3 Biotech (2018) 8:324
https://doi.org/10.1007/s13205-018-1345-5

ORIGINAL ARTICLE

Impact of blue green algae (BGA) technology: an empirical evidence from northwestern Indo-Gangetic Plains

Neeru Bhooshan[1] · Sunil Pabbi[2] · Amarjeet Singh[1] · Akriti Sharma[1] · Chetan[1] · Aman Jaiswal[2] · Anjani Kumar[3]

Received: 9 May 2018 / Accepted: 9 July 2018

Abstract

The focus of the current study is to assess the impact of blue green algae (BGA) technology on farming practices and economic conditions of farming households. The states of Punjab, Uttar Pradesh and Haryana considered as major rice-growing states of India were chosen for the primary survey. It was observed that use of BGA resulted in 25.2% of urea reduction with an overall 3.8% increase in the yield and a marginal decrease in per acre cultivation cost. Tobit model has been used to identify the determinants of increasing cropping area under BGA. Factors such as age, education, operated land holdings and leased-in land have a positive and significant impact on area under BGA. The study also provided the comparative analysis on yield of paddy, urea consumption and income with and without BGA application. It was observed that farmers earned about 3% greater income along with 41.1% reduction in dosage of urea while reaping 1% higher yield of paddy.

Keywords BGA · Impact · Fertilizer · Biofertilizer · Yield · Tobit · Paired *t* test

Introduction

Agriculture sector continues to play a significant role in the national economy of India. It contributes about 17.4% to the national GDP and provides employment to about 50% of the working population of the country (Economic Survey 2017–2018). The 'Green Revolution' made India self-sufficient in food grain production. The production of food grain has increased from 51 million tonnes (MT) in 1950–1951 to 271.98 MT in 2016–2017 (Agriculture Statistics 2017). Modern technologies such as high-yielding varieties of seeds and use of chemical fertilizers along with better irrigation facilities played a vital role in increasing the food production in India. The use of fertilizer continued to rise and now India is using four times the chemical fertilizers per hectare compared to the global average. The usage has increased exponentially over the past six decades. With a non-judicious and blatant use of chemical fertilizers, soil quality has critically deteriorated and it is also polluting the ground water. Moreover, indiscriminate use of urea leads to its leaching in soil, thereby making soil more acidic and sterile. Large amounts of pollutants emitted into the atmosphere during the manufacturing of chemical fertilizers are another cause for concern (Potter et al. 1985). Punjab and Haryana hold the major share of foodgrain production in the country with the consumption of high dosage of chemical fertilizers. The average consumption of chemical fertilizers in Punjab and Haryana in triennium (TE) 2015–2016 was 231.82 kg per hectare and 216.26 kg per hectare, respectively, which was much higher compared to national average of 125.53 kg per hectare (Agriculture Statistics 2016). The focus is being shifted to the use of such fertilizers that do not cause the harmful effects on soil and flora and fauna of the planet (Savci 2012).

Biofertilizers are basically soil-friendly microbial inoculants that are multiplied in controlled conditions and enhance crop yield (Majumdar 2015). In 1895, Nobbe and Hiltner had launched 'Nitragin', a laboratory culture of Rhizobia and thereafter, the list was appended and went on growing with the discovery of *Azotobacter* and blue-green algae biofertilizers along with integrated nutrient management approach as an effective solution to overcome the

✉ Sunil Pabbi
sunil.pabbi@gmail.com

1 Zonal Technology Management and Business Planning Division, ICAR-Indian Agricultural Research Institute, New Delhi 110012, India

2 Division of Microbiology, ICAR-Indian Agricultural Research Institute, New Delhi 110012, India

3 International Food Policy Research Institute, New Delhi, India

Published online: 17 July 2018

problem of excessive use of chemical fertilizers. The Government of India also made concerted efforts to promote the biofertilizers by initiating and supporting national and state projects on Development and Use of Bio-fertilizers (NPDB). Biofertilizers have, therefore, emerged as a potential alternative to chemical fertilizers due to their eco-friendly, easy to apply, non-toxic and cost-effective nature. Also, they provide nutrients that are naturally abundant in soil or atmosphere, usable for plants and act as supplements to agrochemicals. (Majid and Khan 2014). Blue-green algae (BGA) have been found to be an easily available and economically cheap resource material for production and use as biofertilizers. These are free-living, photoautotrophic micro-organisms, many of which also fix atmospheric nitrogen and are found in abundance in rice fields. Since water is a necessity for these organisms to grow and metabolize and fix nitrogen, the BGA technology works very effectively in paddy fields. De (1939) suggested the positive role of blue-green algae in augmenting the nitrogen levels of rice fields. BGA is one of the potent substitutes of urea and can be used extensively in paddy fields. Considering this, BGA has been developed as a biofertilizer especially for lowland rice and can be produced economically (Pabbi 2008). A number of workers from time to time have reported saving or less application of nitrogenous fertilizers with the application of blue-green algae in rice (Pereira et al. 2009; Begum et al. 2011; Mishra and Pabbi 2004; Pabbi 2015). Based on the results of long-term field trials, Watanabe (1965) reported a progressive increase in rice yield in Japan and also reported the effect of application of algae equivalent to that of 60 kg/ha of ammonium sulfate. A study with integrated use of different inputs for better management of available resources for paddy under rice–wheat–mung bean cropping system in north alluvial soils revealed that combined application of BGA and *Azolla* along with 60 kg/ha *N* supply from chemical fertilizer (urea) can improve the nitrogen economy of kharif rice providing grain and straw yield optimum to the one achieved with 90–120 kg *N* supply (DBT Report 1998).

Objective of the present study is to assess the impact of use of blue-green algae technology on yield, use of chemical fertilizer, farmers' income and cost of cultivation, and to identify the main contributing factors responsible for adoption of technology. As stated earlier, there are many studies reporting the effect of BGA technology on crop yield or chemical fertilizer saving but there is hardly any evidence available on the impact of BGA application on farmer's income. This study is probably the first of its kind in India where the impact of BGA technology has been studied along with the analysis of factors responsible for adoption of the technology.

Materials and methods

Data

The study draws its conclusions from primary data and supported by secondary data. From northwestern Indo-Gangetic Plains, **t**he Punjab (PB), Uttar Pradesh (UP) and Haryana (HR) states of India were selected as samples to conduct the primary survey. The farmer was taken as an end consumer who applied the BGA technology on farm. It is pertinent to mention that Indian Agricultural Research Institute (IARI) has evolved a technology for commercial production of BGA biofertilizer. It is a carrier-based ready-to-use BGA biofertilizer which is a consortium consisting of *Anabaena variabilis, Nostoc muscorum, Aulosira fertilissima* and *Tolypothrix tenuis*. It has a cell count of ~ 10^4/g of carrier. IARI produces BGA biofertilizer for distribution to farmers and also licences the technology to agripreneurs for commercial production. Data of a total of 260 households were collected through snowball sampling technique (non-probability sampling technique). Since, in Punjab, there has been wider technology dissemination through technology licensee of IARI, large size sample was collected from PB. In UP and HR, sample has been collected from farmers to whom IARI had distributed the BGA; therefore, the sample size of these two states is small. Plot-wise controlled sample was also selected to check the authenticity and to compare the result of BGA technology for the same varieties of crops with same characteristics of soil in the land holding. The control sample area information was collected from the same farmers, same fields, and varieties that were being used for BGA samples. Keeping in mind the objective of the study, the schedule had been prepared in such a manner, so as to facilitate examination of the socio-economic indicators, such as age, education, source of technology, farm size, area under BGA, yield differences, cost differences, and income per acre, and the impact of BGA technology on farmers.

Methodology

Paired *t* test

Paired *t* test has been applied to study before and after differences in various indicators of BGA technology which have been chosen in this study. The impact of BGA technology on various factors has been identified including use of chemical fertilizers, per acre yield, and per acre income on which the *t* test was run to categorize the significant difference in these values. The *p* and *t* values were used to verify the significant difference at 1, 5 and 10% to indefinite due to impact of BGA technology. The paired *t* test is based on the pairwise differences in the values of the matched observations of two samples $d_i = y_{2i} - y_{1i}$. The difference of matched pairs is treated as a variable; the logic of the paired *t* test and one-sample *t* test is identical. The present study used the following formula for this purpose:

$$t_{\bar{d}} = \frac{\bar{d}}{\mathrm{SE}(\bar{d})}$$

where $\bar{d} = \frac{\sum_{i=1}^{n} d_i}{n}$ and $\mathrm{SE}(\bar{d}) = \frac{\sigma_d}{n}$

$\bar{d}$ is calculating the difference between mean. The null hypothesis is that the population mean of individual differences of paired observations is 0 (zero unless explicitly specified), i.e., H_0: $\mu_d = 0$. If the null hypothesis is rejected, there must be a significant difference (effect) between two samples (pre- and post-outcomes).

Tobit model

The Tobit model is a statistical model that was proposed by James Tobin (1958). This model utilizes censored regression model to estimate the extent of adoption of technologies. Many of the sampled farmers were not using the BGA technology on the entire land. Therefore, there was need to cover the zero observation with the Tobit model. Dependent values may be zero and indented variable values can be regressed with Tobit model. The model assumes that there is a latent variable linearly dependent on Xi via parameter vector β which determined the relationship between independent variable and latent variable. The model specified

Table 1 Socio-economic characteristics of the sampled households (Source: Field survey 2015–2016)

Category	Overall (%)
Education	
Illiterate	3.8
Primary	7.3
Middle	10.8
High school	36.5
Senior secondary	23.5
Graduation and above	18.1
Family size	
01–03	8.8
03–05	42.7
05–07	27.3
07–10	13.5
Above 10	7.7
Age	
20–35	22.3
35–50	54.6
50–65	14.6
Above 65	8.5
Livestock and tractor	
Average livestock (Nos.)	6.0
Households having tractor (%)	91.0
Average land holding status (acres)	
Operated land	21.0
Owned land	15.0
Area under BGA	6.0
Area under BGA (%)	27.0
Adoption % of BGA technology across different categories of farmers	
Marginal and small	15.2
Semi-medium	29.4
Medium	39.6
Large	16.2

$$Y = X\beta + \mu,$$

$$y_i = \begin{cases} y_i^* & \text{if } y_i^* > 0 \\ 0 & \text{if } y_i^* \leqslant 0 \end{cases} \quad Y = \text{depended variable (area under BGA technology)},$$

where *X* is the independent variable {age (years), education (years of schooling), operated land holding (acres), leased-in (yes—1, otherwise—0) type of family (joint and nuclear)}; β is the estimated by regressing the observed *y* on *x*; μ is the error term to capture random influences on the relationship.

Results and discussion

BGA fix atmospheric nitrogen and supply it to plants thereby having the capacity to reduce the consumption of urea. Thus, the adoption pattern of BGA technology was examined along with the human behavior through socio-economic indicators which motivate farmers to adopt the new technologies. The information on education status, family structure of the sampled households, source of information, awareness, size of operational land holding, owned land holding, leased-in land, leased-out land, mortgage-in, mortgage-out of the sample farmers were collected (Table 1). The impact of BGA technology on farmers through different indicators such as yield, usage of fertilizer, cost of cultivation and income was also examined.

Though 96% of sampled farmers in three states were literate, majority of them (60%) had education either up to high school or senior secondary. About 18% of the sampled farmers were graduate and above.

Majority of the sample households have 3–7 members in the family. The result showed that 54.6% of the surveyed farmers using the technology belonged to 35–50-year age group. The farmers of this age group were mature, knowledgeable, experienced with risk-taking capability, empowered and the obligations of family caused them to apply innovative technologies with promise. The survey confirmed that 91% farmers have their own tractor to operate the land. Livestock was also included in the study to gauge the use of cattle dung, and it has been observed that usually farmers were applying livestock dung as organic manure to increase yield and fertility of soil. Nevertheless, the quantity of manure was not enough to meet the requirement of crops. Average number of livestock was only six. The surveyed farmers were broadly of the view that dung of 5–6 animals could be used in 1–1.5-acre agriculture field (annually) as manure.

It was observed that on an average sampled household possessed 21 acres of operated land which included 15 acres of owned land and 6 acres of leased-in land. Average area under BGA technology was six acres, i.e., approximately 27% of the operated land was under BGA practices. It is interesting to note that land-holding status was one of the important indicators, which motivated the farmers to adopt the new technology. It was observed that marginal and small farmers do not have sufficient land and are involved in other activities to sustain their livelihood while semi-medium- and medium–land holding farmers put in efforts to sustain their livelihood through existing fields; therefore, this category of farmers was interested to adopt new technologies to get higher crop yield. It was assessed that 29.2% of semi-medium and 39.6% of medium farmers were applying the BGA technology. Collectively, about 70% farmers belonging to these categories were applying the BGA. This category was risk-taking and aggressive to adopt the new technologies owing to tenacious involvement in agriculture activities to sustain their livelihood. The marginal and small farmers, however, are not averse to apply this technology but do not have enough income to bear the risk. They follow only successful practices of the progressive farmers.

Impact of BGA application on the use of chemical fertilizers, yield, cost and income

Generally, urea is one of the most blatantly used chemical fertilizers in Indian agriculture. The overuse of this chemical is damaging the quality of soil and water and impacting the climatic conditions, which in turn is adversely affecting the crop yield. New human health issues are emerging day by day because urea is degrading the quality of food. Nitrate leaching is particularly linked to agricultural practices such as fertilizing and cultivation. Negatively charged nitrate can reach ground water. Even in ideal conditions, plants use 50% of nitrogenous fertilizers applied to soil, 2–20% is lost through evaporation, 15–25% reacts with organic compounds in the clay soil and the remaining 2–10% interferes with surface and groundwater. DAP is another fertilizer that has 18–21% nitrogen, however, it was not very popular for paddy, and the average use of DAP was just 17 kg/acre. Since BGA fixes nitrogen and supplies to crop plants, it has a scope to minimize the consumption of urea/DAP in farm field of paddy where the conditions are conducive for its growth and multiplication. Furthermore, it was noticed that another chemical fertilizer, potash, was also not widely used for paddy crop in the three sampled states.

It was found that with the adoption of BGA practices in paddy crop, there was decline in use of urea (25.2%) and DAP (17%). The results of paired *t* test showed that the consumption of urea and DAP were significant at 1% level with *t* values to the tune of 14.62 and 4.7, respectively (Table 2). Roychowdhury et al. (2014) have evaluated the impact of using biofertilizers on the consumption of chemical fertilizers in rice and observed that the application of inorganic chemical fertilizers was significantly reduced to 30–50%. Similar observations have been reported by number of workers from time to time (Venkataraman 1979; Hegde and Dwivedi 1993;

Table 2 BGA impact on use of chemical fertilizers, yield, cost and income (Source: Field survey, 2015–2016)

	Before	After	Difference	Change (%)	*t* value
Consumption of urea (kg/acre)	116.3	87	− 29.3	− 25.2	14.62
Consumption of DAP (kg/acre)	17.0	14	− 3.1	− 17.9	4.70
Consumption of potash (kg/acre)	2.9	2.6	− 0.3	− 9.4	0.64
Consumption of zinc (kg/acre)	5.1	5.6	0.6	11.2	1.44
Impact on cultivation cost (INR/acre)	9717.0	9531.0	− 186.0	− 1.9	1.41
Impact on yield (q/acre)	28.3	29.42	1.1	3.8	11.31
Impact on income (INR/acre)	45,184.0	46,940.0	1756.0	3.9	11.42

Singh and Singh 1992; Pabbi 2008; Prasanna et al. 2013a; Dhar et al. 2015). The results of the present study are consistent with earlier studies. No significant difference was found in the use of potash and zinc fertilizers. Furthermore, since per hectare consumption of chemical fertilizer is higher, there is a scope to further minimize it up to certain level. With the use of BGA, the average yield of rice increased from 28.34 to 29.42 quintal per acre. The difference was significant at 1% level. The positive effect of blue-green algal inoculation on grain yield of rice has also been reported (Venkataraman 1979, 1981; Roger and Kulasooriya 1980; Sprent and Sprent 1990; Ghosh and Saha 1997; Dhar et al. 2007). However, the gains in terms of reduction in cost of cultivation and income to the farmers which has a direct impact in terms of money saved or earned have not been studied earlier. No significant difference was found in the cost of cultivation of paddy because the extent of use of other inputs was same with reduction in only urea and DAP. Another important factor to mention is that in PB, BGA is provided to farmers by private companies and the average cost incurred is Indian Rupees (INR) 325 per acre. The total cost per acre required was compared to the total cost per acre when using BGA technology with other inputs and results across the three states are presented in Fig. 1. Main objective of innovation or technology is to improve the living standard of society by helping generate additional income. The income of farmers increased by 3.9%. Overall, average income of the farmers was INR 45,184 per acre and it increased by INR 1756, i.e., 3.9%.

We have also analyzed the impact using with BGA application and without BGA application approach. The findings based on with and without approach reaffirm our results based on before and after approach. In the initial year, farmers were not very much interested in applying the new technology in the entire cultivable land. Therefore, the comparative statistics were also measured with same land characteristics for in-depth analysis of the study and sample was conducted with and without application of BGA technology for various varieties of paddy. Concisely, out of all indicators,

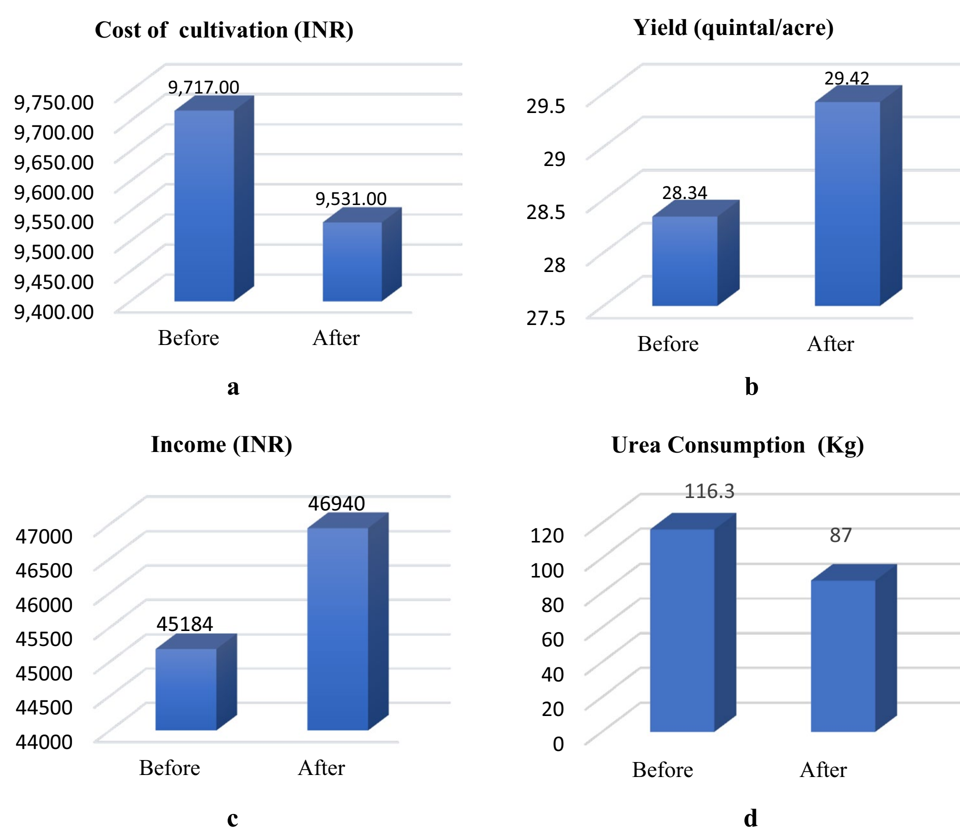

Fig. 1 Average cultivation cost (**a**), yield (**b**), income (**c**) and urea consumption (**d**) in paddy per acre before and after use of BGA technology

Table 3 Average yield, average use of urea and average income with and without BGA technology (Source: Field survey)

	With BGA	Without BGA	Difference	Change (%)
Yield (Q/acre)	29.4	29.1	0.3	1.0
Urea application (kg/acre)	87.0	123.0	36.0	41.4
Income (INR/acre)	46,940.0	45,668.0	1272.0	2.7

the results of yield, chemical fertilizers and income difference were measured with all other circumstances being constant in sampled households. It was clear that with BGA practice the farmers were reaping 1% higher yield (Table 3). The increase in crop yield is beneficial for farmers as it directly translates to a better harvest and returns. It is important to mention that the yield gain was possible even with reduced practice of chemical fertilizers revealing that the consumption of urea was 41.4% less in BGA-adopted plot. Venkataraman (1981) suggested that in many areas, 10–20% increase in grain yield could be obtained through algal application in the absence of any added chemical nitrogen fertilizer.

The reduction in use of urea gave further scope that BGA technology could be extended in non-adopted areas as per respondent interrogation with motive to reduce the quantity of urea. Farmers having assimilated BGA technologies in their farming practices reported an increased income from their fields. The average income per acre for farmers using BGA technologies was calculated at INR 46,940 which was higher when compared to the farmers growing the same crops without using BGA. It was estimated that 2.7% higher income could be generated in adopted plot.

Determinants of adoption of BGA technology: estimates of Tobit model

Tobit model is censored regression, which is generally fit to know the linear relationship between dependent and independent variables when there is censor variable in dependent variable. The adoption of technology was influenced by a number of socio-economic characteristics of the households. To identify these factors, we have used Tobit model and the results are depicted in Table 4. Area under BGA technology is a dependent variable and independent variables comprise age, education, operated land holding, leased-in land, type of family etc. Age, education, land size, leased-in land were found to have significant impact on area under BGA, thereby meaning that significant variables were accountable that would increase the area under BGA technology. The positive relationship between age (proxy experience) and BGA application indicates that the farmers with higher experience and maturity have high probability of BGA application. The education increases the skills, expertise and the awareness, thus helping the farmers in better realization of the benefits of the potential impact of BGA application. The results showed that households having joint family were less likely to adopt the BGA technology. It may be because of complex nature of decision-making in the joint family system.

Potential impact of BGA application at macro-level

The study found that technology was introduced through organized *melas* (farmers fair) and marketed through distributors, dealers, co-operative societies, etc., mostly by industry partners and made available to farmers at their door step. But, it is important to mention that lack of technical guidance (information) was apparent and technical knowhow is indeed vital to extend the application knowledge for the effective results in field. In all, 57% of the farmers were lacking in

Table 4 Results of Tobit model

Area under BGA	Co-eff.	Std. err.	t	$P>\|t\|$
Age	0.1.065405	0.4890861	2.18	0.030*
Education (years of schooling)	0.516418	0.292651	1.76	0.079*
Land leased-in (yes = 1, otherwise = 0)	1.469456	0.8107225	1.81	0.071*
Type of family (joint = 1, otherwise = 0)	− 0.17969	0.10402	− 1.73	0.085*
Operated land (acres)	0.0438904	0.0165087	2.66	0***
Information (yes = 1, otherwise = 0)	0.427026	0.746683	0.57	0.568
_cons	3.053165	1.982343	1.54	0.125
/sigma	6.269345	0.2811827		

***, ** and *Significance at 1, 5 and 10%, respectively

Table 5 Average cost of BGA per acre incurred by farmers (Source: Field Survey)

	Average cost of BGA per acre (INR)	Reduction in cost of BGA as expected by farmers (INR)	Expected price per acre (INR)
Punjab (PB)	314.7	35.8	279.0
Uttar Pradesh (UP)	20.0[a]	0.0	20.0
Haryana (HR)	20.0[a]	0.0	20.0
Overall	259.8	29.2	231.0

[a]BGA provided to farmers as sample in INR 20 per acre

technical knowhow on application of BGA in their fields. Some farmers had adequate knowledge about using the BGA technologies as they were purchasing the BGA biofertilizer packets directly from Indian Agricultural Research Institute (IARI) and were applying the technology as suggested by the scientists. Therefore, there is need to provide technical knowledge to farmers, may be through organizing training camps at village level in collaboration with industry partner to ensure right and timely application of BGA.

Table 5 shows the average cost per acre incurred by farmers on using BGA in their fields. As BGA is to act as a substitute for urea, farmers expect it to be available at the same or lesser cost than that of urea, which is costing about INR 290 per acre. Farmers in Punjab currently incur a cost of INR 314.7 (average) per acre when they use BGA in their fields. These farmers stated that by using BGA their average cost per acre increased by INR 35.8. This was not economical for farmers as they wanted it at reduced cost of around INR 231 per packet of 750 gm. On the other hand, BGA packets from IARI were made available to the farmers of UP and HR at INR 20 only.

From 2012–2013 to 2014–2015, area under paddy (average for 3 years) in PB, HR and UP was 2.80, 1.26 and 5.87 million hectares (MHa), respectively. In the present study, it was observed that with the use of BGA, urea consumption decreased up to an extent of 25.2% (Table 2). Supposedly, and based on our results of BGA adoption by farmers (27% area under BGA, Table 1), if BGA technology covers 20% of rice-growing area, the consumption of urea may decrease to 31.36, 9.61 and 43.73 thousand tonnes in PB, HR and UP, respectively (Table 6). The data also portray the probable reduction in urea consumption with 25 and 30% coverage of area by BGA technology.

Total urea consumption was estimated to be 1713 thousand tonnes in PB, 3842 thousand tonnes in UP and 1165 thousand tonnes in HR during 2013–2014. This is a huge amount consumed by agricultural fields in three states. There is scope to reduce the total consumption of urea in these states of India up to 428, 961 and 291 thousand tonnes, respectively, with application of BGA as per empirical result found under the present study. It is possible to extend this technology with the motive to fetch the maximum area through transfer of technology in all over India which could further lead to decline in the consumption of urea. In the year 2012–2013, government had provided the subsidy of INR 40,016 crores (~ US$ 5800 million) on urea. Decline in the consumption of urea will reduce the burden of subsidy and have a long-term impact on soil health. In a country like India, where agriculture is mainly practiced at small and marginal level and farmers cannot afford costly inputs, the organic manures and biofertilizers can make the system viable and reduce the ecological hazards (Tripathi et al. 2001).

Conclusion

As observed, application of BGA reduced urea application by 25.2% without negotiating the yield of paddy with an overall increase of 3.8% in the yield and a marginal decrease in per acre cultivation cost. The study also revealed that farmers' income increased from INR 45,184 to INR 46,940 per acre. Tobit model was adopted to identify the determinants

Table 6 Total area under paddy crop in PB, HR and UP, quantity of urea consumption, price paid by farmers and opportunity to reduce the urea consumption

	Area under paddy*	Expected area under BGA at different levels of adoption			Existing use of urea (kg per hectare)	Application of urea as calculated for area**			Potential reduction in urea use[a]		
		20%	25%	30%		20%	25%	30%	20%	25%	30%
Punjab											
2012–2013	2.8	0.6	0.7	0.9	243.0	138.5	173.1	207.8	34.6	43.3	51.9
2013–2014	2.8	0.6	0.7	0.9	249.0	141.9	177.4	212.9	35.5	44.4	53.2
2014–2015	2.8	0.6	0.7	0.9	217.0	125.4	156.8	188.1	31.4	39.2	47.0
Haryana											
2012–2013	1.2	0.2	0.3	0.4	158.0	38.6	48.2	57.8	9.6	12.1	14.5
2013–2014	1.2	0.3	0.3	0.4	180.0	44.3	55.4	66.4	11.1	13.8	16.6
2014–2015	1.3	0.3	0.3	0.4	149.0	38.4	48.1	57.7	9.6	12.0	14.4
Uttar Pradesh											
2012–2013	5.8	1.2	1.5	1.8	165.0	193.4	241.7	290.1	48.4	60.4	72.5
2013–2014	6.0	1.2	1.5	1.8	180.0	215.3	269.1	322.9	53.8	67.3	80.7
2014–2015	5.9	1.2	1.5	1.8	149.0	174.9	218.7	262.4	43.7	54.7	65.6

**Area* million hectare (MHa); ***Quantity* thousand tonnes

[a]These are authors' calculations assuming that BGA adopters use 25% less urea

of increasing cropping area under BGA and it has been found that age, education, family size, owned land holdings and leased-in land have a positive and significant impact on extending the area under BGA. This is an important observation which is critical for successful adoption of any agriculture-based technology. That farmers lacked technical knowledge related to technology application was another important observation which may again affect its adoption as little or no knowledge may lead to wrongful and untimely use leading to variable results or even make the technology defunct. Consequently, it also provided a comparative study on yield of paddy, urea consumption and income vis-a-vis BGA application in a part of their operational land. The effect of time has been nullified while comparing the variables. It has also been observed that farmers earned 2.7% more income with 41.1% reduced dosage of urea while reaping 1% higher yield of paddy. Moreover, the success of technology always motivates farmers to infiltrate the technology in whole part of land holding and even attract the attention of neighboring farmers. Farmers can increase their income with the protection of and improvement in their farms' soil health and help the nation realize its dream of doubling farmers' income. The diffusion of subsidy on biofertilizers must be considered as a rewarding option to increase the usage. Apart from this, more investment in research and development is required to develop area-specific innovative, efficient as well as cost-effective technologies, which will further lead to sustainability, fertility and higher productivity. No doubt, it is a fact that farmers have been applying modern input practices for the last four decades and are always ready to adopt yield-growing technologies. Consequently, production of wheat and paddy has increased leading to self-sufficiency in food production.

Compliance with ethical standards

Conflict of interest On behalf of all authors, the corresponding author states that there is no conflict of interest.

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