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Rejuvenation of Biofertilizer for Sustainable Agriculture and Economic Development

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Abstract

The economy of India thrives on agriculture, the most practiced occupation in the country. Agricultural fertilizers are essential to enhance proper growth and crop yield. Recently, farmers have been using chemical fertilizers for quicker and better yield. But these fertilizers endanger ecosystems, soil, plants, and human and animal lives. In contrast, naturally grown biofertilizers not only give a better yield, but are also harmless to humans. This paper aims to study the rejuvenation of biofertilizers for sustainable agriculture economic development (SAED) in comparison to chemical fertilizers. Field experiments were conducted with azolla, a biofertilizer, in the district of Balasore in Odisha. The results show that the yield, the number of tillers, plant height, profit to farmers, and the benefit to cost ratio of azolla were higher than chemical fertilizer, proving that rejuvenating biofertilizers would lead to better sustainable economic development for the farmers and their country.

Keywords: SAED, biofertilizers, agriculture management

1. Introduction

Agriculture is one of the most important factors contributing to the economic growth of India. Out of the 329 million hectares of India's geographical area, about 114 million hectares are under cultivation (Raghuwanshi, 2012). In order to reap a better harvest, farmers inoculate the soil with fertilizers. Fertilizers come in two types—they are either chemical or biofertilizers. Increasingly high inputs of chemical fertilizers during last 150 years have not only left soils degraded, polluted and less productive but have also posed severe health and environmental hazards. Organic farming methods (such as the use of biofertilizers) would solve these issues and make the ecosystem healthier. The current global market for organically raised agricultural products is valued at around US$ 30 billion with a growth rate of around 8 percent. Nearly 22 million hectares of land are now cultivated organically. Organic cultivation represents less than 1 percent of the world's conventional agricultural production and about 9 percent of the total agricultural area.

There are 17 essential elements required for proper plant growth. The dearth of any of these essential nutrients, listed in Table 1, can result in severe damage to crop health. Of the mineral elements, the primary macronutrients (nitrogen, phosphorous, and potassium) are needed in the greatest quantities and are most likely to be in short supply in agricultural soils. Secondary macronutrients are needed in smaller quantities, and are typically found in sufficient quantities in agricultural soil, and therefore do not often limit crop growth. Micronutrients, or trace nutrients, are needed in very small amounts and can be toxic to plants in excess. Silicon (Si) and sodium (Na) are sometimes considered essential plant nutrients, but due to their ubiquitous presence in soils, they are never in short supply (Parikh and James, 2012).

Essential plant element		Symbol	Primary form
Non-Mineral Elements			
	Carbon	C	CO_2 (g)
	Hydrogen	H	H_2O (l), H^+
	Oxygen	O	H_2O (l), O_2(g)
Mineral Elements			
Primary Macronutrients	Nitrogen	N	NH_4^+, NO_3^-
	Phosphorus	P	HPO_4^{2-}, $H_2PO_4^-$
	Potassium	K	K^+
Secondary Macronutrients	Calcium	Ca	Ca^{2+}
	Magnesium	Mg	Mg^{2+}
	Sulfur	S	SO_4^{2-}
Micronutrients	Iron	Fe	Fe^{3+}, Fe^{2+}
	Manganese	Mn	Mn^{2+}
	Zinc	Zn	Zn^{2+}
	Copper	Cu	Cu^{2+}
	Boron	B	$B(OH)_3$
	Molybdenum	Mo	MoO_4^{2-}
	Chlorine	Cl	Cl^-
	Nickel	Ni	Ni^{2+}

Table 1: Essential plant nutrient elements and their primary form utilized by plants (Parikh and James, 2012).

Agriculture alters the natural cycling of nutrients in soil. Intensive cultivation and harvesting of crops for human or animal consumption can effectively deplete the soil of plant nutrients. In order to maintain soil fertility for sufficient crop yields, soil amendments are typically required. In the past, farmers nourished their fields with animal manure, charcoal, ash, and lime ($CaCO_3$) to improve soil fertility. Today, farmers add inorganic chemical fertilizers and organic nutrient sources to enhance soil fertility, often resulting in surplus quantities of primary macronutrients.

Chemically enhanced productivity has depleted the natural resource base for sustainable agricultural growth. Earlier technology has disturbed the biological composition, which might have lasting adverse impact on equilibrium. Unless the disturbed natural resource base equilibrium is restored, sustainable agricultural growth with a competitive edge will not be possible. To increase agricultural production, it is necessary for chemical fertilizers and organic manure to be used in moderation. Present fertilizer consumption in the state of Odisha is 53 kg/ha, compared to the national average of more than 100 kg/ha. While suitable measures will be taken to increase fertilizer consumption in the State, emphasis would be laid on 'balanced fertilization', meaning an accurate fertilizer application equal to the plant need and soil nutrient content. Integrated Nutrient Management (INM) is very important for balanced nutrition in sustainable crop production. INM aims to integrate the use of all natural and man-made sources of plant nutrients required for high agricultural productivity as well as ensure the health of the soil. The State will endeavor to promote INM practices and biofertilizer use through suitable programs and incentives. The prolonged overuse of chemicals on soil results in soil health deterioration, human health hazards and pollution of the environment. Therefore, it is necessary to switch to an alternate source of nutrient supply to the crops that is ecologically protective of farming.

1.1 Objective of the Study

This study has been undertaken with the following objectives.

- To compare biofertilizers with chemical fertilizers
- To study the role of biofertilizers in rejuvenating sustainable agriculture economic development (SAED)

2. Literature Review

A biofertilizer is an organic product containing a specific microorganism in concentrated form, which is derived either from the plant roots or from the soil of root zone (Chen, 2006; Gupta and Sen, 2013). These bioinputs, or bioinoculants, improve plant growth and yield. Biofertilizers are the products containing living cells of different types of microorganisms that have the ability to mobilize nutritionally important elements from non-usable forms through biological stress. Biofertilizers can be defined as substances that contain living microorganisms that colonize in the rhizosphere, or the interior of the plant. These promote growth by increasing the availability of primary nutrients and/or growth stimulus to the target crop when applied to seed, plant surfaces, or soil (Muraleedharan et al, 2010). Biofertilizers have shown great potential as supplementary, renewable and environmental friendly sources of plant nutrients and are an important component of Integrated Nutrient Management (INM) and Integrated Plant Nutrition System (IPNS) (Raghuwanshi, 2012). The production of biofertilizers in the country is 10,000 mt / annum and the production capacity is 18,000 mt / annum. Average annual consumption of biofertilizers in the country is around 64g/ha.

2.1 Biofertilizers vs. Chemical fertilizers

Fertilizers act as catalysts in providing nutrients to plants for their optimum growth and yield. They can be roughly categorized into three types: chemical, organic and biofertilizer. Each type has its advantages and disadvantages. These advantages need to be integrated in order to achieve optimum performance by each type of fertilizer and to realize balanced nutrient management for crop growth.

2.1.1. The Advantages of Using Chemical Fertilizer

1. Nutrients are soluble and immediately available to plants, creating a direct and fast effect.
2. The price is lower and more competitive than organic fertilizer, which makes it more popular with farmers.
3. They are quite high in nutrient content; only relatively small amounts are required for crop growth.

2.1.2 The Disadvantages of Using Chemical Fertilizer

1. Overuse can result in negative effects such as leaching, pollution of water resources, destruction of microorganisms and beneficial insects, crop susceptibility to disease attack, acidification or alkalization of the soil, or reduction in soil fertility, all of which cause irreparable damage to the overall ecosystem.
2. Oversupply of nitrogen leads to softening of plant tissue resulting in increased susceptibility to diseases and pests.
3. They reduce the colonization of plant roots with mycorrihizae and inhibit symbiotic nitrogen fixation by *Rhizobia* due to high nitrogen fertilization.
4. They enhance the decomposition of soil, which leads to degradation of soil structure.
5. Nutrients are easily lost from soils through fixation; leaching or gas emission and can lead to reduced fertilizer efficiency.

2.1.3. The Advantages of Using Biofertilizers

1. The nutrient supply is more balanced, which helps keep plants healthy.
2. They enhance soil biological activity, which improves nutrient mobilization from organic and chemical sources and decomposition of toxic substances.
3. They enhance the colonization of mycorrhizae, which improves phosphorous supply.
4. They enhance soil structure, leading to better root growth.
5. They increase the organic matter content of the soil, thereby improving the exchange capacity of nutrients, increasing soil water retention, promoting soil aggregates and buffering the soil against acidity, alkalinity, salinity, pesticides and toxic heavy metals.
6. They release nutrients slowly and contribute to the residual pool of organic nitrogen and phosphorous in the soil, reducing nitrogen leaching loss and phosphorous fixation; they can also supply micronutrients.
7. They encourage the growth of beneficial microorganisms and earthworms.
8. They help to suppress certain soil-borne plant diseases and parasites.

2.1.4. The Disadvantages of Using Biofertilizer

1. They are comparatively low in nutrient content, so a larger volume is needed to provide enough nutrients for crop growth.
2. The nutrient release rate is too slow to meet crop requirements in a short time, hence some nutrient deficiency may occur.
3. The major plant nutrients may not exist in organic fertilizer in sufficient quantity to sustain maximum crop growth.
4. The nutrient composition of compost is highly variable.
5. The cost is high compared to chemical fertilizers.
6. Short shelf life, lack of suitable carrier materials, susceptibility to high temperature, problems in transportation and storage are all biofertilizer bottlenecks that still need to be solved in order to promote effective inoculation (Chen, 2006).

2.2 Azolla

Azolla is a tiny free-floating fresh water fern of tropical and sub-tropical Asia, Africa and America. There are now seven extant species of the family Azollaceae – *Azolla caroliniana, A. maxicana, A. filiculoides, A. microphylla, A. rubra, A. nilotica and A. pinnata*. *Azolla* is an ancient associate of green plants on earth, dating back to the Cenozoic era (which began 65 million years ago). There are fossil records of *A. filiculoides* and *A. pinnata* from Pleistocene deposits (West 1953; Moore 1969). Moore (1969) first reported the agronomic significance of *Azolla*. Literature on *Azolla* is now voluminous (Lumpkin and Plucknett 1982; Khan 1988; Kumarasinghe and Eskew 1993; Mian 1993). *Azolla* has the unique capacity to fix significant amounts of atmospheric dinitrogen (N2) through its phycsymobiont *Anabaena azollae* and thereby can act as the nitrogenous biofertiliser for irrigated rice. Since *Azolla* can be grown simultaneously with irrigated rice without extra land or water use, its utility as biofertilizer has become a reality (Kikuchi et al. 1984; Singh and Singh 1990; Mian and Kashem 1995). Systematic research was necessary to find out the proper methods of culturing *Azolla* year-round to ensure the proper supply of inoculum and the adjustment of the growth of *Azolla* in coordination with the rice crop. The technology Azobiofer is the product of our continuous target-oriented research on *Azolla* since 1978. This technology can be a model for most tropical and sub-tropical rice growing countries. *Azolla* is used as green manure and for dual crop cultivation. As green manure, *Azolla* is grown in fields prior to transplantation of rice seedlings. When fully grown it is mixed with the soil and acts as green manure for the plants. As a dual crop, *Azolla* is grown in the same field after the rice seedlings are transplanted and acts as a biofertilizer.

2.3 Types of Biofertilizers

2.3.1 Nitrogen Fixers

Rhizobium: belongs to family ***Rhizobiaceae,*** symbiotic in nature, fixes nitrogen 50-100 kg/ ha, with legumes only. It is useful for pulse legumes like chickpea, red-gram, pea, lentil, black gram, and oil-seed legumes like soybean and groundnut, and forage legumes like berseem and lucerne. It colonizes the roots of specific legumes to form tumor like growths called root nodules, which act as factories of ammonia production. *Rhizobium* has the ability to fix atmospheric nitrogen in symbiotic association with legumes and certain non-legumes like ***Parasponia***.

Azospirillum: belongs to family ***Spirilaceae***; it is heterotrophic and associative in nature. In addition to their nitrogen fixing ability of about 20-40 kg/ha, they also produce growth-regulating substances. There are many species under this genus such as *A.amazonense, A.halopraeferens,* and, *A.brasilense*. However, worldwide distribution and benefits of inoculation have been seen mainly with the *A.lipoferum* and *A.brasilense*. The *Azospirillum* form associative symbiosis with many plants particularly with those with the C4-dicarboxyliac pathway of photosynthesis (Hatch and Slack pathway), because they grow and fix nitrogen on salts of organic acids such as malic and aspartic acid. Thus it is mainly recommended for maize, sugarcane, sorghum, pearl millet etc. The *Azotobacter* colonizing the roots not only remains on the root surface but also penetrates into the root tissues and lives in harmony with the plants. They do not, however, produce any visible nodules or outgrowth on root tissue.

Azotobacter: belongs to family Azotobacteriaceae; it is aerobic, free living, and heterotrophic in nature. *Azotobacters* are present in neutral or alkaline soils and *A. chroococcum* is the most commonly occurring species in arable soils, while *A. vinelandii, A. beijerinckii, A. insignis* and *A.macrocytogenes* are also common species. The number of *Azotobacter* rarely exceeds of 104 to 105 g-1 of soil due to lack of organic matter and presence of antagonistic microorganisms in soil. Azotobacter produces anti-fungal antibiotics that inhibit the growth of several pathogenic fungi in the root region and help prevent seedling mortality. The occurrence of this organism has been reported in the rhizosphere of a number of crop plants such as rice, maize, sugarcane, bajra, vegetables and plantation crops.

Blue Green Algae (Cyanobacteria) and Azolla: These belong to eight different families. They are phototrophic in nature and produce auxin, indole acetic acid and gibberllic acid, and fix 20-30 kg nitrogen/ha in submerged rice fields. As they are abundant in paddies, they are also referred as 'paddy organisms'. Nitrogen is the key input required in large quantities for low land rice production. Soil nitrogen and Biological Nitrogen Fixation (BNF) by associated organisms are major sources of nitrogen for low land rice. The 50-60% nitrogen requirement is met through the combination of mineralization of organic nitrogen from the soil and BNF by free living and rice plant associated bacteria (Roger and Ladha, 1992). To achieve food security through sustainable agriculture, the requirement for fixed nitrogen must be increasingly met by BNF rather than by industrial nitrogen fixation. Most nitrogen-fixing blue green algae (BGA) are filamentous, consisting of chains of vegetative cells including specialized cells called heterocysts, which function as micronodules for synthesis and nitrogen-fixing machinery. BGA forms symbiotic associations capable of fixing nitrogen with fungi, liverworts, ferns and flowering plants, but the most common symbiotic association is that found between a free floating aquatic fern, the Azolla and *Anabaena azollae* (BGA). The important factors in using *Azolla* as biofertilizer for rice crop are its quick and the efficient availability of its nitrogen to rice plants.

Besides nitrogen fixation, these biofertilizers, or biomanures, also contribute significant amounts of phosphorous, potassium, sulfur, zinc, iron, molybdenum and other micronutrients. *Azolla* can be applied as green manure by incorporating it in the fields prior to rice planting. The most commonly occurring species in India is *A. pinnata*, which can be propagated on commercial scale by vegetative means.

2.3.2 Phosphate Solubilizers

Several reports have examined the ability of different bacterial species to solubilize insoluble inorganic phosphate compounds, such as tricalcium phosphate, dicalcium phosphate, hydroxyapatite, and rock phosphate. Among the bacterial genera with this capacity are *pseudomonas, Bacillus, Rhizobium, Burkholderia, Achromobacter, Agrobacterium, Microccocus, Aereobacter, Flavobacterium* and *Erwinia.* There are considerable populations of phosphate-solubilizing bacteria in soil and in plant rhizospheres. These include both aerobic and anaerobic strains, with a greater prevalence of aerobic strains in submerged soils. A considerably higher concentration of phosphate solubilizing bacteria is commonly found in the rhizosphere in comparison with non-rhizosphere soil. The soil bacteria belonging to the genera *Pseudomonas* and *Bacillus* and *Fungi* are more common. The major microbiological means by which insoluble-phosphorous compounds are mobilized is by the production of organic acids, accompanied by acidification of the medium. The organic and inorganic acids convert tricalcium phosphate to diand-monobasic phosphates, resulting in an enhanced availability of the phosphorous to the plant.

2.3.3 Zinc Solubilizers

Nitrogen fixers like *Rhizobium, Azospirillum, Azotobacter, BGA* and phosphate-solubilizing bacteria like *B. magaterium, Pseudomonas striata,* and phosphate mobilizing mycorrhiza have been widely accepted as bio-fertilizers. However, these biofertilizers only supply major nutrients. But a host of microorganisms found in the soil can be used as biofertilizers to supply micronutrients like zinc, iron, copper, etc. Zinc is of utmost importance. It is found in the earth's crust at a concentration of 0.008 percent, but more than 50 percent of Indian soils exhibit zinc deficiency with content far below the critical level of 1.5 ppm of available zinc.

The plant deficiencies in absorbing zinc from the soil are overcome by external application of soluble zinc sulfate ($ZnSO_4$). There appears to be two main mechanisms of zinc fixation; one operates in acidic soils and is closely related with cation exchange and other operates in alkaline conditions where fixation takes place by means of chemisorptions (chemisorptions of zinc on calcium carbonate form a solid-solution of $ZnCaCO_3$), and by complexation by organic ligands. Zinc can be solubilized by microorganisms viz., *B. subtilis, Thiobacillus thioxidans* and *Saccharomyces sp*. These microorganisms can be used as biofertilizers for the solubilization of fixed micronutrients like zinc. The results have shown that a *Bacillus sp.* (zinc solubilizing bacteria) can be used as a biofertilizer for zinc or in soils where native zinc is higher or in conjunction with insoluble cheaper zinc compounds like zinc oxide (ZnO), zinc carbonate ($ZnCO_3$), and zinc sulfide (ZnS), instead of costly zinc sulfate.

2.4 Rejuvenating Sustainable Economic Development (SED)

Rejuvenation leads to increased market share and profit maximization (Berenson and Jackson, 1994). It is less risky than New Product Development, cost effective, saves time and helps gain market share. Product rejuvenation can be done in two ways—reintroducing an abandoned product by marketing it to old or new users, or reviving a seriously declining product by creating new value, then marketing it to old or new users (Berenson and Jackson, 1994).

Sustainable development (SD) refers to a mode of human development in which resource use aims to meet human needs while preserving the environment so that these needs can be met for both present and future generations. Sustainable development has three constituent parts: environmental sustainability, economic sustainability, and sociopolitical sustainability. Economic sustainability is also known as the development and maintenance of the present and future economic growth of a country. Achieving this sustainability in agriculture is essential as the economy of India depends on agriculture. Sustainable agriculture can be defined as environmentally friendly methods of farming that allow the production of crops and livestock without damage to human or natural systems. More specifically, it can be said to avoid adverse effects to soil, water, biodiversity, and surrounding or downstream resources—or to those working or living on the farm or in neighboring areas. Furthermore, the concept of sustainable agriculture extends intergenerationally, as it means passing on a conserved or improved natural resource, biotic, or economic base instead of one that has been depleted or polluted. Combining agriculture and economy, the term sustainable agriculture economic development (SAED) has been coined as used in the study. This study also formulates strategies for sustainable agriculture economic development by comparing biofertilizers like Azolla to chemical fertilizers.

The government of India and other agencies are coming up with rejuvenation strategies for sustainable agriculture economic development such as promoting the nascent biofertilizer market both at the level of the user-farmer and the producer-investor. They use the following measures: (i) farm level extension and promotion programs, (ii) financial assistance to investors in setting up units, (iii) subsidies on sales and (iv) direct production in public sector and cooperative organizations and in universities and research institutions. Over time, as the industry emerges from infancy with public guidance, the government expects to see the following: (a) increasing sales volumes and diffusion across the country, (b) greater role of profit motivated private enterprise (Ghosh, 2013). The government of Odisha also endeavors to train farmers to use *Azolla* as a biofertilizer (Orissa reference annual, 2011).

3. Methodology

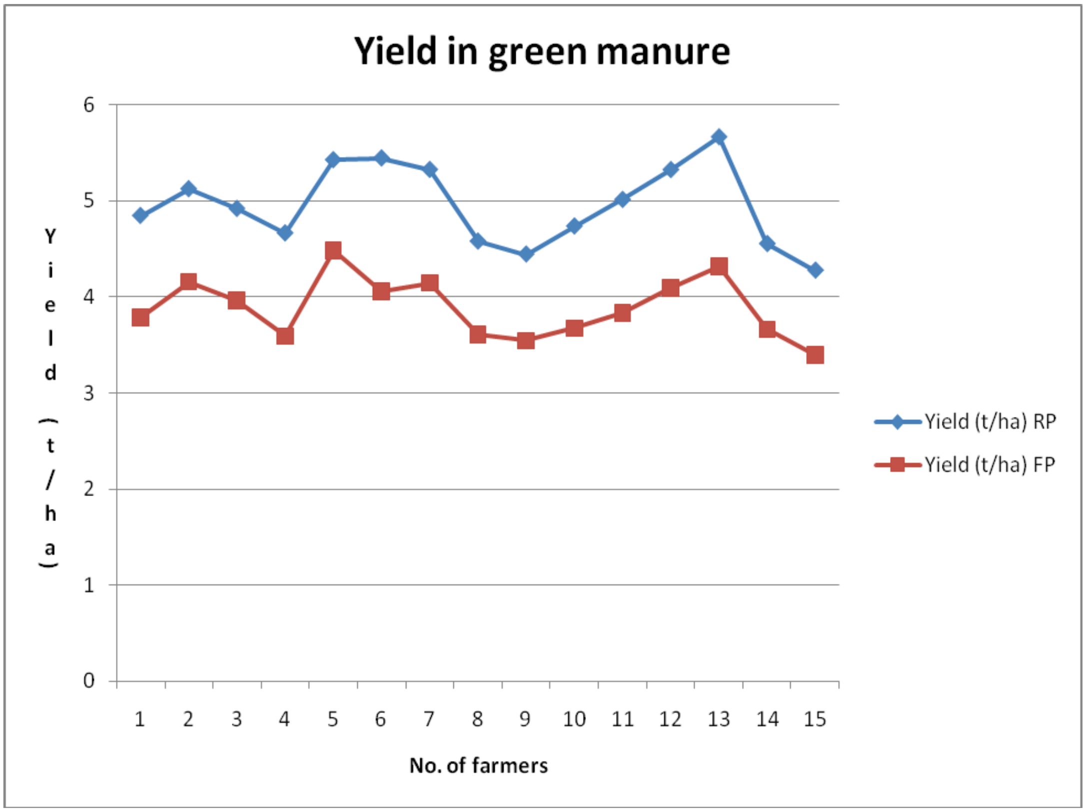
The research was exploratory and experimental in nature. A sample of 15 farmers from the Balasore district of Odisha participated in the study. The experiment was performed on rice, the most cultivated crop in Balasore. *Azolla* was used as a green manure and dual crop and compared with chemical fertilizer.

4. Results and Discussion

The study was conducted by comparing the application of *Azolla* as a biofertilizer in green manure and dual crop with chemical fertilizer. The analysis and discussion follow.

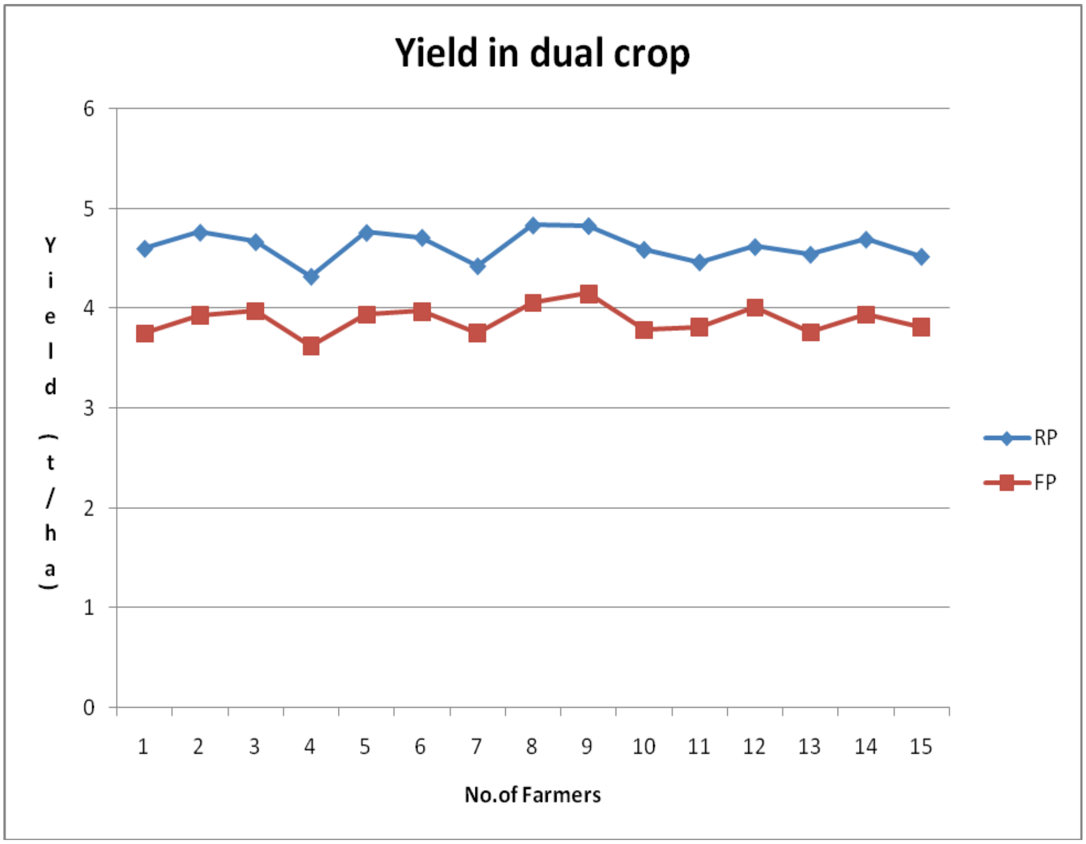
4.1 Paddy Yield

When *Azolla* was incorporated in to the paddy field; the increase in paddy yield varied from 21 % to 34 % due to green manuring (Graph 1.1) and 15 % to 23% due to dual cropping (Graph 1.2).



Graph 1.1: Yield of rice in green manure

The utilization of *Azolla* as green manure has been extensively investigated and an increase in paddy yield ranging from 9-38% has been observed in field experiments when *Azolla* was incorporated to the soil (Singh 1977). Incorporation of *Azolla* into the soil also enhances the release of other nutrients. A 50% reduction in chemical fertilizer use can be achieved without significant loss to the rice yield with the use of *Azolla* along with chemical fertilizer (Francisco Carrapico, Generosa Teixeira and M. Adelia Diniz 2000).

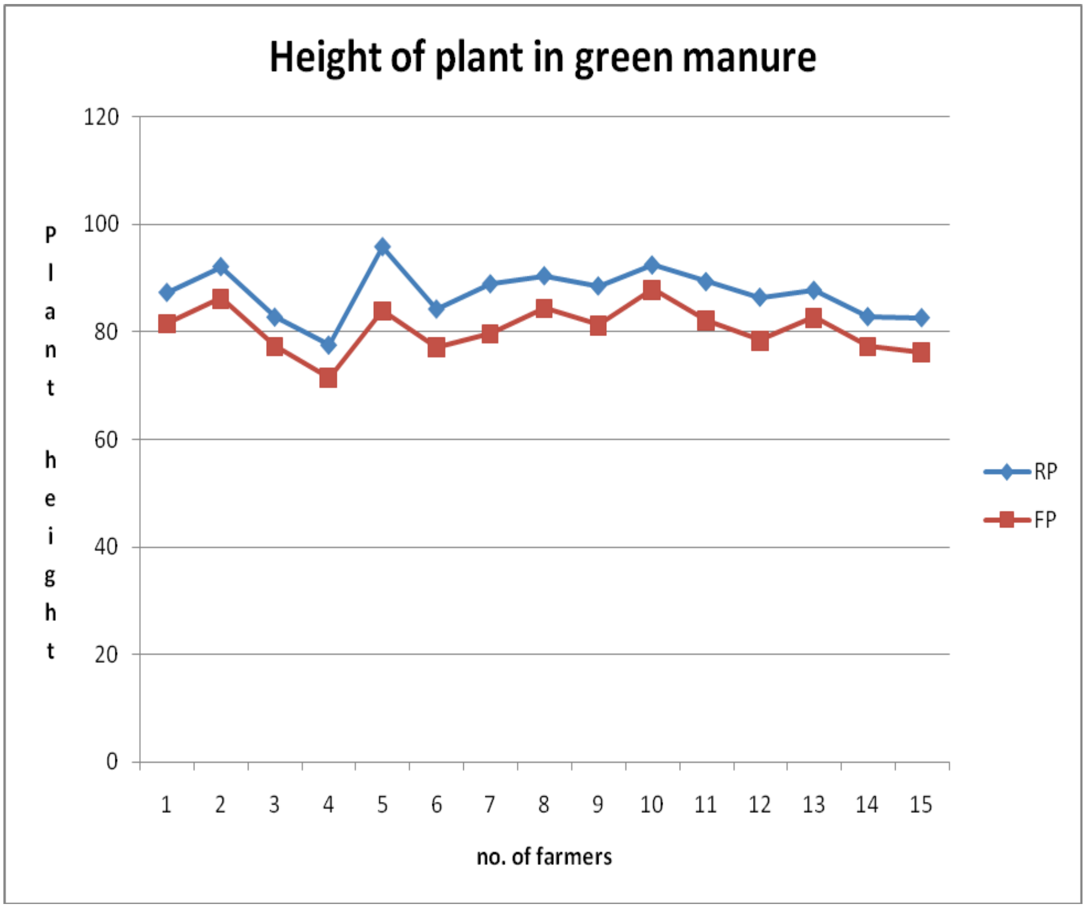


Graph 1.2: Yield of rice in dual crop

Application of *Azolla* as green manure and dual crop improved the fertility status of soil. Application of *Azolla* also plays a definite role in enhancing soil fertility by increasing available nitrogen, organic carbon, phosphorous and potassium (Mandal et al. 1999, Sharma et al. 1999). Their utilization also helps curb NH_3 volatilization, prevent rise in pH, reduce water temperature, build up organic matter, and influence the transformation and availability of iron, manganese, zinc, and copper, which improves the infiltration and movement of water in soil (Vlek & Craswell 1981, Mandal et al. 1999, Pabby et al. 2004). Mian and Azmal (1989) found that when Azolla was cultured with rice and incorporated, about 28% of the phosphorus present in *Azolla* was subsequently taken up by rice plant tissue.

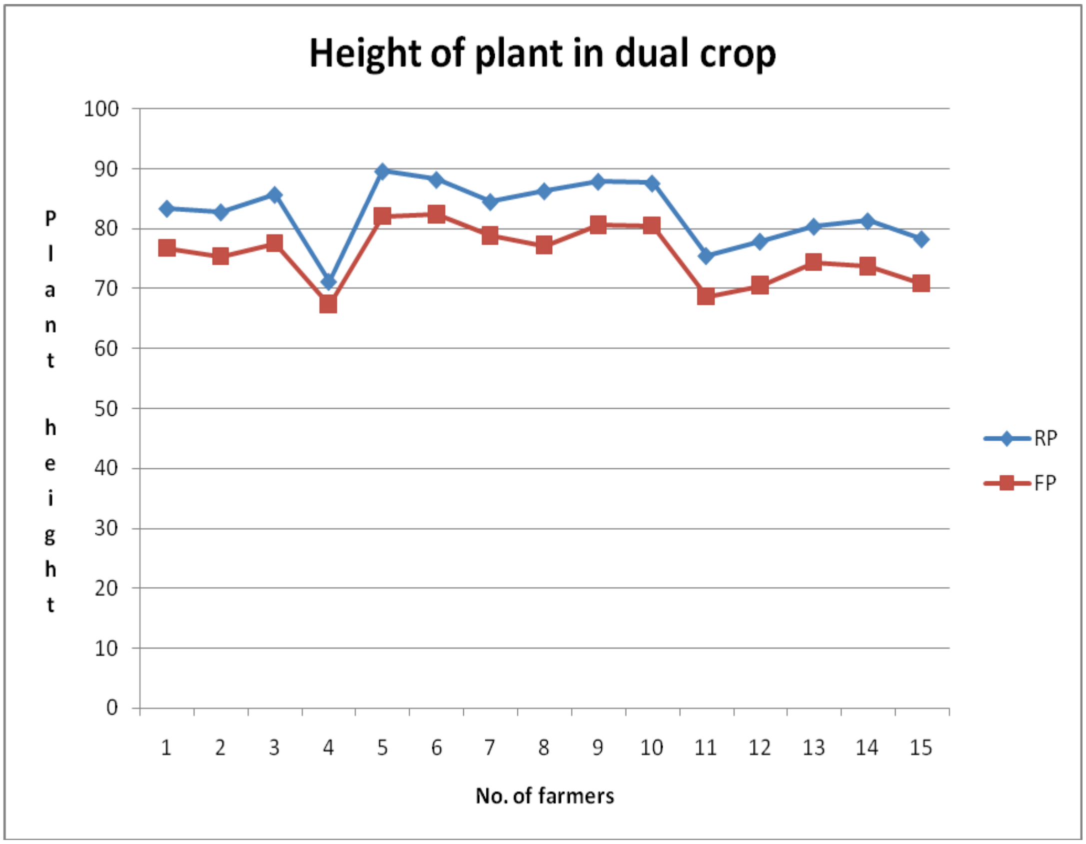
4.2 Plant Height

The application of *Azolla* biofertilizer as green manure in the paddy fields resulted in continuous growth throughout the paddy crop in comparison to conventionally grown, chemically fertilized paddies as shown in graph 1.3.



Graph 1.3: Plant height in green manure

The graph clearly depicts the increase in plant height in the case of paddy crops greenmanured with *Azolla* as compared to chemically grown paddy crops. Similarly, the dual growth paddies showed far more growth than conventionally grown paddies, as shown in graph 1.4.

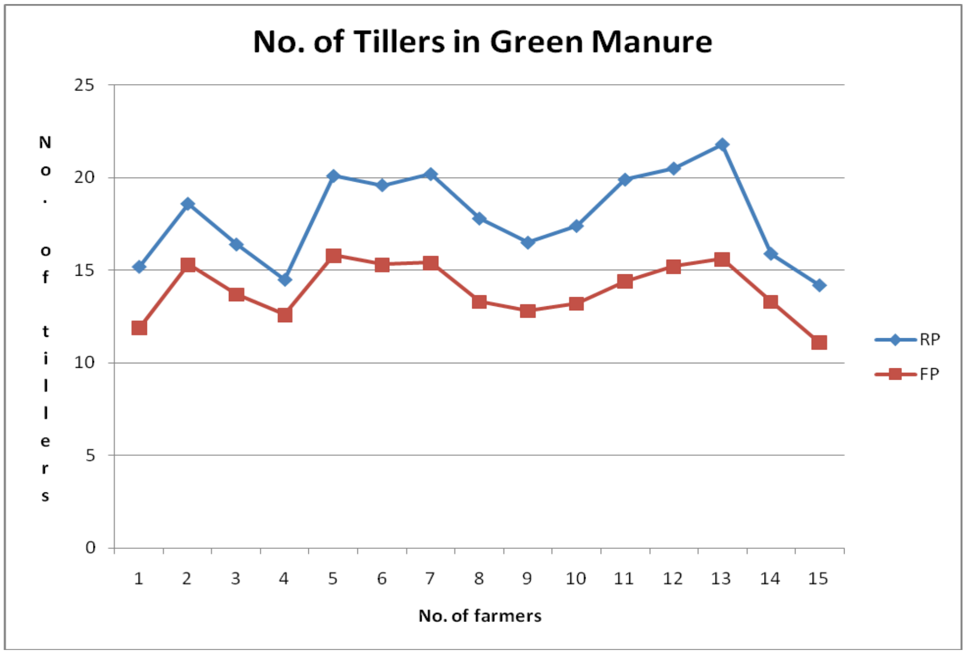


Graph 1.4: Plant height in dual crop

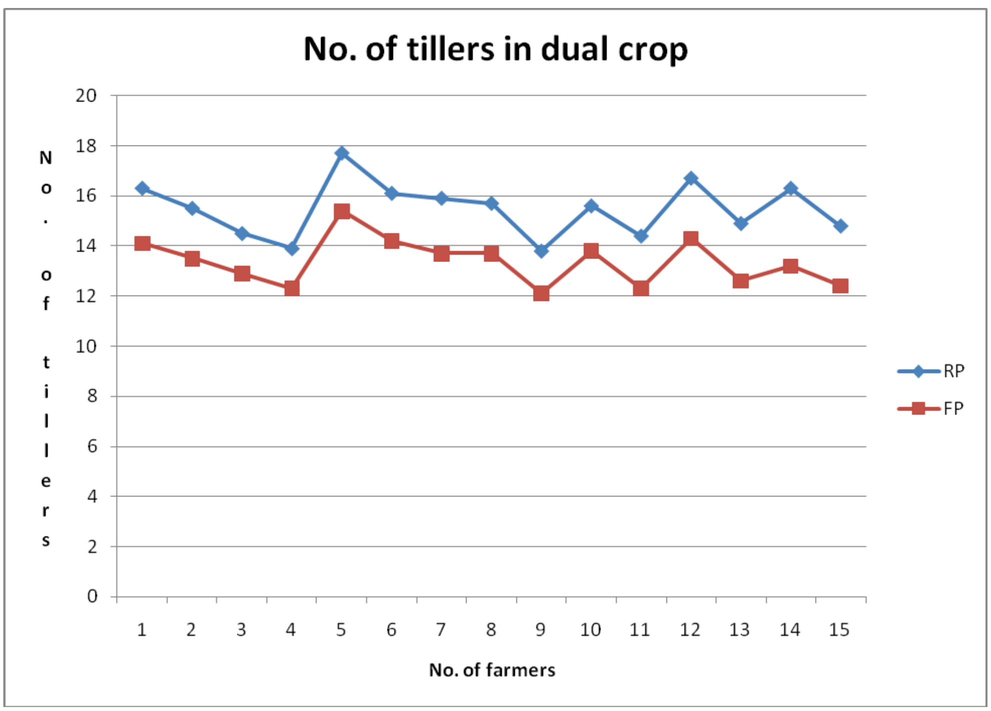
Since incorporation of *Azolla* as green manure and dual crop enhanced the fertility status of soil, a growth of paddy crop was evident. Many researchers have revealed the beneficial effects of *Azolla* such as enhancing soil fertility by increasing total available nitrogen, organic carbon, phosphorous and potassium. *Azolla* also curbs NH_3 volatilization, prevents rise in pH, reduces water temperature, builds up organic matter and influences the transformation and availability of iron, manganese, zinc, and copper, improving the infiltration and movement of water in soil (Vlek & Craswell 1981, Mandal et al. 1999, Sharma et al. 1999, Pabby et al. 2004).

4.3 Number of Tillers

The increase in the number of tillers of paddy crop was clearly observed in both green manure and dual crop paddies, as shown in graphs 1.5 & 1.6.



Graph 1.5: Number of tillers in green manure

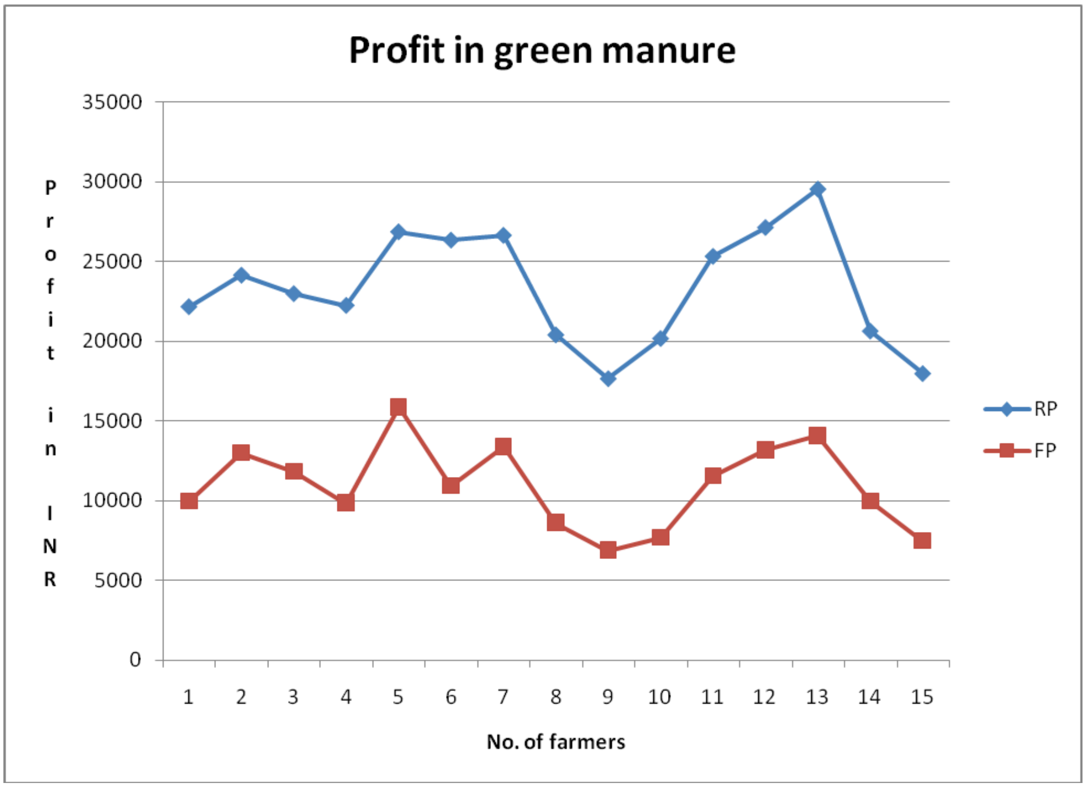


Graph 1.6: Number of tillers in dual crop

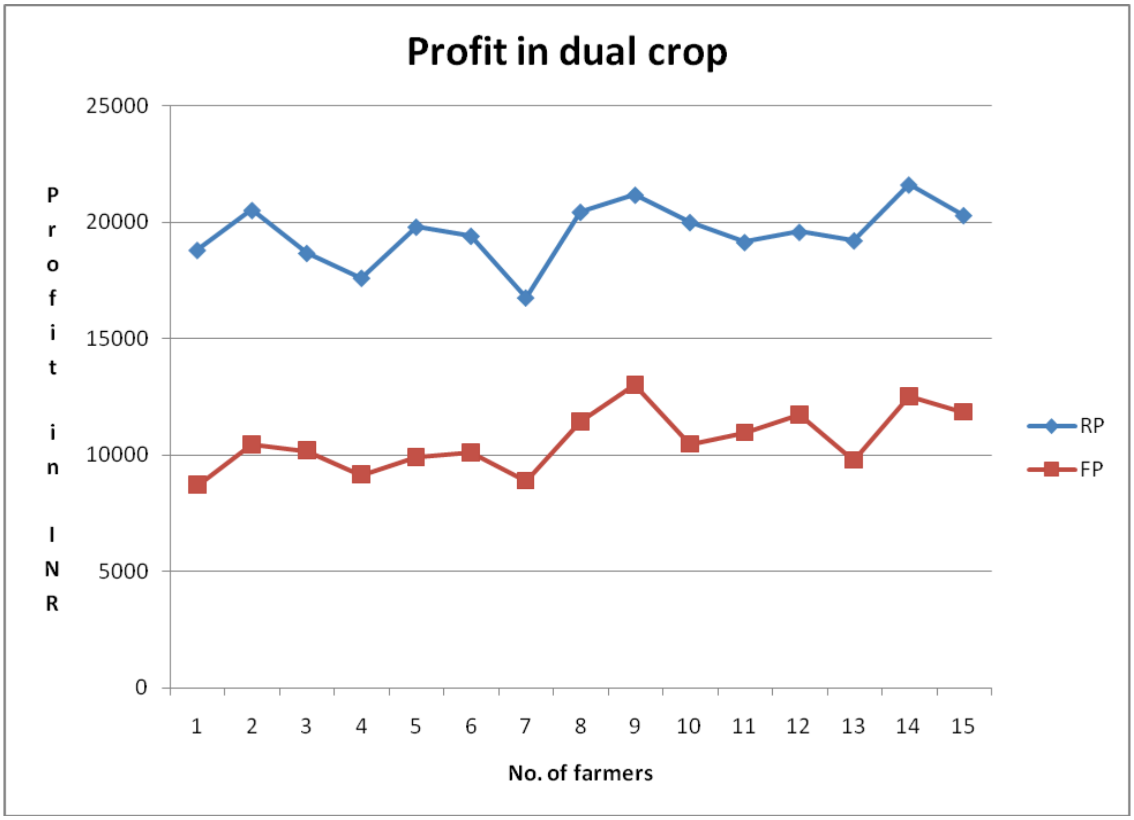
The number of effective tillers is a yield-attributing characteristic. The increase in tiller production might be due to a greater supply and more efficient utilization of nitrogen for cell multiplication, as well as the formation of nucleic acids and other vitally important organic compounds in the cell sap (Chandravanshi and Singh, 1974; Simons, 1982). Besides N-fixation, *Azolla* also contribute significant amounts of P, K, S, Zn, Fe, Mo and other micronutrients, potentially also contributing to the increase in the number of tillers.

4.4 Profit to Farmers

Graph 1.7 and 1.8 represent the effects of *Azolla* as a green manure and dual crop on rice cultivation profits, as compared to a chemically grown paddy crop.



Graph 1.7: Profit in green manure

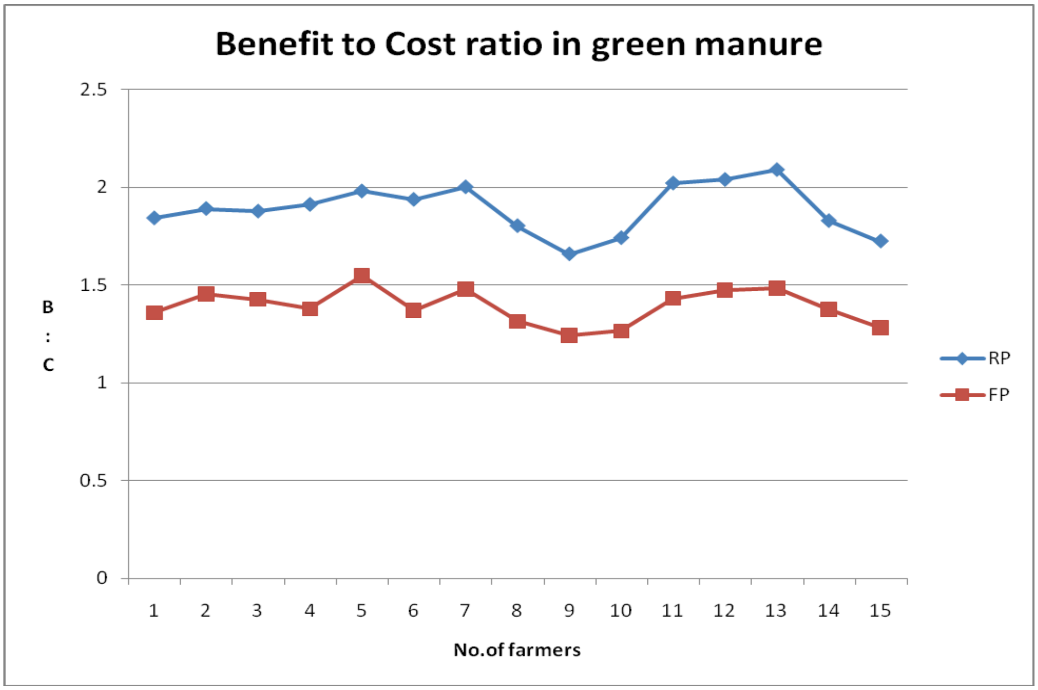


Graph 1.8: Profit in dual crop

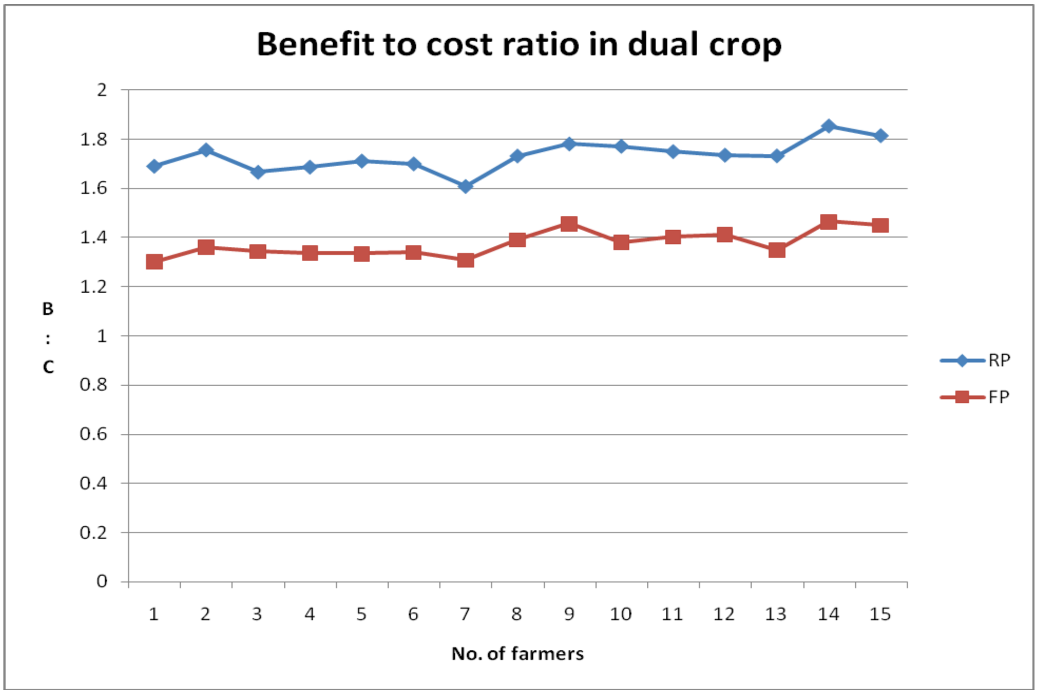
The data shows that the average profits of Rs. 23,342/- and Rs. 19534.67 were obtained from the application of *Azolla* as green manure and dual crop, respectively. The average net return of Rs. 10,943.33 and Rs. 10,604/- when using chemical fertilizer is additionally depicted. The data shows that the profit obtained by the use of *Azolla* as biofertilizer is significantly greater than chemical fertilizer showing better SAED.

4.5 Benefit to Cost Ratio

Graph 1.9 shows that the average B:C ratio observed was 1.89 and 1.39 in the cases of green manuring and chemically grown paddies. Similarly, in graph 1.10, one can see that the average B:C ratio was observed 1.73 & 1.38 in case of the dual crop.



Graph 1.9: Benefit to cost ratio in green manure



Graph 1.10: Benefit to cost ratio in dual crop

The above data confirms that there is higher sustainable agriculture economy development with the use of *Azolla* rather than chemical fertilizer.

5. Rejuvenation Strategies of Biofertilizers for Sustainable Agriculture Economic Development

The following strategies can be used for rejuvenating sustainable agriculture economic development:

- Identifying and selecting efficient locations, crop, soil, and specific strains for N-fixing, P, Zn solubilizing and absorbing (mycorrhizal) to suit different agro climatic conditions.
- Strain improvement through biotechnological methods.
- Exchanging cultures between countries of similar climatic conditions and evaluating their performance for a better strain for particular crop as well as checking the activity of cultures during storage to avoid natural mutants.
- Developing suitable alternative formulations viz., liquid inoculants / granular formulations for all bioinoculants, to carrier based inoculants, standardizing the media, method of inoculation etc., for the new formulations.
- Employing microbiologists in production units to monitor the production.
- Developing cold storage facilities in production centers.
- Technical training on the production and quality control to the producers and rendering technical advice and projects to manufacturers.
- Organizational training to the extension workers and farmers to popularize the technology.
- Disseminating information through mass media, publications and bulletins.(Gupta and Sen, 2013)

6. Conclusion

Biofertilizers represent a new technology for Indian agriculture that promises to balance many of the shortcomings of the conventional chemical-based technology. Biofertilizers are products that are likely to be commercially promising in the long run once adequate information becomes available to producers and farmers. The use of biofertilizers in India will not only have an impact on sustainable agriculture's economic development but it will also contribute to a sustainable ecosystem and the holistic well-being of the country.

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