} + \beta_{13} X_1 + \beta_{14} X_{14} + \beta_{15} X_{15} + \beta_{16} X_{16} + \epsilon \quad (5)$$

Where; Y = Farm yield (Kg/acre) / Income (Rupees)1 family X_1=Family size (number); X_2=Gender (1= female, 00male); X_3= Age (years); X_4= Level of education (Primary and below=1, Secondary=2, Tertiary & Above=3); X_5= Employment status (Farmer=0, Non farmer=1); X_6= Farming experience (years); X_7= Household income (Rupees); X_8= Asset index (index value); X_9= Total own paddy land (Acres); X_{10}= Total fertilizer cost (Rupees); X_{11}= Hired labour usage (Yes= 1 No=0); X_{12}= Extension on organic (Yes= 1 No=0); X_{13}= Previous experience on organic (Yes= 1 No=0); X_{14}= Subsistence (Yes= 1 No=0); X_{15}= District (*Kurunegala*=1, *Anuradhapura*=2, *Polonnaruwa*=3, *Kaluthara*=4); X_{16}= Willingness on organic (Yes=1 No=2); α, $\beta_1 \ldots \beta_{16}$= coefficients to estimated; ϵ = error term

Data

The data was collected using a questionnaire-based survey conducted among 400 farm households, focus group discussions (FGDs), and key informant interviews (KIIs). The survey was conducted among paddy farmers who used organic fertilizer and those who used chemical fertilizers during the 2021/22 *Maha* Season to capture data on the last *Maha* Season (2021/22) in four districts namely *Anuradhapura, Polonnaruwa, Kurunegala,* and *Kaluthara.* Two-stage sampling techniques were used to identify respondents. In the first stage, purposive sampling of Divisional Secretariat Divisions (DSDs) was used leading to the selection of the specific area of data collection. In the second stage, systematic sampling was used to choose a sample of adopters of organic fertilizer whereas a simple random sampling technique was used to choose a sample of non-adopters.

The survey questionnaire consisted of information related to household characteristics, farming characteristics, yield levels, land management practices, paddy cultivation inputs, agrochemical usage, irrigation, market details, debts and credits, access to extension, the decision on conversion into organic farming, perception on organic farming and health and environmental concerns. The farmers who were converted from using inorganic fertilizer during the 2020/21 previous *Maha* season to using organic fertilizers such as compost, manure, organic liquid, and other organic fertilizer only during the 2021/22 *Maha* season were considered adopters while the remaining respondents in the sample were considered non-adopters to estimate the program effect. Out of the total sample of 400 farmers, 120 farmers were organic adopters, while 280 farmers were non-adopters at the end of the survey according to the fertilizer types that were used by each farmer. The study also involved FGDs with farmers and KIIs with other stakeholders such as millers, collectors, and traders based on specific pre-determined interview guides covering the key themes relevant to the study aimed at collecting information relevant to the rice value chain.

Results and Discussion

Implications of Chemical Fertilizer Ban: Value Chain Analysis

The existing marketing channels are illustrated in the value chain map in Figure 2. The value chain of paddy/rice includes core actors (Producers/Farmers; Collectors; processors/ Millers; wholesalers and Retailers); input suppliers (e.g., fertilizer companies) and other support service providers (e.g. farmer organizations, agrarian services centers, etc.). Annually, 800,000 families cultivate over 1 million ha of land in two seasons. The collection of paddy from farmers is done by paddy collectors, either village collectors or town collectors. They include private sector collectors, brokers, and local millers (small/medium/large scale) and state sector Paddy Marketing Board (PMB) and Multi-purpose co-operative societies (MPCSs).

Both the village collectors and town collectors deliver paddy to processors/millers who undertake functions like grading, sorting, refining, and packaging. The well-established large millers in surplus areas depend less on paddy collectors and they have established links directly with farmers. Small and medium-scale millers mostly depend on the collectors. Milled rice is commonly sold to wholesalers but is also sometimes sold directly to retailers. Large-scale millers supply the bulk of the milled rice to wholesalers, either branded in packages of different weights or unbranded. Retailers (e.g. village shops, cooperatives, supermarkets, and retail chains like Cargills, Keels, etc.) source rice through direct mill purchases or wholesalers. Usually, retail chains purchase branded rice directly from large-scale millers or purchase unbranded milled rice from small and medium millers and pack using their brand names.

The government fertilizer distribution has been dominant in supplying chemical fertilizer inputs to registered paddy farmers in Sri Lanka for a few decades. This distribution is implemented among paddy farmers through Agrarian Services centres (ASC) in particular Divisional Secretariat Divisions. The majority of paddy farmers receive subsidized fertilizer and few farmers purchased fertilizer from private shops when they had inadequate fertilizers to conduct farming activities. After banning the importation of chemical fertilizers in April 2021 organic fertilizer usage was encouraged by the government. However, many farmers were able to procure chemical fertilizers from the remaining stocks through private sellers and some farmers already had remaining stocks from the previous season. However, during the 2021/22 Maha season, a severe shortage of chemical fertilizers (Urea, TSP, and MOP) was experienced all over the country.

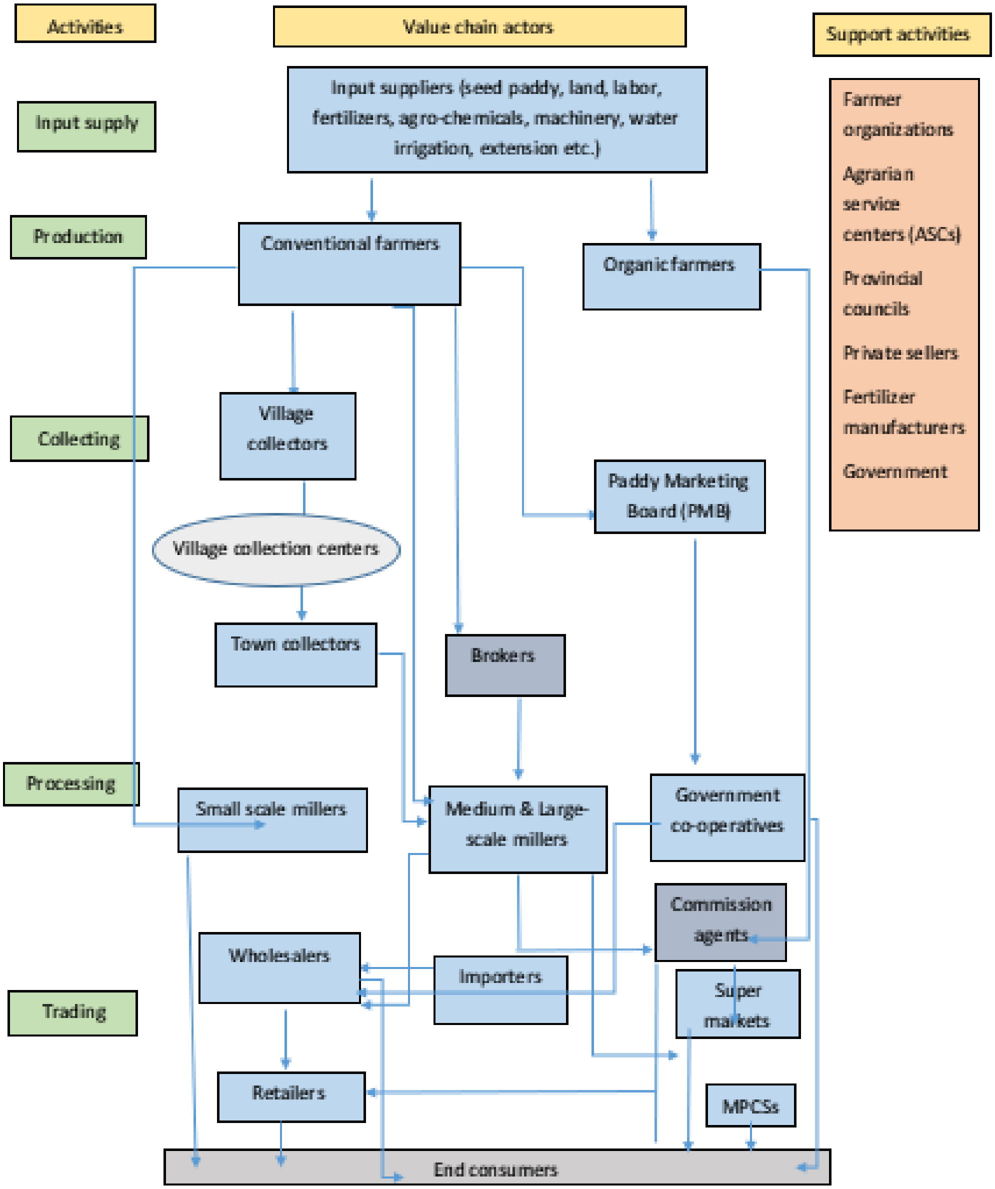

Figure 2. Rice Value Chain Map in Sri Lanka

Several registered organic fertilizer manufacturers manufacture compost and organic liquid fertilizers for the market. Paddy farmers too have been involved in their production of compost and manure by widely using Gliricidia and straw to apply the farmlands on an ad-hoc basis. However, the lack of supply of both chemical and organic fertilizer has been well observed during the period of the chemical fertilizer ban and afterwards. Figure 3 illustrates the farmers' perceptions of organic farming based on the sample survey. Most farmers are willing to engage in organic farming and strongly believe that the transition to organic farming can have positive benefits for human health and the environment. Yet, their perception of the production capacity of organic fertilizer and the expected output from using organic fertilizer is negative.

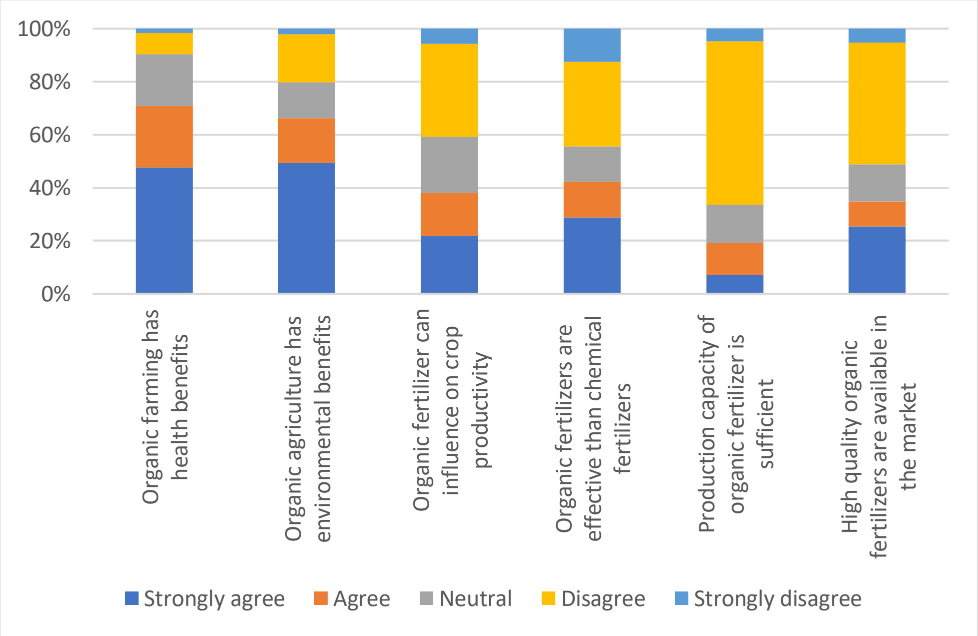

Figure 3. Farmers' Perceptions on Organic Farming

Most of the farmers believe that the current production capacity by the farmers and the industry is not enough to fulfil the farmers' demand for organic fertilizers. The issues highlighted by the farmers include a lack of ingredients necessary for organic fertilizer manufacturing such as Gliricidia plantations and animal husbandry. Also, farmers still lack knowledge in respect of raw materials handling, correct dosage, and execution in farmlands of organic fertilizers. While they have been provided with some extension facilities by the Agrarian Service Department through Agricultural Instructors, these extension programs haven't been properly implemented within some agricultural areas. Also, the officers haven't had sufficient exposure and experience in organic farming.

In terms of product quality, 46 percent of farmers were on the perception that the quality of organic fertilizers in the market is less than satisfactory based on their experiences with higher quantities of impurities like mud, ash, sand, paddy husks, etc. which they believed to have increased weed infestation. Also, a majority of farmers have the perception that organic fertilizers are less effective than chemical fertilizers because organic fertilizers cannot influence crop productivity as chemical fertilizers. Because of these reasons, more than half of the respondents (56 percent) were not willing to pay for organic fertilizers. A reduction of harvest collection has been experienced by the collectors, particularly the small-scale collectors adversely affecting their market operations while risking being thrown away from the industry in the face of increasing competition. It is difficult to handle fertilizers since this is very time-consuming for farmers rather than chemical fertilizers.

In summary, value chain analysis indicated that transforming the whole country from chemical fertilizer application to organic farming without a proper action plan would be a great challenge. Since the whole value chain has been accustomed to farming high-yielding varieties compatible with chemical fertilizers, the need for a reasonable period for proper adoption has been highlighted by the value chain stakeholders.

Impacts of the Fertilizer Ban on Paddy Production: Secondary Data Analysis

The ban on chemical fertilizers was one of the major supply shocks that affected food production while contributing to food shortages and high food prices. While the ban was lifted in November 2021, the damage of flaws in this policy decision had already occurred giving rise to a string of adverse events on food security.

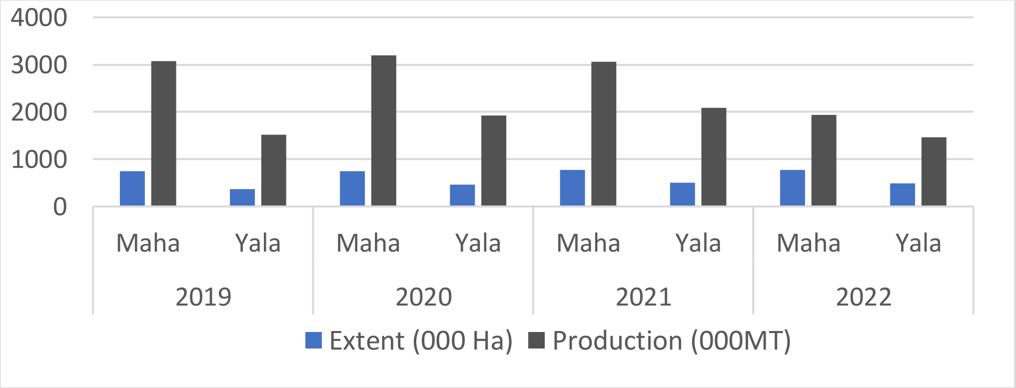

Figure 4. Changes in Paddy Production During the Chemical Fertilizer Ban

When the ban was imposed, the Yala cultivation season in 2021 had already started with the available fertilizer, and therefore, no observed impact was found on paddy cultivation relative to the previous Yala season. However, even with the lifting of the ban, both paddy production (37%) and paddy yield (34%) dropped significantly in the Maha 2021/2022 season relative to the previous Maha season even without any reduction of cultivated extent due to a shortage of fertilizer (Figure 4).

Since then, exorbitant fertilizer prices in the world market and export restrictions set out by fertilizer-producing countries exacerbated the problem further. The price of urea plummeted by 267% from USD 245/MT in November 2020 to an all-time high of USD 900/MT in November 2021. This has had severe implications for Sri Lanka's food security, requiring the country to import and seek support from different countries to fill the production gap. Among these were rice imports estimated roughly at 800,000 MT. The implications of continuing fertilizer shortages continued even in the Yala 2022 season with a drop in production by 30% and the yield levels by 26% due to fertilizer shortages (Figure 4). Further, Sri Lanka had to import a significant amount of rice from the world market despite the foreign exchange shortages the country was plagued with (Figure 5).

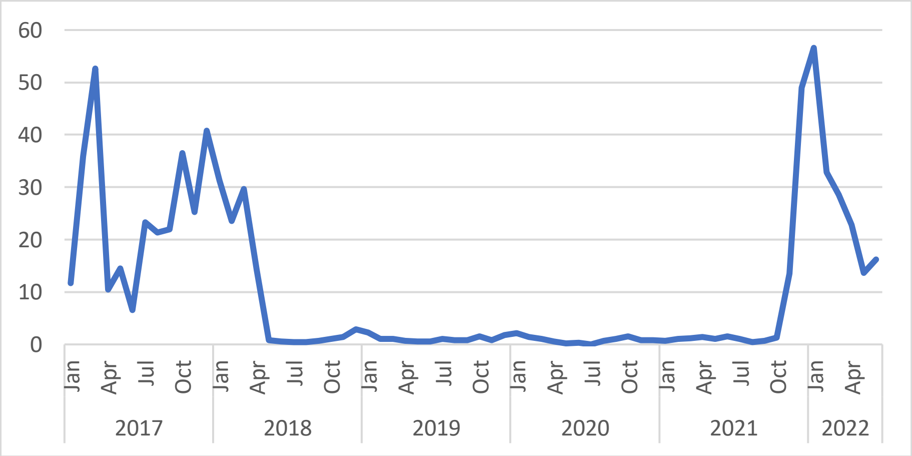

Figure 5. Monthly Rice Import Value of Sri Lanka in Recent Times (USD Mil)

Impacts of the Fertilizer Ban on Farm Yield and Income: PSM Analysis

Table 1 reports the logit model results of conditional probabilities for shifting to organic fertilizer application after the chemical fertilizer ban in PSM. The model is statistically significant, as measured by the likelihood ratio test. Some of the variables are also significant at 1% and 5% levels. The household's income and asset index have positive relationships with adopting organic though only the asset index is significant. Farmers from the Polonnaruwa District have a significantly lower probability of adopting organic fertilizer than the other districts. Farm sizes are relatively bigger in this district and organic fertilizer application is relatively difficult in large farms due to the lower availability of organic fertilizer. This is further confirmed by the negative and significant relationship between the land extent and the adoption of organic fertilizer. Farm households with higher access to credit have a higher probability of adopting organic fertilizer.

Table 1. Logistic model results for conditional probabilities for participation

Variable	Coefficient	Std. Err.	[95% Conf. Interval]	
Age	0.0054	0.0104	-0.0149	0.0258
Gender	0.5257	0.3537	-0.1676	1.2191
Education: Primary	-0.4007	0.6046	-1.5858	0.7844
Secondary	-0.2563	0.2942	-0.8330	0.3203
Family Size	0.1583	0.11898	-0.0748	0.3915
Employment Status	-0.1898	0.3129	-0.8031	0.4234
HH income	1.74e-06	1.57e-06	-1.34e-06	4.83e-06
Asset Index	0.3176**	0.1557	0.01236	0.6229
Farming experience	0.0059	0.0111	-0.0158	0.0277
Subsistence	0.4404	0.3579	-0.2610	1.1419
District: Kurunegala	-0.3290	0.5508	-1.4085	0.7505
Anuradhapura	0.7887	0.6076	-0.4022	1.9796
Polonnaruwa	-1.5875***	0.49391	-2.5556	-0.6195
Hired labour use	0.0949	0.2897	-0.4730	0.6628
Total cost of fertilizer	-5.55e-07	2.56e-06	-5.56e-06	4.45e-06
Total paddy land	-0.2332**	0.0983	-0.4259	-0.0405
Willingness for Organic	0.5231	0.3708	-0.2036	1.2500
Previous organic experience	-0.5158	0.3147	-1.1327	0.1011
Extension on Organic	-0.0244	0.4510	-0.9085	0.8596
Access to credit	0.9006**	0.3790	0.1578	1.6435
Access to market	0.0659	0.0605	-0.0527	0.1846
_cons	-2.8241**	1.1821	-5.1411	-0.5072

Note: Dependent variable: organic adopted=1 if not=0; *, **and *** indicates 10%, 5% and 1% significance level; Log likelihood = -205.99, LR chi^2 = 76.71***, Pseudo R^2= 0.1570

The assumption that the PSM satisfies equilibrium and common support needs to be tested. Table 2 reports unmatched and matched means of covariates among adapters (Treted) and non-adapters of the *Chemical fertilizer ban* (Control). Before the matching, adapters significantly differed from non-adapters for most of the characteristics. In total, 120 adopters were matched to non-adapters with similar propensity scores. The differences between treatments and controls are much smaller and, in most cases, not significantly different from zero even at the 1 percent level after the nearest neighbour (NN) matching. We can thus infer from the results that all observable differences in means between adapters (treatments) and non-adapters (controls) have been removed through matching, in other words, the balancing property is satisfied. Therefore, we can conclude that the experimental group and the control group are balanced after the match which passes the equilibrium test.

Table 2. Balancing mean values of variables for treated and control groups.

Variable	Unmatched Matched	Mean		Bias (%)	Reduction (%)	t-test	
		Trtmnt	Control			t	p>|t|
Age	U	54.692	53.679	8.6		0.79	0.433
	M	54.692	55.008	-2.7	68.7	-0.22	0.827
Gender	U	0.175	0.1	21.8**		2.10	0.036
	M	0.175	0.1916	-4.9	77.8	-0.33	0.740
Edu: Primary	U	0.05	0.0535	-1.6		-0.15	0.884
	M	0.05	0.05	0.0	100.0	0.00	1.000
Secondary	U	0.375	0.3857	-2.2		-0.20	0.840
	M	0.375	0.3833	-1.7	22.2	-0.13	0.895
Tertiary	U	0.575	0.5607	2.9		0.26	0.792
	M	0.575	0.5666	1.7	41.7	0.13	0.897
Family Size	U	3.4667	3.1964	25.2**		2.30	0.022
	M	3.4667	3.6417	-16.3	35.2	-1.25	0.212
Emp. status	U	0.45	0.325	25.8**		2.39	0.017
	M	0.45	0.4083	8.6	66.7	0.65	0.516
HH Income	U	75100	54864	20.9**		2.22	0.027
	M	75100	79283	-4.3	79.3	-0.29	0.770
Asset Index	U	3.3333	2.8429	35.0***		3.21	0.001
	M	3.3333	3.225	7.7	77.9	0.57	0.569
Farming Exp	U	25.342	26.464	-9.1		-0.83	0.407
	M	25.342	24.408	7.6	16.9	0.59	0.557
Subsistence	U	0.6416	0.4535	38.4***		3.49	0.001
	M	0.6416	0.6	8.5	77.8	0.66	0.508
Dis:Kurunegala	U	0.1416	0.2892	-36.4***		-3.18	0.002
	M	0.1416	0.125	4.1	88.7	0.38	0.706
Anuradhapura	U	0.3583	0.1964	36.7***		3.49	0.001
	M	0.3583	0.3916	-7.5	79.4	-0.53	0.596
Polonnaruwa	U	0.1083	0.3071	-50.4***		-4.31	0.000
	M	0.1083	0.125	-4.2	91.6	-0.40	0.689
Kalutara	U	0.3916	0.2071	41.0***		3.91	0.000
	M	0.3916	0.3583	7.4	81.9	0.53	0.596
Hired labour use	U	0.5	0.5428	-8.6		-0.79	0.433
	M	0.5	0.5083	-1.7	80.6	-0.13	0.898
Fertilizer cost	U	8397.4	20865	-16.4		-1.31	0.190
	M	8397.4	9368.3	-1.3	92.2	-0.26	0.795
Land extent	U	1.8	2.2714	-23.3*		-1.95	0.052
	M	1.8	1.8833	-4.1	82.3	-0.50	0.617
Willingness	U	0.6416	0.55	18.7*		1.70	0.089
	M	0.6416	0.6083	6.8	63.6	0.53	0.596
Prior Experience	U	0.65	0.5964	11.0		1.01	0.315
	M	0.65	0.6583	-1.7	84.4	-0.14	0.893
Extension	U	0.9166	0.9	5.8		0.52	0.603
	M	0.9166	.9	5.8	0.0	0.45	0.656
Credit Access	U	0.1916	0.1285	17.2		1.63	0.103
	M	0.1916	0.2166	-6.8	60.4	-0.48	0.633
Market access	U	3.9333	3.675	7.2		0.70	0.486
	M	3.9333	4.2167	-7.9	-9.7	-0.55	0.580

Note: Treated and control groups are organic fertilizer adapters and non-adapters. *, **and *** indicate mean difference is not equal to zero at 10%, 5% and 1% significance level

The diagnostic graph assessment of the covariate balance between adapters and non-adapters showed that standardized percentage bias among covariates between the two groups reduced drastically after matching (Figure 6a). The density functions before and after matching reveal the sample-matching effect further (Figure 6b).

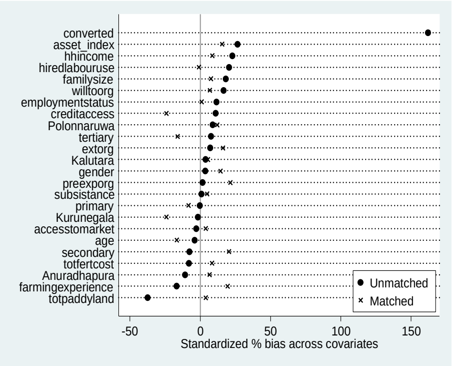

Figure 6a. Covariate balance between adapters and non-adapters

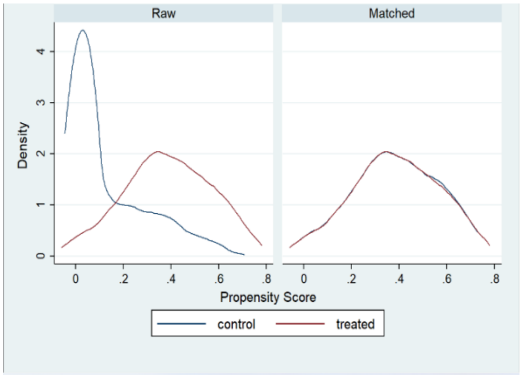

Figure 6b. Density distribution of propensity scores before and after matching

Figure 7 shows the propensity scores of this common support in a graph. The horizontal axis of the graph indicates propensity scores, and the vertical axis indicates frequency. The upper part shows the treatment group that does organic farming activities, and the lower part shows the control group that does not do such activities. It can be concluded that the more similar the height of the two bars, the more similar the propensity scores of the two groups. As shown in Figure 7, the density functions of the propensity scores of the two groups overlap with each other and the common support property is satisfied.

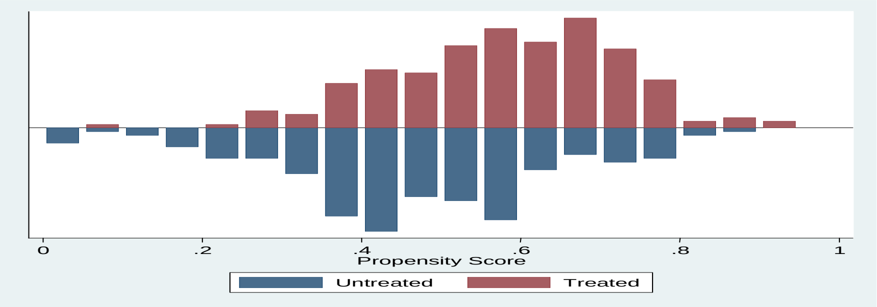

Figure 7. The Common Support of Propensity Scores

The average effect of the adoption of organic fertilizer is estimated by comparing the changes in individual outcomes between participants and their matched counterparts. Table 3 displays the average treatment effect on treated (ATT) and average treatment effect on untreated (ATU) values for paddy yield and total income from paddy. Based on the unmatched samples, there is a significant difference between those who adopted organic farming and those who didn't adopt organic farming. Even though non-adopted farmers performed better than the adopted farmers for both the yield (3,213 and 1,529 Kg/Acre) and for farm income (Rs. 244, 237, and Rs. 69,345), it doesn't show significance at the 5% level. ATU results show a similar pattern.

Table 3. ATT and ATU for paddy yield and farm income for adopted and non-adopted groups

Variable	Sample	Adopted	Non-Adopted	Difference	S.E.	T stat
Paddy Yield	Unmatched	1,529.19	2,443.05	-913.85	490.66	1.86
	ATT	1,529.19	3,213.80	-1,684.60	1,284.35	1.31
	ATU	2,443.05	1,868.56	-574.48		
Farm Income	Unmatched	69,345.83	169,811.72	-100,465.89	49,425.54	2.03
	ATT	69,345.83	244,237.91	-174,892.08	12,7988.71	1.37
	ATU	169,811.72	103,381.78	-66,429.94		

Conclusions

This paper aimed to achieve two objectives; identifying the major challenges faced by the paddy farmers due to the fertilizer ban and examining the impact of organic fertilizer adoption on farm yield and income during the 2021/22 *Maha* season using both secondary data and primary survey data of 400 farm households. The survey data was analyzed by using propensity score matching methods. The FGDs and KIIs were conducted to collect qualitative data relevant to rice value chain stakeholders.

The study findings show a drop in paddy production and yield levels due to the ban on chemical fertilizers at the national level. Similar results were obtained for farm yield and farm income during the 2021/22 *Maha* season according to the comparison of outcome means in the unmatched sample. However, despite the drop in outcome variable, there is no significant impact on farm yield or income with the effect of the organic fertilizer adoption program based on the matched sample as shown by ATT results. This can be attributed to the fact that the ban was limited to one season/ few months and the impact of a short supply of chemical fertilizers would take a few years to show as the soil would still have been rich with nutrients.

However, value chain analysis showed that the farmers have faced severe challenges in accessing necessary fertilizer during the 2021/22 *Maha* season. Urea was rarely available in markets and even the available fertilizers were sold at unaffordable prices while MOP and TSP were heavily in shortage. Organic liquid fertilizers, compost, and manure have not sufficiently been provided for farmlands. Inadequate raw materials for organic fertilizer production, quality issues of organic fertilizers, fertilizers not being provided on time, and not properly implementing subsidy programs at ground levels were major constraints regarding fertilizer supply for paddy production.

Considering all these, if the future government policies decide to go for transformation to organic farming, the government should establish a specific national policy for organic farming with a comprehensive action plan including strategies and outcomes that need to be achieved during a specific period. Quality standards and guidelines for organic fertilizer manufacturing and use should be established and promoted with incentives for adoption. Extension programmes related to plant nutrient management should be strengthened with modern knowledge, expertise, and techniques. Chemical fertilizer should be offered in the short term at market prices to the registered farmers and integrated plant nutrition management (IPNM) and site-specific application techniques should be promoted to gradually reduce the overuse of chemical fertilizer. Further investments should be made in the R&D in organic, chemical, and IPNM techniques.

References

Abeysinghe, A. M. P. (2014). *A study on the effectiveness of fertilizer subsidy scheme on paddy production in Matale district* (Doctoral dissertation, thesis no: mpm–11–71, SLIDA).

Alene, A. D., & Manyong, V. M. (2007). The effects of education on agricultural productivity under traditional and improved technology in northern Nigeria: an endogenous switching regression analysis. *Empirical economics*, *32*(1), 141-159.

Amare, M., Asfaw, S., & Shiferaw, B. (2012). Welfare impacts of maize–pigeonpea intensification in Tanzania. *Agricultural Economics*, *43*(1), 27-43.

Annual report of Central Bank of Sri Lanka, (2021).

Asfaw, S., Shiferaw, B., Simtowe, F., & Lipper, L. (2012). Impact of modern agricultural technologies on smallholder welfare: Evidence from Tanzania and Ethiopia. *Food policy*, *37*(3), 283-295.

Blundell, R., & Costa Dias, M. (2002). Alternative approaches to evaluation in empirical microeconomics.

Beillard, M. J., & Galappattige, A. (2021). Sri Lanka restricts and bans the import of fertilizers and agrochemicals.

Chala and Tilahun, (2014); Gelgo, B., Mshenga, P. M., & Zemedu, L. (2017). Analysis of the impact of organic fertilizer use on smallholder farmers' income in Shashemene District, Ethiopia. *International Journal of Agricultural Economics*, *1*(4), 117-124.

Dandeniya, W. S., & Caucci, S. (2020). Composting in Sri Lanka: Policies, practices, challenges, and emerging concerns. *Organic Waste Composting through Nexus Thinking: Practices, Policies, and Trends*, 61-89.

Delcourt, C., Cougnard-Grégoire, A., Boniol, M., Carriere, I., Doré, J. F., Delyfer, M. N., ... & Korobelnik, J. F. (2014). Lifetime exposure to ambient ultraviolet radiation and the risk for cataract extraction and age-related macular degeneration: the Alienor Study. *Investigative Ophthalmology & Visual Science*, *55*(11), 7619-7627.

Dulanjani, P.A., and Aruna Shantha, A., (2021). MICRO-ECONOMIC IMPACT OF FERTILIZER SUBSIDY IN PADDY CULTIVATION IN SRI LANKA, Pakistan Journal of Humanities and Social Sciences Research 05(04):86-95.

Eliasova, L. (2016). Agricultural policy-making in Cuba: the case of organic agriculture.

FAO. 2018b. Sikkim, India's first 'fully organic' state wins FAO's Future Policy Gold Award. http://www.fao.org/india/news/detail-events/en/c/1157760/

Feuerbacher, A., Luckmann, J., Boysen, O., Zikeli, S., & Grethe, H. (2018). Is Bhutan destined for 100% organic? Assessing the economy-wide effects of a large-scale conversion policy. *PloS one*, *13*(6), e0199025.

Heckman, J. (1997). Instrumental variables: A study of implicit behavioural assumptions used in making program evaluations. *Journal of human resources*, 441-462.

Kaplinsky, R., & Morris, M. (2000). *A handbook for value chain research* (Vol. 113). Brighton: University of Sussex, Institute of Development Studies.

Katchova, A. L. (2010). Agricultural cooperatives and contract price competitiveness. *Journal of Cooperatives*, *24*(1142-2016-92781), 1-12.

Khurana, A., & Kumar, V. (2020). State of organic and natural farming: challenges and possibilities. *New Delhi*.

Kumar, V., (2021). “Sri Lanka’s inorganic transition to organic farming”. Down to earth, October 06, 2021. https://www.downtoearth.org.in/news/agriculture/sri-lanka-s-inorganic-transition-to-organic-farming-79532

Leong, H. S., Mahesh, B. M., Day, J. R., Smith, J. D., McCormack, A. D., Ghimire, G., ... & Rose, M. L. (2008). Vimentin autoantibodies induce platelet activation and formation of platelet-leukocyte conjugates via platelet-activating factor. *Journal of Leucocyte Biology*, *83*(2), 263-271.

Meek, D., & Anderson, C. R. (2020). Scale and the politics of the organic transition in Sikkim, India. *Agroecology and Sustainable Food Systems*, *44*(5), 653-672.

Nelson and Startz, (1990). Shea, J. (1997). Instrument relevance in multivariate linear models: A simple measure. *Review of Economics and Statistics*, *79*(2), 348-352.

Nordhaus, T., (2022). “In Sri Lanka, Organic Farming Went Catastrophically Wrong”. FP News, March 05, 2022. https://foreignpolicy.com/2022/03/05/sri-lanka-organic-farming-crisis/

Pahalvi, H.N., Rafiya, L., Rashid, S., Nisar, B., Kamili, A.N. (2021). Chemical Fertilizers and Their Impact on Soil Health. In: Dar, G.H., Bhat, R.A., Mehmood, M.A., Hakeem, K.R. (eds) Microbiota and Biofertilizers, Vol 2. Springer, Cham.

Paul, J. (2017). Four new strategies to grow the organic agriculture sector. *AGROFOR-International Journal*, *2*, 61-70.

Ponisio, L. C., M'Gonigle, L. K., Mace, K. C., Palomino, J., De Valpine, P., & Kremen, C. (2015). Diversification practices reduce organic to conventional yield gap. *Proceedings of the Royal Society B: Biological Sciences*, *282*(1799), 20141396.

Porter’s, V. C. M. (1985). What Is Value Chain. *E-Commer.*, 1-13.

Ranathilaka, M. B., & Arachchi, I. I. (2019). The effect of fertilizer subsidy on paddy production of small scale farmers: Special reference in Polonnaruwa District in Sri Lanka. *Review of Behavioral Aspect in Organizations and Society*, *1*(1), 33-44.

Salam, M. A., Sarker, M. N. I., & Sharmin, S. (2021). Do organic fertilizers impact on yield and efficiency of rice farms? Empirical evidence from Bangladesh. *Heliyon*, *7*(8), e07731.

Sangakkara, U. R., & Katupitiya, S. (2021). Organic farming in Sri Lanka.

Sathish Rao, S.B., (2017). "Study of organic cultivation in Sikkim".

State Policy on Organic Farming, Government of Sikkim (GOS).

Thibbotuwawa, M., Dissanayake, N., and Niwarthana, S. *The Ukraine War and its Food Security Implications in Sri Lanka*. Policy Note 24. International Food Policy Research Institute (IFPRI). Washington DC.

Vilhjálmsson, B. J., Yang, J., Finucane, H. K., Gusev, A., Lindström, S., Ripke, S., ... & Marsal, S. (2015). Modelling linkage disequilibrium increases the accuracy of polygenic risk scores. *The american journal of human genetics*, *97*(4), 576-592.

Wright, J. (2005). *Falta Petroleo! Perspectives on the emergence of a more ecological farming and food system in post-crisis Cuba*. Wageningen University and Research.

Wimalawansa, S. J. (2014). Escalating chronic kidney diseases of multi-factorial origin in Sri Lanka: causes, solutions, and recommendations. *Environmental health and preventive medicine*, *19*(6), 375-394.

Wijesinghe, A. (2021). Chemical Fertilizer Imports and the Environment: Evidence-based Approach for a Green Economy Accounting for the Tradeoff. *Economic Research*, *9*, 1.

Wordofa, M. G., Hassen, J. Y., Endris, G. S., Aweke, C. S., Moges, D. K., & Rorisa, D. T. (2021). Adoption of improved agricultural technology and its impact on household income: a propensity score matching estimation in eastern Ethiopia. *Agriculture & Food Security*, *10*, 1-12.