SULPHUR UPTAKE, SULPHUR DERIVED FROM FERTILIZER (SDFF), S UTILIZATION AND YIELD OF 'ROBUSTA' BANANA (*MUSA* × *PARADISIACA*) AS INFLUENCED BY PLACEMENT AND SPLIT APPLICATION OF ^{35}S LABELLED SUPERPHOSPHATE UNDER HIGH DENSITY PLANTING

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(Received 9th Apr 2023; accepted 30th Jun 2023)

Abstract. Sulphur uptake, sulphur derived from fertilizer (Sdff), S utilization, dry matter production and bunch yield of 'Robusta' banana (*Musa* × *paradisiaca*) under high density planting were studied on a sandy clay loam (Udic Paleustalf) soil at ICAR-Indian Institute of Horticultural Research, Bangalore using ^{35}S labelled superphosphate applied in different split at early vegetative (I split), late vegetative (II split) and bud differentiation (III split)) stages and placement (15-35, 35-55 and 55-75 cm band width) from pseudostem of the plant. From the results, it is noteworthy that it was the first split application from which Sdff of 8.22% was observed compared to 3.31 and 0.94% from II and III split applications, respectively as observed from the isotope found in leaves from 20 to 80 days after application. However, in respect of total fertilizer utilized by plant, both I and II split applications contributed 39-40% while the III split application supplied 20% of the fertilizer sulphur to the plant. Higher dry matter production, fruit weight and bunch yield of 'Robusta' banana was recorded with I and II split application. Among the placements 15-35 and 35-55 cm placements showed an edge with the highest fruit weight, bunch weight and dry matter production over the farthest placement (55-75 cm). The experiments revealed that inter-plant competition of roots for nutrients was practically negligible. Leaf and fruit were the largest sinks (35.2 and 31.9%, respectively) for fertilizer sulphur while pseudo stem appropriated 15.8%. Application of recommended sulphur in 2 splits as circular bands at 5cm depth, between 15 and 35cm in the first and between 35 and 55cm distance from the base of the plant in the second split was optimal to attain high fruit and bunch yield in Robusta banana under high density planting. Application of fertilizer at the farthest distance between 55 and 75 cm distances was distinctly inferior showing that there is little scope of application of fertilizers between the rows under the high-density planting of banana.
Keywords: *Sdff, S utilization, radiotracer, bunch yield, banana, Robusta*

Introduction

Bananas are the fifth largest agricultural commodity in world trade after cereals, sugar, coffee and cocoa. In India, it is the second most important fruit crop after mango. India is the largest producer of banana in the world, contributing 25.58 per cent to the global production of banana, with a total production of 30.81 million tonnes from an area of 0.884 million hectare with a productivity of 34.86 tonnes per hectare (Indian Horticulture Database, 2018). Tamil Nadu, Gujarat and Maharashtra are the topmost Banana

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2105_44894504

producing Indian states. However, the wide gap existing between production potential and realized productivity can be reduced by efficient crop, nutrient and water management practices (Mueller et al., 2012). Banana crop with the fruit yield of 50 tonnes from one hectare removes, 320 kg N, 23 kg P and 925 kg K per year. Besides major nutrients, other micronutrients are also essential for satisfactory production (Kalaivanan et al., 2014). To maintain soil fertility and to permit continuous production, these nutrients must be replenished every year through manures and fertilizers (Bhalerao et al., 2009; Ndabamenye et al., 2013).

Among the secondary nutrients, sulphur (S) is an essential element for plant growth because it is present in major metabolic compounds such as amino acids (methionine and cysteine), glutathione, proteins, and sulpho-lipids. Sulphur is considered as the fourth most important nutrient, as banana requires 17 kg per ha per year (Walmsley and Twyford, 1968). The most rapid uptake of sulphur in banana occurs between the sucker and shooting stages. After shooting, the uptake rate is reduced, and sulphur needed for fruit growth comes from the leaves and Pseudostem. There has been a steady decline in the sulphur status of soils leading to its deficiency, which has become more pronounced and widespread throughout India. Decrease in S availability in many areas of India has been noticed during recent years due to intensive agriculture and use of sulphur free fertilizers (Rajagopalan, 1985). Sulphur use must therefore become essential and much more efficient in the future. Therefore, the amount of S application is projected to increase as soils become increasingly deficient in S due to low industrial S emission, high crop removal, and immobilization (Sutar et al., 2017). In this context, fertilizers containing sulphur such as superphosphate would be more useful (Zhao et al., 1999). Concepts and management practices for a better crop S use efficiency from soil or from fertilizer will be based on a better understanding and quantification of soil-plant processes at different spatial and temporal scales.

Since fertilizer is a major input, studies on its management involving appropriate time and method of placement are of great importance. Precise placement often improves the efficiency by which plants take up nutrients and consequently encourages maximum yields of intensively managed crops (Obreza and Sartain, 2010; Nkebiwe et al., 2016). Fertilizer use efficiency is the key to achieve the highest possible yield with a minimum fertilizer input. Radioactive tracers are useful in sulphur research in banana under high density planting beyond conventional techniques as they give a direct and quantitative measure of isotope-labelled fertilizer nutrients utilized by the crop, quite independent of native nutrients present in the soil (Kotur, 2012). Studies using the ^{35}S tracer methodology on the S dynamics in the soil-plant system, mainly evaluating the efficiency of soluble sulphate fertilizers, have shown that the crops rarely utilize more than 10% of the applied amount (Nkebiwe et al., 2016). The root feeding zone of banana and the effect of time and method of placement have been studied by Keshava Murthy and Iyengar (1990, 1994); Keshava Murthy and Kotur (1998) and Kalaivanan et al. (2014). But quantitative information regarding efficiency of absorption of fertilizer nutrients and fertilizer utilization under high density planting is lacking. The objective of the study, therefore, was to determine the effect of split application of ^{35}S labelled superphosphate at three different placements from pseudo stem on sulphur uptake, sulphur derived from fertilizer (Sdff), S utilization and yield of ‘Robusta’ banana (*Musa* × *paradisiaca*) under high density planting.

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN1785 0037 (Online)
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Material and Methods

Experimental site and design

A field experiment was conducted to study the sulphur uptake, sulphur derived from fertilizer (Sdff), sulphur utilization, fruit and bunch yield of banana under high density planting with application of ^{35}S labelled superphosphate at three split *viz.*, early vegetative (8^{th} leaf/65 DAP), late vegetative (16^{th} leaf/115 DAP) and bud differentiation stages (165 DAP) in three different placement *viz.*, 15-35, 35-55 and 55-75 cm distance from pseudostem during the year 2009-2011 in the farm soil of ICAR - Indian Institute of Horticultural Research, Bangalore. The experimental site is situated in the latitude of 13°58' N and the longitude of 78°35' E with an elevation of 890 metres from mean sea level (MSL) (Keshava Murthy and Iyengar, 1990, 1994). Indian Institute of Horticultural Research (IIHR) enjoys tropical climate and receives an average annual rainfall of 891.5 mm with U.S.W.B class Pan Evaporation of 1468 mm. The mean annual temperature ranges from a minimum of 17.82°C to a maximum of 29.50°C. The experiment was conducted on a reddish-brown sandy clay loam soil belonging to Thyamagondalu series (family Udic Paleustalf) with pH of 5.9, cation exchange capacity of 8.7 cmol (p^+) kg^{-1} soil, organic carbon of 5.0 g kg^{-1}, available N of 246 kg ha^{-1}, available P of 15.5 kg ha^{-1} and available K of 180 kg ha^{-1} (Kalaivanan et al., 2014). A total of 9 treatments were replicated thrice in a randomized block design. Planting of 'Robusta' banana was done by following a spacing of 1.5 m x 1.5 m (4444 plants/hectare).

The recommended dose of fertilizer (180 g of N, 84g of P_2O_5, 225 g of K_2O and 63g of S per plant) was applied to banana in three equal splits at early vegetative (8^{th} leaf/65 DAP), late vegetative (16^{th} leaf/115 DAP) and bud differentiation stages (165 DAP). Urea, ^{35}S labelled single superphosphate (with specific activity of 0.270 mCi/gS) and muriate of potash were used as N, P & S and K sources, respectively and were applied in circular bands (15-35, 35-55 and 55-75 cm distance from pseudo stem) around the banana plants. The I, II and III split dose of fertilizers were applied on 26.09.2009, 19.11.2009 and 13.01.2010. Amount of precipitation received is 150.8 mm, 122.2 mm and 0 mm for September 2009 (8 rainy days), November 2009 (6 rainy days) and January 2010, respectively. A layout of single experimental plot consisting of main plant (labelled superphosphate receiving plant), neighbour I and neighbour II is given in *Figure 1*. Since measurable activity of ^{35}S persisted in the plant even after 100 days, two series of the crop were raised simultaneously. Series I' received first and third split application of ^{35}S labelled superphosphate while series II' received second split application of the labelled superphosphate. To ensure that all the experimental plants received the same dose of N, P, K and S, 'Series I' received the second split application using unlabelled (ordinary) superphosphate.

Monitoring of ^{35}S activity or absorption of S by the plant

The absorption of fertilizer S by banana leaf was monitored by collecting middle 25 cm^2 of leaf lamina from both sides of the mid-rib from the third fully opened leaf of banana at 20^{th}, 40^{th}, 60^{th} and 80^{th} days after application of labelled superphosphate at each growth stage. The collected banana leaf samples were dried in hot air oven at 70°C. Then dried leaf samples were powdered and digested by using di-acid mixture of nitric (HNO_3) and perchloric ($HClO_4$) acids in the ratio of 9:4. The digested sample was then made up to 100 ml volume. From this, 15 ml was pipetted out to 50 ml plastic vial. The ^{35}S activity or absorption of S in the digested sample was determined in Liquid Scintillation Counter

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2105_44894504

through Cerenkov technique. Total S was determined in the diacid wet digest by the turbidimetric method. The sulphur derived from fertilizer (% Sdff), fertilizer S uptake and fertilizer S utilization by leaf, midrib, pseudostem, flower, fruit, rachis and entire plant of banana was calculated as follows.

$$\text{Sdff (\%)} = \frac{Specific\ activity\ of\ 35S\ in\ the\ leaf\ sample}{Specific\ activity\ of\ 35S\ in\ the\ fertilizer} \times 100 \qquad \text{(Eq.1)}$$

$$\text{Fertilizer S uptake} = \text{Total S uptake (kg/ha)} \times \frac{Sdff}{100} \qquad \text{(Eq.2)}$$

$$\text{Fertilizer S utilization (\%)} = \frac{Fertilizer\ S\ uptake}{Rate\ of\ S\ application} \times 100 \qquad \text{(Eq.3)}$$

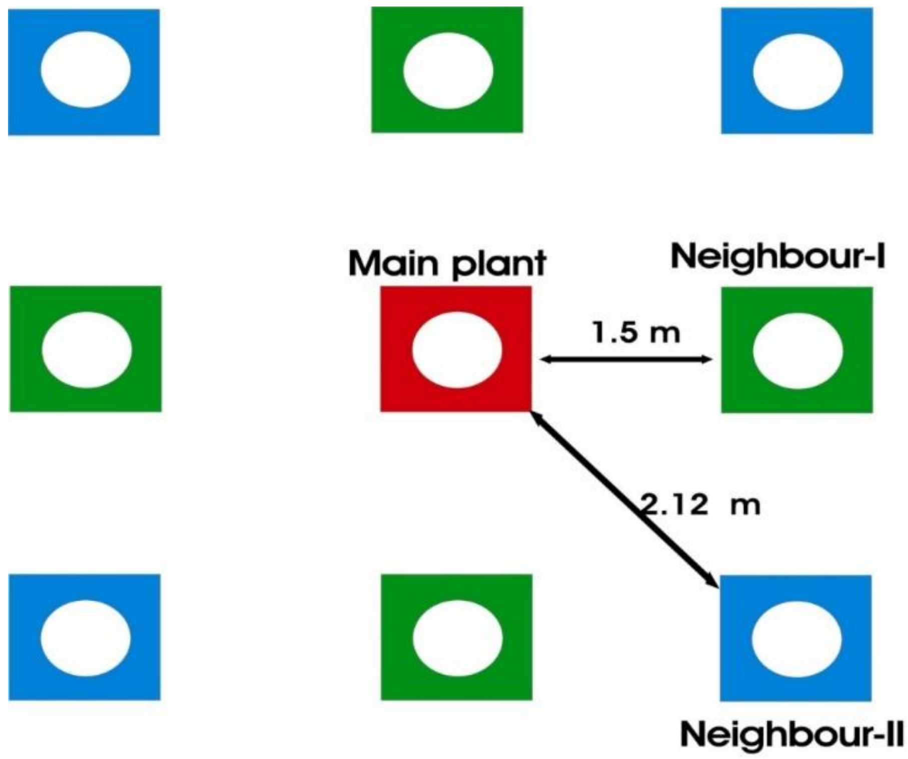

Figure 1. *Single Experimental plot*

Observations on yield of banana

Bunch weight and bunch yield as influenced by different split application and placement of ^{35}S labelled SSP were recorded. The fruits were considered to be ready for harvest when the angular girth of skin of the fruit disappeared, and colour turned from dark green to light green. Yield of banana in tonnes per hectare was calculated by multiplying the average bunch weight with the total number of plants per hectare.

Statistical analysis

Data generated from the experimental plots were analyzed using SAS 9.3 version of the statistical package (SAS Institute Inc, 2011). Analysis of variance (ANOVA) was

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN1785 0037 (Online)
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performed using SAS PROC ANOVA procedure. Means were separated using Fisher's protected least significant difference (LSD) test at a probability level of $p<0.05$.

Results and Discussion

Dry matter production (DMP)

The accumulation and distribution of biomass in different plant parts plays a vital role in determining the growth and production in banana. The dry matter production is one of the trustworthy measures for judging the optimum plant growth, besides it elucidates the pattern of distribution and redistribution of biomass between different plant parts at various stages of crop growth. In the present investigation, the total dry matter production (DMP) did not vary significantly with different split and placement of fertilizers (*Table 1*). In general, an increased trend in dry matter production was observed with first two split application and it was reduced during third split application. The plant supplied with labelled SSP fertilizer at 35-55 cm distance recorded the maximum dry matter production per plant (8.33 kg), while the minimum dry matter production per plant (7.87 kg) was recorded with application of labelled fertilizers at wider placement of 55-75 cm. Among the plant parts, highest dry matter production was recorded with fruits followed by pseudo stem, lamina, midrib, flower, and rachis (*Tables 2-4*). Higher accumulation of dry matter in the treatments supplied with ^{35}S labelled fertilizers at closer and middle placement indicated that the nutrients seem to be readily and sufficiently available for absorption, translocation, and uptake by the plants. These findings confirmed the reports of Turner and Barkus (1981) and Thippesha (2004). The exposure of the root system to zones with high S concentrations due to fertilizer placement at 35-55 cm distance resulted in higher dry matter production. Similar kind of findings was reported by Hansel et al. (2017) in soybean. Another possible explanation for increased dry matter production is due to the role of sulphur contained in SSP, which normally enhances the starch accumulation and better protein synthesis. Additionally, the high dry matter production logged in this study may be due to effectual synthesis and translocation of photosynthates (Singh and Trehan, 1988).

Table 1. *Fruit and bunch weight and dry matter production (kg/plant) of Robusta banana when applied in different split and placements*

Placement between (cm)	Fruit weight	Bunch weight	Total dry matter production
15 and 35	25.295	26.337	8.319
35 and 55	26.481	27.816	8.333
55 and 75	23.870	24.817	7.872
Split application			
I application	27.103	28.341	8.456
II application	24.982	26.142	8.105
III application	24.154	25.210	7.963
SEm(±)	0.4562	0.4606	0.1407
LSD (p=0.05)	1.3675	1.3808	NS

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2105_44894504

Table 2. *Dry matter, sulphur content, activity of absorbed ^{35}S and parameters of sulphur utilization in lamina and midrib of leaf of Robusta banana plant as influenced by placement and split application of fertilizer*

Treatment (Placement, between/Split application)	Dry matter (g/plant)	S content (%)	S uptake (mg/plant)	Activity of ^{35}S (dpm/g dry matter)	Specific activity if ^{35}S (dpm/mg S)	Sulphur derived from fertilizer (%)	Fertilizer S uptake (mg/plant)	Percent S utilization
Lamina								
15-35cm	1165.7	0.162	1883.8	90724	56236	9.92	187.8	0.93
35-55cm	1239.1	0.159	1984.6	70068	45640	7.88	157.1	0.78
55-75cm	1233.1	0.159	1961.1	74992	49244	8.37	160.4	0.80
I split	1183.0	0.178	2124.5	52744	29888	8.46	176.1	0.88
II split	1237.0	0.150	1857.6	125108	82990	12.40	230.5	1.15
III split	1217.8	0.151	1847.4	57933	38241	5.30	98.3	0.49
SEm(±)	27.16	0.0037	66.96	2228.3	1806.5	0.307	5.23	0.026
LSD (p=0.05)	NS	0.0152	200.72	9203.4	7461.2	1.267	21.61	0.107
Midrib								
15-35cm	428.4	0.109	468.6	46136	42644	8.03	37.8	0.19
35-55cm	501.9	0.101	521.4	32520	31704	5.81	32.6	0.16
55-75cm	434.8	0.098	430.6	31864	33216	5.88	26.35	0.13
I split	536.1	0.103	553.5	30367	29516	8.35	44.81	0.22
II split	511.7	0.105	544.9	53612	50900	7.61	40.3	0.20
III split	317.2	0.099	322.1	26540	27151	3.76	11.6	0.06
SEm(±)	8.82	0.0032	21.69	1651.9	1662.8	0.310	1.58	0.008
LSD (p=0.05)	36.42	NS	89.60	6822.8	6867.8	1.282	6.53	0.032

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2105_44894504

Table 3. *Dry matter, sulphur content, activity of absorbed ^{35}S and parameters of sulphur utilization in pseudo stem and flower of Robusta banana plant as influenced by placement and split application of fertilizer*

Treatment (Placement, between/Split application)	Dry matter (g/plant)	S content (%)	S uptake (mg/plant)	Activity of ^{35}S (dpm/g dry matter)	Specific activity if ^{35}S (dpm/mg S)	Sulphur derived from fertilizer (%)	Fertilizer S uptake (mg/plant)	Percent S utilization
Pseudo stem								
15-35cm	1490.0	0.052	715.3	35432	70056	12.09	86.1	0.43
35-55cm	1256.0	0.053	653.7	23432	45976	8.60	54.8	0.27
55-75cm	1445.8	0.055	788.4	28764	51848	9.99	88.0	0.43
I split	1336.3	0.056	703.5	24454	46947	13.28	98.9	0.49
II split	1412.2	0.063	897.6	48451	82552	12.34	101.9	0.50
III split	1443.4	0.040	556.2	14722	38378	5.32	28.1	0.14
SEm(±)	19.36	0.0011	18.74	718.5	2058.4	0.403	2.58	0.013
LSD (p=0.05)	79.97	0.0045	77.42	2967.6	8501.7	1.664	10.67	0.053
Flower								
15-35cm	107.1	0.135	143.1	109604	82832	14.16	20.4	0.102
35-55cm	204.6	0.125	257.7	125188	99636	17.04	45.1	0.224
55-75cm	154.2	0.135	207.8	164840	122868	18.52	36.9	0.183
I split	151.3	0.138	205.7	58472	42391	12.00	25.0	0.124
II split	170.4	0.134	227.6	156134	116587	17.42	40.9	0.203
III split	144.2	0.123	175.3	185024	146318	20.30	36.5	0.182
SEm(±)	4.77	0.0018	4.52	3805.8	2478.2	0.433	1.00	0.0050
LSD (p=0.05)	19.71	0.0075	18.66	15719.0	10235.7	1.789	4.14	0.0206

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2105_44894504

Table 4. *Dry matter, sulphur content, activity of absorbed ^{35}S and parameters of sulphur utilization in fruit and rachis of bunch of Robusta banana plant as influenced by placement and split application of fertilizer*

Treatment (Placement, between/Split application)	Dry matter (g/plant)	S content (%)	S uptake (mg/plant)	Activity of ^{35}S (dpm/g dry matter)	Specific activity if ^{35}S (dpm/mg S)	Sulphur derived from fertilizer (%)	Fertilizer S uptake (mg/plant)	Percent S utilization
Fruit								
15-35cm	4621.0	0.053	2468.0	21480	42928	7.35	176.7	0.82
35-55cm	5098.0	0.052	2662.0	18704	36536	6.62	182.3	0.90
55-75cm	4985.0	0.047	2366.0	13080	27664	5.52	112.7	0.56
I split	5188.4	0.052	2708.3	13580	26234	7.77	202.3	0.99
II split	4719.8	0.051	2414.1	22368	45929	6.87	155.7	0.77
III split	4795.6	0.049	2374.1	17314	34964	4.85	133.7	0.56
SEm(±)	86.77	0.0008	68.86	204.6	794.0	0.147	4.45	0.023
LSD (p=0.05)	358.40	NS	284.42	845.0	3279.5	0.606	18.38	0.096
Rachis								
15-35cm	59.2	0.290	165.1	175688	60020	10.73	15.0	0.08
35-55cm	66.8	0.308	191.5	165104	52728	9.44	15.3	0.09
55-75cm	85.7	0.271	203.3	109920	46400	6.93	12.4	0.07
I split	92.3	0.280	223.5	110747	44955	8.28	20.3	0.10
II split	61.0	0.282	167.8	171532	60116	8.99	14.5	0.07
III split	58.5	0.308	168,6	168436	54078	7.50	8.8	0.06
SEm(±)	2.23	0.0028	6.50	2142.3	996.2	0.194	0.62	0.001
LSD (p=0.05)	9.22	0.0118	26.83	8848.2	4114.5	0.803	2.55	0.014

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2105_44894504

Sulphur derived from fertilizer (Sdff %)

Sulphur derived from fertilizer is a robust measure of the recovery of the tracer. From *Table 5*, significantly and distinctly higher sulphur was absorbed from fertilizer when applied between 15 and 35 cm as well as between 35 and 55 cm distances from the plant. At 20 and 40 days after fertilizer application, the Sdff values at these distances were on par. But at later stages of 60 and 80 days, the application of fertilizer at 35-55 cm placement resulted in significantly higher sulphur absorption compared to closer application at 15 and 35 cm distances. The results indicate that superphosphate as a source of sulphur nutrient is best utilized when placed between 15 and 55 cm radial distances. The ^{35}S recovery was decreased with increasing S application distance from the pseudostem of the plant. Among the split applications, the maximum absorption of 8.22-29.67% of sulphur was absorbed which declined sharply to 1.41-3.3% from the II application and 0.78-1.94% from the III application of the fertilizer. Since the absorption of sulphur among the split applications was maximum from first (I) split application, there is reason to increase the proportion of superphosphate in favour of first (I) split application and apply a smaller proportion in the second (II) split application. Per cent Sdff was steeper when fertilizer S was applied at the early vegetative (I split) as compared to application at late vegetative stages (II split) and bud differentiation stage (III split). This indicates quicker absorption of fertilizer S during early stages of growth as the early stage of growth in banana is critical for subsequent development (Keshava Murthy and Iyengar, 1994; Kurien et al., 2006). It might also be due to higher rate of absorption of applied S fertilizers and S requirement in vegetative stage. On the other hand, during bud differentiation stage, the S requirement of the new shoot growth might be largely met by internal mobilization of S stored within the plant resulting in a lower Sdff at this growth stage. The supporting data of activity of ^{35}S, S content and specific activity of ^{35}S in leaf sampled from 20 and 80 days after application of each of the 3 split applications are presented in *Table 6*.

Table 5. *Sulphur derived from fertilizer (Sdff %) in leaf sampled at different intervals after 3 split applications of ^{35}S-labelled super phosphate to Robusta banana*

Placement between	Days after application of the fertilizer			
	20	**40**	**60**	**80**
15-35cm	11.00	10.90	4.38	4.33
35-55cm	9.46	10.37	5.51	5.97
55-75cm	11.40	4.88	2.48	2.18
Split application				
I application	29.67	22.39	9.19	8.22
II application	1.41	1.81	2.18	3.31
III application	0.78	1.94	1.00	0.94
SEm(±)	0.796	0.415	0.076	0.164
LSD (p=0.05)	3.288	1.715	0.318	0.677

In interaction effects between placement and split application, the highest Sdff in leaf was observed with I split application at 15-35 cm distance during 20th and 40th days after application of ^{35}S labelled fertilizer. However, the highest Sdff in leaf was recorded in

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DOI: http://dx.doi.org/10.15666/aeer/2105_44894504

first split application of labelled fertilizer at middle distance (35-55 cm) during 60th and 80th days after application (*Table 7*). This was due to efficient placement of fertilizers within the shoot canopy and also due to the presence of more number of active roots within this zone (Keshava Murthy and Iyengar, 1990, 1994). Low Sdff in bud differentiation stage (III split) compared to vegetative stages (I and II split) might be due to dilution of the labelled S within the plant (Keshava Murthy and Kotur, 1998; Kalaivanan et al., 2014). Interaction effect of placement and different split application of fertilizer on activity of ^{35}S, S content and specific activity of ^{35}S in banana leaf is also given in *Table 7*.

Table 6. *Activity of ^{35}S in leaf (dpm/g dry matter), S content (%) and specific activity (dpm/g dry matter) in banana leaf sampled at different intervals after application of ^{35}S-labelled superphosphate to Robusta banana*

Placement between/split applications	Days after application of the fertilizer			
	20	40	60	80
Activity of ^{35}S in banana leaf				
15-35cm	75145	133620	38273	41626
35-55cm	65628	133465	48907	44043
55-75cm	87107	64612	34614	23596
I application	198256	27060	58599	43045
II application	18346	32793	49621	53690
III application	11277	28144	13575	12567
SEm(±)	9664.1	5090.9	760.2	636.7
LSD (p=0.05)	39915.8	21026.9	3139.7	2629.9
S content of banana leaf				
15-35cm	0.194	0.267	0.187	0.190
35-55cm	0.193	0.274	0.345	0.191
55-75cm	0.196	0.274	0.194	0.205
I application	0.188	0.343	0.247	0.154
II application	0.192	0.272	0.228	0.245
III application	0.202	0.200	0.252	0.187
SEm(±)	0.0021	0.0033	0.0027	0.0016
LSD (p=0.05)	0.0087	NS	0.0112	0.0067
Specific activity of ^{35}S in banana leaf				
15-35cm	41929	42379	18157	21497
35-55cm	35839	41276	23421	25477
55-75cm	42087	21465	12512	11075
I application	104832	78972	32385	29074
II application	9412	12086	14597	22149
III application	5607	14062	7108	6827
SEm(±)	2825.2	1459.8	268.8	592.2
LSD (p=0.05)	11669.1	6029.5	1110.4	2445.9

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Table 7. *Interaction effect of placement and different split application of fertilizer on activity of ^{35}S, S content, specific activity of ^{35}S and sulphur derived from fertilizer in banana leaf*

Split application	Days after application of ^{35}S-labelled fertilizer											
	20			40			60			80		
	Placement of fertilizer between (cm)											
	15-35	35-55	55-75	15-35	35-55	55-75	15-35	35-55	55-75	15-35	35-55	55-75
Activity of ^{35}S in banana leaf (dpm/g dry matter)												
I	186469	167583	240716	345658	33795	132826	07364	80576	27857	43687	65865	19585
II	25999	17983	11056	29655	35520	33205	30782	49639	68441	61785	58929	40355
III	12966	11318	9548	25548	31079	37805	16675	16506	7544	19405	7454	10841
SEm(±)	9664.1			8817.7			1316.6			1102.8		
LSD(p=0.05)	39915.8			36419.7			5438.1			4555.1		
S content of banana leaf (%)												
I	0.174	0.181	0.209	0.336	0.350	0.343	0.178	0.176	0.208	0.165	0.135	0.161
II	0.208	0.190	0.178	0.275	0.269	0.271	0.351	0.338	0.347	0.228	0.247	0.260
III	0.199	0.208	0.198	0.191	0.204	0.207	0.211	0.170	0.200	0.176	0.191	0.195
SEm(±)	0.0047			0.0058			0.6972			0.0028		
LSD(p=0.05)	0.0193			NS			1.9401			0.0116		
Specific activity of ^{35}S in banana leaf (dpm/g dry matter)												
I	106752	92555	115190	102841	95351	38724	37838	45905	13412	26437	48667	12118
II	12530	9484	6212	10796	13205	12257	8760	14681	20349	27053	23862	15533
III	6504	5459	4858	13501	15272	13414	7873	9676	3774	11002	3903	5576
SEm(±)	4893.5			2528.5			465.6			1025.7		
LSD(p=0.05)	NS			10443.4			1923.2			4236.5		
Sulphur derived from fertilizer (Sdff, %)												
I	30.2	26.2	32.6	29.2	27.0	11.0	10.7	13.0	3.8	7.4	13.8	3.4
II	1.9	1.4	0.9	1.6	2.0	1.8	1.3	2.2	3.1	4.0	3.6	2.3
III	0.9	0.8	0.7	1.9	2.1	1.8	1.1	1.4	0.5	1.5	0.6	0.8
SEm(±)	1.38			0.72			0.13			0.28		
LSD(p=0.05)	NS			2.97			0.55			1.15		

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Sulphur content, S uptake, fertilizer S uptake and fertilizer S utilization

Banana requires high amount of mineral nutrients for its growth and production. Rapidly differentiating tissues in banana throughout the life cycle are associated with high concentration of nutrients. Therefore, large changes in concentration and uptake of nutrients take place in the plant from planting to fruit development. In any nutrient management study, uptake of nutrients should reflect on yield, to claim the favourable effect on nutrient use efficiency, which was well pronounced in the current investigation. The data pertaining to S content in different plant parts and in entire plant, total S uptake, fertilizer S uptake and per cent fertilizer S utilization with different split and placement of labelled ^{35}S fertilizers are given in the *Tables 8 to 9*. Data on total S concentration in the entire plant of banana cv. Robusta collected at different time intervals after fertilizer S application differed significantly with different split and placement of ^{35}S labelled single super phosphate even though the slight variation was found in the concentration of S between split applications and placements. Highest total S and fertilizer S uptake was recorded with I and II split application of fertilizer in 15-35 cm and 35-55 cm placement. The lowest amount of total and fertilizer S uptake was recorded with III split application of fertilizer in 55-75 cm placement. Higher uptake of nutrients from I and II split application might be due to higher availability of S to the plants. Band placement of S fertilizer can contribute to increase S availability to the root system by reducing potential S fixation in soils. Extensive root distribution promoted by band placement of S fertilizer may contribute to increase S use efficiency (Hansel et al., 2017). The uptake of S was observed to be positively correlated to plant dry matter production, fruit, and bunch weight and Sdff. The results were in confirmation with the findings of Thippesha (2004) and Mitra (2015).

Table 8. *Fertilizer S utilization (%) by different parts of banana plant from the applied fertilizer*

Treatment	Lamina	Midrib	Pseudo Stem	Flower	Fruit	Rachis	Total
Fertilizer placement between (cm)							
15-35cm	0.93	0.19	0.43	0.10	0.82	0.08	2.59
35-55cm	0.78	0.16	0.27	0.22	0.90	0.09	2.38
55-75cm	0.80	0.13	0.43	0.18	0.56	0.07	2.19
Split applications							
I split	0.88	0.22	0.49	0.12	0.99	0.10	2.79(39.2)*
II split	1.15	0.20	0.50	0.20	0.77	0.08	2.89(40.6)
III split	0.48	0.06	0.14	0.18	0.52	0.06	1.49(20.2)
Summary							
Total	2.51	0.48	1.13	0.50	2.28	0.24	7.14(100)
Percentage*	35.2	6.7	15.8	7.0	31.9	3.4	100

*Percentage contribution from the total fertilizer dose applied to banana

With reference to the per cent fertilizer utilization, the maximum fertilizer utilization was registered with I split application, followed by II & III split application of recommended sulphur. The higher utilization of S at I and II split application was mainly due to synchronization of plant growth with fertilizer application and period of better/maximum root activity.

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DOI: http://dx.doi.org/10.15666/aeer/2105_44894504

Table 9. *Sulphur use efficiency of* ^{35}S*-labelled superphosphate by the entire plant of Robusta banana plant as influenced by placement and split application of fertilizer*

Treatment (Placement, between/Split application)	Dry matter (g/plant)	S content (%)	S uptake (mg/plant)	Activity of ^{35}S (dpm/g dry matter)	Specific activity if ^{35}S (dpm/mg S)	Sulphur derived from fertilizer (%)	Fertilizer S uptake (mg/plant)	Percent S utilization
15-35cm	8319.0	0.071	5933.0	92168	61136	10.83	524.7	2.59
35-55cm	8333.0	0.072	6004.0	79256	52020	9.57	480.6	2.38
55-75cm	7872.0	0.075	5867.0	86828	52548	9.27	442.5	2.19
I split	8456.2	0.076	6414.5	60920	38309	10.80	564.8	2.79
II split	8105.1	0.075	6090.0	102894	70993	10.61	582.8	2.89
III split	7963.3	0.068	5409.5	94441	56533	7.84	300.2	1.49
SEm(±)	95.93	0.0012	120.12	277.5	696.2	0.122	8.62	0.075
LSD (p=0.05)	396.22	0.0049	496.13	1146.1	2875.7	0.505	35.60	0.180

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DOI: http://dx.doi.org/10.15666/aeer/2105_44894504

From *Table 8* it is observed that a total of 7.14% of sulphur applied through superphosphate was utilized by banana plant when applied in 3 split applications. The value appears to be low, but it was computed from only the above ground parts of banana plant. There is a substantial part of dry matter in rhizome and the roots that remain underground. These parts also appropriate considerable amounts of sulphur absorbed from the applied superphosphate. The underground parts of banana plant (rhizome and roots) were not sampled because of their massive size and consequent difficulty in washing and decontaminating these plants. However, the observations made on the above ground parts do give useful and practical information on nutrient uptake, partitioning etc., for guidance in the follow up experiments, if any. Among different plant parts, it is noteworthy that the lamina apportioned 35.2% of sulphur while the fruits utilized 31.9%. Pseudo stem utilized 15.8% and other parts utilized a relatively smaller proportion of fertilizer sulphur (3.4-7.0%). Among the 3 split applications made, the first two applications utilized nearly same amounts of applied sulphur (39.2-40.6%) but the third application showed only restricts superphosphate application to 2 equal split doses in banana raised under high density planting. Most of the plant S derived from the fertilizer came from I and II split application, indicating better utilization of the applied S during the initial growth period. Similar kind of results was reported by George et al. (1992) in rice. The detailed parameters of sulphur absorption by different plant parts and whole plant of banana are presented in *Tables 7 to 9*.

Fruit and bunch yield

Yield in banana is a function of bunch weight and number of plants per hectare. Therefore, any fertilizer/nutrient management research should aim at producing maximum bunch weight, so that, the productivity could be enhanced reasonably. Fruit and bunch yield as influenced by different placement and split application of ^{35}S labelled superphosphate was recorded and given in *Table 1*. The results revealed that the placement of ^{35}S labelled fertilizer between 35 and 55 cm from base of the plant yielded the maximum fruit weight as well as that of the bunch. This was at par with the fruit yield obtained at 15-35 cm placement and was significantly higher than the bunch yield obtained in the placement between 15 and 35 cm distances. The lowest fruit and bunch yield obtained when fertilizer was placed farthest between 55 and 75 cm distances. Similar kind of results was also reported by Kotur (2012). Application of fertilizer at the farthest distance between 55 and 75 cm was distinctly inferior showing that there was little scope of application of fertilizers between the rows under the high-density planting of banana and it is best to apply fertilizer in a circular strip between 15 and 55 cm distances at 5 cm depth. First (I) split application of labelled SSP during early vegetative stage recorded the highest fruit and bunch yield and found on par with II split application during late vegetative stage. The lowest fruit and bunch weight was obtained with III split application of labelled fertilizer at bud differentiation stage.

Fruit and bunch weight of banana was higher with application of ^{35}S labelled SSP which is clearly highlighting the beneficial role of sulphur in banana nutrition. Studies conducted by Martin-Prevel (1972) also revealed the beneficial role of S nutrition in enhancing bunch weight in bananas. The favourable influence of SSP on the production of heavier bunches might be attributed to the heavier dry matter and starch accumulation. The influence of sulphur in enhancing fruit yield in bananas was stressed by Lahav and Turner (1983). Sulphur application increased the yield since it is a constituent of amino acid and protein production (Ahmed et al., 1998). Another plausible explanation for a

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DOI: http://dx.doi.org/10.15666/aeer/2105_44894504

higher yield with application of S containing fertilizer is due to its role of a synergistic effect of S with other nutrient elements. Sulphur can increase the absorption of potassium, or it can react with nitrogen and potassium (Farrag et al., 1990).

Conclusion

From the results on Sdff, fertilizer S uptake, fertilizer S utilization, fruit and bunch yield, it can be concluded that the application of recommended S and P using superphosphate and recommended N and K through urea and muriate of potash in 2 splits as circular bands at 5 cm depth, between 15 and 35 cm in the first (early vegetative stage) and between 35 and 55 cm distance from the base of the plant in the second split (late vegetative stage) was optimum to attain high fruit and bunch yield in Robusta banana under high density planting. Application of fertilizer at the farthest distance between 55 and 75 cm was distinctly inferior showing that there was little scope of application of fertilizers between the rows under the high-density planting of banana and it is best to apply fertilizer in circular strips between 15 and 55 cm distances at 5 cm depth.

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