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Performance of Groundnut (*Arachis hypogaea* L.) as Influenced by Integrated Nutrient Management under Fertigation

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ABSTRACT

Background: Groundnut (*Arachis hypogaea* L.) is a prominent legume oilseed after mustard in India and it's lower productivity is a matter of concern attributed to the major constraints of inefficient irrigation and nutrient management in *rabi* season. Fertigation is the recent innovative gearing up technology in which the nutrients are applied in précised quantity along with drip irrigation at regular intervals throughout the crop growth matching with their requirement, resulting in enhanced resource use efficiency and crop yields. Liquid formulations of biofertilizers can be diluted sufficiently and applied through drip irrigation uniformly to the root zone of crop. Humic acid is widely used as fertilizer synergist and hence in combination with inorganic fertilizers can enhance their use efficiency and improve root zone activity. The present experiment was conducted to develop an integrated nutrient management practice in combination of chemical fertilizers with organic sources *i.e.*, co-inoculation of liquid biofertilizers and humic acid under fertigation for *rabi* groundnut under irrigated condition.

Methods: The experiment was comprised of seven treatments of integrated nutrient management practices *viz*. T_1 - Soil application of 100% RDF (30-40-50 kg N, P_2O_5 and K_2O ha^{-1}) + drip irrigation; T_2 - 75% RDF + liquid biofertilizers @ 3.75 l ha^{-1} ; T_3 - 75% RDF + humic acid @ 12.5 l ha^{-1}; T_4 - 50% RDF + liquid biofertilizers @ 3.75 l ha^{-1}; T_5 - 50% RDF + humic acid @ 12.5 l ha^{-1}; T_6 - 100% RDF + liquid biofertilizers @ 3.75 l ha^{-1}; T_7 - 100% RDF + humic acid @ 12.5 l ha^{-1} which were tested in randomized block design with three replications.

Result: The integrated nutrient management practice with 30-40-50 kg N, P_2O_5 and K_2O + liquid biofertilizers @ 3.75 l ha^{-1} (*Rhizobium*, Phosphorus solubilizing bacteria and Potassium solubilizing bacteria each @ 1.25 l ha^{-1}) through fertigation recorded tallest plant height (49.9 cm), maximum LAI (2.05), SCMR value (34.5), number of nodules plant^{-1} (60.2), pods plant^{-1} (11.2), 100 pod weight (125.7 g), kernel weight (52.9 g) which resulted in highest pod yield (3902 kg ha^{-1}), seed yield (2666 kg ha^{-1}), haulm yield (4363 kg ha^{-1}), higher nutrient uptake (77.3 kg N, 18.9 kg P and 57.8 kg K ha^{-1}) and net return (Rs. 130818 ha^{-1}) of groundnut, which were comparable to 100% RDF + humic acid @ 12.5 l ha^{-1}.

Key words: Fertigation, Groundnut, Humic acid, Integrated nutrient management, Liquid biofertilizers.

INTRODUCTION

Groundnut (*Arachis hypogaea* L.) is a prominent oil seed crop in India sharing about 40% of total oil production. It is being cultivated around on 5.57 m ha area with a total production of 1.02 million tonnes and a productivity of 1831 kg ha^{-1} contributed nearly 13% of world groundnut production. The low productivity of groundnut is a greater concerned which might be due to the major constraints of production practices with inadequate irrigation, nutrient and weed management under the present situation of intensive agriculture. Further, the recently released improved varieties are energy rich and exhaustive, which deplete enormous quantity of nutrients from the soil and even suffers from nutrient deficiencies under sub optimal application of fertilizers.

The drip method of irrigation cuts off water consumption by 30-70% over surface method and improves productivity by 20-30% in different crops (Singh *et al.,* 2009 and Jaya Kumar *et al.,* 2014). Further, the net present worth estimated by discounting cash flow technique shown that investment in drip irrigation is highly viable for groundnut cultivating farmers (Narayanamoorthy *et al*., 2020). Hence, development of appropriate agro-techniques with precise management of irrigation and mineral nutrition has become the prime concern area of research for exploitation of higher yield potential of groundnut. Rising prices, shortage of supply and polluting nature of chemical fertilizers is driving towards search for alternate suitable integrated balanced nutrient management strategies. Fertigation is the recent innovative

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gearing up technology in which the nutrients are applied in précised quantity along with drip irrigation at regular intervals throughout the crop growth matching with the requirement, resulting in enhanced resource use efficiency (RUE) and crop yield. Fertigation allows for a higher nutrient use efficiency in terms of plant nutrient recovery with much higher results up to 90% than other application methods (40-45%) as reported by Agostini *et al*. (2010).

Biofertilizers are the inexpensive and eco-friendly source of nutrient management with multifaceted advantages such as nitrogen fixation, solubilization of fixed phosphorus and increasing of potassium absorption from the inaccessible zones and in turn improve soil microbial population. Liquid biofertilizers are the best alternative to conventional carrier - based biofertilizers with higher cell count and longer shelf life in the modern agriculture as suitable for wide range of application technologies. Liquid formulations can be diluted sufficiently and applied through drip irrigation uniformly to the root zone of crop which results in their effective utilization as reported by Singh *et al*. (2018).

Humic acids are very large and complex molecules extracted from organic matter which serves as an excellent natural and organic source with multifarious role in improvement of soil physico-chemical and biological properties and positively influencing physiological functions of plant growth. It is widely used as fertilizer synergist and hence in combination with inorganic fertilizers can enhance their use efficiency and improve root zone activity. Previous research results reported that application of humic acid improved the agronomic traits and increased yield and quality of peanut as reported by Li *et al*. (2021) and Zhang *et al*. (2014).

In groundnut, there is a tremendous scope for modern agronomic research for fine tuning optimum integrated nutrient management strategies with twin objectives of higher productivity with sustainable development goal. The present field experiment was planned to develop an integrated nutrient management practice in combination of chemical fertilizers with organic sources *i.e*., co-inoculation of liquid biofertilizers and humic acid under fertigation for *rabi* groundnut.

MATERIALS AND METHODS

A field experiment was conducted for three consecutive *rabi* seasons of 2019-20, 2020-21 and 2021-22 at the farm of Regional Agricultural Research Station, Tirupati, ANGRAU, situated at 13.27°N latitude, 79.36°E longitude and an altitude at 182.9 m above mean sea level, in the southern agro-climatic zone of Andhra Pradesh, India. The experiment was comprised of seven treatments of integrated nutrient management practices *viz*., T_1 - Soil application of 100% RDF (30-40-50 kg N, P_2O_5 and K_2O ha^{-1}) + Drip irrigation; T_2 - 75% RDF + Liquid biofertilizers @ 3.75 l ha^{-1}; T_3 - 75% RDF + Humic acid @ 12.5 l ha^{-1}; T_4 - 50% RDF + Liquid biofertilizers @ 3.75 l ha^{-1}; T_5 - 50% RDF + Humic acid @ 12.5 l ha^{-1}; T_6 -100% RDF + Liquid biofertilizers @ 3.75 l ha^{-1}; T_7 - 100% RDF + Humic acid @ 12.5 l ha^{-1}. It was laid out in randomized block design with three replications. Groundnut variety 'Dharani' was sown at 22.5 cm × 10 cm spacing on 27th, 23rd and 25th November during 2019, 2020 and 2021 respectively. The nutrient sources of nitrogen, phosphorus and potassium were urea, SSP and muriate of potash, respectively. In treatment of T_1, the fertilizers were applied to soil, as phosphorus and potassium as basal and nitrogen in two splits (20 kg N as basal and10 kg N at 30 DAS). In remaining treatments from T_2 to T_7, phosphorus was applied as basal. Whereas, N and K were applied in five splits through fertigation at 15, 25, 35, 45 and 55 DAS, respectively.

Further, in T_2, T_4 and T_6 treatments, the liquid formulation of biofertilizers (*Rhizobium*, Phosphate solubilizing bacteria and Potassium solubilizing bacteria) @ 3.75 l ha^{-1} and in T_3, T_5 and T_7 treatments added humic acid @ 12.5 l ha^{-1} through drip fertigation at 10 DAS. For drip irrigation, 16 mm laterals consisting of in-line drippers with water discharge of 4 l ha^{-1} at 40 cm spacing were connected on the submain pipes laid out at 60 cm spacing interval in between the rows of groundnut crop. Irrigation was scheduled based on IW/CPE ratio of 0.8. On an average groundnut crop received 247.8, 252.3 and 260.8 mm of water during the crop growth period including the rainfall during *rabi*, 2019-20, 2020-21 and 2021-22. Pre-emergence application of pre-mix herbicide pendimethalin 30% EC + Imazethapyr 2% EC, a selective herbicide @ 3 ml l^{-1} water immediately after sowing followed by one hand weeding at 30 DAS to control weeds in experimental plots.

At 60 DAS, ten plants in each plot were up rooted, nodules were carefully excised and the number with pink and white pigmentation were counted and averaged as nodules plant^{-1}, SPAD chlorophyll meter reading (SCMR) as an index of chlorophyll content were recorded with the fully expanded second leaf from the tip with five random observations and was averaged. At the time of harvesting, growth and yield attributes were recorded from the randomly selected plants. The groundnut pod yield was recorded from the net plot area after through drying and expressed as kg ha^{-1}. Further plant samples were collected, oven dried at 65°C, processed and analyzed for nitrogen, phosphorus and potassium content. The nutrient uptake was calculated by multiplying the dry weight with their respective concentrations and expressed as kg ha^{-1}. The effect of each nutrient given at different quantities on pod yield to applied nutrients with the following formula:

$$\text{Partical factor productivity} = \frac{\text{Pod yield (kg ha}^{-1}\text{)}}{\text{Amount of nutrients applied (kg ha}^{-1}\text{)}}$$

Regarding economics, gross returns were worked out based on the prevailing market prices of pod and haulm yields. Net returns were calculated by deducting the cost of cultivation from gross returns whereas, the benefit: cost ratio was worked out by dividing the gross returns with respective cost of cultivation.

RESULTS AND DISCUSSION

Growth parameters

The tallest plants, highest leaf area index, SCMR readings and nodules plant^{-1} were recorded with the application of 100% RDF + Liquid biofertilizers, which were comparable with100% RDF + Humic acid and 75% RDF + Liquid biofertilizers which was at par with 75% RDF + Humic acid. However, the growth performance resulted with 50% RDF in combination with either liquid biofertilizers or humic acid was comparable with soil application of 100% RDF + drip irrigation (Table 1). Thus, the treatments with 100% RDF or 75% RDF in combination either with biofertilizers or humic acid applied through fertigation were noticed to be superior to 100% RDF through soil application might be due to the fact that nitrogen and potassium applied in five split doses continuously at 10 days interval up to 55 DAS at different stages provided the crop nutrition matching according to the crop requirement. Further, resulted in improved nutrients availability and enhanced their use efficiency without any visible losses like leaching and volatilization. Optimum maintenance of soil moisture along with precise supply of nitrogen and potassium in readily available form had increased the meristematic cell activity with higher growth rate of stem and produced taller plants with a greater number of branches. Further SCMR meter readings, which indicates the chlorophyll content was significantly higher with better nutrient mobilization under 100% RDF + Liquid biofertilizers (T_6), which was comparable with100% RDF + Humic acid (T_7). Thus, the chlorophyll content is positively related with nitrogen as its constituent. Co-inoculation of *Rhizobium* and *Bacillus megatherium* is reported to increase chlorophyll a and b, carotenoids, protein, amino acid, total sugars and starch in groundnut (Gayathri and Aiswariya*,* 2020). The highest numbers of nodules plant^{-1} noticed with 100% RDF + biofertilizers was statistically on par with 100% RDF + Humic acid. Root development is highly influenced by phosphorus nutrient and serves as an energy source for *Rhizobium* which might have led to increase in number of nodules and in turn enhancing nitrogen fixation. Further, phosphate solubilizing bacteria by virtue of their property of producing organic acids solubilized insoluble form phosphorus in the rhizosphere, promoted root development and nodule formation.

With regard to the potassium solubilizing bacteria, it is effective in releasing of insoluble pools of soil potassium and made available to the crop and might have favored in increased net photosynthesis, assimilation and partitioning of photosynthates. These findings are in accordance to the results reported by Patil *et al*. (2014), Pravin *et al*. (2018) and Li *et al*. (2021).

Yield attributes and yield

The highest number of pods plant^{-1}, 100 pod and kernel weight, pod yield (3902 kg ha^{-1}), kernel yield (2666 kg ha^{-1}), haulm yield (4363 kg ha^{-1}) were recorded with 100% RDF (Recommended Dose of Fertilizers) + Liquid biofertilizers on par with 100% RDF + Humic acid through fertigation to groundnut and 75% RDF + Liquid biofertilizers. The synergistic effect of inorganic fertilizers had been applied precisely in limited quantities at regular interval and liquid biofertilizers like *rhizobium*, PSB (Phosphorus solubilizing bacteria) and KSB (Potassium Solubilizing Bacteria) at 10 DAS (Days after sowing) through fertigation had improved vegetative growth with higher crop growth rate, influenced flowering and resulted in more number of pods (Akbari *et al*. 2023). Continuous supply of nitrogen and potassium through irrigation water have enhanced their solubility and immediate availability of nutrients in the active root zone under optimum moisture conditions throughout the critical stages *i.e*. flowering, peg formation and pod development in groundnut. Further, the enhanced availability of metabolites might have promoted better translocation of assimilates to the sink and resulted in improved stature of yield attributes and ultimately higher yield. These findings are in agreement with Mathukia *et al*. (2014) and Jain *et al*. (2018).

Regarding application of 100% RDF + Liquid biofertilizers (T_6) through fertigation resulted in significantly higher yield attributes, 24.4% increase in pod yield, 25.2% in kernel yield and 19.6% in haulm yield, similarly and 75% use of RDF along with biofertilizers at fertigation (T_2) recorded 19.5% pod yield, 13.3% kernel yield and 10.71% haulm yield higher than 100% RDF through soil application + Drip irrigation (T_1) (Table 2). Humic acid as an organic component incombination with inorganic fertilizers had altered the soil physical and chemical properties and improved microbial population in the rhizosphere and nutrient use efficiency

Table 1: Effect of integrated nutrient management practices on growth parameters of groundnut (Mean data of three years).

Treatment	Plant height (cm)	LAI	SCMR	Nodules plant^{-1}	Filled pods plant^{-1}	100 pod weight (g)	100 kernel weight (g)
T_1- 100% RDF + Drip irrigation	45.4	1.78	31.6	41.1	9.5	111.7	47.2
T_2- 75% RDF + Liquid biofertilizers @ 3.75 l ha^{-1}	47.9	1.99	33.9	57.0	10.3	119.1	50.6
T_3- 75% RDF + Humic acid @ 12.5 l ha^{-1}	47.0	1.86	32.8	54.2	9.9	116.4	49.4
T_4- 50% RDF + Liquid Biofertilizers @ 3.75 l ha^{-1}	43.1	1.42	30.9	43.0	9.0	106.3	45.0
T_5- 50% RDF + Humic acid @ 12.5 l ha^{-1}	42.0	1.35	30.2	40.9	9.7	106.4	44.3
T_6- 100% RDF + Liquid biofertilizers @ 3.75 l ha^{-1}	49.9	2.05	34.5	60.2	11.2	125.7	52.9
T_7- 100% RDF + Humic acid @ 12.5 l ha^{-1}	48.9	1.98	34.2	58.1	10.8	121.8	51.6
S.Em ±	0.94	0.07	0.85	0.80	0.31	2.32	0.72
C.D. (P=0.05)	2.9	0.22	2.62	2.46	0.94	7.2	2.3

which promoted crop growth and increased the yield under conductive environment. Li *et al*. (2019) also noticed that humic acid can improve the groundnut yield, quality, soil properties and also microbial composition under continuous cropping.

Nutrient uptake and partial factor productivity

The uptake of nitrogen, phosphorus and potassium by groundnut at harvest was higher with 100% RDF + Liquid biofertilizers through fertigation and on par with 100% RDF + Humic acid. Soil application of 100% RDF + Drip irrigation registered nitrogen uptake (70.2 kg ha^{-1}) and potassium uptake (49.3 kg ha^{-1}) comparable to 50% RDF + Liquid biofertilizers through fertigation. Increased flexibility with split application of fertilizers maintained continuous availability of nutrients in the root zone according to the crop requirement and might have enhanced nutrient uptake under 100% RDF as well as 75% RDF. Further, the addition of either biofertilizers or humic acid noticed to increase the nutrient uptake by groundnut plant with their positive impact on improving soil physico-chemical and biological properties towards enhancing the nutrient availability. Humic acid is reported to stimulate microbial activity in soil and enhance nutrient uptake as it is a good source of nitrogen, phosphorus, potassium and Sulphur and therefore it might have increased the supply of native and added nutrients to the crop. Similar findings were also reported by Patil *et al*. (2011), Singh *et al*. (2018) and Ananthi *et al*. (2023).

Partial factor productivity (PFP) is calculated as the ratio of pod yield to applied nutrients and expressed as kg pods kg^{-1} nitrogen, phosphorus and potassium applied. The maximum partial factor productivity for nitrogen, phosphorus and potassium was accorded with 50% RDF + liquid biofertilizers and was comparable with 50% RDF + Humic acid through fertigation. Successive increase in fertigation levels from 50% RDF to 100% RDF in combination either with liquid biofertilizers or humic acid resulted in significant reduction in partial factor productivity (PFP). The lowest PFP for nitrogen, phosphorus and potassium was noted with soil

Table 2: Effect of integrated nutrient management on yield and economics of groundnut (Mean data of 3 years).

Treatment	Pod yield (kg ha^{-1})	Kernel yield (kg ha^{-1})	Haulm yield (kg ha^{-1})	Gross returns (` ha^{-1})	Net returns (` ha^{-1})	B:C ratio
T_1- 100% RDF + Drip irrigation	3137	2130	3602	199119	81912	1.69
T_2- 75% RDF + Liquid biofertilizers @ 3.75 l ha^{-1}	3555	2469	3988	230587	130654	2.31
T_3- 75% RDF + Humic acid@12.5 ha^{-1}	3459	2313	3864	220325	123763	2.28
T_4- 50% RDF + Liquid biofertilizers @ 3.75 ha^{-1}	3142	2154	3588	203283	127971	2.69
T_5- 50% RDF + Humic acid@ 12.5 ha^{-1}	2973	2030	3344	187993	114440	2.55
T_6- 100% RDF + Liquid biofertilizers @ 3.75 ha^{-1}	3902	2666	4303	249313	130818	2.10
T_7- 100% RDF + Humic acid @ 12.5 ha^{-1}	3738	2517	4173	243258	123630	2.03
S.Em ±	114	69	117			
C.D. (P=0.05)	352	213	360			

Table 3: Effect of integrated nutrient management on nutrient uptake, partial factor productivity of groundnut and postharvest soil microbial population (Mean data of 3 years).

Treatment	Nutrient uptake (kg ha^{-1})			Partial factor productivity (kg pod yield/kg nutrient)			Microbial population	
	Nitrogen	Phosphorus	Potassium	Nitrogen	Phosphorus	Potassium	Fungi (×10^{9} CFU/ml)	Bacteria (×10^{5} CFU/ml)
T_1- 100% RDF + Drip irrigation	70.2	15.6	49.3	104.5	78.4	62.7	1.25	1.15
T_2- 75 % RDF + Liquid Biofertilizers @ 3.75 l ha^{-1}	75.6	17.1	56.5	144.5	105.7	3.67	3.67	4.8
T_3- 75% RDF + Humic acid @12.5 l ha^{-1}	74.8	16.5	54.2	141.0	108.4	86.7	3.59	3.97
T_4- 50% RDF + Liquid Biofertilizers @ 3.75 l ha^{-1}	64.1	14.5	45.8	173.7	130.3	98.4	2.05	2.88
T_5- 50% RDF + Humic acid @ 12.5 l ha^{-1}	62.5	13.4	44.6	163.9	122.9	104.2	2.43	3.05
T_6- 100% RDF + Liquid Biofertilizers @ 3.75 l ha^{-1}	77.3	18.9	57.8	130.1	97.6	74.8	3.65	4.18
T_7- 100% RDF + Humic acid @ 12.5 l ha^{-1}	78.5	18.2	55.3	124.6	93.4	78.0	3.74	4.20
S.Em ±	2.1	0.9	1.17	3.53	2.65	2.1	0.090	0.084
C.D. (P=0.05)	6.5	2.8	3.6	10.9	2.65	2.1	0.090	0.084

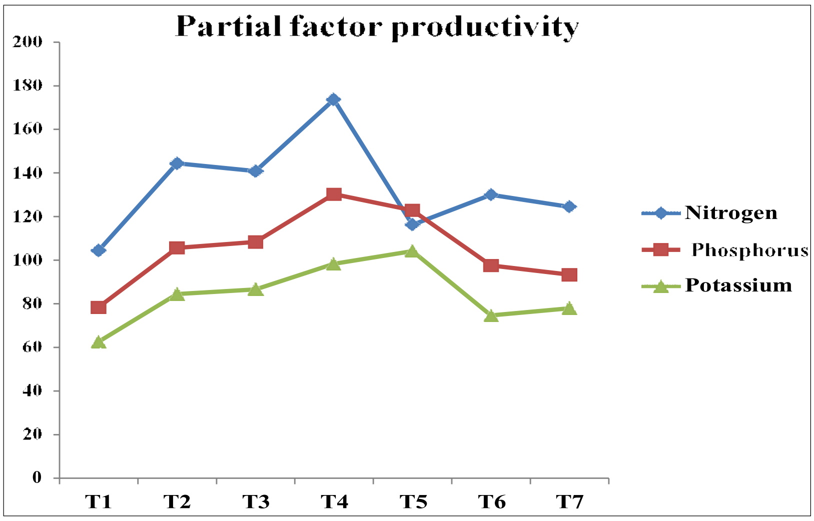

Fig 1: Partial factor productivity of nitrogen, phosphorus and potassium on groundnut pod yield as influenced by integrated nutrient management practice under fertigation.
(Pooled mean of *rabi,* 2019-20, 20-21 and 21-22).

application of 100% RDF + drip irrigation, as it also had resulted in the lowest groundnut pod yield. It reveals that pod yield per unit of nutrient added with 50% or 75% or 100% RDF either with biofertilizers or humic acid in combination is higher with that obtained through soil application of 100% RDF with drip irrigation. As the PFP is the simplest form of yield efficiency which observed to be higher values recorded at lower nutrient levels where as lower values were noticed with increasing of nutrient doses (Table 3 and Fig 1). The reduction of PFP values at higher fertilization rates was due to the fact that an unit of imported nutrient formed lower production compared to the higher production per unit at their lower rates.

Soil microbial population

After harvesting of groundnut the soil microbial population *i.e*. bacteria and fungi count was noticed to be higher with 100 % RDF in combination with either liquid biofertilizers or humic acid and was comparable with 75% RDF in combination of either with liquid biofertilizers or humic acid. Supply of liquid biofertilizers *i.e*. *Rhizobium*, phosphorus solubilizing bacteria and potassium solubilizing bacteria through fertigation might have augmented the microbial multiplication in the soil and maintained till the harvest of crop as reported Kumar *et al*. (2021). Application of humic acid also had been noticed to change the community structure of soil microorganisms by increasing of beneficial microbes and reducing of harmful, with a beneficial effect on groundnut growth under continuous cropping (Li *et al*. 2019). The lowest count of bacteria and fungi in the soil after harvest of groundnut was noticed to be with application of 100% RDF + drip irrigation.

Economics

All the treatments which involved 50%, 75% and 100% RDF with liquid biofertilizers or humic acid through fertigation have recorded higher gross returns, net returns and B:C ratio compared to soil application of 100% RDF + drip irrigation. Maximum gross returns and net returns were accrued with application of 100% RDF + liquid biofertilizers through fertigation followed by 75% RDF + Liquid biofertilizers, 50% RDF + Liquid biofertilizers and they were higher compared to the humic acid combined with their different respective fertilizer doses. It might be due to the higher cost of humic acid and lesser pod yield resulted compared to biofertilizers at the same levels of fertilizers tried. However, the highest Benefit-cost ratio was obtained with 50% RDF in combination with liquid biofertilizers followed by combination with humic acid. The highest B:C was attained with 50% RDF + liquid biofertilizers followed by 50% RDF + Humic acid, 75% RDF + liquid biofertilizers, 75% RDF + Humic acid. However, the Benefit-cost ratio from 75% RDF either with liquid biofertilizers or humic acid through fertigation is lesser than soil application of 100% RDF with drip irrigation.

CONCLUSION

On the basis of 3 years of experimentation, foregoing results and discussion, it was found that the best integrated nutrient management approach is the application of 100% RDF in combination with liquid biofertilizers @ 3.75 l ha^{-1} or humic acid @ 12.5 l ha^{-1} (N, K applied in equal five equal split doses at 15, 25, 35, 45 and 55 DAS and liquid biofertilizers/humic acid at 10 DAS through fertigation) in groundnut for obtaining higher productivity. However, application of 75% RDF in combination with liquid biofertilizers (N, K applied in equal five splits at 15, 25, 35, 45 and 55 DAS and liquid biofertilizers/humic acid at 10 DAS through fertigation) also proved to be the better practice as it resulted in comparable performance in terms of yield and economic returns with the best treatment (100% RDF in combination with liquid biofertilizers) for groundnut during *rabi* season.

Conflict of interest: None.

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