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Determination of Optimum Rate of Nitrogen and Sulphur Application for Sesame (*Sesamum Indicum L.)* Production in Ibadan and Ogbomoso, Nigeria

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Abstract
Sesame is a high-valued crop grown for its oil and protein-rich edible seed, which requires Nitrogen (N) and sulphur (S) for biosynthesis of oil and protein, and optimum seed production and nutritional content. In a 2×4×3 factorial arrangement fitted in completely randomised design with four replicates, sesame varieties E8 and NCRIBEN-01M were grown on 6 kg soil/pot with nitrogen at N0, N60, N90 and N120 kg N/ha (using urea) in combination with sulphur at S0, S30 and S60 kg S/ha (through magnesium tetra oxo sulphate VI) in screenhouses at Ibadan and Ogbomoso, Nigeria. Data were collected on plant height, stem diameter, seed weight, and seed N and S contents. Seed weight (g/plant) was used as benchmark for determining optimum N and S application rates on polynomial regression curves, which were obtained at points where second derivatives (d^2y/dx^2) of regression equations turn to zero. In Ibadan and Ogbomoso, seed weight ranged from 1.90±0.04 (N0×S0×E8) to 2.60±0.04 (N120×S60×NCRIBEN-01M) and 2.1±0.05 (N0×S0×E8) to 2.8±0.05 (N120×S60×NCRIBEN-01M), respectively. The seed weight of 2.6 g/plant (N90×S30×NCRIBEN-01M-Ibadan) and 2.7 g/plant (N90×S30×NCRIBEN-01M-Ogbomoso) were the optimum seed yields, while the optimum rates of nitrogen were 89 kg/ha (R^2= 0.71) and 88 kg/ha (R^2= 0.78) in Ibadan and Ogbomoso locations, respectively. Optimum S rates were 30.8 kg/ha (R^2= 0.92) and 33.0 kg/ha (R^2= 0.97). Therefore, 90 kg N/ha + 35 kg S/ha could be adopted as N-S application rate at Ibadan and Ogbomoso.

Keywords: Optimum N and S rate, Protein-rich, seed weight, Sesame varieties.

1. Introduction
Sesame (*Sesamum indicum* L.) otherwise known as beniseed, is an annual plant belonging to the family 'Pedialaceae'. It has long history of cultivation mostly for its seed and oil yields. It is usually well thought-out as one of the world's most important, oldest spice and oilseed crop , which could contain up to 50% oil and 25% protein according to Burden [1]. The original area of domestication of the crop is seemingly uncertain though it was reported to have been firstly brought into large scale cultivation in India [2], but widely believed to have originated from Africa [3,4]. The plant is deep-rooting and well adapted to withstand dry conditions. Hence, it is a drought tolerant crop [5]. It can grow on relatively poor soils in climates generally unsuitable for other crops, thereby being widely valued for its nutritional and economic yield from mild/low rainfall areas.

In Nigeria, most soils are becoming less fertile as a result of continuous crop production without adequate maintenance of their fertility due to increasing costs of inorganic fertilisers beyond the financial ability of farmers. Alongside nitrogen, oilseed crops require large amounts of sulphur (S) for proper growth, development and yields [6]. Oilseed crops require adequate nitrogen (N) and sulphur (S) nutrition for high seed and oil yields and synergistic effect of N and S in plant metabolism could only take place optimally when both elements are supplied to plants in balanced proportion [7]. Tijare *et al.*[8] reported significant sesame seed yield increases of up to 1024 kg/ha with application of 50 kg N/ha in combination with varied levels sulphur from different sulphur sources (Single super phosphate, elemental sulphur and bensulf) in field trials. Kushawaha *et al.* [9] reported that the application of nitrogen at 75 kg/ha and sulphur at 45 kg/ha was the best treatment for enhancing growth, yield and quality of sesame under agrihorti system. Intensive cropping with inadequate supplementation of sulphur has led to general widespread of its deficiency in soils of Nigeria. According to Isitekhale *et al.* [10], soils of Nigeria are characterized by low S content, a development which requires inevitable efforts to be made in order to curtail the negative consequence of sulphur deficiency on oilseed crops as it affects their seed and oil yields. Low sulphur content of soils in Nigeria has also been affirmed by Oseni *et al.* [11]. Therefore, this study was carried out to determine optimum nitrogen (N) and sulphur (S) application rate for growth, yield and nutrient (N and S) contents of sesame in screenhouses at Ibadan and Ogbomoso.

2. Materials and Methods

The experiment was set up as a factorial arrangement fitted into completely randomized design with four replicates and conducted in a screenhouse at University of Ibadan (7°22′N; 3°55′E) and another one at Ladoke Akintola University of Technology (8°07′N; 4°14′E), Ogbomoso. Six-kilogramme soil was measured into each polythene pot (31 x 24 x 22.5 cm) and moistened to 60% field capacity. Prior to planting, soil samples were analysed. The pH (H_2O) was determined with the aid of a pH meter buffered between pH 4 and 7. Total N was determined by macro-kjeldahl method as described by Bremner [12]. Available P was determined by Bray-1 P method [13]. Exchangeable bases (Ca, Mg, K, and Na) were determined according to Jackson [14] using 1M neutral ammonium acetate (1M NH_4OAc pH 7.0) solution. Available sulphur was determined by turbimetric method [15]. Organic carbon was determined by wet dichromate method [16]. Texture was determined by Bouyoucos hydrometer method [17] . Ten seeds of sesame varieties (E8 and NCRIBEN-01M) were sown into each pot but later thinned to two after fifteen days of sowing. Fertiliser application was done at four rates of nitrogen (0, 60, 90 and 120 kg N /ha) in combination with three rates of sulphur (0, 30 and 60 kg S /ha) using urea (46%N) and magnesium tetra oxo sulphate VI (24%S), respectively. Ninety-six experimental pots (4 N rates × 3 S rates × 2 varieties) in 4 replicates were used in each screenhouse study at Ibadan and Ogbomoso, giving a total of 192 pots for the two locations. Data were collected per plant on height, stem diameter, seed weight, and seed N and S contents. Seed N content was determined by micro-Kjeldahl method. Milled seed samples (0.25 g) were put in separate digestion tube (75 ml capacity) for digestion after which, it was allowed to cool and made up to 70 ml by addition of distilled water with thorough shaking. This was followed by colorimetric determination of N with Technicon autoanalyser. Seed S content was determined by turbimetric method [15]. Twenty-five millilitres of 1M potassium hydrogen phosphate was added to 0.5 g sample of milled seed samples, the mixture was shaken, filtered and subjected to turbimetric reagent (barium chloride + gelatin) for determination of S. Data were subjected to Analysis of Variance (ANOVA) using Minitab 19 statistical software, while mean separation was done using Tukey pairwise comparison at 5% level of significance.

3. Results and Discussion

3.1. Pre-Cropping Soil Properties

The pH (6.2) of the soil of Ibadan was slightly acidic, while that of Ogbomoso location (5.8) was medium acidic. The available phosphorus was above critical level of 10. 0 mg/kg specified by Akinrinde and Obigbesan [18]. The total N values of soils from the two locations were low considering the critical values of 1.5 g/kg [18, 19]. Exchangeable potassium contents of soil at Ibadan, and Ogbomoso experimental site were above critical limit of 0.15 cmol/kg reported by Akinrinde and Obigbesan [18] and Chude *at al.* [19]. Also, available sulphur of soil from Ibadan and Ogbomoso locations were quite low when compared with 10 mg/kg critical level according to Oseni *et al.* [11]. Textural components of the soil indicated sandy loam and loamy sand for Ibadan and Ogbomoso experimental locations. Hence, responses to applications of nitrogen and sulphur were obtained because their levels were below critical limit.

Table 1. Soil properties before cropping in the screenhouse at Ibadan and Ogbomoso.

Parameter	Ibadan	Ogbomoso
pH (H_2O)	6.2	5.8
Organic C (g/kg)	12.9	11.3
Total N (g/kg)	1.4	1.2
Available nutrients (mg/kg)		
P	11.0	12.0
S	6.2	5.8
Exchangeable cations (cmol/kg)		
Ca^{2+}	1.8	1.50
Mg^{2+}	1.3	1.10
. K^+	0.2	0.2
Na^+	0.1	0.1
Exchangeable Acidity (cmol/kg)	0.1	0.2
ECEC (cmol/kg)	3.6	3.1
Extractable micronutrients (mg/kg)		
Cu	2.0	3.0
Fe	23.0	21.0
Mn	4.0	3.0
Zn	47.0	49.0
Particle size analysis (g/kg)		
Sand	685	765
Silt	121	124
Clay	194	111
Textural class	Sandy loam	Loamy sand

3.2. Height and Stem Diameter of Sesame as Affected by Variety, Nitrogen and Sulphur Application and Their Interaction

In screenhouse at Ibadan and Ogbomoso, sesame variety NCRIBEN-01M produced significantly taller plants than variety E8 (Table 2). Nitrogen and sulphur applications had significant influence on height. Plants grown with 60 kg N/ha were significantly shorter than those supplied with 90 and 120 kg N/ha. Plants treated with 60 kg S/ha, were superior in tallness to those grown with 30 kg S/ha, which produced significantly taller plants than plants grown without fertiliser treatments. The higher height might be due to more synthesis of amino acids, increase in chlorophyll content in growing region and improvement of photosynthetic activity, which eventually enhanced cell division to facilitate improved plant height as earlier reported by Sujatha *et al.* [20]

In soil of Ibadan and Ogbomoso locations, sesame varieties did not differ in their responses to stem diameter. Nitrogen application enhanced stem thickness but sulphur application did not. (Table 2). There was significant interaction of nitrogen, sulphur and variety on height of sesame plants, while interaction was not significant on stem diameter at the two locations (Table 3).

Table 2. Height (cm) and stem diameter (cm) of sesame plants at twelve weeks after planting as affected by variety, nitrogen and sulphur treatments in Ibadan and Ogbomoso under screenhouse conditions.

	Ibadan		Ogbomoso	
Treatments	**Height**	**Stem diameter**	**Height**	**Stem diameter**
Variety (V)				
E8	111.76b	2.37a	120.82b	2.27a
NCRIBEN01M	115.23a	2.29a	122.20a	2.22a
Nitrogen (N) rates (kg/ha)				
0	102.28c	2.06c	105.07d	1.99b
60	114.67b	2.32b	121.47c	2.26a
90	118.27a	2.46a	128.24b	2.32a
120	118.76a	2.47a	131.25a	2.42a
Sulphur (S) rates (kg/ha)				
0	108.52c	2.31a	111.77c	2.25a
30	114.58b	2.33a	127.08a	2.26a
60	117.39a	2.34a	125.68b	2.23a

Means with similar letters along a column within a group are not significantly different according to Tukey pairwise comparison at 5% level of significance

Table 3. Interaction of nitrogen, sulphur and variety on height (cm) and stem diameter (cm) of sesame at twelve weeks of planting in Ibadan and Ogbomoso under screenhouse conditions.

	Ibadan		Ogbomoso	
Treatments (N × S × V)	**Height**	**Stem diameter**	**Height**	**Stem diameter**
N0 × S0 × V1	94.27k	2.02e	104.63j	2.06abc
N0 × S0 × V2	102.63J	2.04e	103.06j	2.11abc
N0 × S1 × V1	102.53J	2.07e	105.16j	1.94abc
N0 × S1 × V2	104.53J	2.09e	106.43j	1.77c
N0 × S2 × V1	104.03J	2.03e	104.96j	2.06abc
N0 × S2 × V2	105.67IJ	2.08e	106.16j	2.00abc
N1 × S0 × V1	109.20hi	2.54a	108.23ij	2.24abc
N1 × S0 × V2	112.27fgh	2.23b-e	112.16hi	2.37abc
N1 × S1 × V1	114.27efg	2.36a-d	127.67de	2.26abc
N1 × S1× V2	118.57cde	2.20cde	128.03j	2.19abc
N1 × S2 × V1	113.57fg	2.44abc	123.20ef	2.30abc
N1 × S2 × V2	120.17c	2.16de	129.53cd	2.21abc
N2 × S0 × V1	111.73fgh	2.51a	115.87gh	2.27abc
N2 × S0 × V2	114.13fg	2.36a-d	114.43gh	2.36abc
N2 × S1 × V1	119.23cd	2.55a	134.90abc	2.48abc
N2 × S1 × V2	11953cd	2.48ab	138.40a	2.55a
N2 × S2 × V1	120.17c	2.47ab	133.57bc	2.45abc
N2 × S1 × V2	124.8ab	2.44abc	132.27bcd	1.78bc
N3 × S0 × V1	113.70fg	2.40a-d	116.23gh	2.24abc
N3 × S0 × V2	110.20gh	2.39a-d	119.50fg	2.37abc
N3 × S1 × V1	115.67def	2.48ab	138.03a	2.47abc
N3 × S1 × V2	122.27bc	2.36a-d	138.03a	2.40abc
N3 × S2 × V1	122.73bc	2.53a	137.34ab	2.52ab
N3 × S2 × V2	128.00a	2.53a	138.37a	2.54a

Means with similar letters along a column are not significantly different according to Tukey pairwise comparison at 5% level of significance

N0-nitrogen at 0 kg/ha, N1- nitrogen at 60 kg/ha, N2- nitrogen at 90 kg/ha, N3- nitrogen at 120 kg/ha, S0 – sulphur at 0 kg/ha, S1- sulphur at 30 kg/ha, S2- sulphur at 60 kg/ha, V1- E8, V2-NCRIBEN-01M.

Means with similar letters along a column within a group are not significantly different according to Tukey pairwise comparison at 5% level of significance

3.3. Seed Weight, Nitrogen and Sulphur Contents of Sesame as Affected by Variety, Nitrogen and Sulphur Application and Their Interaction

Sesame varieties differed in seed weight and nitrogen content as NCRIBEN-01M had significantly higher seed weight, and N content than E8 (Table 4). On the contrary, the two varieties had similar sulphur contents. There was significant influence of nitrogen and sulphur application on seed weight, and nitrogen and sulphur contents. Plants nourished with fertiliser had significantly higher seed weight, and nitrogen and sulphur contents than control plants as depicted in Table 4. The interaction of variety, nitrogen and sulphur application on seed weight and N content was significant but not significant on sulphur content (Table 5).

Table 4.
Seed weight (g/plant), nitrogen and sulphur contents (%) as affected by variety, nitrogen and sulphur treatments in Ibadan and Ogbomoso under screenhouse conditions.

	Ibadan			Ogbomoso		
Treatments	**SW**	**N content**	**S content**	**SW**	**N content**	**S content**
Variety (V)						
E8	2.35b	1.82b	0.35a	2.39b	1.85b	0.35a
NCRIBEN01M	2.41a	1.87a	0.34a	2.44a	1.88a	0.36a
Nitrogen (N) rates (kg/ha)						
0	2.17c	1.64d	0.28c	2.22c	1.63d	0.29c
60	2.36b	1.77c	0.35b	2.49b	1.82c	0.35b
90	2.49a	1.93b	0.38a	2.71a	1.97b	0.39a
120	2.51a	2.04a	0.38a	2.65a	2.05a	0.39a
Sulphur (S) rates (kg/ha)						
0	2.24b	1.73c	0.31b	2.32b	1.74c	0.30b
30	2.47a	1.85b	0.36a	2.58a	1.87b	0.38a
60	2.44a	1.96a	0.37a	2.59a	1.99a	0.38a

Means with similar letters along a column within a group are not significantly different according to Tukey pairwise comparison at 5% level of significance
SW-seed weight

Table 5. Interaction of nitrogen, sulphur and variety on seed weight (g/plant), nitrogen and sulphur contents (%) of sesame in Ibadan and Ogbomoso under screenhouse conditions.

	Ibadan			Ogbomoso		
Interaction	**SW**	**N content**	**S content**	**SW**	**N content**	**S content**
N0 × S0 × V1	1.90g	1.53k	0.24j	2.07gh	1.60jk	0.26j
N0 × S0 × V2	2.00g	1.58jk	0.25ij	2.10fgh	1.59k	0.26j
N0 × S1 × V1	2.23def	1.63ijk	0.27hij	2.10fgh	1.63jk	0.29hij
N0 × S1 × V2	2.47a-d	1.66h-k	0.30ghij	2.67d-h	1.68ijk	0.32f-j
N0 × S2 × V1	2.23def	1.62ijk	0.30ghij	2.00h	1.63jk	0.29hij
N0 × S2 × V2	2.17ef	1.79d-h	0.31e-i	2.17e-h	1.64ijk	0.31g-j
N1 × S0 × V1	2.23def	1.67h-k	0.30ghij	2.30d-h	1.72hij	0.34d-j
N1 × S0 × V2	2.30cde	1.71g-k	0.31e-i	2.40b-f	1.72hij	0.33e-j
N1 × S1 × V1	2.40a-e	1.75f-i	0.36a-g	2.43b-e	1.84e-g	0.33e-j
N1 × S1× V2	2.43a-d	1.86d-g	0.38a-d	2.27d-h	1.89d-g	0.38b-g
N1 × S2 × V1	2.37b-e	1.76e-i	0.39a-d	2.47a-e	1.89d-g	0.35d-i
N1 × S2 × V2	2.43a-d	1.87def	0.36b-g	2.50a-d	1.85efg	0.40a-f
N2 × S0 × V1	2.30cde	1.74f-j	0.33c-h	2.43b-e	1.82fgh	0.36c-h
N2 × S0 × V2	2.37b-e	1.77e-i	0.35b-g	2.53a-d	1.76ghi	0.28ij
N2 × S1 × V1	2.57ab	1.94cd	0.40ab	2.70ab	1.90def	0.44ab
N2 × S1 × V2	2.60ab	1.91de	0.39abc	2.57a-d	1.97de	0.45ab
N2 × S2 × V1	2.50abc	2.05bc	0.42ab	2.67ab	2.18ab	0.40a-e
N2 × S2 × V2	2.63a	2.17ab	0.37a-f	2.76a	2.22ab	0.43abc
N3 × S0 × V1	2.37b-e	1.91cde	0.35b-g	2.33c-g	1.89d-g	0.32f-j
N3 × S0 × V2	2.47a-d	1.88def	0.32d-h	2.40b-f	1.83fgh	0.30hij
N3 × S1 × V1	2.53abc	1.93cd	0.43a	2.57a-d	1.99cd	0.41a-d
N3 × S1 × V2	2.50ab	2.14ab	0.36b-g	2.67ab	2.10bc	0.45ab
N3 × S2 × V1	2.60ab	2.23a	0.43a	2.63abc	2.17b	0.43abc
N3 × S2 × V2	2.60ab	2.17ab	0.37a-f	2.70ab	2.30a	0.46a

Means with similar letter along a column are not significantly different according to Tukey pairwise comparison at 5% level of significance

SW-seed weight. N0-nitrogen at 0 kg/ha, N1- nitrogen at 60 kg/ha, N2- nitrogen at 90 kg/ha, N3- nitrogen at 120 kg/ha, S0 – sulphur at 0 kg/ha, S1- sulphur at 30 kg/ha, S2- sulphur at 60 kg/ha, V1- E8, V2-NCRIBEN-01M.

3.4. Optimum Level of Nitrogen and Sulphur on the Basis of Seed Weight

Figure 1 showed the relationship between seed weight and N application rates, while Figure 2 showed the relationship between seed weight and S application rates. On the basis of seed weight, optimum rates of nitrogen application were 89.0 (R^2= 0.71) and 88.0 kg/ha ((R^2= 0.78) in Ibadan and Ogbomoso locations, respectively as obtained from the regression curve at a point where second order derivative (d^2y/dx^2) of the regression equation turns to zero. Optimum S application rates were 30.8 kg (R^2= 0.92) S/ha and 33.0 kg S/ha (R^2= 0.97). Therefore, 90 kg N/ha + 35 kg S/ha could be adopted as optimum N-S application rate in Ibadan and Ogbomoso for seed production of sesame. Raja *et al.* [21] have earlier used their discretion in fixing recommended optimum rate of sulphur for sesame production slightly above actual and economic optimum values obtained from polynomial regression analysis. In a study conducted in the screenhouse at Ibadan and Ogbomoso by Babajide and Oyeleke [22] 80 kg N/ha was reported as optimum, whereas Haggai [23] reported increase in seed yield from 472 kg /ha with 0 kg N/ha to 779 kg /ha with 90 kg N /ha as the optimum. Optimum S rates of 30 and 35 kg/ha in the two locations aligned with Tiwari *et al.*[24] who reported that sulphur application at a rate of 30 kg /ha resulted to a significant increment in 1000-seed weight, seed weights per plant and seed yield but at variance with those of Saren *et al.* [25], which indicated that application of sulphur at 45 kg /ha recorded higher seed yield (815 kg/ha) compared with other application rates On the other hand, Shilpi *et al.* [26] asserted that combined application of 60 kg N/ha and 40 kg S/ha produced highest number of capsules per plant, capsule length, capsule diameter, seeds per capsule, and thousand seed weight and thus considered 60 kg N/ha+40 kg S/ha as optimal for achieving higher yields in sesame production. Khan [27] optimized sesame seed production with 70 kg N/ha + 30 kg S/ha application, while Kushawaha *et al.* [9] reported the application of nitrogen at 75 kg/ha and sulphur at 45 kg/ha as the best treatment for enhancing growth, yield and quality of sesame under agrihorti system.

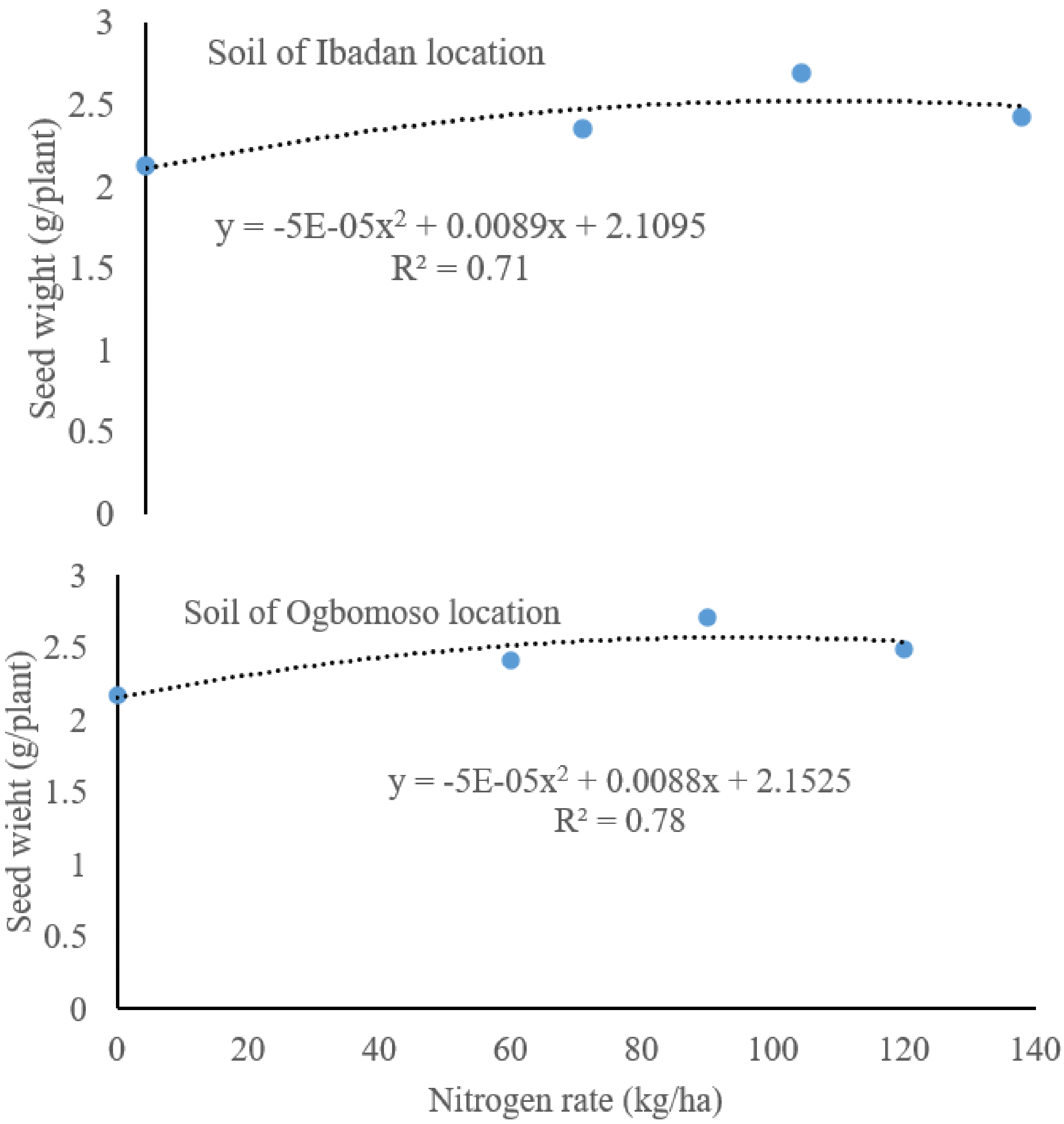

Figure 1. Relationship between seed weight and nitrogen rates in soils of Ibadan and Ogbomoso locations in the screenhouse study.

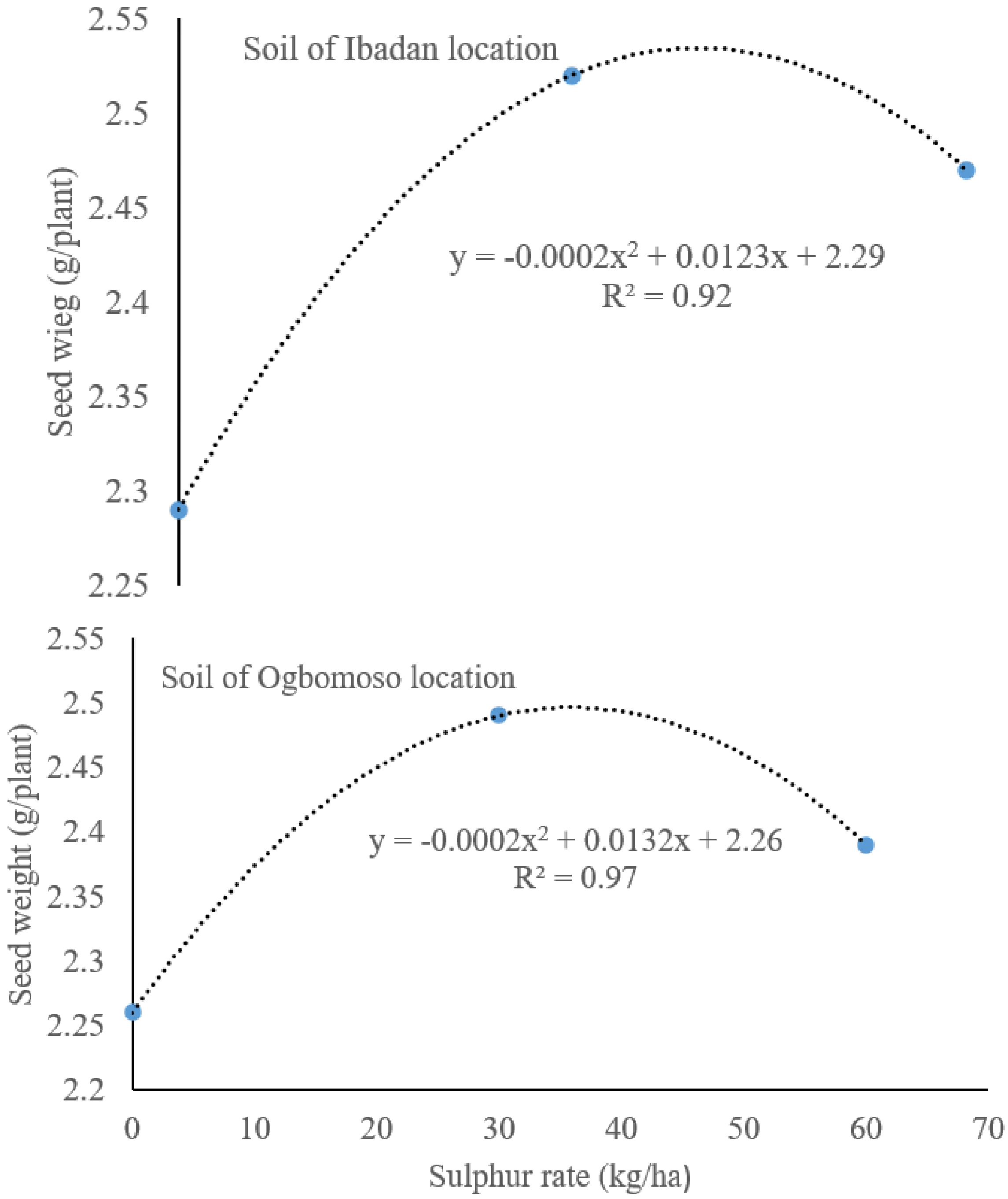

Figure 2. Relationship between seed weight and sulphur rates in soils of Ibadan and Ogbomoso in the screenhouse study.

4. Conclusion

Optimum N-S rate of 90 kg N/ha + 35 kg S/ha could be adopted for sesame seed production at Ibadan and Ogbomoso, Nigeria.

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