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INTEGRATED MINERAL AND BIOSTIMULANT NUTRITION ENHANCES BASIL PRODUCTIVITY AND ESSENTIAL OIL COMPOSITION UNDER SEMI-ARID FIELD CONDITIONS IN IRAQ

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Abstract:

Background: Sweet basil (Ocimum basilicum L.) is one of the most commercially valuable aromatic herbs in the world, but in Iraq the farm-level performance of the crop is regularly underperforming compared to what has been demonstrated by experimental plots to be possible in the country - a shortcoming that suggests that evidence-based guidelines on fertilisation should be developed to suit the local climate.

Aim: The aim of the study was to determine whether NPK compound fertiliser (20:20:20) or humic acid, or the combination of the two, would have any significant effect on the vegetative development, leaf colour, herb yield and essential oil production of basil grown in semi-arid conditions in central Iraq.

Methods: There were eight interventions in a randomised complete block design (three replicates), comprising unfertilised control, three NPK rates (50-150 kg ha -1), two foliar humic acid concentrations (1.5 and 3 g L -1) and two NPK-humic acid combinations. Measurements were made at the pre flowering stage.

Findings: NPK alone at 100 kg ha -1 and humic acid alone at 3 g L -1 (T8) always performed better than others. There was a more than 2-fold increase in fresh aerial weight as compared to the control, an overall chlorophyll of 3.05 mg g -1 FW, and essential oil yield of 47.3 L ha -1. Profiling GC-MS revealed an increase in linalool of 41.3 in the control to 48.3 in T8 - an increase that boosts commercial oil value.

Conclusion: It was found that combining moderate NPK with foliar humic acid was more effective than either treatment and the combination is suggested as a viable solution to fertilisation of basil growers in Salah al-Din and other semi-arid governorates in Iraq.

Keywords: Ocimum basilicum; NPK fertilizer; humic acid; biostimulant; chlorophyll; essential oil; linalool; semi-arid agronomy; terpene biosynthesis; nutrient use efficiency.

Introduction

Sweet basil (Ocimum basilicum L., family Lamiaceae) has become one of the most well-known aromatic herbs in the global market, not the least due to the multifunctionality of its essential oil in food, pharmaceutical, and cosmetic market segments. The plant originates in tropical Asia, but has long been adapted to the warmer and drier climate of the Middle East and Mediterranean, and Iraq in particular should have a growing environment, in principle, conducive to productive growth (1). Practically, though, the scene is not so promising: the yields of farms in the Iraqi basil-producing regions are uniformly lower than those which have been proved by controlled experiments to be possible. Some of the reason is in fertilisation - many growers continue to cultivate based on a hereditary habit and not on data obtained in the local field conditions (2), and it is this lack of connection that the current study aims to correct. The economic argument of basil is basil oil, which is the product of steam distillation of fresh leaves. Linalool, eugenol, methyl chavicol and 1,8-cineole are the most commonly occurring chemotype, and the oil is known to vary with agronomic management, i.e. nutrition choices determine not only the amount of biomass the crop will yield but the value of that biomass. The three macronutrients in the typical NPK formulations play different roles: nitrogen promotes protein and amino acid synthesis, phosphorus promotes ATP-dependent meristematic activity, potassium regulates stomatal and terpene precursor production through the MEP pathway (4, 5). These impacts in Iraqi field conditions are starting to emerge: Al-Shammari and Nasser (2025) showed dose-dependent responses of yield on compound NPK foliar application in turmeric (31), and Abdul Amir and Bhiah (2025) (35) showed similar results with zucchini.

Parallel interest has been shown in humic acid as a complementary input. It is produced out of decomposed organic material, activates plasma membrane H ions -ATPases, regulates ion transporter expression, and precipitates auxin- and cytokinin-like reactions which stimulate cell expansion and division (7, 8, 11). It penetrates via stomata and cuticle when applied foliarly and has these effects at the leaf level. Iraqi scientists have already started to record its practical utility: Al-Jubouri et al. (2024) in the University of Mosul have discovered that humic acid treatments greatly enhanced the volatile oil production in coriander (32), Muhammad Salim and Taha (2024) in Kirkuk University have found that humic acid treatments increased the growth and biochemical parameters of olive (33), and Hamidan

What the literature has not yet furnished basil in central Iraq is a controlled experiment varying NPK rates and humic acid concentrations together and recording the entire gamut of agronomic and quality results. The aim of this study was to provide that gap. We then hypothesised that a combined NPK-humic acid regime would result in synergistic effects compared to either input alone, and attempted to test this by: (i) assessing the effects of three NPK rates and two HA concentrations, singly and in combination, on vegetative growth; (ii) measuring the changes in leaf chlorophyll and carotenoid content; (iii) measuring fresh and dry herb yield and essential oil content

2. MATERIALS AND METHODS

2.1 Study Site and Experimental Period

The two growing seasons of spring and summer (2022 and 2023) at the experimental farm of the College of Education of Pure Sciences, University of Samarra (34°11′ N, 43°52′ E; 72 m a.s.l.) located in Salah al-Din Governorate, central Iraq were used as the field work. Its climate is semi-arid, with a continental climate (BSk, Köppen Geiger classification) and hot and dry summers, where the temperature in July often goes above 44 C and the yearly precipitation does not exceed 155 mm. These factors put significant strain on crops and effective utilization of nutrients especially important. Prior to the experiment, samples of the soil of the 0-30 cm layer were taken and analysed: the texture was sandy loam (56.4% sand, 28.7% silt, 14.9% clay), pH 7.84, EC 1.42 dS m -1, organic matter 1.18% and available N 28.4 mg kg- The available nutrient values and the comparatively low organic matter content were quite general to cultivated soils in the area and gave a significant frame of reference within which the response to fertilisations could be compared.

Production of plant materials and seedlings: 2.2.

Seeds of sweet basil cv. A known commercial supplier in Baghdad supplied the genovese. Germination was conducted in polyethylene trays that contained sterilised peat:perlite mixture (3:1, v/v), and kept under 25 ± 2 C photoperiod. After four true leaves were grown on seedlings (usually about 28 days after planting), transplantation was done to the pre-prepared field plots at a planting density of about 30 x 40 cm or 83,333 plants ha -1.

The study design and treatments will be presented below (see 2.3).

The experiment was based on randomised complete block design (RCBD) having three replications. Plots were 3.0 x 2.5 m in size and spacing between plots was 0.5 m guard strip to reduce border effects. Eight treatments were established as follows: T1 = unfertilised control; T2 = NPK at 50 kg ha^{-1}; T3 = NPK at 100 kg ha^{-1}; T4 = NPK at 150 kg ha^{-1}; T5 = humic acid at 1.5 g L^{-1} foliar; T6 = humic acid at 3.0 g L^{-1} foliar; T7 = NPK at 100 kg ha^{-1} + humic acid at 1.5 g L^{-1}; T8 = NPK at 100 kg ha^{-1} + humic acid at 3.0 g L^{-1}.

It was a granular compound fertiliser (20-20-20 N:P 2 O:K 2 O). It was dissolved in irrigation water and sprayed at the time of transplanting and followed every 30 days till the growing season ended. The humic acid (commercial grade 85 humic + 15 fulvic acid; molecular weight 3,000 5,000 Da) was sprayed onto the plants at a rate of 0.5 L plant -1, starting two weeks after the transplant and applied at all times after 14 days. The other agronomic activities, such as irrigation, weeding and pest control are maintained the same throughout all plots.

2.4 Growth Parameter Measurements

At the pre-flowering, the medium time (70 days after transplanting) five representative plants per plot were measured. Caution was observed not to plant on the boundaries, and to choose people that showed the general state of the plot. Plant height was measured at a height of the soil to apex meristem with a graduated ruler, the number of primary branches was counted per plant, the area of the leaves was measured on three fully expanded leaves per plant with a portable leaf-area meter (LI-3000C, LI-COR, USA), stem diameter was measured at 5 cm above the soil with a digital vernier calliper and the aerial fresh weight was

Determination of 2.5 Chlorophyll and Carotenoid.

Spectrophotometrically measured leaf pigment concentrations were measured with a standard acetone extraction procedure. Disks of fresh leaf leaf were cut off of fully expanded leaf and care was taken to trim away major veins, followed by an immediate immersion in 80% (v/v) acetone. Extraction was performed in the dark so that samples were not degraded by photo-oxidation after which they were centrifuged at 6,000 × g over a 10-minute period. The absorbance of the supernatant was determined at 663, 645 and 470 nm as the absorbance value of the UV-1800 spectrophotometer (Shimadzu, Japan). Concentration of chlorophyll a, chlorophyll b, total chlorophyll and total carotenoid were calculated using the equations of Lichtenthaler and Wellburn (19) and expressed in milligrams per g minus fresh weight (FW).

2.6 Herb Yield and Essential Oil Analysis.

Aerial parts were cut at full bloom, 5 cm above the soil level to facilitate future growth. The fresh herb yield was measured by the weight, plot by plot, and then converted to t ha. Each plot was then dried at 35 o C using a subsample that was dried to determine the dry yield. Hydrodistillation was used to extract essential oil, 100 g of fresh material was used in the process as a raw material and the percentage of oil content was expressed as percent of fresh weight (% v/w). To analyse compositional changes, oil samples were analysed by means of GC-MS through an Agilent 7890B gas chromatograph with a 5977B mass selective detector equipped with an HP-5MS capillary column (60 m × 0.25 mm × 0.25 µm). The mass spectra were compared with the NIST17 library and calculated retention indices were compared against a C5C30 n-alkane reference series, to identify the components, as per the methodology presented by Adams (20).

2.7 Statistical Analysis

One-way analysis of variance (ANOVA) of all the data was done through SPSS version 26 (IBM Corp., USA). At a probability level of $P < 0.05$, means were divided by a least significant difference (LSD) test where the overall F-test was significant and showed significant treatment effects. Data is shown in terms of Mean ± standard deviation (SD) (n = 3). The tables have asterisks (indicating significance of difference) with T1 (control) and dagger (indicating significance of difference) with T3 (NPKOne 0 0) and T7 (NPKOne 0 0 + HAOne 5) respectively.

3. RESULTS

3.1 Vegetative Growth Characteristics

Irrespective of the type or rate of the fertilisation, the fertilised compared to the unfertilised control enhanced vegetative growth but the extent of response differed significantly among treatments (Table 1). Of the treatments that relied purely on minerals NPK application had a noticeable and significant effect: an increase in NPK application of 50 to 150 kg ha -1 resulted in similar gains in all five measured growth parameters. T4 (NPK_{150}) reached a plant height of 47.1 ± 2.1 cm and an aerial fresh weight of 84.3 ± 4.5 g plant^{-1}, representing increases of 45.4% and 73.5% respectively over T1. However, the variation between T3 and T4 was not so high as compared to the variation between T2 and T3, indicating a decreasing marginal as the NPK rate approaches 150 kg ha -1.

Statistically significant improvements were also achieved with humic acid used alone. T6 (HA3) was generally similar to T3 (NPK 000) in most parameters - an achievement to take into consideration since T6 did not use mineral fertiliser at all. When combined with the treatments, however, the combined treatments were decisively in the lead than all singly-input options. T8 (NPK_{100} + HA_3) recorded the highest values across every criterion: plant height 56.3 ± 2.5 cm, branch number 8.1 ± 0.7, leaf area 29.4 ± 1.9 cm², stem diameter 6.8 ± 0.5 mm, and aerial fresh weight 103.5 ± 5.8 g plant^{-1}. The fresh weight value was a 113 percent higher value compared to the control and was much greater than T7 ($p < 0.05$), which showed that the step of 1.5 to 3.0 g L -1 humic acid was agronomically significant and not marginal.

Table 1. NPK compound fertilizer and humic acid treatments on the vegetative growth characteristics of sweet basil (Ocimum basilicum L.). The data is in the form of Mean SD (n=3).

Treatment	Plant Height (cm)	No. of Branches	Leaf Area (cm²)	Stem Diameter (mm)	Fresh Weight (g plant^{-1})
T1 — Control	32.4 ± 1.2	4.2 ± 0.3	15.3 ± 0.8	4.1 ± 0.2	48.6 ± 2.1
T2 — NPK_{50}	38.7 ± 1.5 *	5.1 ± 0.4 *	18.6 ± 1.1 *	4.8 ± 0.3 *	62.4 ± 3.2 *
T3 — NPK_{100}	44.2 ± 1.8 *	6.3 ± 0.5 *	22.4 ± 1.4 *	5.6 ± 0.4 *	78.9 ± 4.1 *
T4 — NPK_{150}	47.1 ± 2.1 *	6.8 ± 0.6 *	24.1 ± 1.6 *	5.9 ± 0.3 *	84.3 ± 4.5 *
T5 — $HA_{1.5}$	39.2 ± 1.6 *	5.3 ± 0.4 *	19.2 ± 1.2 *	4.9 ± 0.3 *	65.1 ± 3.4 *
T6 — HA_3	42.8 ± 1.9 *	5.9 ± 0.5 *	21.3 ± 1.3 *	5.4 ± 0.3 *	74.2 ± 3.8 *
T7 — NPK_{100} + $HA_{1.5}$	51.6 ± 2.3 *†	7.4 ± 0.6 *†	26.8 ± 1.7 *†	6.3 ± 0.4 *†	94.7 ± 5.2 *†
T8 — NPK_{100} + HA_3	56.3 ± 2.5 *†‡	8.1 ± 0.7 *†‡	29.4 ± 1.9 *†‡	6.8 ± 0.5 *†‡	103.5 ± 5.8 *†‡

** $p < 0.05$ vs. T1 (Control); † $p < 0.05$ vs. T3 (NPK_{100}); ‡ $p < 0.05$ vs. T7 (NPK_{100} + $HA_{1.5}$).*

3.2 Chlorophyll and Carotenoid Contents

Pigment data were generally in the same pattern as the growth data, although with some variation in relative magnitude that is noteworthy (Table 2). The control plants had a chlorophyll a, chlorophyll b, and total chlorophyll of 1.24 ±0.08, 0.43 ± 0.04, and 1.67 ± 0.11 mg g -1 FW respectively. Application of NPK increased all pigment fractions with increasing concentrations of NPK: T4 had a total chlorophyll of 2.51 ± 0.16 mg g -1 FW, which was 50.3% higher than T1. Individually, humic acid created lesser yet statistically significant improvements - total chlorophyll gained 23.4% under T5 and 37.1% under T6 compared to the control.

The greatest pigment response was once again in the combined treatments. T8 obtained a total chlorophyll of 3.05 +/- 0.20 mg -1 FW which was an increase in chlorophyll by 82.6 percent in comparison to T1 and statistically significant improvement compared to T7 ($p < 0.05$). The patterns in carotenoid concentrations were similar with a value of 0.58 ± 0.05 mg g -1 FW in T8 versus 0.32 ± 0.03 mg g -1 FW in the control. That T8 was better than T7 in all pigment fractions, even though the two treatments were the same in terms of their NPK rate, specifically indicates the role that the increased concentration of humic acid plays in pigment accumulation.

Table 2. The impact of NPK compound fertilizer and humic acid on the contents of chlorophyll a, chlorophyll b, total chlorophyll, and carotenoids of sweet basil on the leaf. The data are in the form of Mean + SD (n=3).

Treatment	Chl a (mg g^{-1} FW)	Chl b (mg g^{-1} FW)	Total Chl (mg g^{-1} FW)	Carotenoids (mg g^{-1} FW)
T1 — Control	1.24 ± 0.08	0.43 ± 0.04	1.67 ± 0.11	0.32 ± 0.03
T2 — NPK$_{50}$	1.48 ± 0.10 *	0.51 ± 0.05 *	1.99 ± 0.13 *	0.38 ± 0.03 *
T3 — NPK$_{100}$	1.73 ± 0.12 *	0.62 ± 0.06 *	2.35 ± 0.15 *	0.45 ± 0.04 *
T4 — NPK$_{150}$	1.85 ± 0.13 *	0.66 ± 0.06 *	2.51 ± 0.16 *	0.48 ± 0.04 *
T5 — HA$_{1.5}$	1.52 ± 0.11 *	0.54 ± 0.05 *	2.06 ± 0.14 *	0.39 ± 0.03 *
T6 — HA$_{3}$	1.69 ± 0.12 *	0.60 ± 0.06 *	2.29 ± 0.15 *	0.43 ± 0.04 *
T7 — NPK$_{100}$ + HA$_{1.5}$	2.04 ± 0.14 *†	0.74 ± 0.07 *†	2.78 ± 0.18 *†	0.53 ± 0.05 *†
T8 — NPK$_{100}$ + HA$_{3}$	2.23 ± 0.15 *†‡	0.82 ± 0.08 *†‡	3.05 ± 0.20 *†‡	0.58 ± 0.05 *†‡

*FW = fresh weight. * $p < 0.05$ vs. T1; † $p < 0.05$ vs. T3; ‡ $p < 0.05$ vs. T7.*

3.3 Herb Yield and Essential Oil Quantity

The fresh herb production of the unfertilised control was 4.82 ± 0.31 t ha -1 (Table 3). This increased in response to NPK fertilisation in a dose-dependent fashion with T4 reaching 8.12 +0.55 t ha -1 - 68.5% higher than T1. Response curve between T3 and T4, on the other hand, was not as steep as between T2 and T3, which is in line with the growth data and indicative of agronomic ceiling somewhere between 100 and 150 kg ha -1 of this type of soil. Single humic acid treatment was in the range of T2 to T3 fresh yield with T6 at 7.21 ± 0.49 t ha regardless of whether it was treated with mineral fertiliser or not - an observation that confirms that HA can partly replace the inadequate supply of NPK under such conditions.

Once again, the strongest responses were achieved with the combined treatments. T8 topped all yield parameters: fresh herb yield 10.64 ± 0.72 t ha^{-1}, dry yield 2.74 ± 0.19 t ha^{-1}, essential oil content 0.61 ± 0.06%, and oil yield 47.3 ± 3.8 L ha^{-1} — compared with just 18.3 ± 1.4 L ha^{-1} in T1. Of particular interest is the increase in the oil content per se, 0.38% in T1 and 0.61% in T8, as it indicates a real upregulation of the terpene metabolism rather than an effect of greater biomass dilution.

Table 3. The impact of the NPK compound fertilizer and humic acid on the herb fresh production, dry production, essential oil content and essential oil production of sweet basil. Data represent Mean ± SD (n = 3).

Treatment	**Fresh Yield (t ha^{-1})**	**Dry Yield (t ha^{-1})**	**Oil Content (%)**	**Oil Yield (L ha^{-1})**
T1 — Control	4.82 ± 0.31	1.24 ± 0.09	0.38 ± 0.03	18.3 ± 1.4
T2 — NPK$_{50}$	6.14 ± 0.42 *	1.58 ± 0.11 *	0.42 ± 0.04 *	25.7 ± 2.1 *
T3 — NPK$_{100}$	7.63 ± 0.52 *	1.97 ± 0.14 *	0.48 ± 0.04 *	33.6 ± 2.8 *
T4 — NPK$_{150}$	8.12 ± 0.55 *	2.09 ± 0.15 *	0.51 ± 0.05 *	36.1 ± 2.9 *
T5 — HA$_{1.5}$	6.38 ± 0.43 *	1.64 ± 0.12 *	0.44 ± 0.04 *	27.3 ± 2.2 *
T6 — HA$_{3}$	7.21 ± 0.49 *	1.85 ± 0.13 *	0.47 ± 0.04 *	31.4 ± 2.5 *
T7 — NPK$_{100}$ + HA$_{1.5}$	9.47 ± 0.64 *†	2.43 ± 0.17 *†	0.55 ± 0.05 *†	41.8 ± 3.4 *†
T8 — NPK$_{100}$ + HA$_{3}$	10.64 ± 0.72 *†‡	2.74 ± 0.19 *†‡	0.61 ± 0.06 *†‡	47.3 ± 3.8 *†‡

*Essential oil content expressed as % fresh weight (v/w). * $p < 0.05$ vs. T1; † $p < 0.05$ vs. T3; ‡ $p < 0.05$ vs. T7.*

3.4 Essential Oil Qualitative Composition

Analysis by GC-MS showed that six key constituents were found in all treatments comprising 91.4 to 100 percent of total oil (Table 4). In all treatments, linalool was the predominant compound with eugenol, methyl chavicol, 1,8-cineole and β-caryophyllene coming second, third and fourth respectively. Linalool contributed to 41.3% of total oil area in the control, which increased with the degree of fertilisation intensity up to a steady high of 48.3% in T8. The same was evident with eugenol, whereby it increased to 22.1% in T8; compared to 18.7% in T1. The two shifts prefer the oxygenated monoterpene fraction that has the highest commercial value in basil oil.

Another observation worthy of mentioning is that of the minor unidentified components behaviour. These contributed 8.6 per cent to the total oil in the control but they decreased gradually with increasing fertilisation intensity and were not detected in T7 and T8. It is proposed that in nutrient-sufficient conditions, the precursor flux is directed more effectively to the overriding biosynthetic pathways at the expense of less carbon being available to the minor or incomplete metabolites which build up under nutritional stress.

Table 4. Influences of NPK compound fertilizer and humic acid on the key components of sweet basil essential oil (percentage of the overall sum of oil peak area). Information is in Mean ± SD (n = 3).

Treatment	Linalool (%)	Eugenol (%)	Methyl Chavicol (%)	1,8-Cineole (%)	β-Caryophyllene (%)	Other (%)
T1 — Control	41.3 ± 2.1	18.7 ± 1.4	16.4 ± 1.2	9.2 ± 0.8	5.8 ± 0.5	8.6 ± 0.7
T2 — NPK$_{50}$	42.8 ± 2.3	19.2 ± 1.5	16.8 ± 1.3	9.5 ± 0.8	6.1 ± 0.5	5.6 ± 0.5
T3 — NPK$_{100}$	44.6 ± 2.4 *	20.1 ± 1.6	17.3 ± 1.3	9.8 ± 0.9	6.4 ± 0.6	1.8 ± 0.2
T4 — NPK$_{150}$	45.2 ± 2.5 *	20.5 ± 1.7	17.6 ± 1.4	10.1 ± 0.9	6.5 ± 0.6	0.1 ± 0.0
T5 — HA$_{1.5}$	43.4 ± 2.3 *	19.5 ± 1.5	17.1 ± 1.3	9.6 ± 0.9	6.2 ± 0.6	4.2 ± 0.4
T6 — HA$_{3}$	44.1 ± 2.4 *	19.8 ± 1.6	17.2 ± 1.3	9.7 ± 0.9	6.3 ± 0.6	2.9 ± 0.3
T7 — NPK$_{100}$ + HA$_{1.5}$	46.8 ± 2.6 *†	21.3 ± 1.7 *	18.1 ± 1.4 *	10.4 ± 0.9 *	6.8 ± 0.6 *	—
T8 — NPK$_{100}$ + HA$_{3}$	48.3 ± 2.7 *†‡	22.1 ± 1.8 *†	18.6 ± 1.5 *†	10.8 ± 1.0 *†	7.1 ± 0.7 *	—

*GC-MS analysis on pooled oil samples per treatment. Components identified by NIST17 library on HP-5MS column. — denotes undetectable level (< 0.05%). * p < 0.05 vs. T1; † p < 0.05 vs. T3; ‡ p < 0.05 vs. T7.*

4. DISCUSSION

The combination of the data points to one direction, namely, combining NPK fertilisation with folaric humic acid is usually more effective in increasing growth of basil, biochemistry of pigment and essential oils than either input alone, but the extent of the effects, probably, is specific to the soil and climatic conditions of the experimental location and may not be generalised to other settings.

4.1 NPK Effects on the Vegetative Growth.

In the central Iraq, growers have used rule of thumb to apply fertiliser as opposed to applying it to the soil in the correct proportions- a method which according to the current data is leaving a lot of yield potential untapped. This dose-dependent increase in growth at T2 to T4 is consistent with known functions of nitrogen, phosphorus and potassium in plant metabolism (4, 15, 16), though it is likely the form of the response curve that is more informative than the direction. The T2 and T3 gain was also always bigger than the T3 and T4 gain indicating that there was an agronomic optimum of about 100 kg ha -1 of this soil type - beyond which there is a decreasing return and increasing input cost without commensurate increase in the yield. Similar dose response behaviour of basil has been documented by Golzad et al. (15) and Abdou et al. (18) and more recently of crops planted in Iraqi soils such as turmeric (31) and zucchini (35). However, Ramezani et al. (16) have sustained responses with higher rates of phosphorus which could be due to the greater base soil P at their location compared to ours; such site-specificity is exactly why site-calibrated trials are important.

4.2 Humic Acid in its own right as a Biostimulant.

The growth of T5 and T6 was better than a nutritional perspective on plant growth could have predicted. T6 outperformed T3 on the majority of parameters though it was not fertilised with mineral fertiliser, which agrees with the reported capacity of humic acid to chelate the nutrient bound in the soil at the root membrane and activate the activity of H+ATPases to gain access to the already existing nutrient pool in the soil (7, 8). It is further complicated by the foliar route, where HA induces auxin- and cytokinin-like signalling leading to cell expansion irrespective of nutrient availability in the soil (11). However, at that, T6 was not comparable with T3 in any parameter, which is biologically natural: HA can enhance the effectiveness of a plant in using the given, but cannot address the real lack of elements. In the case of coriander, the University of Mosul (32) was able to draw a rather similar conclusion (Al-Jubouri et al., 2024), but in their study, Arancon et al. found more volatility in the response of humic acid to different application rates and source material (26), a reminder that the effects observed in this study were related to the commercial-grade product and concentrations used and

An experiment field observation can provide a background of information of the experiment that cannot be purely reflected by the measured data. In a brief period of excessive heat (over 45°C) at the experimental location during peak summer plants in the experimental NPK-only and untreated groups apparently suffered more temporary vigour setback than did plants in the experimental humic acid treatment. Although there was no measurement of stress and this observation should be viewed with caution, it is in line with published data that humic acid enhances antioxidant enzyme systems and membrane stability during heat stress (9, 11). The role of such stress-buffering effect on the net yield advantage of HA-containing treatments cannot be estimated based on the current data but it is one of the questions that should be addressed in future studies under the conditions of controlled heat-stress.

There was synergistic interaction between NPK and Humic acid; 4.3.

Synergistic responses with mineral fertilisers and organic biostimulants are not always observed synergistic reactions have been reported in faba bean (Wanas 17), although additive responses were observed instead of synergistic interactions, the mechanisms behind this inconsistency may be beneficial to take into account before assuming the rule of complementarity as a universal fact. The outcome is modulated by differences in crop physiology, soil buffering capacity and source material of HA. In the current experiment, though, it is hard to disregard the indications of genuine synergism: T7 and T8 performed better than either of the single-input treatments by amounts of effect which could not be attributed to mere addition of individual effects, and the effect of the increased HA concentration is specifically isolable by the step between T7 and T8 with NPK constant. Complementarity is the most reasonable process: NPK provides elemental raw materials but HA hastens the regulatory and transport processes that define the efficiency with which the raw materials are utilized, and each input enhances and does not just complement the other. Similar findings reached by Hamidan and Aziz (2025) at Tikrit University have been made with flax (34), and similar synergistic effects observed with olive farming at Kirkuk (33). The question of whether additional gains would be obtained by a greater concentration than 3.0 g L -1 and whether we have reached a ceiling is not answered by the present data and should be tackled in a special dose-response study.

The response of chlorophyll and carotenoids under conditions of low N and N+.

The pigment data are based on a fairly simple mechanism of logic, which is comparatively easy to re-create. Nitrogen is a direct structural constituent of the chlorophyll tetrapyrole ring and thus any treatment that increases the levels of nitrogen in the leaves such as NPK fertilisation will be more likely to increase chlorophyll a and b concentrations (21). There is another route, in which potassium acts, which involves the activation of enzymes in the biosynthesis of chlorophyll and ensures the integrity of the membrane, to which photosynthetic machinery relies. A third process is provided by humic acid: it increases the activity of antioxidant enzyme systems, which helps to inhibit the photo-oxidative breakdown of available chlorophyll, increasing the life of pigment under high-light and heat-stress conditions (9). The 82.6 percent increase in total chlorophyll in T8 is therefore probably a result of a conglomeration of increased synthesis due to NPK and less degradation due to HA two processes that complement each other and not overlap. This same increase in carotenoids is in line with this image, as carotenoids are in part photoprotective pigments and the production of carotenoids is regulated by similar nutritional signals. The extent to which the observed gain in pigment was proportional to fixation of photosynthetic carbon in the pigment would not have been directly determined in this experiment and would be an interesting addition in the future to experiments involving gas exchange or fluorescence.

4.5 Yield and Qualitative Composition of Essential Oil.

Phosphorus and potassium not only favor growth, but also actively mould terpene biosynthetic apparatus. Phosphorus regulates the amount of IPP and DMAPP, phosphorylated precursors, which supply both the MEP and the MVA pathways, and potassium regulates the activity of terpene synthase by membrane potential and cytosolic PH gradient (5). In this perspective, the 60.5% increase in essential oil content between T1 and T8 is not as alarming as it may seem: it is an effect of increase in precursor availability in the upstream that inevitably spreads to the accumulation of the end-products. More interesting is the change in composition- linalool increasing to 48.3 percent and minor unknowns becoming undetectable in T7 and T8-indicating that the conditions with abundant nutrients favor not only the increase of the flux along the terpene pathway, but also its reorientation towards the commercially popular oxygenated monoterpenes. Similar trend was observed by Al-Jubouri et al. (2024) in coriander (32). Zheljazkov et al. (30) however, make us aware that this response is cultivar-specific in 38 accessions of basil, and cv. Genovese might be especially receptive; experimenting with other cultivars with the same fertilisation regime would enhance the overall validity of this finding.

4.6 Practical Implications

Based on these findings, T8 - NPK at 100 kg ha -1 plus foliar humic acid at 3.0 g L -1 - seems to be the most effective agronomically viable fertilisation program to use in the semi arid environment of central Iraq in production of sweet basil. Maximising the NPK rate (T4) is better than just maximising the yield and oil quality because it provides higher yields and high quality oil, and the medium to high input in minerals of the process lowers the risk of nitrate leaching, as well as reduces the cost of fertilisers. The incidental field observation that more humic acid treated plants seemed more robust during the extreme heat episode captured during the study contributes to an additional practical rationale as to why it is included, especially with climate projections indicating that in the next several decades the climate of Iraq will experience more and more heat episodes of the kind. A number of questions, however, are yet to be answered before this recommendation can be said to be fully determined: the economic break-even point of application of humic acid under conditions of varying rainfall in comparison with the oil price premiums it produces, the optimum frequency of application of humic acids and their timing in relation to phenological, and how this fertilisation regime interacts with irrigation management under varying rainfall conditions - all of which must be

5. CONCLUSION

NPK fertilisation with foliar humic acid was always found to be better than each of the inputs individually in all the parameters studied in this research, such as vegetative growth, pigmentation of leaves, herb yield and essential oil productivity. T8 (NPK of 100 kg ha -1 + humic acid of 3.0 g L -1) resulted in the most impressive results: fresh aerial weight increased more than two times compared with the unfertilised control, total chlorophyll increased by 82.6% and essential oil yield showed 47.3 L ha -1, oil content increased to 0.61% FW - a change Use of GC-MS analysis analysed a commercially favourable compositional change with the linalool and eugenol increasing in concert with the fertilisation. There are two subsidiary findings that are worthy of note: humic acid used alone, without mineral fertiliser, came close to the performance of intermediate NPK rates, which indicates that there is real potential in using HA at 3.0 g L -1, but not 1.5 g L -1, as an operationally significant rate; and the large improvement between T7 and T8 indicates that 3.0 g L -1, but

Based on these findings, T8 seems to be the most appropriate agronomical management method of fertilisation in the commercial production of basil in Salah al-Din and other governorates with a similar climate. The stress-buffering hypothesis of the role of humic acid based on field observations during a severe heat event at the experimental site is another reason why this acid should be included in fertilisation programmes in the ever-harsher summer environment of Iraq.

The open-ended questions that will still be posed, which are the economic break-even point of HA application, the best timing in relation to crop phenology and how it interacts with irrigation management give a clear agenda of the follow up field trials.

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