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SRI – A methodology for substantially raising rice productivity by using farmers' improve thinking and practice with farmers' available resources

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ABSTRACT

The System of Rice Intensification (SRI) shows promise for substantially raising rice productivity by using farmers' improve thinking and practice with resources what farmers already have, besides offering increase soil & plant health, saving resources & lowering GHG emission. The on station field experiments (weed, nutrient & water management) were conducted at the Viswavidyalaya farm, Mohanpur during summer 2012 - 2014 in transplanted puddled paddy cv. IET 4786 following SRI methodology. In nutrient management the experiment was conducted with RBD replicated four times and with five treatments viz. N_1-100% NPK through inorganic fertilizers; N_2 25% organic N + 75% inorganic N + 100% PK through inorganic fertilizers; N_3-50% organic N + 50% inorganic N + 100% PK through inorganic fertilizers; N_4-75% organic N + 25% inorganic N + 100% PK through inorganic fertilizers and N_5- 100 % N through organic + 100% PK through inorganic fertilizers. The field experiment on water management was conducted with four treatments (2-3 cm water submergence in active tillering, panicle initiation and flowering only and rest period irrigation at hair crack stage (2-3 cm WS at AT, PI and F + HC), irrigation at hair crack stage (HC), 2-3 cm water submergence (2-3 cm WS) and Farmers' practice with 3-5 cm water submergence (FP) following RBD replicated six times. There were six treatments on weed management [Weedy check (WC); two mechanical weeding at 15 and 40 DAT (2 MW); three mechanical weeding at 15,25 and 40 DAT (3 MW); hand weeding at 25 DAT + 2 ME (HW + MW); chemical Pretilachlor 50 EC @ 500 g ha^{-1} at 1 DAT + 2 MW (CC+ MW) and aqueous extracts of Pathenium, Calotropis and Tectona leaves @ 5 ml litre of water^{-1} + surfactant Tween 20 at 1 DAT + 2 MW (BC + MW)] and the experiment was laid out in RBD replicated four times. The results revealed that 75 % N as organic + 100% PK through inorganic fertilizers showed better paddy productivity in addition to more soil population of soil biota and nutrient availability. The most interesting result was that keeping PK as constant in 100 % N through organic sources, the insect and pathogenic pest's infestation was reduced to the tune of 31.13 % fb 75 % N as organic (22.2 %), 50 % N as organic (15.5 %) and 25 % N as organic (4.46%) as compared to 100 % N through inorganic treatment. In water management experiment the results revealed that the total water used in this experiment was 6.88, 4.72, 8.06 and 10.23 million lit ha^{-1} against treatments 2-3 cm WS at AT, PI and F + HC, HC, 2-3 cm WS and FP, respectively. The corresponding figures for water saving in respect to FP were 32.78, 53.90 and 21.23 %. The grain yield data also revealed that 3750.00, 3347.22, 3027.78, and 3138.89 kg ha^{-1} were obtained against the treatments 2-3 cm WS at AT, PI and F +HC, HC, 2-3 cm WS and FP, respectively. Therefore, the water required for kg yield of rice were 1833.84, 1409.20, 2661.60 and 3259.40 litre, respectively. With a common 20.80 % O_2 in all plots at 25 DAT in FP the average GHG CO_2, CO, N_2O and Methane emissions were to the tune of 398 ppm, 0.97%, 17 and 40 kg ha^{-1} , respectively and the corresponding figures at 55 DAT were 399 ppm, 0.99%, 21 and 46 kg ha^{-1} but in SRI treatment 2-3 cm WS at AT, PI and F + HC these data were 394 ppm, 0.92%, and 16 and 25 kg ha^{-1} at 25 DAT while at 55 DAT the corresponding figures are 395ppm, 0.95%, 25 and 32 kg ha^{-1}. In weed management experiment the BC + MW could be the best alternative of both HW + MW and CC + MW treatments by increasing the NPV (considering biological yield) 3.14 and 3.77 %, respectively and over the WC by 54.1 %. The experimental results were also verified at on farm locations of nine districts of West Bengal (Nadia, Howrah, Hooghly, Burdwan, Birbhum, Purba and Paschim Medinipur, and North and South 24 parganas) during summer 2013 and 2014. An average of 8.0 - 15.5% more paddy grain yield was also observed over the traditional transplanted rice (TTR) . In Conclusion more organic nutrient application with BC + MW at 15 and 40 DAT weed management and 2-3 cm WS at AT, PI and F + HC water management were the best for increasing paddy productivity in SRI system at this Gangetic plains of India.

Keywords: Nutrient, on station, on farm, SRI, soil micro flora research, water and pest management

The System of Rice Intensification (SRI) shows promise for substantially raising rice productivity by using farmers' improve thinking and practice with resources what farmers already have, besides offering increase soil and plant health, saving resources and lowering GHG emission. Paddy, the most important staple crop by supplying 21 % calorie in world food (39% in Asian food), is producing 697.22 mt by cultivating in an area of 153.43 m ha with average productivity of 4.40 t ha^{-1}. Asian rice consumption is projected to account for 67% of the total increase, rising from 388 mt in 2010 to 465 mt in 2035, despite a continuing decline in per capita consumption in China and India (IRRI, Africa Rice and CIAT 2010). The food grain production touched only 259 mt with paddy

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106 mt by cultivating in 42.4 mha but still productivity of rice is only 2.46 t ha^{-1} using 3000-5000 litre of water for a kg of paddy production (Agricultural statistics at a glance, MOA, GOI, 2013). In West Bengal during 2007-08 paddy occupied almost 53% of the total agricultural crop areas of the state and it contributed the same 53% towards the total production of all agricultural crops. The area and production under food grains were 6.37 m ha and 16.06 mt, respectively, out of which rice alone was 91 and 93 %, respectively. By facing the gradual decrease in land holdings (in 2030 world - 0.17 ha , India 0.32 ha $person^{-1}$), water crisis (15-20 m ha land will have no irrigation) , decrease in soil health and ill effect in environment (in India from agriculture GHG 25 % and the flooding of rice paddies to grow irrigated rice alone is one of the major sources of methane - CH_4 contributing 6-29% which is produced by soil organisms methanogens that live under anaerobic conditions), causing adverse impacts of climate change (increase in temperature - 1.8- 4.0^0C and an increasing number of extreme weather events) it needs in India more challenge as productivity of most crops is below than the world average. In comparison to traditional transplanted rice (TTR), SRI , which is not a fixed set of things that farmers 'must' do but using SRI methods requires no material inputs beyond what farmers already have, just a change in thinking and practice (Uphoff, 1999, Ghosh *et al.*, 2009). In view of this, SRI which is a methodology rather considered as a technology since it consists of concepts and practices to be adapted by farmers to their local conditions for best results (Kabir and Uphoff, 2007), proved better and sustainable productivity in rice throughout the world . But SRI needs research proof in different agro ecosystem (Ghosh *et al.*, 2014) to find out the proper reasons and concepts (12-15 days seedling can give more tillers, Laulanié, H., 1993a or balance nutrition help to convert amino acid to more protein thus reduce the surplus sugar and finally pest attack- Chaboussou, F., 2004; alternaternate wetting and drying helps to save water without productivity loss, Ceesay *et al.*, 2006; Botanical pesticides coming up as an alternate of hand weeding- Ghosh *et al.*, 2012) etc.-sustainable productivity like proper INM by using more organics that increase soil health - more soil microorganisms that results more availability of balance nutrients; increase plant health as a result reduce the pest problems and increase panicle numbers and productivity; in spite of reducing water use reduces the GHG like N_2O, CH_4 etc. (Neue, 1993) by more mineralization of nitrogen and using proper ecosafe weed management reducing the yield losses due to weed pest and ultimately increase the rice productivity.

In view of the above three field experiments on nutrient, water and major pest weed management were conducted at on station and on farm to verify the results with following objectives.

a. To find out proper ecosafe weed management – Effect of IWM (botanicals, mechanical, chemical and physical methods) on weed biomass and soil health (As SRI needs lesser water, weeds are more and therefore yield loss is more thus needs ecosafe management).

b. To find out INM ratio (IN-N + OR- N) - Effect on soil health improvement by computing the nutrient balance sheet and to find out the infestation of plant pests (weed, insect, disease and nematodes) in SRI with more organic manure in comparison to traditional transplanted rice (TTR) with more inorganic fertilizers. How many years after a sustainable INM is achieved for recommendation.

c. To find out amount of water saving without affecting yield and to find out the effect on green house gases (CO, CO_2, N_2O, CH_4 etc.) in SRI vs TTR. SRI needs lesser water so lesser methane is expected than TTR but more nitrous oxide is also expected in SRI than TTR.

d. Nutrient x water interaction- Whether more organic manures (neem cake or vermicompost etc.) can able to reduce nitrous oxide emission in SRI plots where lesser water is applying – Studies on Nitrogen mineralization- role of nitrobactor, nitrosomonas etc. microflora.

e. To verify the SRI research results of new alluvial soil (Inceptisol) in other soils (Entisol, Vertisol, Alfisol, Aridisol, Ultisol etc.) also by conducting best results of SRI at other Institution like Visva Bharati and Regional Research Station, Shekhampur, Birbhum under BCKV (red and laterite soil) and Research stations like Rice Research Station, Chinsurah, Hooghly under Directorate of Agriculture, Government of West Bengal (old alluvial soil).

f. To spread SRI in major rice growing districts of West Bengal like Hooghly, Howrah, Burdwan, Purba and Paschim Medinipur, Nadia, South and North 24 Parganas etc. by conducting on farm research on best treatment of SRI vs TTR.

g. To transfer SRI technology through on farm research and also through KVK, ICAR.

MATERIALS AND METHODS

The on station field experiments (weed, nutrient and water management) were conducted at the Viswavidyalaya farm, Nadia, West Bengal during summer 2012, 2013 and 2014 in transplanted puddled paddy cv. IET 4786. Six treatments on *integrated weed management (IWM)* was laid out in RBD replicated four times [weedy check (WC); two mechanical weeding at 15 and 40 DAT (2 MW); three mechanical weeding at 15,25 and 40 DAT (3 MW); hand weeding at 25 DAT + 2 ME (HW + MW); chemical Pretilachlor 50 EC @ 500 g ha^{-1} at 1 DAT + 2 MW (CC+ MW) and aqueous extracts of *Pathenium, Calotropis* and *Tectona* leaves @ 5 ml litre of $water^{-1}$ + surfactant Tween 20 at 1 DAT + 2 MW (BC + MW)]. In *integrated nutrient management (INM)* the experiment was conducted with RBD replicated four times and with five treatments viz. N_1-100% NPK through inorganic fertilizers; N_2 25% organic N + 75% inorganic N + 100% PK through inorganic fertilizers; N_3 -50% organic N + 50% inorganic N + 100% PK through inorganic fertilizers; N_4 -75% organic N + 25% inorganic N + 100% PK through inorganic fertilizers and N_5 - 100 % N through organic + 100% PK through inorganic fertilizers. The field experiment on *water management* was conducted with four treatments (2-3 cm water submergence in active tillering, panicle initiation and flowering only and rest period irrigation at hair crack stage (2-3 cm WS at AT, PI and F + HC), irrigation at hair crack stage (HC), 2-3 cm water submergence (2-3 cm WS) and Farmers' practice with 3-5 cm water submergence (FP) following RBD replicated six times.

The data related to IWM effects on weed control efficiency(WCE), weed index (WI), herbicide efficiency index (HEI), weed pest management index (WPMI), net production value (NPV); INM effects on soil nutrient status - available in soil and plant uptake (NPK), soil microorganisms population (bacteria, fungi and actinomycetes), pest populations (insect, disease and weed) and water management treatment effects on water saving and GHG emission (by using portable GHG Analyzer, leaf chlorophyll meter etc. supplied by Shailron Technology Pvt. Ltd., New Delhi) and and the plant growth and yield parameters including the biological yield were recorded.

RESULTS AND DISCUSSION

In integrated weed management experiment (Table 1) the predominant weed flora were *Echinochloa colona, Echinochloa formosensis, Leersia hexandra, Paspalum conjugatum, Paspalum distichum* (grass), *Cyperus difformis, Cyperus iria, Fimbristylis dichotoma, Scirpus mucronatus* (sedge) and *Alternanthera philoxeroides. Eclipta alba, Ludwigia parviflora, Marsilea quardrifolia, Ammania baccifera, Lindernia ciliate, Linderria procumbaus, Sphenoclea zeylanica, Hygrophila auriculata* and *Hypericum japanicum* (broad leaf). The T_4, T_5 and T_6 all recorded higher WCE and for this the growth and yield parameters particularly no. of tiller, LAI, CGR, DMA, NAR, panicle m^{-2}, % filled grains all received more in these treatments as compared to only mechanical weeding and weedy check plot. The better weed control effects in botanical aqueous extracts (BC + MW) were observed in monocots only and not in dicots as the chemicals sesquiterpene lactones and phenol (*Parthenium hysterophorus*), calotropin (*Calotropis procera*) and toxic phenolic acids like (Salicylic acid, â- hydroxyl benzoic acid, chlorogenic acid, tanic acid, caffeic acid, vannilic acid etc.) have the capacity to control the monocot weeds in presence of water. As these three treatments received better weed control the crop paddy faced lesser competition for resources (light, water, nutrient and space) from the weed pest which helped rice crop to improve its growth and yield parameters and as a result increase the biological yield. The biological yield data revealed that the grain yield in total mean data of both years T_4 (HW + MW) recorded 88% followed T_5 (CC + MW) 79% and T_6 (BC + MW) 76% over weedy check T_1 (WC) treatment. The corresponding figure for T_3 (3MW) 67% and T_2 (2 MW) 36% among these three treatment T_4, T_5 and T_6 higher yield compare to T_3, T_2 and T_1. The straw yield data was also showed similar trends of variation. The treatment T_4 (HW + MW) recorded 59 %, 55 %, 53 %, 48 % and 28 % more over T_6 (BC + MW), T_5 (CC + MW), T_3 (3 MW), T_2 (2 MW) and T_1 (Mean data of two years 2012 and 2013). Considering the net production value (NPV) the BC + MW could be the best alternative of both HW + MW and CC + MW treatments by increasing the NPV (considering biological yield) 3.14 and 3.77%, respectively and over the WC by 54.1%.

In integrated nutrient management experiment 75% N as organic + 100% PK through inorganic fertilizers showed better paddy productivity in addition to more soil population of soil biota and nutrient availability. The Chlorophyll content also showed better in INM treatments. The most interesting result was that keeping PK as constant in 100% N through organic sources, the insect and pathogenic pest's infestation was reduced to the tune of 31.13% fb 75% N as organic (22.2%), 50% N as organic (15.5%) and 25% N as organic (4.46%) as compared to 100% N through inorganic treatment (Table 2 , 3 and 4).

In water management experiment (Table 5) the results revealed that the total water used in this experiment was 6.88, 4.72, 8.06 and 10.23 million lit ha^{-1} against treatments 2-3 cm WS at AT, PI and F + HC, HC, 2-3 cm WS and FP, respectively. The corresponding figures for water saving in respect to FP were 32.78, 53.90 and 21.23 %. The grain yield data also revealed that 3750.00, 3347.22, 3027.78, and 3138.89 kg ha^{-1} were obtained against the treatments 2-3 cm WS at AT, PI and F +HC, HC, 2-3 cm WS and FP, respectively. Therefore, the water required for kg yield of rice were 1833.84, 1409.20, 2661.60 and 3259.40 litre, respectively.

Table 1: Effect of weed management on Weed Control Efficiency (WCE %), Herbicide Efficiency Index (HEI) and Weed Pest Management Index (WPMI) at 45 DAT in transplanted SRI paddy (2012 and 2013)

Treatments	2012						2013					
	WCE (%)						WCE (%)					
	G	S	BL	T	HEI	WPMI	G	S	BL	T	HEI	WPMI
T_1- WC	-	-	-	-	-	-					-	-
T_2- 2 MW	41	56	56	54	-	1	35	62	42	51	-	3
T_3- 3 MW	73	81	53	64	-	5	61	83	54	69	-	6
T_4- 1 HW+2MW	98	70	92	92	-	23	80	92	87	89	-	17
T_5- CC+2 MW	81	85	86	84	474	11	70	90	80	83	486	11
T_6- BC+2 MW	80	90	76	77	200	7	62	89	74	79	260	8

Table 2: Effect of nutrient management on panicle length and grains per panicle, grain and straw yield of paddy and pest infestation in transplanted SRI paddy during summer 2012 and 2013 (Pooled)

Treatment	Panicle length (cm)	Grain panicle^{-1}	Grain yield (t ha^{-1})	Straw yield (t ha^{-1})	Insect and disease pest infestation at 55 DAT (m^{-2})	Weed density at 55 DAT (m^{-2})
N_1	22.8	185	4.61	5.20	15.00	36.67
N_2	21.5	178	4.31	6.14	11.67	27.33
N_3	20.6	182	4.54	5.98	11.67	28.67
N_4	21.9	185	4.69	5.82	14.33	25.00
N_5	19.9	172	4.64	5.27	10.33	17.00
LSD(0.05)	**2.49**	**10.21**	**0.20**	**0.43**		

Table 3: Nutrient status in SRI plots of on station and on farm locations during 2012-14

Name of the centre	Nitrogen (kg ha^{-1})			Phosphorus (kg ha^{-1})			Potash (kg ha^{-1})		
	2012	2013	2014	2012	2013	2014	2012	2013	2014
BCKV, Nadia	242.5	264.3	282.6	29.1	30.9	50.5	190.3	249.1	271.2
RRS,Chinsurah, Hooghly	No soil sample till date								
RRS,Sekhampur, Birbhum	254.4	212.7	234.2	26.9	11.22	26.0	205.5	201.0	235.6
Visva- Bharati, Sriniketan	-	-	226.8	-	-	24.6	-	-	214.0
Raina, Burdwan	261.8	164.8	-	14.7	36.2	-	204.2	229.4	-
Gurap, Hooghly	-	259.5	-	-	13.9	-	-	245.43	-
Gosaba, 24 Parganas (S)	161.2	204.8	264.4	25.9	27.5	34.10	180.5	195.7	214.6
Uluberia, Howrah	242.2	271.2	278.7	28.7	29.5	32.8	203.5	214.6	231.8
Fulkalmi, Nadia	237.2	212.2	226.0	19.1	12.6	24.4	205.7	225.0	234.0
Purba Medinipur	-	241.5	237.7	-	27.4	21.5	-	245.0	236.9
Paschim Medinipur	-	267.2	291.0	-	26.9	28.7	-	237.8	254.6
Nadia Chandamari	277.2	215.0	-	11.77	31.5	-	286.0	210.8	-

With a common 20.80 % O_2 in all plots at 25 DAT in FP the average GHG CO_2, CO, N_2O and CH_4 emissions were to the tune of 398 ppm, 0.97%, 17 and 40 kg ha^{-1}, respectively and the corresponding figures at 55 DAT were 399 ppm, 0.99%, 21 and 46 kg ha^{-1} but in SRI treatment 2-3 cm WS at AT, PI and F + HC these data were 394 ppm, 0.92%, and 16 and 25 kg ha^{-1} at 25 DAT while at 55 DAT the corresponding figures are 395ppm, 0.95%, 25 and 32 kg ha^{-1} (Table 5).

Table 4: Microflora population at different locations in summer SRI 2012-13

Locations	Actinomycetes ($CFU \times 10^{5}$ g^{-1} soil)		Fungi ($CFU \times 10^{4}$ g^{-1} soil)		Bacteria ($CFU \times 10^{6}$ g^{-1} soil))	
	Initial	**Harvesting**	**Initial**	**Harvesting**	**Initial**	**Harvesting**
BCKV	95.39	177.69	23.77	29.02	49.45	92.18
Fulkalmi	93.73	108.41	18.22	24.65	45.90	65.89
Chandamari	94.75	95.56	20.67	25.78	46.28	65.54
Burdwan	95.09	90.00	22.35	22.09	44.49	60.43
Hooghly	95.75	91.45	22.47	21.54	46.07	56.08
Medinipur	95.51	154.00	22.50	27.17	45.76	71.99
Howrah	95.35	166.56	22.36	27.87	45.21	80.35
Gosaba	94.94	174.18	22.78	35.56	41.64	84.41

Table 5: Effect of irrigation management on water saving, green house gas emission and paddy grain yield litre $^{-1}$ of water in transplanted SRI paddy during summer 2014

Treatments	T_1-SRI (2-3 cm WS at AT, PI and F +HC)	T_2 - Only Hair crack (HC)	T_3 – Only 2-3 cm WS	T_4 - FP (3 - 5 cm WS)
Total water (lit 100 m^{-2})	68,760	47,160	80,580	1,02,300
Total Rainfall lit.ha^{-1} received the crop	887.0 litre ha^{-1}			
Total Water ha^{-1}(without subsidy)	68, 76,887	47,16,887	80,58,887	1,02,30,887
Water savings (%)	32.78	53.9	21.23	-
Total Grain Yield (kg ha^{-1})	3,750.00	3,347.22	3,027.78	3,138.89
Water in litre kg^{-1} paddy yield	1833.84	1409.2	2661.6	3259.4

Green house gas emission in transplanted SRI paddy during summer 2014

	25 DAT	55 DAT	25 DAT	55 DAT	25 DAT	55DAT	25 DAT	55 DAT
Methane (kg ha^{-1})	25	32	20	27	35	42	40	46
Nitrous Oxide (kg ha^{-1})	16	25	16	37	15	23	17	21
CO (%)	0.92	0.95	0.90	0.94	0.96	0.97	0.97	0.99
Co_2 (ppm)	394	395	390	393	392	396	398	399

The experimental results were also verified at on farm locations of different districts of West Bengal (Nadia, Howrah, Hooghly, Burdwan, Birbhum, Purba and Paschim Medinipur, and North and South 24 parganas) during summer 2013 and 2014. An average of on-farm yield increase in SRI was 5.7% (2011-12) , 14.50 % (2012-13) and 15.5% (2013-14) than the Traditional TR. The major success is more number of farmers are joined in this SRI cultivation, thus number of locations are also increased gradually (2012-13 – 4 locations and 2013-14 - 9 locations). However in some location SRI is not continued in same field and that reflected in soil nutrient and microflora status (Table 3 and 4). Therefore there is a need of farmer awareness regarding continuation of SRI in same plots to get a sustainable soil health and ultimately better productivity. In one location the farmers discontinuity is also observed and this is because of lack of that locations monitoring NGOs activity. Thus for on farm acceptance of SRI –land to lab for solution and then again lab to land with safe technology to verify is highly needed. Nutrients through more organics therefore, increased the soil biota and nutrient availability while the balance nutrition was helped to reduce the pest infestation as a result increasing the productivity. Using water as 2-3 cm WS at AT, PI and F +HC saved the cost of most precise water inputs in addition to increasing productivity and reducing the GHG emission in transplanted paddy. Reducing the weed competition at critical crop weed competition period paddy growth parameters were more, using ecofriendly chemicals increased soil microorganisms helped in more uptake of balanced nutrients that also helped increasing yield parameters and biological yield. Therefore, INM with more organic nutrient application 75 % N as organic + 100% PK through inorganic fertilizers with botanical herbicide integrated with paddy weeder weed management BC + MW at 15 and 40 DAT and 2-3 cm WS at AT, PI and F + HC water management were the best for increasing paddy productivity in SRI system at this Gangetic plains of India

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