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Original Article

Sesame Nutrient Diagnosis and Balance Using Diagnosis and Recommendation Integrated System in Response to Co-Applied Fertilizers

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Abstract: Diagnosis and Recommendation Integrated System (DRIS) is a practical and repeatable complimentary method for nutritional diagnosis in various crops. The current study was conducted during the spring growing season of 2024 at the Halabja Agriculture Research Centre, located in the northwest of Halabja city (latitude: 38° 58.95' N, longitude: 45°69.56' E) at an altitude of 595 m. The experimental field was a vertisol with a clay texture. The study was based on three independent variables: four levels of biofertilizer application, including (control, individual inoculation of *Azospirillum* + *Azotobacter*, phosphate solubilizing bacteria, and combined bacterial treatment), three rates of nitrogen (N)-phosphorus (P)-potassium (K) fertilizer (0, 100, and 140 kg ha^{-1}), and three doses of olive mill pomace (0, 15 and 30 megagram (Mg) ha^{-1}) as organic amendment. A split-split plot design was used with 36 treatment combinations arranged in three replications. Yield component and plant nutrient balance data were processed using the DRIS. The results identified the combination of nitroxin, NPK at 100 kg ha^{-1}, and olive mill pomace at 30 Mg ha^{-1} (BNCH1OR2) as the most nutritionally balanced treatment (Nutrient Balance Index = 5.16), which concurrently produced the highest grain yield (0.96 Mg ha^{-1}, 100% relative yield). In contrast, the most unbalanced treatment was the control condition (without biofertilizer, chemical fertilizer, and olive mill pomace), with a nutrient balance index of 82.32, yielded the lowest output (0.41 Mg ha^{-1}, 43% relative yield). For N, P, and K, the critical points were determined as 2.15, 0.23, and 1.68, respectively. Nutritional balance indices and sesame yield as altered by biofertilizer, NPK, and organic fertilization, indicate that the BNCH1OR2 treatment was particularly effective for enhancement of nutrient balance and grain yield.

1. Introduction

Sesame is an important and popular food across the Asia and the world, due to its savory nut like aroma and flavor, which is reflected in high volumes of sesame oil production [1, 2]. Sesame oil is used in cuisine and as a medicine, and thus it is in high demand for food production and the pharmaceutical industry [3]. Although the crop is produced in many regions of the world, and is considered the queen of oil seeds, it has not been designated by most global crop research organizations for arid regions [4].

The average sesame productivity in Iraq is approximately 1,103 kg ha^{-1}, which is considerably lower than the universal yield average of 1,949 kg ha^{-1} [5]. Sesame yield and oil content, like other oilseed crops, are strongly influenced by agronomic and environmental factors, with suboptimal yields in target regions mainly resulting from low-input systems, poor management, and abiotic stresses such as drought [6, 7]. Each fertilizer source has a unique value to nutrient delivery. Chemical fertilizers, such as nitrogen (N)-phosphorus (P)-potassium (K), are vital for agricultural yield increases [8].

Extensive research in tropical zones has confirmed the efficacy of NPK fertilizer in significantly enhancing sesame yield, a crop whose growth and productivity are highly responsive to nitrogen fertilization [9]. The use of NPK fertilizers is a significant input, which improves the vegetative growth, yield and product quality characteristics of sesame [10]. However, the harmful side effects of excess use of chemical fertilizers on agroeconomy necessitates appropriate agents to help restore a dynamic equilibrium in nature, and reduce environmental pollution caused by agriculture [11]. Accordingly, under these environmental conditions, biofertilizers comprising of beneficial microorganisms (bacteria, algae, and fungi) influence soil fertility, and crop yield, and can improve drought tolerance in plants [12]. By promoting a variety of processes, including fixing nitrogen in the atmosphere, solubility of phosphates, and growth production, bio-fertilizers can be an additional source for enhancing the vigor of crops, improving water using efficiency and decreasing reliance on synthetic fertilizers [13].

Nitroxin, a commercial biofertilizer containing *Azotobacter* and *Azospirillum*, has been claimed to increase the yield, nutrient content and seed quality of diverse species, including core staples such as rice, maize and chickpea [14]. The recovery of nutrients and organic matter as soil amendments from bio waste is yet another critical element in the circular economy which benefits sustainable soil fertility and soil health [15]. Olive mill pomace (OMP, also known as olive mill waste), recovered from the extraction process of olive oil, is a potential organic amendment in dry and warm temperate climate areas [16]. It has been reported that OMP increases soil fertility, with higher cation exchange capacity, water retention, and microorganism diversity [17]. It provides vital macronutrients such as N, P, K, magnesium, and numerous micronutrients that improve soil quality all of which decreases dependence on chemical based fertilizers [18]. Such solutions can be incorporated within existing agricultural economic networks with relative ease.

Efficient farm management must increasingly monitor plant nutrition, and tissue analysis are a relatively low cost and simple way to assess crop nutrient status, whereby leaf analysis can be used to make management decisions [19]. The nutritional status of plants has been assessed using algorithms such as Diagnosis and Recommendation Integrated System (DRIS), which evaluate nutrient concentration ratios from tissue analysis and are more effective than the univariate approach, since they consider interaction effects among nutrients in plant tissues [20]. The DRIS calculation takes consideration of relationship between two different nutrient elements, the index indicating how other sequential nutrients are combined in order to be balanced among their own levels at any growth stage [21]. A key benefit of the DRIS technique is its utilization of nutrient levels (e.g., nitrogen/calcium and P/K). This approach cancels out the effects caused by biomass accumulation and age-related changes in tissue nutrient concentration [22, 23].

The DRIS technique has been effectively applied in empirical studies to understand leaf analysis findings for a number of plants including, soybeans [24], broccoli [25], walnut [26], onion [27], and chickpea [28]. The use of DRIS in the diagnosis of plant nutritional imbalance is more recognized as it evaluates nutrient limitations for plant demands, and consequently, make easier to achieve nutritional balance. The intention of this investigation was to diagnose nutritional condition of sesame and determine the critical level of N, P, and K in Halabja city, Iraq using DRIS method, and thereby contribute to the development of nutrient norms that can be used to enhance sesame plant production.

2. Materials and Methods

2.1. Site Description

The investigation was performed under conditions in the field of Halabja Agriculture Research center, over spring growing season 2024. Selected soil physiochemical properties for the location and for the OMP are presented in tables 1 and 2, respectively. The field was ploughed in both horizontal and vertical directions and was kept free of weeds. A rotavator was used for soil preparation followed by partitioning into 108 experimental unit (4 bio x 3 chemical x 3 organic x 3 replication) each plot having an area of 3 m² (2 x 1.5 m). A separation of 1.5 meters was maintained between the two studied units, and a 2-meter distance was kept between replications.

Table 1: Physiochemical characteristics of soil in field studied.

Depth (cm)	pH	Electrical Conductivity (dsm^{-1})	Organic Matter (%)	Total Nitrogen (%)	Availability of P (ppm)	Availability of K (ppm)	Sand (%)	Silt (%)	Clay (%)	Texture
0-30	7.22	0.33	1.8	0.18	7.1	260	5	35	60	clay

Table 2: Physiochemical properties of raw olive mill pomace.

pH	Electrical Conductivity (dsm^{-1})	Organic Matter (%)	Total Nitrogen (%)	Total Phosphorus (g kg^{-1})	Total Potassium (g kg^{-1})	Total Organic Carbon (%)	Carbon/Nitrogen
5.71	1.28	76.27	0.92	0.07	2.38	44.24	48.08

2.2. *Experimental Design and Treatments*

The experiment employed a split-split plot design with three replicates incorporating three factors, biological, organic, and chemical. The biological factor encompasses, four levels, (1) control, (2) individual inoculation of *Azospirillum* and *Azotobacter*, (3) phosphate solubilizing bacteria, and (4) combined bacterial treatment. It was allocated to the main plots and organized in a randomized complete block design. The chemical fertilizer comprising levels (0, 100, 140 kg ha^{-1}) was assigned to the sub-plots, while the organic fertilizer with three doses of OMP (0, 15, and 30 Mg ha^{-1}) was assigned to the sub-sub plots, as summarized in table 3. There were five rows of plants per plot. Local brown sesame seeds were sown manually on June 1, 2024 with a rate of 4 kg ha^{-1}. Seeds were planted 1-2 cm deep. Surface irrigation was practiced on a weekly schedule, depending on the plant demand and climate conditions. OMP was collected from a nearby olive oil factory, it was left for over five months to reduce traces of oil, then it was placed in the sun to dry, and then it was ground and spread on the land two months before planting. Two types of liquid biofertilizer were used: Nitroxing, with A*zotobacter* and *Azospirillum*, as well as phosphate solubilizing bacteria including *Bacillus* and *Pseudomonas*, mixed with seeds at a ratio of 1 L per 100 kg of seed. After coating the seeds, they were left to dry in the shade, before sowing for 24 h. The chemical fertilizer (NPK 20-20-20) was applied in two split applications: the first before sowing the seeds, and the second one month after planting.

Table 3: Description of experimental treatments and fertilizer application rates.

Abbreviation	Description	Application rate
B0	No biofertilizer	0
BN	Nitroxin	1 L / 100 kg seed
BP	Phosphate solubilizing bacteria	1 L / 100 kg seed
BNP	Combined nitrogen + phosphate biofertilizer	1 L / 100 kg seed
CH0	No chemical fertilizer-NPK	0
CH1	Chemical fertilizer-NPK	100 kg ha^{-1}
CH2	Chemical fertilizer-NPK	140 kg ha^{-1}
OR0	Organic fertilizer-olive mill pomace	0 Mg ha^{-1}
OR1	Organic fertilizer-olive mill pomace	15 Mg ha^{-1}
OR2	Organic fertilizer-olive mill pomace	30 Mg ha^{-1}

2.3. *Leaf Sampling and Analysis*

During the flowering stage, ten central plants were sampled from each plot. Subsequently, samples were dried in an oven at 65°C for 72 h to reach a fixed mass. Following drying, the plant material was milled to a fine powder in preparation for chemical analysis. Harvest took place on 24 October, 2024, when the sesame leaves yellowed and the coloration changed to brown. Finally, the seed yield per plant was then determined. Total nitrogen was measured by the Kjeldahl procedure [29]. Phosphate levels were determined colorimetrically by absorbance at 410 nm using a spectrophotometer. Potassium was estimated by flame photometry, zinc levels were evaluated by atomic absorption spectroscopy [30], and sulfate was determined by the precipitation method as described in Lindemann *et al.* [31].

2.4. Norms Calculation

The computation of the norms is the most essential part in implementation of a plant diagnostic system. A critical step in the use of the DRIS nutrition index is to establish reference values by which nutrient concentration and yield can be compared for each crop; but there is little or no such information available for most crops. Such information is necessary to estimate means and variances of individual nutrient ratios that can differentiate high yield from low yield populations [32, 33]. When these norms are established, the Beaufils formula is used to calculate for each nutrient an index that can vary from negative to positive. One basic property of these indices is that their sum is always 0 because each index corresponds to the nutrient deviation from the optimum [34].

2.5. Diagnosis and Recommendation Integrated System Methodology

The DRIS norms and coefficients of variation were calculated in accordance with the method described in Walworth and M. Sumner [21], with leaf nutrient concentrations presented in every feasible binary ratio (e.g., N/Sulfur (S), N/Ca, P/K, and their inverses). Subsequently, DRIS indices were computed for all nutrients separately (A to Z) utilizing the standard expression [35]. The DRIS framework determines the sufficiency of every nutrient index simultaneously. The general state of nutrient balance is then indicated by the sum of the absolute total values of these indices. This method determines the primary nutrient limitation and subsequently ranks the remaining nutrients in their probable order of deficiency. Furthermore, DRIS creates the Nutrient Balance Index (NBI), which represents the total nutritional balance in the plant. It presents a technique of concurrently recognizing balances, both excess and deficits of nutrients, and grading them according to importance [21].

$$\text{N index} = \mathrm{f}\left(\frac{\mathrm{N}}{\mathrm{P}}\right) + \mathrm{f}\left(\frac{\mathrm{N}}{\mathrm{K}}\right) + \mathrm{f}\left(\frac{\mathrm{N}}{\mathrm{S}}\right) \ldots.\mathrm{f}\left(\frac{\mathrm{N}}{\mathrm{Z}}\right)/\mathrm{X} \qquad (1)$$

$$\text{P index} = -\mathrm{f}\left(\frac{\mathrm{N}}{\mathrm{P}}\right) + \mathrm{f}\left(\frac{\mathrm{P}}{\mathrm{K}}\right) + \mathrm{f}\left(\frac{\mathrm{P}}{\mathrm{S}}\right) \ldots.\mathrm{f}(\frac{\mathrm{P}}{\mathrm{Z}})/\mathrm{X} \qquad (2)$$

$$\text{K index} = -\mathrm{f}\left(\frac{\mathrm{N}}{\mathrm{K}}\right) - \mathrm{f}\left(\frac{\mathrm{P}}{\mathrm{K}}\right) + \mathrm{f}\left(\frac{\mathrm{K}}{\mathrm{S}}\right) \ldots.\mathrm{f}(\frac{\mathrm{K}}{\mathrm{Z}})/\mathrm{X} \qquad (3)$$

when $N/P \geq n/p$, $f(N/P) = (N/P \div n/p - 1)1000 / CV$

when $N/P \leq n/p$, $f(A/B) = (1 - n/p \div N/P)1000 / CV$

N/P: is the leaf nitrogen to phosphorus ratio of the tested plant

n/p: is the norm or optimum value of nutrients (population with high yield)

Z: represents the last nutrient in the set of nutrients considered in DRIS formula

CV: represents the coefficient of variation correspond to the (n/p)

$$\mathrm{CV}\ (\%) = \frac{\mathrm{SD}}{\bar{\mathrm{x}}}\ \mathrm{x}\ 100 \qquad (4)$$

Where $\bar{x}$ = mean nutrient concentrations, and SD = standard deviation of nutrients.

$$\mathrm{SD} = \frac{\sum \mathrm{x} - \bar{\mathrm{x}}}{\mathrm{n} - 1} \qquad (5)$$

X: denotes the number of functions within the nutrient index component.

2.6. Relative Yield

Relative yield (RY%) was computed as follows: $RY\ (\%) = \frac{\text{Treatment yield}}{\text{Maximum yield}}\ x\ 100$ (6)

2.7. Establishing Critical Levels of Elements via the Graphical Method

The critical concentration level for nutrients in plant tissue was identified as described in the work of Sabry and Dizayee [28]. It was determined using a graphical method that relied on the correlation between nutrient concentration and relative yield. The technique involves positioning two perpendicular lines aligned with the x and y-axes such that the number of observations in the upper-left and lower-right quadrants is minimized. At this intersection, the corresponding value on the x-axis defines the critical nutrient concentration.

2.8. Statistical Analysis

The SPSS program version 25 (IBM Corp., Armonk, NY, USA) and Microsoft Excel 2010, were used for conducting statistical analysis, multivariate, and DRIS calculations. The means comparison between treatments was performed using Duncan's multiple range test and the level of significance was set at p < 0.05.

3. Results

The soil analysis before planting as reported in tables 2 and 3 indicated slightly alkaline (pH 7.22) soil, with low electrical conductivity (suitable for sesame production). The DRIS technique, as one of the new approaches for assessing plant nutrient status, determines the relative order of plant needs for nutrients. In this method, the amount of each nutrient is compared with the amounts of other elements, whereby nutritional balance is considered an intrinsic and fundamental part of the system. Coefficient of variance and standard deviation values for the (N, P, K, and S) ratio was determined across different sampling locations, as presented in table 4. These parameters are essential in DRIS use. Additionally, this method served to quantify the deviation of the actual cut-off line which means the norms were locally established.

Table 4: Descriptive statistics for yields (>75%) when selecting norms.

	N/P	**N/K**	**N/S**	**N/Zn**	**P/K**	**P/S**	**P/Zn**	**K/S**	**K/Zn**	**S/Zn**
Mean	10.79	1.39	1.94	126.69	0.13	0.18	11.89	1.39	90.24	64.25
SD	2	0.15	0.27	60.88	0.02	0.03	6.04	0.08	41.22	27.64
CV(%)	18.52	10.8	13.91	48.05	15.03	16.13	50.78	5.75	45.68	43.01

N: nitrogen, P: phosphorus, K: potassium, Zn: zinc, S: sulfure.

The mean concentrations of nutrients in sesame leaves as presented in table 5, were significantly different among fertilizer treatments by Duncan's multiple range test ($p \leq 0.05$) indicating that the type and combination of fertilizers strongly influenced the nutritional status of sesame plants. While individual nutrients were found at higher concentrations in some treatments, the treatment (BNCH1O2) that resulted in the highest seed yield was moderate and balanced macro and micronutrient concentrations respectively (N: 2.15%, P: 0.23%, K: 1.68%, S: 1.27%, znic (Zn): 0.02%).

Table 5: Mean comparison of nutrient concentrations and nutrient ratios in sesame leaves under different fertilizer treatments.

Treatment	N (%)	P (%)	K (%)	S (%)	Zn (%)	N/P	N/K	N/S	N/Zn	P/K	P/S	P/Zn	K/S	K/Zn	S/Zn
B0CH1OR2	2.27 de	0.17 gh	1.59 f	1.15 j	0.02 cd	12.85 b	1.42 abc	1.96 abc	113.66 c	0.10 fg	0.15 e	8.83 b	1.38 d	79.83 c	57.66 b
	± 0.045	± 0.005	± 0.023	± 0.011	± 0.00	± 0.54	± 0.010	± 0.060	± 2.516	± 0.005	± 0.005	± 0.288	± 0.030	± 1.154	± 0.577
BNCH0OR2	2.40 bcd	0.15 h	1.58 f	1.21 fg	0.01 d	15.78 a	1.52 ab	1.97 abc	199.0 ab	0.09 g	0.12 f	12.66 b	1.30 ef	131.0ab	101.50 a
	± 0.265	± 0.011	± 0.040	± 0.011	± 0.005	± 2.822	± 0.185	± 0.206	± 70.767	± 0.005	± 0.011	± 4.163	± 0.045	± 43.347	± 35.521
BNCH1OR0	2.29 cde	0.20 fg	1.68 e	1.18 i	0.02 bc	11.51bc	1.36 abc	1.93 bc	103.23 c	0.12 def	0.17 de	8.83 b	1.42 cd	74.77 c	52.39 b
	± 0.153	± 0.017	± 0.026	± 0.010	± 0.005	± 1.425	± 0.085	± 0.142	± 28.285	± 0.010	± 0.017	± 1.755	± 0.030	± 16.870	± 11.018
BNCH1OR1	2.81 a	0.28 ab	1.79 b	1.23 de	0.03 ab	9.98 cd	1.57 a	2.27 a	93.90 c	0.16 ab	0.23 b	9.44 b	1.45 c	59.66 c	41.22 b
	± 0.128	± 0.025	± 0.017	± 0.005	± 0.00	± 0.909	± 0.063	± 0.094	± 4.293	± 0.010	± 0.020	± 0.840	± 0.010	± 0.577	± 0.190
BNCH1OR2	2.15 de	0.23 def	1.68 e	1.27 c	0.02 bc	9.44 cd	1.28 bc	1.69 c	95.00 c	0.13 cde	0.18cde	10.22 b	1.31 e	74.72 c	56.55 b
	± 0.191	± 0.020	± 0.026	± 0.005	± 0.005	± 1.474	± 0.132	± 0.141	± 17.088	± 0.011	± 0.015	± 2.432	± 0.020	± 16.553	± 12.02
BNCH2OR0	2.68 abc	0.21 efg	1.78 b	1.18 hi	0.02 cd	12.81 b	1.50 ab	2.25 ab	134.33 bc	0.11 ef	0.1 cde	10.50 b	1.50 b	89.16 bc	59.33 b
	± 0.252	± 0.026	± 0.025	± 0.020	± 0.00	± 0.861	± 0.136	± 0.225	± 12.583	± 0.015	± 0.023	± 1.322	± 0.045	± 1.258	± 1.040
BNCH2OR1	2.39 bcd	0.25 bcd	1.76 bc	1.24 d	0.01 d	9.62 cd	1.35 abc	1.90 c	204.66 ab	0.14 abc	0.20 cd	20.50 a	1.42 cd	147.83 a	104.01 a
	± 0.335	± 0.032	± 0.040	± 0.011	± 0.005	± 2.174	± 0.189	± 0.308	± 88.951	± 0.020	± 0.026	± 5.220	± 0.020	± 53.175	± 36.386
BNCH2OR2	2.73 ab	0.30 a	1.89 a	1.20 gh	0.01 d	8.97 cd	1.44 abc	2.27 a	224.66 a	0.16 a	0.26 a	25.50 a	1.58 a	158.16 a	99.83 a
	± 0.269	± 0.025	± 0.020	± 0.010	± 0.005	± 1.483	± 0.153	± 0.219	± 71.591	± 0.011	± 0.020	± 9.013	± 0.030	± 56.00	± 34.07
BPCH0OR2	1.95 e	0.18 gh	1.62 f	1.17 i	0.02 bc	10.69 bcd	1.20 c	1.66 c	87.40 c	0.11 ef	0.15 e	8.11 b	1.38 d	72.00 c	52.11 b
	± 0.141	± 0.011	± 0.010	± 0.005	± 0.005	± 1.460	± 0.091	± 0.125	± 23.510	± 0.005	± 0.005	± 1.620	± 0.010	± 15.59	± 11.07
BPCH1OR1	2.25 de	0.24 cde	1.73 cd	1.31 b	0.03 ab	9.30 cd	1.30 bc	1.71 c	75.10 c	0.14 bcd	0.18cde	8.11 b	1.31 e	57.66 c	43.89 b
	± 0.162	± 0.015	± 0.026	± 0.011	± 0.00	± 1.049	± 0.096	± 0.124	± 5.434	± 0.010	± 0.015	± 0.509	± 0.005	± 0.884	± 0.381
BPCH1OR2	2.22 de	0.27 bc	1.70 de	1.35 a	0.03 a	8.26 d	1.31 bc	1.65 c	68.23 c	0.16 ab	0.20 bc	8.22 b	1.25 f	51.97 c	41.22 b
	± 0.098	± 0.017	± 0.026	± 0.010	± 0.005	± 0.511	± 0.070	± 0.072	± 12.608	± 0.017	± 0.011	± 1.168	± 0.028	± 8.461	± 6.257
BNPCH1OR1	2.44 abd	0.23 cde	1.72cde	1.22 ef	0.02 cd	10.33 bcd	1.42 abc	1.99 abc	122.33 c	0.13 cde	0.19 cd	11.83 b	1.40 cd	86.16 bc	61.33 b
	± 0.287	± 0.011	± 0.011	± 0.005	± 0.00	± 1.204	± 0.166	0.225	± 14.571	± 0.011	± 0.005	± 0.577	± 0.015	± 0.577	± 0.288

Standard deviation of means, means followed by different letters in each column indicate significant differences at $p \leq 0.05$, according to the Duncan's multiple range test**.** N: nitrogen, P: phosphorus, K: potassium, Zn: znic, S: sulfur.

For instance, the total of nutrient index for control treatment (B0CH0OR0) equals zero, as shown in table 6:

N-index (2.76) + P-index (-32.69) + K- index (8.08) + S-index (30.32) + Zn-index (-8.47) = zero

The nutrient index is based on the mean of the deviation from the norm values. Negative index values indicate a suboptimal nutritional status, signifying a deficiency, conversely, a positive index denotes nutrient levels above the optimum. Furthermore, nutrient excess, quantified as a deviation from the standard sufficiency range, is indicated by a proportionally higher positive index.

Table 6: DRIS indices, nutrient balance index, total yield, and relative yield for sesame plant.

NO	Treatment	N index	P index	K index	S index	Zn index	NBI	Yield (Mg ha^{-1})	RY (%)
1	B0CH0OR0	2.76	-32.69	8.08	30.32	-8.47	82.32	0.41	43
2	B0CH0OR1	8.62	-20.81	6.78	16.63	-11.22	64.06	0.44	46
3	BNCH0OR0	3.34	15.67	-0.23	0.89	-19.67	39.8	0.45	47
4	B0CH2OR0	5.96	21.89	-0.62	-3.91	-23.32	55.7	0.48	50
5	BNPCH0OR1	-3.37	0.17	7.07	10.99	-14.86	36.46	0.49	51
6	BPCH0OR1	-4	6.8	0.14	11.84	-14.78	37.56	0.5	52
7	BPCH0OR0	1.48	-5.67	7.45	11	-14.26	39.86	0.55	57
8	B0CH2OR1	2.46	-2.92	-5.29	2.86	2.89	16.42	0.56	58
9	BNPCH0OR0	4.27	-1.89	-0.17	11.71	-13.92	31.96	0.56	58
10	BNPCH1OR0	3.66	0.44	1.3	11.25	-16.65	33.3	0.56	58
11	BNPCH2OR2	3.29	11.65	-2.82	-11.54	-0.58	29.88	0.57	59
12	BNPCH2OR0	3.34	15.67	-0.23	0.89	-19.67	39.8	0.6	63
13	BNCH0OR1	8.62	-20.81	6.78	16.63	-11.22	64.06	0.6	63
14	B0CH1OR1	-1.41	-5.49	2.86	0.85	3.19	13.8	0.61	64
15	BNPCH1OR2	-4.25	7.78	-10.8	7.56	-0.29	30.68	0.62	65
16	B0CH0OR2	7.21	-30.75	9.35	5.32	8.87	61.5	0.63	66
17	B0CH2OR2	4.46	1.6	-5.75	-1.27	0.96	14.04	0.63	66
18	BPCH2OR0	5.96	21.89	-0.62	-3.91	-23.32	55.7	0.63	66
19	BPCH1OR0	-9.72	7.21	4.96	-4.35	1.9	28.14	0.63	66
20	BNPCH0OR2	1.53	8.2	2.51	5.81	-18.05	36.12	0.64	67
21	BPCH2OR1	-8.16	15.02	1.81	-8.49	-0.18	33.66	0.64	67
22	B0CH1OR0	13.27	10.97	-5.84	-6.14	-12.26	48.48	0.65	68
23	BNPCH2OR1	15.13	-22.21	6.68	15.17	-14.77	73.96	0.66	69
24	BPCH2OR2	4.48	9.98	-5.14	-8.97	-0.35	28.92	0.66	69
25	BNCH0OR2	3.87	-0.28	-11.94	5.38	2.97	24.44	0.72	75
26	BNCH1OR0	-0.24	-4.05	2.43	-0.55	2.41	9.68	0.72	75
27	BPCH0OR2	-8.08	-7.76	5.75	5.75	4.34	31.68	0.73	76
28	BNCH2OR2	7.48	19.87	7.26	-10.08	-24.53	69.22	0.76	79
29	BNCH2OR1	-0.77	22.56	1.53	-0.6	-22.72	48.18	0.77	80
30	B0CH1OR2	-0.19	-4.05	-5.46	-3.13	12.83	25.66	0.77	80
31	BPCH1OR1	-9.71	0.4	-4.1	1.7	11.71	27.62	0.78	81
32	BNCH1OR1	3.14	7.8	-7.24	-12.94	9.24	40.36	0.8	83
33	BNPCH1OR1	-7.66	2.77	-2	5.32	1.57	19.32	0.81	84
34	BNCH2OR0	7.82	-5.02	3.06	-6.81	0.95	23.66	0.81	84
35	BPCH1OR2	-12.62	8.2	-10.15	3.56	11.01	45.54	0.84	88
36	BNCH1OR2	0.62	1.01	-0.23	-2.35	0.95	5.16	0.96	100

According to the data in table 6, the treatment combination B0CH0OR0 yielded the highest NBI of 82.32, significantly exceeding all other treatments. This same treatment also produced the most extreme DRIS indices, with a strongly negative value for phosphorus (P) of -32.69, and a positive value for nitrogen (N) of +2.76. Conversely, there is an imbalance for the other elements (K: 8.08, S: 30.32, and Zn: 8.47), and the DRIS indices also indicate imbalance (through both negative and positive values). This suboptimal nutrient balance corresponded with a low grain yield of 0.41 Mg ha^{-1} and a relative yield of only 43%.

The application of biofertilizer, chemical fertilizer, and milled OMP had a significant effect on reducing absolute total. According to the results, application of NPK in combination with biofertilizer and OMP showed better nutrient balance index. Notably, the combination treatment of all three fertilizers effectively improved the nutritional balance of plant. Thus, with the increase of these applied fertilizers, crop yield was gradually increasing, and nutrient balance was maintained accordingly. The highest grain yield (0.96 Mg ha^{-1}) was yielded by the application of nitrogen fixers (*Azospirillum* and *Azotobacter*), with NPK dose (100 kg ha^{-1}) and raw OMP (30 Mg ha^{-1}) in the BNCH1OR2 treatment. This was found to be the best nutrient-balanced combination, as supported by absolute nutrient index value of 5.16 and near optimal DRIS indices for (N: 0.62, P: 1.01, K: -0.23, S: -2.35, and Zn: 0.95).

The DRIS index for treatment BNCH1OR2, indicated a nutrient balance very near optimum. The relationships between the nutrient balance index were compared and a significant difference between the treatments was found. The B0CH0OR0 combination showed the highest index value (82.32), suggesting severe nutrient imbalance, and BNCH1OR2 had the lowest index value (5.16), indicating near optimal nutrient status. While the highest grain yield (0.96 Mg ha^{-1}) was achieved with the BNCH1OR2 treatment, the lowest (0.41 Mg ha^{-1}) was derived from the B0CH0OR0 treatment. In addition, treatment BNCH1OR2 showed the highest mean relative yield of 100% whereas B0CH0OR0 was at the lowest level of 43%.

A nitrogen index (N) of 2.76 for the BNCH1OR2 treatment was reduced to 0.62 after time. This reduction means that the (N) status was moved from above the optimum to close level of balance, Phosphorus index switched from severe villous deficit (-32.69) to a slight surplus (1.01). This final positive value of P indicates a now excessive level of optimum. The potassium index declined from excess of 8.08 to deficit -0.23. This is a negative final value, which implies that the K level is close to or below its optimal. The sulfur index was highly reduced from an excess of 30.32 to −2.35. This negative value signifies that the S level much closer to the optimum range, although it still indicates a slight shortage. The zinc index jumped from a short (-8.47) to the long side (0.95). This final positive value indicates that Zn is now near to or above the optimal level. As shown in figure 1, the results also indicate that the DRIS norms were developed from treatments that resulted in yields higher than 75%.

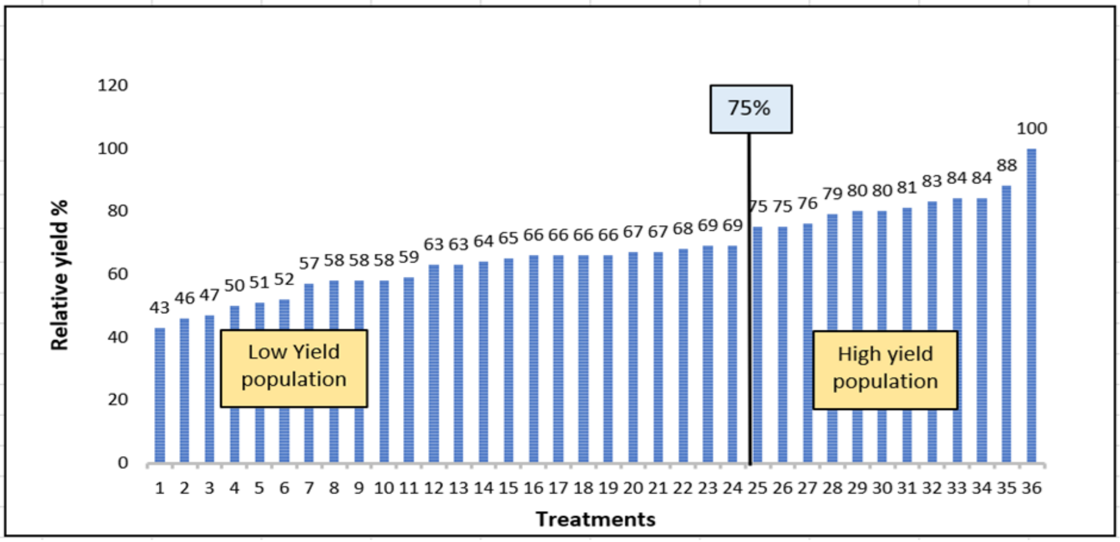

Figure 1: Interaction influence between biofertilizer, NPK fertilizer, and OMP on seed yield (Mg ha^{-1}). The numbers 1-36 represent the treatments as shown in table 6.

Table 7: Optimum and critical values for nutrient ratios in sesame plant.

Limits of confidence	N/P	N/K	N/S	N/Zn	P/K	P/S	P/Zn	K/S	K/Zn	S/Zn
30%	14.03	1.81	2.52	164.7	0.17	0.23	15.46	1.81	117.31	83.53
15%	12.41	1.6	2.23	145.69	0.15	0.21	13.67	1.6	103.78	73.89
Norm	10.79	1.39	1.94	126.69	0.13	0.18	11.89	1.39	90.24	64.25
-15%	9.17	1.18	1.65	107.69	0.11	0.15	10.11	1.18	76.7	54.61
-30%	7.55	0.97	1.36	88.68	0.09	0.13	8.32	0.97	63.17	44.98

The graphical representation as shown in figure 2, and the supporting data in table 7, illustrate a state of optimal nutrient sufficiency. In this model, the central intersection of the six axes denotes the precise nutrient combination associated with maximum yield. Nutrient status is interpreted using concentric confidence limits: the inner circle (±15%) and outer circle (±30%) from the mean. The following graph is formed up of ten dimensions for (N/P), (N/K), (N/S), (N/Zn), (P/K), (P/S), (P/Zn), (K/S), (K/Zn) and (S/Zn) with the norms of the maximum yield (greater than 75% of R.Y) placed at the crossing for every ratio in the middle of the sphere.

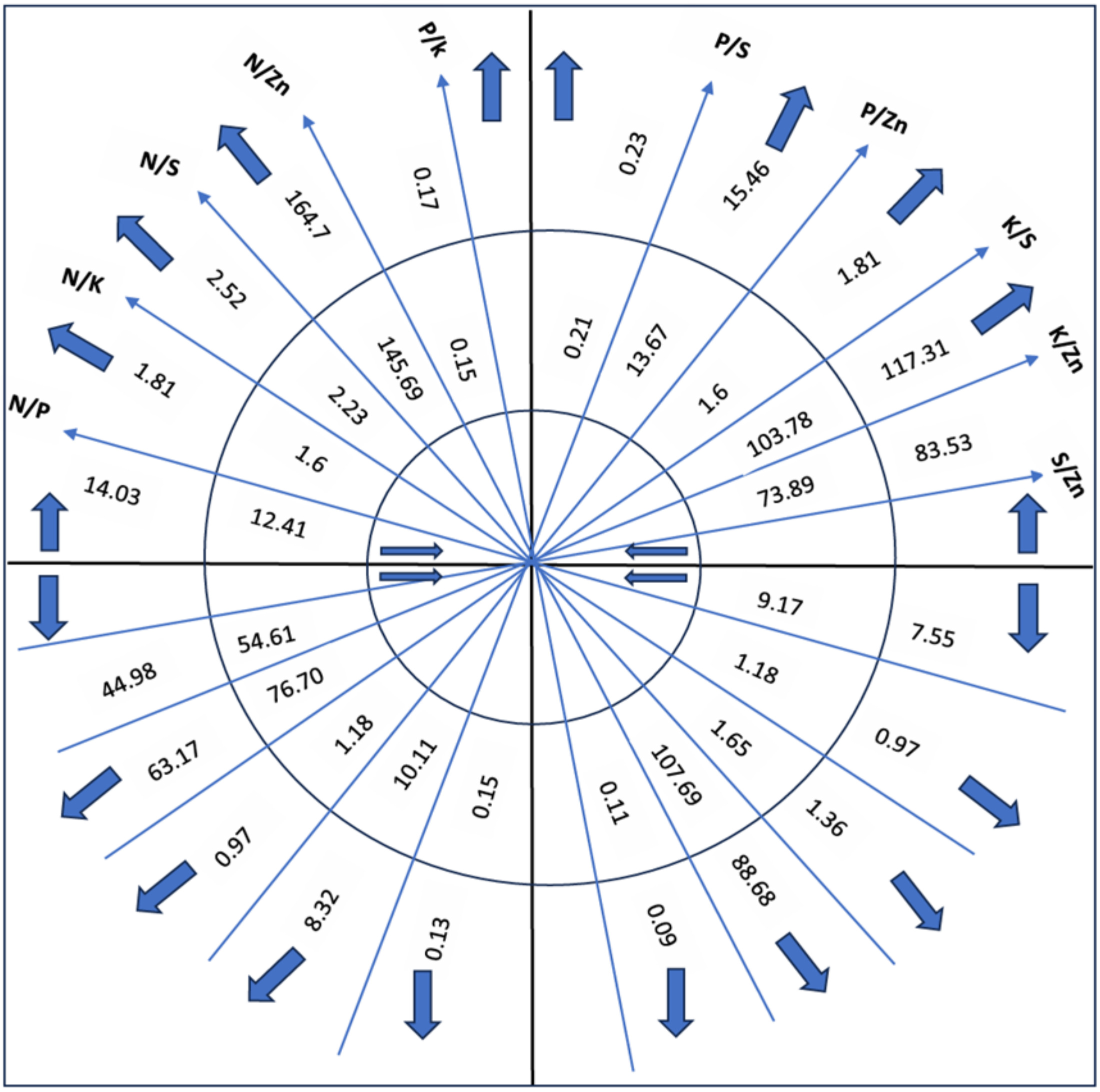

Figure 2: DRIS chart for N, P, K, S, and Zn for nutrient ratios in sesame plants.

From the correlation of plant nutrient concentrations with relative yield as shown in tables 5 and 6, a graphical analysis was performed using MS Excel, to calculate the critical nutrient concentration of sesame. The individual treatment observations (relative yield versus leaf nutrient concentration) are indicated by the blue points in figures 3, 4, and 5. The horizontal reference line of 75% emerged, dividing the populations of higher and lower production while the vertical was traced on point corresponding to the relative maximum yield value in order to determine the critical nutrient concentration. From this aproach, critical nutrient concentrations were 2.15% for N, 0.23% for P, and 1.68% for K.

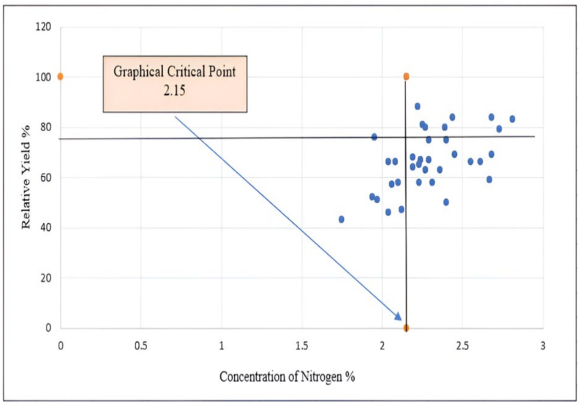

Figure 3: Critical point of nitrogen in sesame plant.

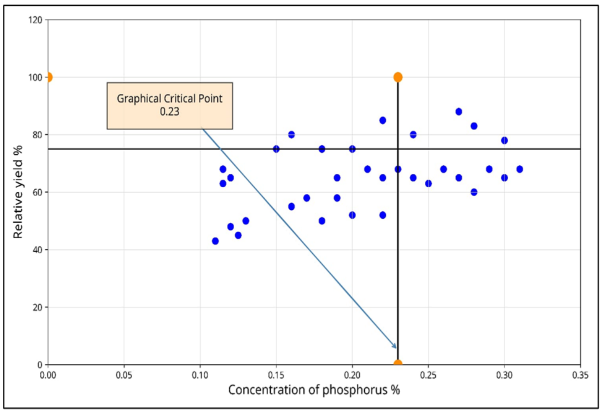

Figure 4: Critical point of phosphorus in sesame plant.

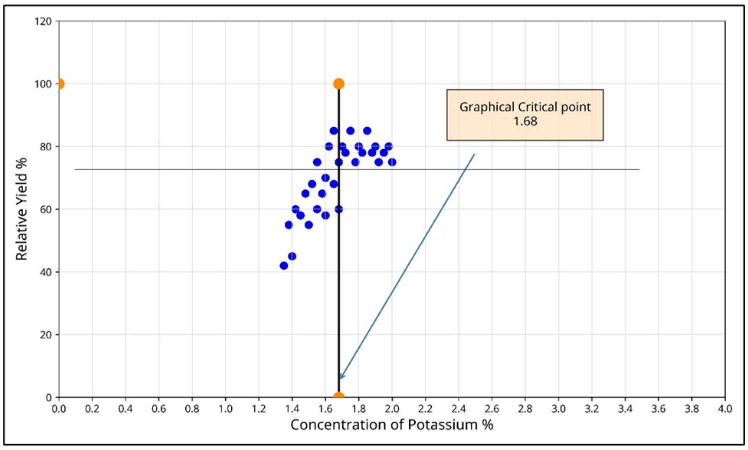

Figure 5: Critical point of potassium in sesame plant.

4. Discussion

Although, the unfertilized treatment (B0CH0OR0) had low content of organic matter, total nitrogen and available phosphorus: such conditions, with a limited nutrient supply, lead to nutrient imbalance and low grain yield [36]. By simultaneously assessing the adequacy of each nutritional index for all elements, the DRIS method computes the NBI, indicating the overall state of nutrient balance within plant tissues [37]. This is in accordance with the principle of DRIS, which argues that crop productivity is more closely related to nutrient balance rather than maximum concentration of any given nutrients [38]. The correlation between nutrient concentration and yield confirms plant analysis as a diagnostic tool. In addition, the correlation between nutrient concentration and DRIS indices may be used to validate known DRIS norms. It could be an effective method to simply compute the optimum leaf nutrient concentration, as at the dosage that correspondently leads to DRIS index equals zero, the current leaf nitrogen most likely does not limit crop yield.

The DRIS index values in the (B0CH0OR0) control treatment, showed a major imbalance, as indicated by a highly negative value of P (-32.69), while other nutrients exhibited positive value. This suboptimal balance of nutrients was associated with low grain yield (0.41 Mg ha^{-1}), and relative yield as 43%. The DRIS index in the (BNCH1OR2) treatment indicates a situation of balance, according to which is any explanation for the 96% yield grain obtained [39]. The treatment combination with three fertilizers being applied worked particularly well in improving nutrient balanced growth of the plant.

As a result, the crop yield gradually increased according to the increase levels of these fertilizers and nutrient balanced. The DRIS vide for the treatment BNCH1OR2 was kept at a selected level near to optimum balance. The arrows that extend outward beyond the confidence limits shown in figure 2, indicating a nutrient status being of high sufficiency (upwards arrow) or severe deficiency (downwards arrow). The point at which the ten axes met provided the ideal nutrition and maximum production. The transition of indices from control (B0CH0OR0) to optimized treatment (BNCH1OR2) clearly indicated a nutritional correction filed effect in this experiment.

The N index declined from supra optimal to near optimal. P went from severe deficiency to slight excess, well beyond the optimum. K followed a path from high excess to slight deficiency, approaching the optimum. S also decreased, from a huge surplus to a small deficit (-2.35), suggesting a large shift towards balance. Zn increased from deficit to a surplus at or above optimum. This result, which demonstrates an inverse relationship between higher grain yield and a lower NBI, is consistent with the findings of previous studies on chickpea [28], black pepper [40], and soybean [32]. The results shown in figure 1, verify the considerable correlation between the nutrient balance index and the percentage of yield. The determined critical concentrations of 2.15% (N), 0.23% (P), and 1.68% (K) are in agreement with the existing literature [28, 41].

5. Conclusions

The results demonstrate the BNCH1OR2 treatment was identified as the most nutritionally balanced, with an optimal absolute total of 5.16, as calculated from DRIS indices for N (0.62), P (1.01), K (-0.23), S (-2.35), and Zn (0.95). A strong inverse relationship was observed between the absolute total and grain yield. This most balanced treatment (BNCH1OR2) yielded the highest grain production (0.96 Mg ha^{-1}, 100% relative yield), whereas the most imbalanced treatment, B0CH0OR0, with the highest nutrient balance index of 82.32, produced the lowest yield (0.41 Mg ha^{-1}, 43% relative yield). Based on these results, it can be suggested that the grain yield, can be improved if crop management follows a balanced supply of nutrients, rather than seeking only to maximize profile acquirement of each nutrient. Fertilization must be monitored from tissue analysis, and be corrected for individual deficiencies and excesses reported by the DRIS indices, in order to avoid unacceptable nutritional imbalance.

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