Integrated Nutrient Management Strategies in Cucumber (*Cucumis sativus* L.) for Enhancing Nutrient Uptake and Post-Harvest Soil properties

ABSTRACT

Integrated Nutrient Management (INM) aims to integrated applications of both natural and artificial sources of plant nutrients to boost crop productivity in an environmentally friendly manner, without compromising soil health for future generations. The synergistic benefits of integrating inorganic chemical fertilizers, organic materials, and biological sources of nutrients have been shown to be more effective than their sole applications. The present study assesses the impact of various nutrient sources on the nutrient uptake, recovery and post-harvest soil properties in test crop, cucumber (*Cucumis sativus* L.). A field experiment was conducted at All India Coordinated Research Project on Vegetable Crops, located at OUAT in Bhubaneswar, Odisha, India to study the impact of Integrated Nutrient Management on nutrient uptake, recovery and Post-Harvest Soil properties in cucumbers. The study spanned two years and took place *in situ* conditions in sandy loam acidic soil, which was of medium status in terms of organic carbon content and available major nutrients (N, P, and K). The study utilized four agro-inputs: fertilizers, farmyard manure (FYM), vermicompost and biofertilizers, which were combined in 12 different combinations with three replications and designed with RBD to determine the most effective practice for achieving optimum nutrient uptake while maintaining the soil health. Crops treated with the Integrated Nutrient Management (INM) practice had a shorter time to harvest, with the first and last harvest days being 45 and 80 days, respectively, compared to 51 and 72 days with only recommended dose of fertilizers (RDF), 50 and 75 days with full FYM, and 51 and 73 days with full vermicompost. The INM practice resulted in the maximum N uptake (30.2 kg ha^{-1}) with a recovery efficiency of 25%. P uptake was 19.1 kg ha^{-1} with a recovery efficiency of 33%, while K uptake (28.1 kg ha^{-1}) had a recovery efficiency of 29%. Post-harvest soil analysis showed an increase in organic carbon but a decrease in available N, P, and K content, regardless of the agricultural practices used. The effectiveness of these nutrient sources depends on factors like the right source, amount, timing, and method of application. Soil factors like texture and organic carbon content also play a key role in nutrient efficiency. Adding organic inputs like vermicompost and biofertilizers not only improve growth and productivity of crops like cucumbers but also enhance the nutrient uptake and maintain the post-harvest soil health.

Key words: Vermicompost, Integrated Nutrient Management, biofertilizer, Nutrient uptake

Introduction:

Integrated Nutrient Management (INM) is gaining more importance as it ensures scientific management of soil health for optimum growth, yield and quality of crops in a sustainable manner. Excessive application of chemical fertilizer alone has adverse impact on the environment as it causes deterioration of soil health and the consumption of these inorganic products may jeopardize our health. Organic manures on the other hand are bulky in nature and has less analytical value due to its low nutrient content (Sahu et al., 2022; Kumar et al., 2024). Cucumber (*Cucumis sativus* L.) is the most popular vine vegetable of Cucurbitaceae family due to its early maturing nature. Believed to have originated in northern India (De Candolle, 1882), cucumber is the 4^{th} most significant vegetable crop in Asia, following tomato, cabbage, and onion (Singh *et al.,* 2017). Cucumber is a low-calorie food, consisting of 90% water, which is why it provides superior hydration. Its eminent texture and flavor are the main reasons for its use in salads in fresh form and pickles in processed form (Sallam et al., 2021). It is primarily cultivated for its tender, edible fruits, which are commonly used in salads and pickles, cucumbers are known for their cooling properties and effectiveness in preventing jaundice, indigestion, and constipation (Mohan *et al.,* 2016). As a crucial component of salads, cucumbers respond well to both manures and fertilizers. However, prolonged and indiscriminate use of synthetic fertilizers can deplete soil fertility over time. The findings from long-term fertilizer experiments conducted in different locations of India by ICAR, New Delhi have demonstrated that neither inorganic chemical fertilizers nor organic sources alone can sustainably support production in intensive cropping systems. The synergistic benefits of integrating inorganic chemical fertilizers, organic materials, and biological sources of nutrients have been shown to be more effective than their sole applications (Naik *et al*., 2013). Therefore, there is an urgent need for research to focus on the efficient and judicious utilization of available nutrient resources to enhance production, productivity, and profitability per unit area, in order to meet the growing demands of the population along with maintenance of optimum soil fertility status for sustainable production.

INM aims to integrate applications of both natural and artificial sources of plant nutrients to boost crop productivity in an environmentally friendly manner, without compromising soil health for future generations. With these objectives, two years field experiments were conducted to assess the impact of various nutrient sources on the nutrient uptake, recovery and post-harvest soil properties in the test crop, cucumber.

Materials and Methods:

The field experiment was conducted at AICRP on Vegetable Crops, operating under Odisha University of Agriculture and Technology (OUAT), Bhubaneswar, Odisha, India for two consecutive years during the summer seasons of 2017 and 2018. Twelve nutrient management modules, including an absolute control, were evaluated using a Randomized Block Design replicated thrice. Standard package of practices were adopted uniformly to raise a good crop of cucumber except nutrient management practices. The nutrient management practices were developed by using various sources of nutrients, including inorganic chemical fertilizers, organic materials (FYM and / or Vermicompost), and biofertilizers consortia (BF) consisting of *Azotobacter*, *Azospirillum* and *PSB* (1:1:1), along with the absolute control. The details of all 12 treatments are presented in Table 1. The cucumber variety "Seven Star" was sown on March 21^{st} during the summers of 2017 and 2018, with a spacing of 1.5 m x 1 m and a plot size of (3.0 x 2.7) m^2. A composite soil sample was collected from the surface layer (0-15 cm) to determine the initial soil status before the start of the experiment.

Post-harvest soil samples were collected from each treatment separately, shade dried, properly sieved with a 10mm mesh sieve, and used to estimate post-harvest soil properties such as soil pH. Nutrient uptake of vine and fruit was calculated by multiplying the concentration of individual nutrients with the dry matter yield (vine and fruit) under each treatment and then adding them to obtain the total nutrient uptake. The results were expressed in kg ha^{-1}.

Nutrient uptake (kg ha^{-1}) = Nutrient Concentration of dry matter (%) x Dry matter yield (qha^{-1})

Fresh plant samples were collected after harvesting, and the entire plants were weighed on a fresh weight basis, expressed in t ha^{-1}. To assess the effectiveness of different treatment combinations in nutrient recovery, the apparent nutrient recovery (%) was calculated using the following formula on a plot basis.

$$AR = \frac{\text{Amount of nurient uptake kg/ha}}{\text{Amount of nutrient added kg/ha}} \times 100$$

$$RAE = \frac{\text{Yield in treated treatment t / h} - \text{Yield in Absolute control t / ha}}{\text{Yield in RDF treatment t / ha} - \text{Yield in Absolute control t / ha}} \times 100$$

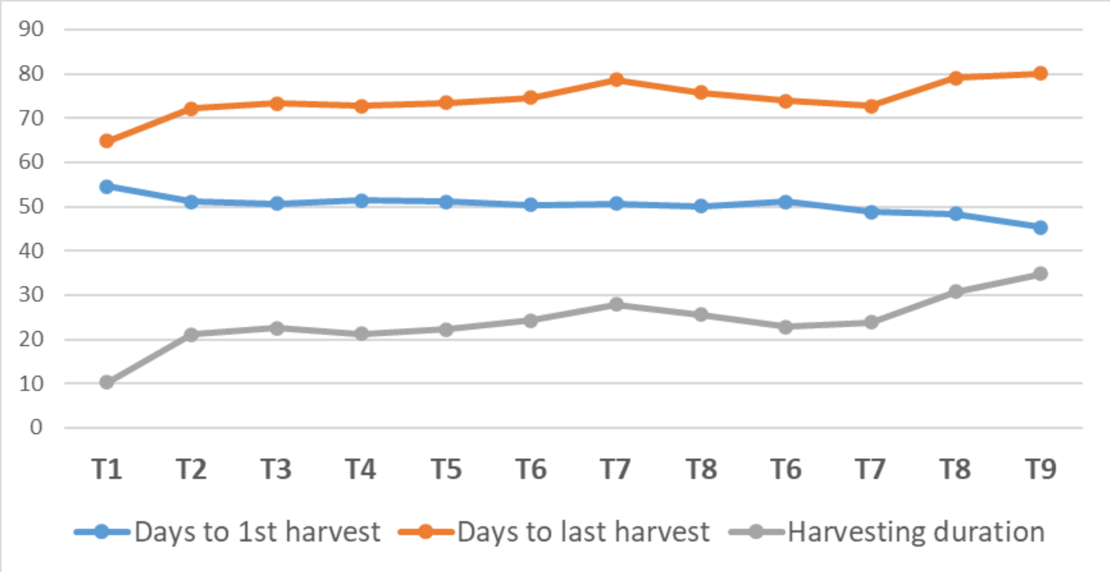
Data recorded were analysed by adopting his standard statistical procedure as suggested by Gomez and Gomez (1996)

Table1: Treatment details:

Sl. No.	**Treatment details**	**Abbreviation**
T_1	Absolute Control	AC
T_2	Recommended dose of fertilizers	RDF
T_3	½ RDF + consortia Biofertilizer *	½ RDF + BFs
T_4	Vermicompost @ 4 tha^{-1}	VC_4
T_5	Vermicompost @ 2 tha^{-1} + consortia Biofertilizer	VC_2 + BFs
T_6	½ RDF + Vermicompost @ 2 tha^{-1} + consortia Biofertilizer	½ RDF + VC_2 + BFs
T_7	RDF + Vermicompost @ 2 tha^{-1} + consortia Biofertilizer	RDF + VC_2 + BFs
T_8	FYM @ 20 tha^{-1}	F_{20}
T_9	FYM @ 10 tha$^{-1 +}$ consortia Biofertilizer	F_{10} + BFs
T_{10}	½ RDF + FYM @ 10 tha^{-1} + consortia Biofertilizer	½ RDF + F_{10} + BFs
T_{11}	RDF + FYM @ 10 tha^{-1} + consortia Biofertilizer	RDF + F_{10} + BFs
T_{12}	½ RDF + FYM @ 10 tha^{-1} + Vermicompost @ 2 tha-1 + consortia Biofertilizer	½ RDF + F_{10} + VC_2 + BFs

Result and Discussion

Fig.1: Days to 1st and last harvest of cucumber



Such integrated practice enabled the crop to attain 1st harvest 10 days early against 55 days to 1st harvest in no nutrient supply practice and 5-6 days delayed harvest dates in sole/incomplete INM practices. Similarly, harvest was delayed by 16 days (80 days after sowing) of fruits with the complete integrated practices against early maturity of crop by 65th days after seed sowing in no nutrient supply practice. The nutrient management practices influenced the days to last harvest during 2nd year of experimentation by almost seven days against 70 days for last harvest during 1st year of the programme.

Table 2:Nitrogen concentration and uptake under the influence of INM practices

Sl. No.	Treatment	1st year						2nd year						Total uptake (Pooled)	ANR (%)
		Concentration (%)		Uptake (kg ha^{-1})			ANR (%)	Concentration (%)		Uptake (kg ha^{-1})			ANR (%)		
		Fruit	Vine	Fruit	Vine	Total		Fruit	Vine	Fruit	Vine	Total			
1	AC	0.32	0.44	0.9	2.3	3.2	-	0.29	0.43	0.9	3.0	3.9	-	3.5	-
2	RDF	0.82	0.44	3.4	12.4	15.8	13	1.12	0.84	5.1	15.7	20.8	17	18.3	15
3	½RDF+ BFs	0.76	0.40	2.6	9.7	12.3	18	1.01	0.74	4.1	12.1	16.2	25	14.3	22
4	VC_4	0.40	0.48	2.1	12.5	14.6	38	0.42	0.69	2.2	16.3	18.6	49	16.6	44
5	VC_2+BFs	0.34	0.48	1.3	9.3	10.6	49	0.35	0.70	1.7	13.2	15.0	74	12.8	62
6	½ RDF+VC_2+BFs	0.39	0.50	1.6	11.8	13.4	16	0.43	0.71	1.8	14.0	15.8	18	14.6	17
7	RDF+VC_2+BFs	0.44	0.48	2.4	10.5	12.9	8	0.55	0.68	2.9	14.9	17.7	12	15.3	10
8	F_{20}	0.66	0.55	3.1	12.9	16.0	15	0.66	0.82	4.5	20.1	24.7	24	20.3	20
9	F_{10}+ BFs	0.55	0.50	2.2	11.4	13.5	24	0.62	0.88	4.1	15.9	20.0	37	16.9	31
10	½RDF+F_{10}+BFs	0.58	0.55	2.3	12.9	15.3	13	0.65	0.86	4.4	15.7	20.1	17	17.7	15
11	RDF+F_{10}+BFs	0.68	0.63	4.0	16.9	20.9	12	0.80	0.90	5.5	17.7	23.2	13	22.1	13
12	½RDF+F_{10}+VC_2+ BFs	0.77	0.68	4.5	21.2	25.7	21	0.84	1.13	6.9	27.8	34.7	29	30.2	25
	Mean	**0.56**	**0.51**	**2.53**	**11.9**	**14.5**		**0.65**	**0.78**	**3.7**	**15.6**	**19.2**		**16.9**	
	SE(m) ±	**0.03**	**0.03**	**0.16**	**0.66**	**0.95**		**0.04**	**0.05**	**0.24**	**0.86**	**1.07**		**1.26**	
	LSD (P=0.05)	**0.10**	**0.09**	**0.46**	**1.94**	**2.77**		**0.11**	**0.14**	**0.70**	**2.52**	**3.15**		**3.92**	

Table 3:Phosphorous concentration and uptake under the influence of INM practices

Sl. No.	Treatment	1st year						2nd year						Pooled	APR (%)
		Concentration (%)		Uptake (kg ha^{-1})			APR (%)	Concentration (%)		Uptake (kg ha^{-1})			APR (%)		
		Fruit	Vine	Fruit	Vine	Total		Fruit	Vine	Fruit	Vine	Total			
1	AC	0.38	0.91	1.04	4.84	5.9	-	0.20	0.74	0.90	5.09	6.0	-	5.9	-
2	RDF	0.30	0.29	1.26	8.27	9.5	17	0.29	0.38	1.37	7.10	8.5	11	9.0	14
3	½RDF+ BFs	0.36	0.27	1.22	6.42	7.6	16	0.40	0.40	1.63	6.50	8.1	19	7.9	18
4	VC_4	0.29	0.36	1.59	9.32	10.9	31	0.36	0.41	1.89	9.64	11.5	35	11.2	33
5	VC_2+BFs	0.36	0.37	1.32	7.24	8.6	34	0.45	0.43	2.18	8.01	10.2	53	9.4	43
6	½ RDF+VC_2+BFs	0.40	0.38	1.66	8.89	10.6	25	0.62	0.44	2.64	8.63	11.3	28	10.9	26
7	RDF+VC_2+BFs	0.35	0.39	1.86	8.46	10.3	15	0.65	0.44	3.42	9.58	13.0	23	11.7	19
8	F_{20}	0.38	0.41	1.77	9.57	11.4	13	0.51	0.45	3.50	11.13	14.6	21	13.0	17
9	F_{10}+ BFs	0.42	0.41	1.63	9.31	11.0	24	0.46	0.46	3.03	8.37	11.4	26	11.2	25
10	½RDF+F_{10}+BFs	0.41	0.42	1.60	9.9	11.5	18	0.63	0.47	4.22	8.60	12.8	21	12.2	19
11	RDF+F_{10}+BFs	0.51	0.44	3.0	11.83	14.8	21	0.70	0.49	4.83	9.60	14.4	20	14.6	20
12	½RDF+F_{10}+VC_2+ BFs	0.51	0.54	3.01	16.92	19.9	35	0.67	0.52	5.50	12.8	18.2	31	19.1	33
	Mean	**0.39**	**0.43**	**1.75**	**9.25**	**10.99**		**0.49**	**0.51**	**2.92**	**8.75**	**11.67**		**11.33**	
	SE(m)±	**0.02**	**0.03**	**0.12**	**0.54**	**0.70**		**0.03**	**0.03**	**0.15**	**0.53**	**0.71**		**0.70**	
	LSD (P=0.05)	**0.06**	**0.08**	**0.34**	**1.59**	**2.06**		**0.08**	**0.08**	**0.43**	**1.56**	**2.08**		**2.20**	

Table 4:Potassium concentration and uptake under the influence of INM practices

Sl. No.	Treatment	2017						2018						Pooled	AKR (%)
		Concentration (%)		Uptake (kg ha^{-1})			AKR (%)	Concentration (%)		Uptake (kg ha^{-1})			AKR (%)		
		Fruit	Vine	Fruit	Vine	Total		Fruit	Vine	Fruit	Vine	Total			
1	AC	0.65	0.36	1.74	1.94	3.7	-	0.35	0.24	1.12	1.64	2.8	-	3.2	-
2	RDF	1.17	0.40	4.93	11.34	16.3	32	1.58	0.54	7.18	9.97	17.2	36	16.7	34
3	½RDF+ BFs	1.09	0.33	3.73	7.88	11.6	40	1.32	0.42	5.43	6.94	12.4	48	12.0	44
4	VC$_4$	0.68	0.50	3.71	12.85	16.6	23	0.95	0.50	5.05	11.87	16.9	26	16.7	25
5	VC$_2$+BFs	0.92	0.52	3.43	10.14	13.6	35	0.92	0.53	4.43	9.95	14.4	41	14.0	38
6	½ RDF+VC$_2$+BFs	1.18	0.53	4.94	12.31	17.3	28	1.23	0.59	5.25	11.66	16.9	29	17.1	29
7	RDF+VC$_2$+BFs	1.01	0.60	5.86	13.05	18.9	22	1.33	0.60	6.94	13.02	20.0	25	19.4	24
8	F$_{20}$	1.03	0.64	4.77	15.03	19.8	21	1.05	0.68	7.17	16.79	24.0	28	21.9	24
9	F$_{10}$+ BFs	0.98	0.62	3.80	14.05	17.9	36	1.01	0.63	6.66	11.41	18.4	40	18.1	38
10	½RDF+F$_{10}$+BFs	0.97	0.63	3.78	14.8	18.6	25	1.26	0.67	8.44	12.26	20.7	30	19.7	28
11	RDF+F$_{10}$+BFs	1.05	0.65	6.11	17.5	23.6	25	1.37	0.69	9.45	13.60	23.1	26	23.3	25
12	½RDF+F$_{10}$+VC$_2$+ BFs	1.06	0.67	6.18	20.9	27.1	27	1.39	0.72	11.40	17.66	29.1	30	28.1	29
	Mean	**0.98**	**0.54**	**4.41**	**12.57**	**17.01**		**1.14**	**0.57**	**6.54**	**11.40**	**17.98**		**17.52**	
	SE(m)±	**0.06**	**0.03**	**0.25**	**0.77**	**0.89**		**0.06**	**0.03**	**0.31**	**0.66**	**0.99**		**0.68**	
	LSD (P=0.05)	**0.19**	**0.08**	**0.74**	**2.26**	**2.61**		**0.17**	**0.08**	**0.92**	**1.92**	**2.91**		**2.11**	

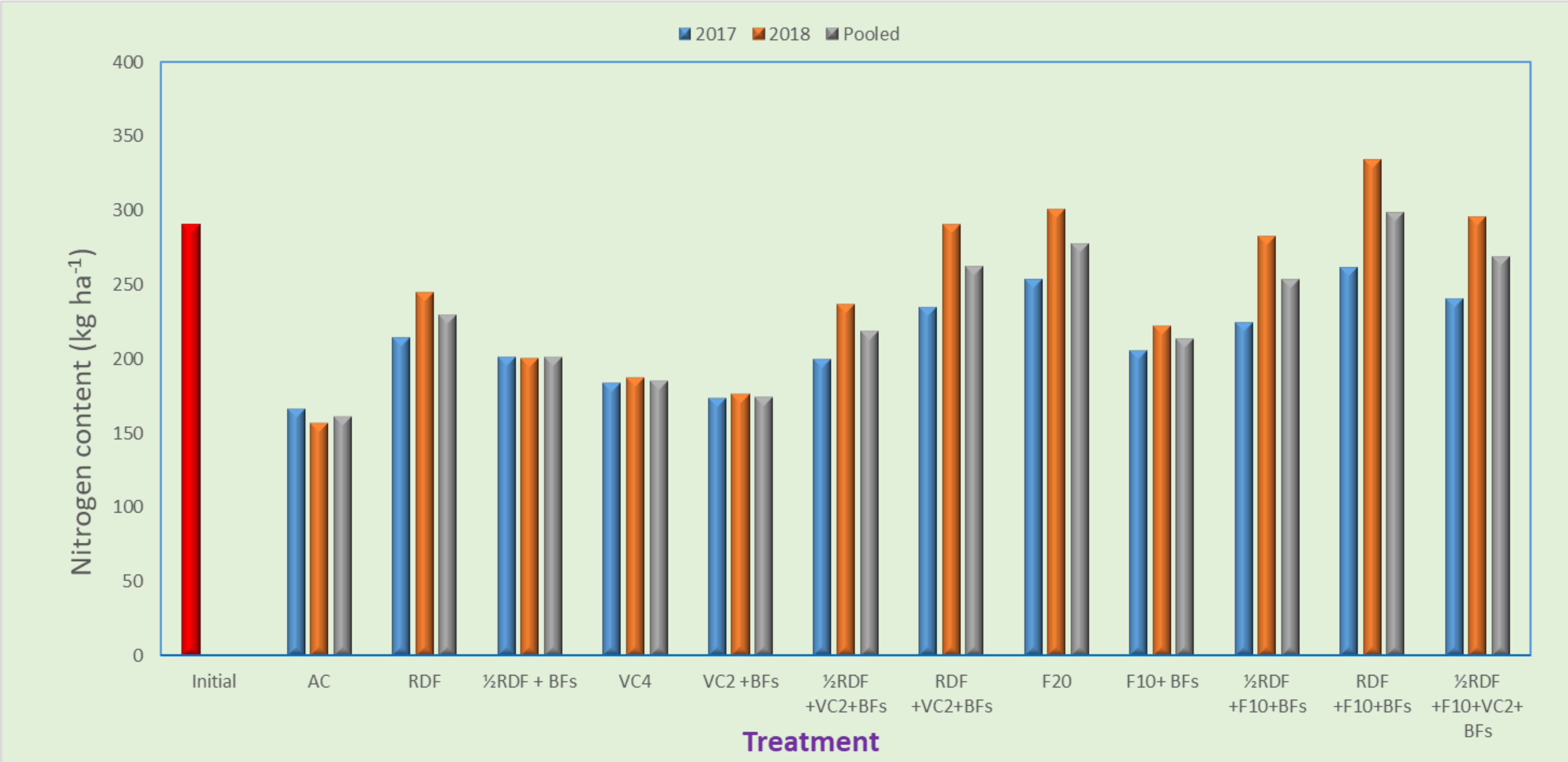


Fig 2: Post-harvest soil content of nitrogen (kg ha^{-1}) under the influence of INM practices

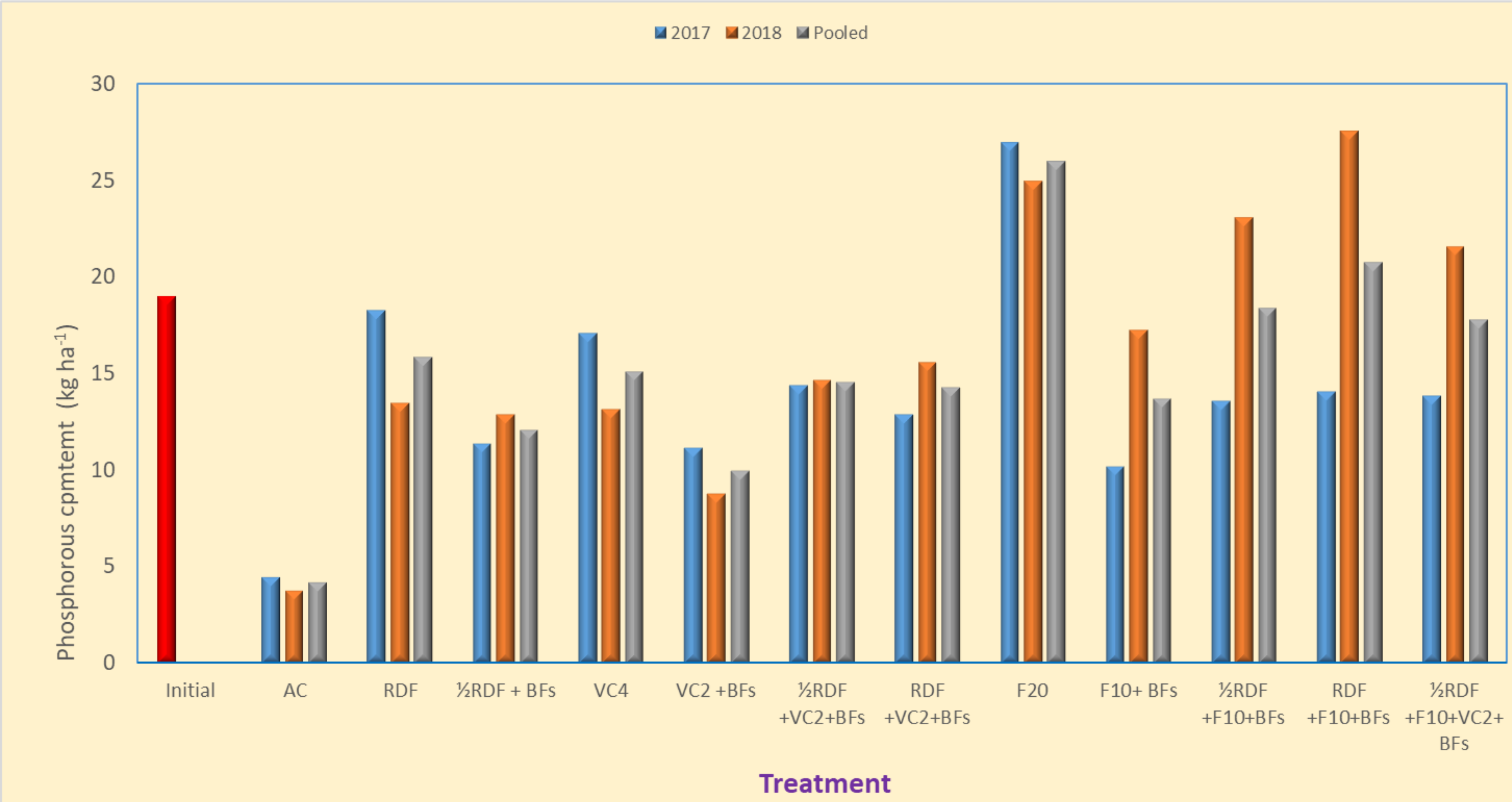


Fig 3: Post-harvest soil content of phosphorous (kg ha^{-1}) under the influence of INM practices

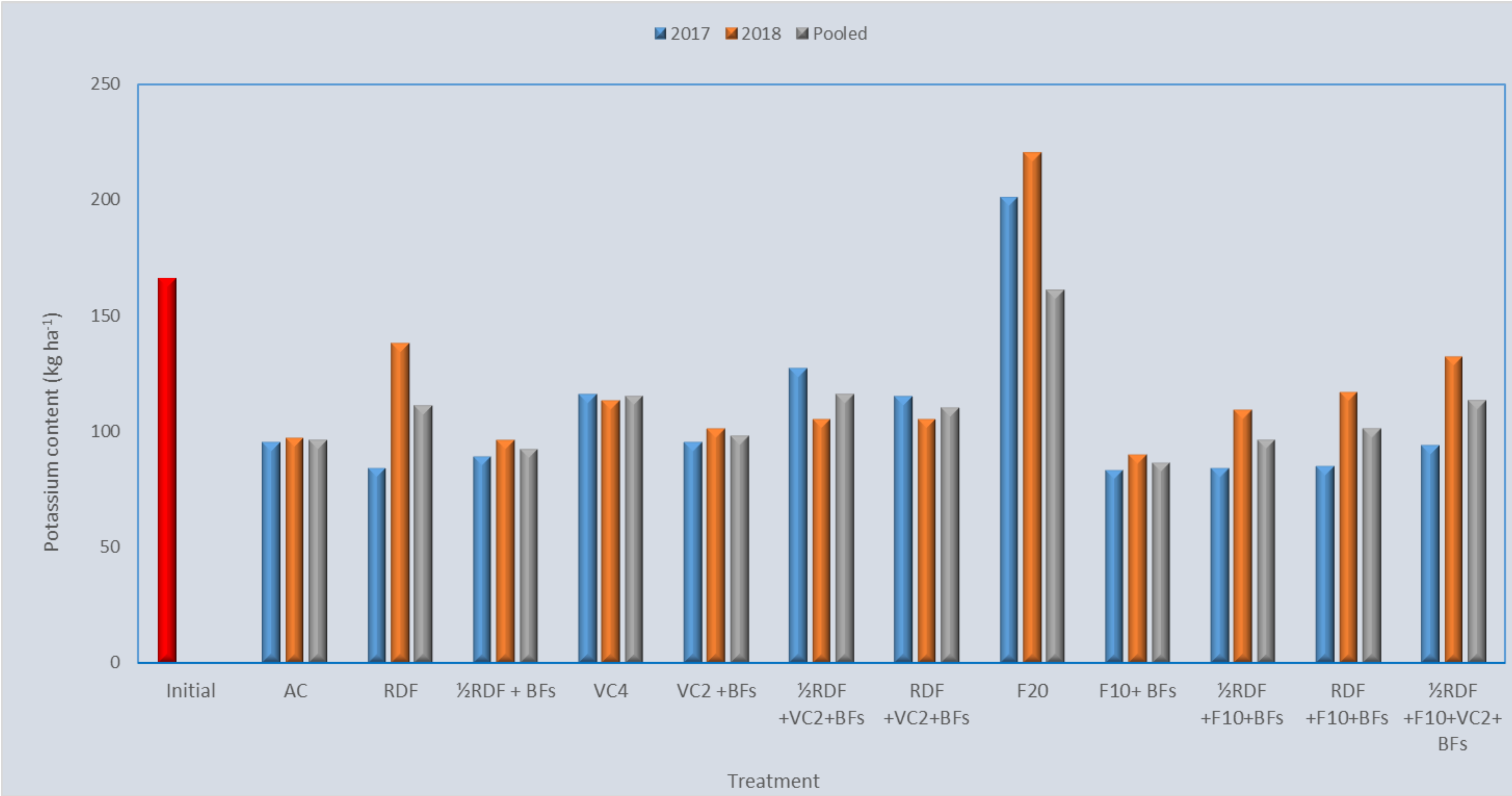


Fig 4: Post-harvest soil content of potassium (kg ha^{-1}) under the influence of INM practices

Nutrient concentration and uptake under the influence of INM practices:

The experiment involved using a combination of inputs including fertilizers, vermicompost, and biofertilizer consortia to meet immediate and long-term nutritional needs. The use of organic inputs not only provided nutrients but also supported microbial populations, leading to better soil conditions for crop growth. In the 2^{nd} year of the experiment, crop performance was better due to the residual benefits from the 1^{st} year's nutrient management practices. The cucumber crop in the 2^{nd} year benefited from leftover nutrients from the previous year as well as recent nutritional practices.

The data presented in Table - 2 indicated a 10 times variation in N uptake by the crop under the influence of complete INM practice (30.2 kg ha^{-1}) against 3.5 kg ha^{-1} in restricted nutrient supply practice (control). Any other combinations (lone/integrated) failed to influence N uptake compared to ½RDF+F_{10}+VC_2+BFs practice which recorded the apparent recovery of 25 % against 15 % with only RDF. Though the practice of F_{10}+BFs recorded 31 % N recovery but failed to achieve the yield as in complete INM practice (17.2 tha^{-1}). Residual fertility of 1st year positively influenced N uptake during 2^{nd} year, so also the ANR (29% against 21% during 1^{st} year). The crop was found to be a poor N recovering crop which emphasized the need for further research. The complete INM practice enabled the crop for better utilization of P rather than N, with the complete integrated practice, three times more P could be used by the crop against 5.9 kg ha^{-1} with restricted nutrient supply practice (Table-3). None of the INM combinations could influence such utilization of P. Its recovery of 14 % with only RDF, 17 % with F_{20}, could be enhanced to 33 % with complete INM practice. Crop utilization of P was 6 % higher during 2^{nd} year than 1^{st} year of experimentation.

The complete INM practice comprising of ½ RDF, F_{10}, VC_2 and BFs exhibited 8.8 times higher K uptake compared to only 3.2 kg ha^{-1} under restricted supply practice (control)(Table-4). Other possible combinations of INM practice failed to utilise soil available K. This practice recorded a recovery of added K of 29 % with the highest yield against 34, 24 and 25 % with only RDF, F_{20} and VC_4 practices, respectively.

The efficiency of these nutrient sources depends upon 4 "R"s: right source, right dose, right time of their application and with right method. Any deviation influences the recovery efficiency of the nutrients. Organic matter in the form of organic carbon in soil is considered as heart and soul of soil as well as for agriculture which makes the soil live and active, controlling many biochemical functions related to plant growth. The soil organic carbon (soil organic matter) helps improve soil physical properties like bulk density, porosity, structure, water holding capacity, water transmission characteristics, available water content and infiltration rate in soil, thereby regulating soil aeration, root respiration, and nutrient uptake by growing plants. The consortia source of biofertilizers includes *di-azotrophs* (*Azotobacter* and *Azospirillum)* are N_2 fixers, fixes atmospheric N_2 in their own body utilizing carbon of soil similar findings are also reported by Patel *et al.,* 2018 and Khagra *et al.,* 2019 in cucumber.

The phosphorous solubilizing micro-organisms in consortia constitute both bacteria and fungi, and release organic acids which help dissolution of insoluble phosphates in acid soils and regulate P availability for crop uptake. The organic acids chelate or complexes Fe, Al and Mn the toxic elements in acid soils, keep P free for plant availability, which could have been fixed or converted to plant unavailable forms and resulted increase in the recovery of added P. Similar findings were given by Sarkar *et al.*, 2020 and Pattanayak *et al.*, 2021 in vegetable crops.

Harvesting Duration:

Use of full dose of inorganic fertilizers or half dose integrated with BFs significantly shorten the days to 1st harvest. Sole inorganic practice and ½RDF integrated with BFs shorten the days to 1st harvest by 4 days (6.2 %) and 6 days (7.0 %) over absolute control, respectively. The use of full dose of FYM (F_{20}) and half dose (F_{10}) integrated with BFs had a similar influence towards days to last harvest. But use of RDF+F_{10}+BFs considerably extended the harvesting duration which was *at par* due to the integrated application of ½RDF+F_{10}+VC_2+BFs practice.

Post harvest soil properties:

In initial soil was medium in available N status (291 kg ha^{-1})(Fig-2). The practice not using any external sources of nutrient control exhibited depletion of the content (167 to 157 kg ha^{-1}) as well as only inorganic fertilizers also failed to increase its status even after two years of experimentation (291 to 245 kg ha^{-1}). The vermicompost sources influence the maintenance of the status of N during 1st year but improved after 2nd year of application. However available N status in soil could not be maintained compared to the initial year.

The phosphorous was not limiting nutrient in soil before experimentation (19.0 kg ha^{-1}). Reduction of the inorganic dose accelerated depletion of it in soil (Fig. 3). The use of FYM source influenced the P build-up process in soil in spite of crop removal but vermicompost source at their lower dose of application failed in this aspect. The complete integrated dose, though failed to supply P during 1^{st} year but after 2^{nd} year practice ensured build up.

Non-supplementation of K in the experiment (AC practice) depleted its status and after 2 years it became low status. Even if there was supplementation of K through RDF there was depletion after the harvest of the 1^{st} year crop but supplementation during 2^{nd} year improved the status. The use of ½RDF with any integration of inputs did not meet the crop demand and the situation did not improve. Use of full dose of FYM (F_{20}) significantly improved the situation for two consecutive years but the reduction of rate of application worsens the situation because of high crop demand in light-textured soil situations. Post-harvest soil properties after two years of *in situ* cropping indicated depletion of available N (269 kg), P (17.8 kg) and K (113 kg) status compared to the same of pH 5.75, EC 0.07 d Sm^{-1}, 5.91 g kg^{-1} of OC, 291 kg N ha^{-1}, 19 kg P ha^{-1} and 166 kg K ha^{-1} before initiation of the experiment. The findings are also supported by Kanaujia and Daniel, 2016 and Olalekan, 2017.

Conclusion

The integrated approach to plant nutrition involves using various sources such as chemical fertilizers, manures, atmospheric nitrogen, and soil-fixed phosphorous to supply nutrients to crops. The effectiveness of these nutrient sources depends on factors like the right source, amount, timing, and method of application. Soil factors like texture and organic carbon content also play a key role in nutrient efficiency. Adding organic inputs like vermicompost and biofertilizers not only improves growth and productivity of crops like cucumbers but also enhances nutrient uptake and maintain the post-harvest soil health.

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