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Sustainability and impact assessment of IPM in Basmati rice (*Oryza sativa*)

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ABSTRACT

Integrated pest management (IPM) strategy has greatly contributed to a progressive commitment for sustainable agriculture in India. Long term studies conducted on validation and promotion of IPM in basmati rice (*Oryza sativa* L.) in district Gautam Budh Nagar, Uttar Pradesh, India resulted in a gradual enhancement in the area under IPM from 40 ha in 2010 by participation of 25 farmers to 990 ha in 2019 by participation of 654 farmers from 42 villages. Implementation of IPM technology resulted in a significant ($P<0.05$) reduction in the incidence of yellow stem borer (69.64%), leaf folder (70.9%), brown plant hopper (55.52%), bakane (90.98%) and the population of root-knot nematode (76.8%) over farmers' practices (FP). It enhanced the population of predatory spiders (84.2%), beneficial soil nematodes (159.27%) and bio-agents, viz. *Pseudomonas fluorescens* (78.74%) and *Trichoderma harzianum* (81.34%) over FP. Application of chemical pesticides was reduced to 75.25 g/ha in IPM against 892.93 g/ha in farmers' practice. The maximum residue level of buprofezin, a widely used insecticide, was recorded below detectable level in paddy grains. Long term studies indicated higher yield (38.0 q/ha) as well as benefit:cost ratio (3.6) in IPM as compared to FP yield (30.5 q/ha) and benefit:cost ratio (2.3) with 58.3% enhancement in net return over FP. Thorough analysis of the data indicated the availability of critical inputs, accessibility of farmers to subject matter specialists through Farmer Field Schools and market for IPM produces as the main factors responsible for sustainability and horizontal spread of IPM in Gautam Budh Nagar.

Keywords: Basmati rice, Farmer Field School, Impact assessment, Integrated pest management, Sustainability

IPM is a knowledge-based technology that needs to be adopted in specific locations and situations. High use of fertilizers, a favourable option for the farmers to enhance rice production (Stewart *et al.* 2005), enhances rice insect pest population by altering rice plant suitability and attractiveness toward herbivorous insects (Ge *et al.* 2013). Modern concept of IPM is based on ecological understanding of the crop and its interaction with soil nutrients and varieties (Heinrichs and Muniappan 2017). IPM in India, in principle, has been accepted as the most attractive option for protecting the crop from the ravages of insect pests and diseases but its large-scale implementation has been rather limited. Most of the efforts made by different researchers are confined to small validation trials in farmers' fields and research farms (Chaudhary *et al.* 2017, Garg *et al.* 2008). There is a need to conduct IPM on community basis and study the sustainability, and carry out quantitative analysis of the impact of IPM on various socio-economic parameters; this requires exact data on the benefits per unit to calculate costs and benefits, its diffusion, and variables such as the number of farmers trained and the quality of the training.

During last one decade sincere efforts made by ICAR-National Research Centre for Integrated Pest Management (NCIPM), New Delhi on validation and promotion of IPM has resulted in successful implementation of IPM in basmati rice (*Oryza sativa* L.) in a cluster of 42 villages in and around Bambawad in Gautam Budh Nagar, Uttar Pradesh (latitude 28'55°N; longitude 77'59°E). Validation of IPM trial, initially conducted in 286 ha at Bambawad during 2010–14 (Tanwar *et al.* 2016), has now been extended to 990.4 ha. The present study (2016–20) is the compilation of impact of large-scale implementation of IPM strategy on major insect pests and diseases, beneficial chemical pesticide uses, and benefit:cost ratio in basmati rice. Efforts have also been made to investigate various factors responsible for sustainability and horizontal spread of IPM in basmati rice.

MATERIALS AND METHODS

IPM module: IPM module validated during 2010–14 (Tanwar *et al.* 2016) comprises: (i) growing *Sesbania* or mung bean for green manuring: *Sesbania,* planted by middle of May and incorporated in soil after 45–55 days of sowing during land preparation. In case of mung bean

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(sown in April), plants buried in the soil after picking of mature pods; (ii) seed treatment with carbendazim @1 g a.i./kg seed for bakane and sheath blight management; (iii) planting of 2–3 seedlings/hill, (iv) judicious application of fertilizer (60 N: 50 P: 40 K kg/ ha) and $ZnSO_4$ @25 kg/ha; (v) use of straw bundles (20 per ha) for augmentation and conservation of spiders (Tanwar *et al.* 2011); (vi) pest monitoring at weekly interval by a trained field scout and fixing pheromone traps @5 traps/ha to monitor yellow stem borer (YSB) population; (vii) one release of egg parasitoid, *Trichogramma japonicum* (supplied by Biological Control Laboratory, SVB Patel University of Agriculture and Technology, Meerut-SVBPUA&T) @1,50,000 per ha against YSB in September after appearance of YSB moths in pheromone traps or its egg masses on leaves in paddy fields; (viii) manual weed management; (ix) seedling root dipping in *Pseudomonas fluorescens* solution (3.0×10^{10} cfu; 5 ml/litre of water) for bakane; (x) need-based application of chemical pesticides against insect pests and diseases based on economic threshold level (ETL) (Prakash *et al.* 2014); (xi) soil application of *Trichoderma harzianum* (2.8×10^8 cfu) at 1 kg/ha applied after harvest of each crop.

Farmers' practices (FP) comprised growing crop without green manuring and no seed treatment, planting of one seedling/hill, higher doses of fertilizers (220 N: 40 P: 0 K kg/ha), no pest monitoring and 2–5 chemical pesticide applications on the advice of pesticide dealers. Among chemical pesticides, cartap hydrochloride was applied in most of the FP fields (@500 g a.i./ha; 1–3 applications) followed by buprofezin (@200 g a.i./ha; 55–85% fields), phorate (@1000 g a.i./ha; 15–40% fields), carbofuran (@750 g a.i./ha; 20–34% fields), hexaconazole (@50 g a.i./ha; 30–45%), dichlorovos (@750 g a.i./ha; 15–25%) and streptocycline (@20 g a.i./ha; 5–15% fields).

IPM validation and promotion activities: Validation trial during 2010–16 included supply of critical inputs such as carbendazim, *P. fluorescens*, pheromone traps, *T. harzianum* and tricho-cards by NCIPM to farmers and organizing Farmer Field School (FFS) at 10–15 days interval in IPM villages. From 2017–20, FFSs were organized only once in a month and no critical inputs were provided as these were available at block office and farmers could understand the ETL concept of pesticide application. For pesticide residue analysis of rice grains, samples collected from five IPM fields (50 g from each field) were thoroughly mixed and analysed by Accredited Pesticide Laboratory for the presence of residues of buprofezin, most common pesticide used by farmers against brown planthopper (BPH), using Liquid Chromatography (LC/MS/MS). Rice samples were analysed from FP fields.

Data collection and analysis: Incidence or population of major insect pests and diseases along with beneficial spiders was recorded at weekly intervals from 40 IPM fields and 20 FP fields of 0.40 ha each by selecting 20 hills from five spots per field (4 hills from each spot). From each spot total number of tillers, leaves, leaf folder damaged leaves, dead hearts of tillers and white ear head of panicle bearing tillers after flowering stage caused by YSB were observed to score per cent incidence of leaf folder (LF) and YSB. In case of BPH and spiders, total number of nymphs or adults/hill were counted. Rice root-knot nematode, *Meloidogyne graminicola* population from soil samples were assessed using Cobb's sieving and decanting gravity method followed by Baerman's funnel extraction technique (Southy 1986). Records of all the inputs applied in fields and the grain yield were maintained to calculate benefit:cost ratio (total return/total cost). Total cost included the material cost along with labour cost for land preparation, nursery sowing, transplanting, fertilizer application, hand weeding, pesticide application, etc.

Data collected on various parameters from IPM and FP fields were subjected to student's t-test to compare the mean difference at 1–5% level of significance (SPSS V16). In the present study, pest and socio-economic analysis data of the trial conducted during 2010–14 by Tanwar *et al.* 2016 has also been included to investigate the horizontal spread and impact of the technology.

RESULTS AND DISCUSSION

Impact of the technology

Insect pests and predators: Implementation of IPM technology resulted in significant ($P<0.05$) reduction in the incidence of YSB (68.64%), LF (70.9%) and BPH (55.52%) over FP (Table 1) and indicated significantly ($P>0.02$) higher population (1.1–4.5 adults/hill) of spiders in IPM as compared to FP (0.4–3.4 adults/hill) fields with an overall enhancement of 84.2% over FP (Table 1). Spider bundles help in conservation of spiders (Tanwar *et al.* 2011). Spiders represent more than 90% of the natural enemies of stem borer, LF and BPH in rice agro-ecosystem (Lee *et al.* 1997). Likewise, significantly ($P>0.01$) higher population of beneficial soil nematodes (BSN) was recorded in IPM fields (2048 to 2894 per 100 cc soil) as compared to FP fields (572 to 1186 per 100 cc soil) (Supplementary Table 1). Role of saprophytic nematodes in increasing the nutrient availability through organic matter decomposition is well established (Gebremikael 2016).

Diseases and microbials: Bakane, a major disease prevailing in Pusa Basmati 1121, has been reduced to 90.98% in IPM over FP fields (Table 1). It is interesting to note that the incidence of bakane was 19.04% in FP fields during 2013, it reduced to 10.2% in 2019 as the entire village was under IPM except a few FP fields. Bakane is considered to be soil (Sharma *et al.* 2011) as well as seed-borne (Ma *et al.* 2008). Seed treatment of rice with rice-associated antagonistic bacteria has been found effective in reducing bakane (Sharma *et al.* 2011). In the present study, seed treatment with carbendazim along with seedling root dipping in *P. fluorescens* effectively contained the bakane. It is further supported by Pannu *et al.* (2013), whose findings revealed that seed treatment + seedling dip with carbendazim @0.2% was most effective in reducing the disease. Farmers' interaction during the surveys has also strengthened the

Table 1 Incidence of pest and diseases during 2010–19 and spider (natural enemies) in 2016–19

Pest incidence/ population		Year											
		2010*	2011*	2012*	2013*	2014*	2015	2016	2017	2018	2019	Mean	Per cent reduction (-) over FP (%)
Yellow stem borer (%)	IPM	0.11	0.04	1.10	0.14	0.07	0.04	0.5	1.52	0.68	0.92	0.51	(-) 69.64
	FP	1.29	0.56	1.29	0.84	0.69	1.35	1.35	4.17	2.25	3.05	1.68	
t-test		S	S	S	S	S	S	S	S	S	S		
Leaf folder (%)	IPM	0.08	0.05	0.15	0.09	0.14	0.05	0.17	1.22	0.2	0.31	0.25	(-) 70.9
	FP	1.06	0.34	0.35	0.28	0.34	0.38	0.38	4.4	0.4	0.56	0.85	
t-test		S	S	S	S	S	S	S	S	S	S		
Brown plant hopper (no.)	IPM	7.74	9.55	1.22	4.32	0.49	1.44	4.76	1.06	8.76	5.72	4.51	(-) 55.52
	FP	31.13	14.16	1.36	7.24	0.82	1.65	8.91	6.17	19.28	10.67	10.14	
t-test		S	S	S	S	S	S	S	S	S	S		
Bakane (%)	IPM	0.32	5.21	3.31	0	0.05	0.03	0.06	0.75	0.03	0.10	0.99	(-) 90.98
	FP	2.87	17.04	14.67	19.04	9.8	9.41	9	8.37	9.3	10.20	10.97	
t-test		S	S	S	S	S	S	S	S	S	S		
Spider	IPM							2.7 (1.9-3.7)*	3.9 (3.0-4.5)	3.4 (2.7-3.9)	3.4 (1.1-6.1)		(+84.21)
	FP							2.1 (1.0-3.4)	2.1 (1.2-3.0)	1.6 0.4-2.7)	1.8 (0.4-2.9)		
t-test								S	S	S	S		

*Tanwar *et al.* 2016

Note: Test of significance (student's t-test), significantly different at 5% level of significance. S–Significant; IPM–Integrated pest management; FP–Farmer's practice. Figures presented in parentheses are range per hill during the season.

concept that seed treatment with carbendazim @2.0 g/kg or carbendazim + thiram (1:1) @2.5 g/kg seed is the most efficient method for bakane disease management (Gupta *et al.* 2014).

Rice root-knot nematode, *M. graminicola* was recorded low (21.0±12.6 to 52.2±11.3 per 100 cc soil) in IPM as compared to FP (98.8±19.0 to 224.0±26.4 per 100 cc soil) throughout the season (Supplementary Table 1). Singh *et al.* (2019) suggested that incorporation of IPM components over the years not only improved the soil health and fertility but also helped manage *M. graminicola*.

Soil analysis indicated higher population of bio-agents in IPM as compared to FP (Supplementary Table 2). Implementation of IPM resulted in 81.34% and 78.74% enhancement in the population of *T. harzianum* and *P. fluorescens* over FP, respectively. Increasing soil microbial biomass also leads to greater suppression of crop pathogen and pests (Larkin and VanAlfen 2015, Singh 2019) and higher yield thus bio-agents have been considered a more natural and environmentally acceptable alternative to chemicals (Suarez *et al.* 2004).

Socio-economic studies: IPM implementation resulted in low application of chemical pesticides i.e. 0.82 sprays (75.25 g a.i./ha) in IPM against 2.48 application in FP (892.93 g a.i./ha) [average of 10 years; Supplementary Table 3]. Analysis of rice grain samples for pesticide residue of buprofezin indicated 93.85% reduction in IPM over FP.

Socio-economic analysis indicated higher yield (38.01 q/ha) as well as benefit:cost ratio (3.59) in IPM as compared to FP yield of 30.47 q/ha and B:C ratio 2.41 (Table 2). In all the IPM trials conducted during 2010–19, net return remained higher (₹72631.1, average of 10 years) in IPM as compared to FP (₹45880.2). Effectiveness of IPM in reducing pesticide use by 85% (Fett 2011), with enhancement of 42% yield had earlier been recorded by Pretty *et al.* (2006).

The present module has helped the farmers in reducing the application of chemical pesticides, thereby reducing the overall cost and enhancing the benefit:cost ratio by fetching high price in market for IPM product.

Sustainability and horizontal spread of IPM

Compilation of results indicated a gradual enhancement in the area under IPM from 40 ha in 2010 by participation of 25 farmers to 990.40 ha in 2019 by participation of 654 farmers from 42 villages in Gautam Budh Nagar districts of Uttar Pradesh (Table 2). Thorough analysis of the data indicated the availability of critical inputs, accessibility

Table 2 Area, number of farmers participated, yield, net return and benefit:cost ratio in 2010–19

Year	Total Cost (₹)#		Yield (q/ha)		Net return (₹)##		Total return (₹)		B:C ratio		Area (ha) and no. of farmers
	IPM	FP	IPM	FP	IPM	FP	IPM	FP	IPM	FP	
2010*	20880.0	21305.0	33.2	16.2	67598.0	20410.0	88478.0	41715.0	4.24	1.96	40 (25)**
2011*	24550.0	25670.0	33.9	20.9	65793.5	28147.5	90343.5	53817.5	3.68	2.10	80 (37)
2012*	26690.0	28487.0	39.8	33.2	79377.0	57003.0	106067.0	85490.0	3.97	3.00	120 (115)
2013*	25480.0	28740.0	34.6	27.7	66808.9	42561.8	92288.9	71301.7	3.62	2.48	200 (198)
2014*	24841.0	28405.0	38.5	33.2	77761.5	57085.0	102602.5	85490.0	4.13	2.01	286 (201)
2015	30183.0	33930.0	37.4	28.8	69594.6	40230.0	99777.6	74160.0	3.31	2.19	350 (430)
2016	31990.0	36810.0	40.7	35.9	76555.5	55709.8	108545.5	92519.8	3.39	2.51	417 (450)
2017	32760.0	38451.0	44.1	36.9	84819.8	56437.8	117579.8	94888.8	3.59	2.47	488 (480)
2018	34996.0	44216.0	40.3	37.2	72616.7	51651.3	107612.7	95867.3	3.08	2.17	605 (508)
2019	34285.0	44735.0	37.4	34.7	65386.0	49566.0	99671.0	89301.3	2.91	2.25	990 (654)
Mean ± SE	28665.5 ±4807.4 [-12.0]***	32574.9 ± 7184.7	38.0 ± 3.4 [+24.59]	30.5 ± 7.1	72631.1 ± 6695.7 [+58.3]	45880.2 ±12954.4	101296.7 ± 9143.4 [+29.11]	78455.0 ± 18300.4	3.6	2.3	
t-test	*S*		S		S		S				

*Tanwar *et al.* 2016.

Note: Figures presented in table are mean values. IPM–Integrated pest management; FP–Farmers' practice; *S*–Significant; B:C – Benefit cost ratio. **Figures presented in parentheses ( ) are no. of participant farmers in the program; ***Figures presented in parentheses [ ] are percent increase or decrease over FP.

#Total cost included labour cost for land preparation, nursery sowing, puddling, transplanting, fertilizer application, hand weeding, pesticide application, etc. and material cost like seed, fertilizer, pesticides, bio-control agents, irrigation, etc. ## Net Return = Total return – total cost

Rates of paddy (₹ per q) at Bambawad: ₹2665/- in IPM [Average of 10 years; ₹2400, 1700, 2400, 3800, 2850, 1850, 2150, 3150, 3500, 2850 per quintal for IPM] and ₹2575/- in FP [Average of 10 years; ₹2400, 1700, 2400, 3800, 2700, 1700, 2000, 3000, 3350, 2700 for FP produce during 2010 to 2019]. ₹150 was given as bonus to farmers from 2014 onwards for IPM produce over and above price.

of farmers to subject matter specialists through FFSs and market for IPM produces as the main factors responsible for sustainability and horizontal spread of IPM in tested location. FFS-IPM is farmer-driven which follows the principles of participation and better understanding of the subject through important interactions in the agroecosystem. Farmers' participation in FFS on rice IPM has not only reduced insecticide use but also enhanced yield over time.

Since IPM is a dynamic process and needs regular updating with respect to emerging pests, additional research is required to identify pest resistant rice varieties, investigate constraints to manage rice pests, examine the level of knowledge of farmers about the environmental pollution due to pesticide application and explore other options to reduce chemical pesticide use. According to Horgan (2017) the major future challenge for sustainable rice IPM is to simultaneously respond to a range of global challenges including climate change, food insecurity, increasing poverty and environmental degradation.

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