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RESEARCH ARTICLE

Fertigation studies on physiological parameters and yield attributes in nutmeg (*Myristica fragrans* Houtt)

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Abstract

A field experiment was conducted to study the influence of fertigation of N, P and K fertilisers along with micronutrients on the physiological parameters of Nutmeg (*Myristica fragrans*. Houtt) variety Vishwasree at Tamil Nadu Agricultural University, Coimbatore. Nutmeg is a neglected spice and needs special attention to boost its yield. The present study proved that the fertigation of water-soluble fertilisers could enhance the yield. The fertigated plants especially with water-soluble fertilisers along with micronutrients were better in physiological states at vegetative, flowering and fruit development stages of crop growth than plants fertilised through conventional methods. Among the treatments, a 100% recommended dose of fertilisers as Water-Soluble Fertilisers (WSF) along with micronutrients through drip irrigation increased the physiological parameters *viz*., specific leaf weight, maximum up to 4.7 mg cm^{-2} at the fruit development stage, total chlorophyll content, maximum up to 2.6 mg g^{-1} in the vegetative stage and declined towards maturity stage, nitrate reductase (9.7 NO g^{-1} h^{-1}) up to the flowering stage, IAA oxidase (41.4 µg $g^{-1}h^{-1}$) at the fruit development stage and maximum peroxidase activity at the fruit development stage (3.28 at 430 nm $min^{-1}g^{-1}$) for both the seasons. The results revealed that the seed yield (1326.00 and 1357.20 kg ha^{-1}), mace yield (552.24 kg ha^{-1} and 561.60 kg ha^{-1}), pericarp yield (12158.91 kg ha^{-1} and 13136.58 kg ha^{-1}) were higher under the fertigation treatment with 100% water-soluble fertiliser along with micronutrients. This field experiment clearly proved that fertigation plays a major role in increasing the quantitative and qualitative yield.

Keywords

fertigation; nitrate reductase; nutmeg; peroxidase; physiological parameters

Introduction

A significant tree spice, nutmeg, is a member of the Myristicaceae family. It is native to Indonesia and can also be found in the Pacific Islands, India, Sri Lanka, the Philippines and the West Indies. Kerala, Tamil Nadu, Karnataka, Goa, Maharashtra, North East India and the Andaman Islands are among the places where the plant flourishes. The flowers are dioecious, drooping, pale yellow, fragrant, bell-shaped with a fleshy and waxy texture. The male and female inflorescences are similar glabrous and axillary cyme. The main axis is 1-1.5 cm long and usually unbranched. The pedicel is pale green. Nutmeg is a fruit with a single seed which makes it a drupe. This peculiar seed has many uses; mace, a dried aril and nutmeg, a dried seed, are 2 of the tree's distinctive spices. Both are used as medications and seasonings. *M. fragrans* essential oil is a colourless to pale yellow liquid with a pronounced spicy smell (1).

A member of the Myristicaceae family, nutmeg, is an important tree spice. Though it is originally from Indonesia, it is also found in the Philippines, the West Indies, India, Sri Lanka and the Pacific Islands. In India, the plant is found in North East India, Kerala, Tamil Nadu, Karnataka, Goa, Maharashtra and the Andaman Islands. *Myristica fragrans*, commonly known as nutmeg, is primarily cultivated in the tropical regions of Indonesia (particularly the Maluku Islands), with significant production also occurring in Grenada, India (mainly in the Kerala state), Sri Lanka and parts of the Caribbean, making these areas the major contributors to global nutmeg production; Indonesia remains the leading exporter of nutmeg, accounting for over 50% of the world's export. In India, "*Myristica fragrans*" (nutmeg) is primarily cultivated in the state of Kerala, with significant growing areas also in Tamil Nadu, Karnataka, Goa, Maharashtra and the Andaman & Nicobar Islands. The total cultivated area for nutmeg in India is around 23478 ha.

Nutmeg kernel oil yields varied from 5 to 15% (2). Sesquiterpenes (germacrene D and β-bergamotene), phenylpropene (eugenol, methyl eugenol and myristicin), monoterpenes (sabinene, β-pinene, β-terpineol, p-menth-8-en-1-ol and terpinen-4-ol) and other elements were the main components of MFEO. Sabinene, eugenol, myristicin, caryophyllene and β-myrcene were the main components of the leaf (3–5). The main components of mace were sabinene, α-pinene, β-pinene, D-limonene and 3-carene. Sabinene, α-pinene, β-pinene, D-limonene and β-myrcene were the main components of the kernel and seed (6). Nutmeg thrives when interplanted with coconut and areca nut. Fertigation not only provides precise and timely nutrient supply but also prevents contamination of groundwater resources, which promotes ecological security and economic gain (7).

Fertigation is currently widely used in underdeveloped nations after gaining acceptance in wealthier nations. With the least amount of labour, this method might greatly aid in the effective and consistent application of fertiliser and water. The only effective way to control these resources is through fermentation. Applying fertiliser at the right time and in accordance with crop demand is thought to be crucial. To increase fertiliser use efficiency, water-soluble fertilisers and irrigation water are applied close to the root zone based on crop needs. Water-soluble fertilisers have just entered the market. Because of their increased solubility, fewer applications are needed and they can be applied with ease using a drip system to increase their effectiveness.

With this background in mind, the study compared the effects of the farmer's practices (surface irrigation plus soil application of RDF) on the physiological parameters of nutmeg while examining different quantities of fertilisers and micronutrients.

Materials and Methods

The study was undertaken at a farmer's field in Devanurpudur, Udumalpet Taluk, Tamil Nadu. The experiment was laid out with 10 treatments replicated 3 times in a randomised block design. The treatment includes T_1- 100% RDF as soil application (300:300:960 g NPK plant^{-1} year) with flood irrigation (control), T_2 - 100% RDF as soil application without micronutrients, T_3 - 75% RDF as straight fertilisers through drip irrigation + micronutrients, T_4 - 100% RDF as straight fertilisers through drip irrigation + micronutrients, T_5 - 125% RDF as straight fertilisers through drip irrigation + micronutrients, T_6 - 100% RDF as straight fertilisers through drip irrigation + without micronutrient, T_7 - 75% RDF as water-soluble fertilisers through drip irrigation + micronutrient, T_8- 100% RDF as water-soluble fertilisers through drip irrigation + micronutrient. T_9 - 125% RDF as water-soluble fertilisers through drip irrigation micronutrient and T_{10} - 100% RDF as water-soluble fertilisers through drip irrigation + without micronutrients. For individual leaf measurements, the fourth leaf from the apex of the matured branch was taken as an indicator leaf (15 leaves per tree). The leaf samples were analysed as per the standard procedures suggested. The soils of the experimental unit were clayey in texture, alkaline in nature with normal electrical conductivity, low in organic carbon and available nitrogen, medium in available phosphorus and fairly high in available potassium. Randomly, 5 plants per plot were chosen and analysed for the Total chlorophyll content (8), specific leaf weight (9), Nitrate reductase activity (10), IAA oxidase activity (11) and Peroxidase activity (12, 13). Data were statistically analysed by the standard procedure (14).

Results

Specific leaf weight

The specific leaf weight was significantly influenced by fertigation at vegetative, flowering and fruit development and fruit maturity stages in both years. Among the different treatments, 100% RDF through fertigation along with micronutrients registered the highest specific leaf weight of 3.47, 4.01, 4.62 and 4.12 g cm^2 in 2011 and 3.51, 4.11, 4.67, 4.09 g cm^2 in 2012 during vegetative, flowering, fruit development and fruit maturity stages, respectively (Fig. 1). It was followed by T_7 (75% RDF through fertigation along with micronutrients), which recorded 3.25, 3.76, 3.89 and 3.73 g cm^2 and 3.32, 3.83, 3.96 and 3.78 g cm^2 in 2011 and 2012, respectively at all the stages of crop growth. The lowest specific leaf weight was recorded by absolute control (T10) in 2011 and 2012 (2.45, 2.65, 2.80 and 2.59 g cm^2 and 2.51, 2.67, 2.82 and 2.62 g cm^2) at all the stages of crop growth. Pooled mean values showed that the application of 100% RDF through fertigation along with micronutrients recorded the highest specific leaf weight (3.49, 4.06, 4.65 and 4.10 g cm^2) at vegetative, flowering, fruit development and fruit maturity stages respectively for both the years.

Total chlorophyll content

The data on the total chlorophyll content of the leaf revealed a steady increase in the vegetative stage followed by a slight decline at flowering, fruit development and fruit maturation stages, respectively. The entire nutrient levels applied through fertigation strongly influenced the leaf chlorophyll content throughout the growth stages in 2011 and 2012. A significant difference was observed among the treatments for

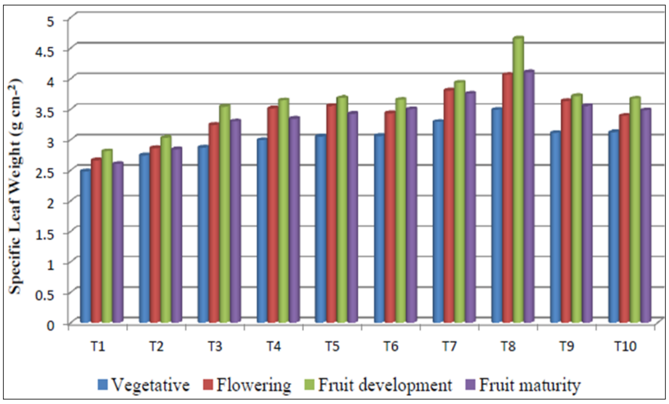

Fig. 1. Effect of fertigation on specific leaf weight at different growth stages of nutmeg.

the total chlorophyll content of leaves. Application of 100% RDF through fertigation along with micronutrients registered the total chlorophyll content (2.47, 2.23, 2.16 and 2.10 mg g^{-1} and 2.72, 2.57, 2.45 and 2.28 mg g^{-1}) in both the years. It was followed by T_7 (2.42, 2.21, 2.13 and 2.06 mg g^{-1} and 2.68, 2.51, 2.41 and 2.25 mg g^{-1} in 2011 and 2012, respectively, at vegetative, flowering, fruit development and at fruit maturity stages of crop growth and found on par with T_8. While the lowest total chlorophyll content was registered in absolute control (1.86, 1.63, 1.49 and 1.07 mg g^{-1} and 1.90, 1.74, 1.59 and 1.32 mg g^{-1}) in 2011 and 2012, respectively, at vegetative, flowering, fruit development and fruit maturity stages of crop growth (Table 1). Pooled mean values showed that the application of 100% RDF through fertigation along with micronutrients recorded the highest total chlorophyll (2.60, 2.40, 2.31 and 2.19 mg g^{-1}) at vegetative, flowering, fruit development and fruit maturity stages respectively, in both the years.

IAA oxidase

IAA oxidase, an auxin-degrading enzyme, showed an increasing trend from the vegetative stage to the fruit development stage with a decrease at the fruit maturity stage. Significant differences in IAA oxidase activity among the treatments at all stages of crop growth were observed. Application of 100% RDF through fertigation along with micronutrients (T_8) recorded the highest IAA oxidase activity in leaves (37.63, 39.23, 41.40 and 38.11 g unoxidised auxin g^{-1} h^{-1} and 34.63, 38.17, 41.44 and 38.18 g unoxidised auxin g^{-1} h^{-1} in 2011 and 2012, during vegetative, flowering, fruit development and at fruit maturity stages of crop growth, respectively). It was followed by the treatment T, which recorded the IAA oxidase activity in leaves (36.83, 38.13, 40.34 and 37.65 g unoxidised auxin g^{-1} h^{-1} and 33.97, 38.01, 41.05 and 36.73 g unoxidised auxin g^{-1} h^{-1} in 2011 and 2012, respectively), at all the stages of crop growth. The lowest IAA oxidase activity of leaves was registered by T10 (Control) (17.15, 19.12, 21.22 and 18.41 g unoxidised auxin g^{-1} h^{-1} and 16.43, 19.45, 21.96 and 19.21 unoxidised auxin g^{-1} h^{-1} in 2011 and 2012, respectively) at all the stages of crop growth (Table 2).

Pooled mean values showed that the application of 100% RDF through fertigation along with micronutrients recorded the lowest IAA oxidase activity (36.13, 38.70, 41.42 and 38.15 g unoxidised auxin g^{-1} h^{-1}) at vegetative, flowering fruit development and fruit maturity stages, respectively, in both the years.

Nitrate reductase

The data recorded on 'nitrate reductase activity' of leaves at different stages revealed significant differences among the different fertigation treatments. On comparison of the performance of the treatments, it was found that treatment T_8 recorded the highest nitrate reductase activity at all the stages of crop growth during both the years viz., 2011 and 2012 (3.46, 9.71, 9.66 and, 9.54 and 3.51, 9.78, 9.52 and 9.49 g NO g^{-1} h^{-1}) at vegetative, flowering fruit development and 7 fruit maturity stages of crop growth. It was followed by T_7 (75% RDF through fertigation along with micronutrients) which registered nitrate reductase activity of 3.29, 9.02, 8.97 and 8.90 g NO g^{-1} h^{-1} and 3.35, 9.15, 9.06 and 9.04 g NO g^{-1} h^{-1} in 2011 and 2012 respectively, at all the stages of crop growth. The lowest nitrate reductase activity of 1.96, 5.04, 4.95 and 4.44 g NO g^{-1} h^{-1} and 2.07, 5.52, 5.47 and 5.09 g NO g^{-1} h^{-1} in 2011 and 2012, respectively, was noticed in control at all the stages of crop growth (Fig. 2). Pooled mean values showed that the application of 100% RDF through fertigation with micronutrients (T_8) recorded the highest nitrate reductase activity (3.49, 9.75, 9.59 and 9.52 g NO g^{-1} h^{-1}) at vegetative, flowering, fruit development and fruit maturity stages, respectively, in both the years.

Peroxidase activity

The results showed a steady increase in peroxidase activity from the vegetative to the fruit development stage (Fig. 3) with a slight reduction at the fruit maturation period. At all stages of crop growth, the peroxidase enzyme activity was significantly influenced by all the treatments. The treatment T_8 (100% RDF through fertigation along with micronutrients) registered the highest peroxidase activity (3.20, 3.24, 3.28 and

Table 1. Effect of fertigation on Total Chlorophyll Content at different growth stages of nutmeg

Treatments	Total Chlorophyll Content (mg g^{-1})											
	Vegetative			Flowering			Fruit development			Harvest		
	Season I	Season II	Pooled mean	Season I	Season II	Pooled mean	Season I	Season II	Pooled mean	Season I	Season II	Pooled mean
T1	1.86	1.90	1.88	1.63	1.74	1.69	1.49	1.59	1.54	1.07	1.32	1.20
T_2	2.02	2.27	2.15	1.95	2.14	2.05	1.81	2.08	1.95	1.25	1.96	1.61
T_3	2.17	2.35	2.26	1.97	2.23	2.10	1.85	2.15	2.00	1.37	2.03	1.70
T4	2.19	2.42	2.31	1.99	2.33	2.16	1.89	2.22	2.06	1.48	2.08	1.78
T5	2.24	2.44	2.34	2.00	2.36	2.18	1.97	2.24	2.11	1.56	2.11	1.84
T_6	2.28	2.47	2.38	2.07	2.4	2.24	1.99	2.3	2.15	1.63	2.17	1.90
T7	2.42	2.68	2.55	2.21	2.51	2.36	2.13	2.41	2.27	2.06	2.25	2.16
T8	2.47	2.72	2.60	2.23	2.57	2.40	2.16	2.45	2.31	2.10	2.28	2.19
T9	2.3	2.31	2.31	2.09	2.21	2.15	2.03	2.12	2.08	1.87	2.01	1.94
T10	2.27	2.41	2.34	2.10	2.29	2.20	2.01	2.17	2.09	1.84	2.05	1.95
Sed	0.050	0.057	0.035	0.045	0.055	0.037	0.046	0.053	0.039	0.039	0.051	0.032
CD (P=0.05)	0.106	0.120	0.070	0.095	0.116	0.743	0.098	0.114	0.079	0.827	0.105	0.064

Table 2. Effect of fertigation on IAA oxidase activity at different growth stages of nutmeg

Treatment	IAA Oxidase Activity (µg of unoxidised auxin g^{-1} h^{-1})											
	Vegetative			Flowering			Fruit development			Harvest		
	Season I	Season II	Pooled mean	Season I	Season II	Pooled mean	Season I	Season II	Pooled mean	Season I	Season II	Pooled mean
T1	17.15	16.43	16.79	19.12	19.45	19.29	21.22	21.96	21.59	18.41	19.21	18.81
T2	23.76	22.14	22.95	25.15	24.65	24.90	27.91	28.06	27.99	24.25	26.24	25.25
T3	26.23	23.17	24.70	28.57	25.32	26.95	30.11	28.12	29.12	26.22	25.27	25.75
T4	27.72	23.21	25.47	29.81	25.39	27.60	31.29	29.04	30.17	28.54	27.23	27.89
T5	28.12	24.02	26.07	30.05	27.14	28.60	32.26	30.15	31.21	29.23	28.47	28.85
T6	2838	26.45	27.42	30.07	29.03	29.55	33.24	32.08	32.66	30.14	29.22	29.68
T7	36.83	33.97	35.40	38.13	38.01	38.07	40.34	41.05	40.70	37.65	36.73	37.19
T8	37.63	34.63	36.13	39.23	38.17	38.70	41.40	41.44	41.42	38.11	38.18	38.15
T9	29.52	25.04	27.28	31.14	28.07	29.61	32.44	31.26	31.85	29.84	29.15	29.50
T10	28.02	27.11	27.57	29.95	29.10	29.53	31.97	31.14	31.56	28.62	29.54	29.08
Sed	0.6979	0.6232	0.4678	0.7388	0.6936	0.5067	0.7895	0.76	0.54	0.7187	0.7041	0.5031
CD (P=0.05)	1.4655	1.3087	0.9403	1.5514	1.4565	1.0184	1.6580	1.60	1.105	1.5098	1.4787	1.0112

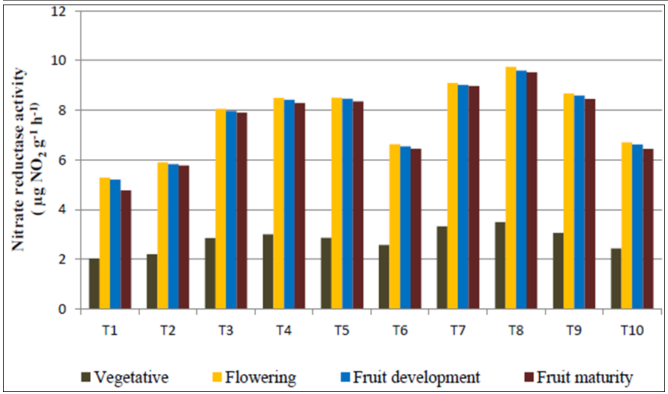

Fig. 2. Effect of fertigation on nitrate reductase activity at different growth stages of nutmeg.

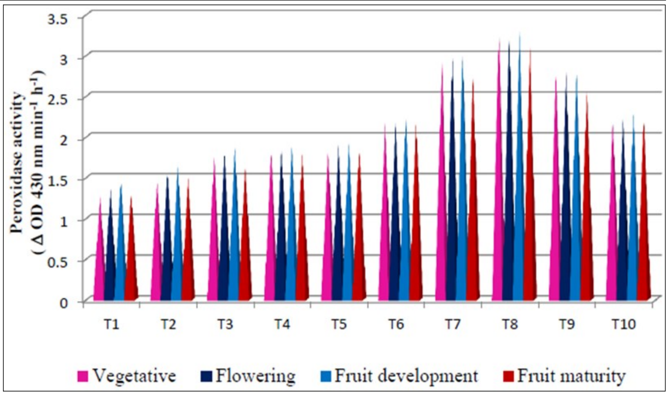

Fig. 3. Effect of fertigation on peroxidase activity at different growth stages of nutmeg.

3.08 Δ OD at 430 nm min^{-1} h^{-1} and 3.27, 3.28 3.29 and 3.10 Δ OD at 430 nm min^{-1} h^{-1}) in 2011 and 2012 at vegetative, flowering, fruit development and fruit maturity stages, respectively. It was followed by, the treatment T_7, (75% RDF through fertigation along with micronutrients) registered the highest peroxidase activity (2.93, 2.97, 3.00 and 2.75 Δ OD at 430 nm min^{-1} h^{-1} and 2.95, 2.94, 3.02 and 2.81 Δ OD at 430 nm min^{-1} h^{-1}) in 2011 and 2012 at vegetative, flowering fruit development and fruit maturity stages, respectively. Whereas, the lowest peroxidase activity registered by absolute control (1.25, 1.32, 1.44 and 1.29 Δ OD at 430 nm min^{-1} h^{-1} and 1.27, 1.38, 1.47 and 1.32 Δ OD at 430 nm min^{-1} h^{-1}) in 2011 and 2012, respectively, at vegetative, flowering, fruit development and fruit maturity stages. Pooled mean values showed that the application of 100% RDF through fertigation along with micronutrients recorded the highest peroxidase activity (3.24, 3.26, 3.28 and 3.09 Δ OD at 430 nm min^{-1} h^{-1}) at vegetative, flowering, fruit development and fruit maturity stages, respectively, in both the years.

Estimated seed yield

Estimated seed yield per tree differed significantly among the treatments. Treatments involving water soluble fertilisers invariably produced higher estimated seed yield than straight fertilisers. Application of 100% recommended dose of water-soluble fertilisers along with micronutrients (T_8) recorded the highest estimated seed yield of 1326.00 kg ha^{-1} in 2011 and 1357.20 kg ha^{-1} in 2012 (Table 3). The recommended dose of fertilisers through soil application registered the lowest estimated seed yield of 546 kg ha^{-1} in 2011 and 530.40 kg ha^{-1} in 2012. Application of 75% recommended dose of water-soluble fertilisers along with micronutrients (T_7) recorded significantly higher estimated seed yield of 1266.72 kg ha^{-1} and 1301.04 kg ha^{-1} in 2011 and 2012, respectively. The pooled mean also revealed significant variations among the treatments. The treatment (T_8) (Application of 100% recommended dose of water-soluble fertilisers along with micronutrients through drip registered the highest estimated

Table 3. Effect of fertigation on estimated yield of nutmeg

Treatments	Estimated Seed yield (kg ha^{-1})			Estimated Mace yield (kg ha^{-1})			Estimated Pericarp yield (kg ha^{-1})		
	2011	2012	Pooled mean (2011 & 2012)	2011	2012	Pooled mean (2011 & 2012)	2011	2012	Pooled mean (2011 & 2012)
T_1	546.00	530.40	538.20	188.76	187.20	187.98	5735.97	5997.60	5866.79
T_2	577.20	580.32	578.76	273.00	274.56	273.78	7152.75	7377.66	7265.21
T_3	733.20	748.80	741.00	468.00	502.32	485.16	8962.74	10289.25	9626.00
T_4	858.00	889.20	873.60	499.20	531.96	515.58	9394.20	10235.70	9814.95
T_5	780.00	811.20	795.60	510.12	517.92	514.02	9623.70	10564.65	10094.18
T_6	686.40	717.60	702.00	391.56	408.72	400.14	9039.24	9669.60	9354.42
T_7	1266.72	1301.04	1283.88	527.28	541.32	534.30	11444.40	11881.98	11663.19
T_8	1326.00	1357.20	1341.60	552.24	561.60	556.92	12158.91	13136.58	12647.75
T_9	1232.40	1248.00	1240.20	517.92	535.08	526.50	10133.19	10810.98	10472.09
T_{10}	717.60	733.20	725.40	452.40	468.00	460.20	9438.57	10312.20	9875.39
Sed	21.852	22.448	15.664	11.351	11.760	8.172	230.139	248.390	124.560
CD (0.05)	45.889	47.142	31.485	23.837	24.697	16.426	483.512	521.856	245.364

seed yield of 1341.60 kg ha^{-1}.

Estimated mace yield

Variations in estimated mace yield due to fertigation treatments were observed in both years of the experimentation. Fertigation with water-soluble fertilisers recorded higher mace yield as compared to soil application of fertilisers. Fertigation with a 100% recommended dose of water-soluble fertilisers along with micronutrients recorded the highest estimated mace yield of 552.24 kg ha^{-1} in 2011 and 561.60 kg ha^{-1} in 2012. This was followed by the application of a 75% recommended dose of water-soluble fertilisers along with micronutrients), which recorded an estimated mace yield of 527.28 kg ha^{-1} and 541.32 kg ha^{-1} in 2011 and 2012, respectively. During both years, soil application of fertilisers recorded the lesser estimated mace yield as compared to all other treatments. The pooled mean analysis also indicated significant variations among the treatments. The highest estimated pooled mean mace yield of 556.92 kg ha^{-1} was recorded in T_8.

Estimated pericarp yield

Fertigation significantly increased the estimated pericarp yield over soil application of fertilisers. Application of 100% recommended dose of RDF through water-soluble fertilisers along with micronutrients (T_8) recorded the highest estimated pericarp yield of (12158.91 kg ha^{-1}) and (13136.58 kg ha^{-1}) in 2011 and 2012, respectively. This was followed by which registered an estimated pericarp yield of 11444.40 kg ha^{-1} in 2011 and 11881.98 kg ha^{-1} in 2012. Soil application of the recommended dose of fertilisers registered the lowest estimated pericarp yield in 2011 (5735.97 kg ha^{-1}) and in 2012 (5997.60 kg ha^{-1}). Pooled mean also indicated a similar trend and T8 recorded the highest mean estimated pericarp yield of 12647.75 kg ha^{-1}.

Discussion

Effect of fertigation on physiological parameters

Fertiliser industry is considered to be a source of natural radionuclides and heavy metals that may affect the accumulation in soil and plant systems. Plants absorb the fertilisers through the soil; they can enter the food chain. Thus, fertilisation leads to water, soil and air pollution (15, 16). The metrics of yield and quality are intimately linked to physiological characteristics. According to reports, there is a strong positive association between leaf photosynthesis and Specific Leaf Weight (SLW), a measure of leaf thickness (T_7). One reliable measure of a leaf's ability to photosynthesize is its specific leaf weight. Thicker leaves have a higher photosynthetic capability than thinner leaves in many crop species because they contain more mesophyll cells with a high density of chlorophyll. The plants that received NPK at 100% level through fertigation using water-soluble fertiliser had the highest specific leaf weight in the current study, while the plants that received NPK at the conventional technique had the lowest.

There has already been a report on the beneficial impact of leaf weight on yield. By storing more palisade cells, fertigation may improve photosynthetic efficiency, which in turn may increase specific leaf weight. One measure of a plant's metabolic efficiency is the amount of chlorophyll in its leaves, which is crucial in determining the rate of photosynthesis. In reaction to nutrients provided through fertigation, this pigment, which is in charge of capturing solar energy and transforming it into chemical energy, shows a distinct pattern in its accumulation. Chlorophyll content observations showed that water-soluble fertilisers were more effective than straight fertilisers at raising total chlorophyll concentrations.

Drip fertilisation with a 100% recommended dose of WSF had a significant impact on the amount of chlorophyll in the leaves. When compared to earlier stages, the concentration of chlorophyll was higher during the vegetative stage. This rise may have resulted from improved vegetative development brought on by improved nutrient intake and water absorption, both of which are closely linked to chlorophyll biosynthesis. This result is consistent with the previous reports on mango (18, 19). In a similar vein, fertigated banana plants showed an early increase in chlorophyll concentration (20). Enhanced photosynthetic efficiency and robust crop growth are closely correlated with higher concentrations of photosynthetic pigments brought on by greater absorption of available nutrients in olive trees (21). Previous researchers have also documented the phenomenon of higher chlorophyll content with increasing nutrition, as seen in the current study (22). Nitrate reductase's enzymatic conversion of nitrate to nitrite is the primary nitrogen assimilation mechanism in crop plants. As a result, nitrite is later converted to ammonia, which then joins the keto acids to create amino acids and ultimately, proteins. However, moisture stress negatively impacts nitrate reductase activity; drought resistance may be linked to the stability of enzyme activity during moisture stress.

One frequent occurrence that impacts protein production is a reduction in nitrate reductase activity brought on by moisture stress. However, the current study found that fertigation treatment with 100% of the authorised amount of NPK had increased nitrate reductase activity. The high intake of water and nutrients may have resulted in an increased supply of moisture and nitrogen. By applying water and nutrients at regular intervals, the drip fertigation method keeps the soil moist and prevents the trees from experiencing soil moisture stress, which leads to heightened nitrate reductase activity and a physiologically active condition. Researchers on Mango also found that this enzyme was necessary for the consumption of nitrogen and that high activity was associated with high yield and protein content (23). The current study's findings showed that fertigation-applied N fertiliser had a stronger effect on raising nitrate reductase activity. Since nitrate reductase was a substrate-induced enzyme, its activity rose with an increase in N content (24). Indole acetic acid (IAA) is one of the growth hormones that control the apical dominance and initiation of vegetative and floral buds. The enzyme that breaks down auxin through oxidation is called IAA oxidase. IAA production is influenced by the amounts of zinc and the amino acid tryptophan in the leaves.

Consequently, a decrease in auxin levels due to increased IAA oxidase activity results in slower tree development. IAA oxidase enzyme activity was consistently highest in plants that were given 100% RDF as WSF through fertigation in addition to micronutrients. The same thing happened with coffee as well (25). The current study also showed that a low amount of IAA, which indicates increased enzymatic activity, was found in soil applied with 100% RDF without micronutrients. In plants with lower soil nutrient availability, especially zinc, IAA production may not have been adequate to promote IAA oxidative metabolism. Peroxidase activity was another metric that was impacted by the fertigation techniques. The enzyme peroxidase is found in plants and at the cell wall; it has a role in the formation of lignin (26). According to the current study, applying a 100% recommended amount of water-soluble fertilisers and micronutrients in both years significantly increased the activity of the peroxidase enzyme. This might have something to do with the reactive oxygen species' scavenging mechanisms. Another element of a plant's early defense against pathogen and pest attacks is peroxidase, which is also essential for the manufacture of lignin, which restricts the spread of disease. When hydrogen peroxidase, the enzyme's product, was present, it exhibited antibacterial and even antiviral properties. One of the main elements of both systemic and local disease resistance is believed to be the rise in peroxidase activity. Furthermore, the majority of the harm done to cellular compartments may be attributed to the production of reactive oxygen species.

Detoxifying enzymes such as catalase and peroxidase were activated in response to stress in order to counteract its negative effects and control physiological and metabolic functions.

Effect of fertigation on yield and yield components

A complicated characteristic, yield, is the result of multiple yield-attributing traits. The application of 100% RDF as WSF together with micronutrients by fertigation resulted in a notable improvement in nut weight and mace weight, which in turn led to a remarkable enhancement in nutmeg seed yield and mace yield expressed as kg tree^{-1} and kg ha^{-1} in the current experiment. The significant size of nuts (seed) and mace, which ultimately led to an increase in their yield, may have been directly influenced by a variety of physiological processes, including increased uptake of water and nutrients, photosynthetic rate, vigorous growth, efficient translocation and partitioning of assimilate towards the reproductive sink. In addition to the yield of seeds and mace, the pericarp yield was also successfully increased.

Mangoes that were fertigated with water-soluble fertilisers at the recommended dosage likewise showed comparable outcomes (27). In the present study, the specific leaf weight was highest in the plants which received NPK at 100% level through fertigation using water-soluble fertiliser and it was the least conventional method. An instance of the positive influence of leaf weight on yield has been already reported (28-30). The increase in specific leaf weight by fertigation could be directly related to better photosynthetic efficiency by stocking more palisade cells (31). The notably low yield seen with the traditional fertiliser administration strategy may be the consequence of inadequate nutrient availability, which leads to reduced photosynthetic efficiency, assimilate accumulation and dry matter production.

Seed weight and mace weight were 2 important factors that contributed to the nutmeg's economic worth. In addition to these commercial attributes, the pericarp weight also plays a role in their economic worth, such as in the production of pickles. The fertigation treatments in the current investigation had a direct impact on these parameters. In comparison to the traditional way of fertiliser administration, fertilisation with the nutrient level of 100% of the required dose of WSF coupled with micronutrients produced the maximum seed and mace weight, increasing by a factor of 2. The availability of necessary nutrients in the soil is directly responsible for the notable rise in economically viable components. This resulted in increased growth, leaf weight, nutrient uptake, improved photo assimilation and improved assimilate translocation from source to sink, all of which raised the yield of mace and nuts (seed).

Conclusion

In light of the results obtained from this investigation, it can be concluded that to get higher physiological parameters of Nutmeg, the crop should be fertilised with 100% water-soluble fertiliser along with micronutrients.

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Authors' contributions

VG conducted the field trial and collected the data. SM drafted the entire manuscript, checked for plagiarism and finalized it according to the journal guidelines. MK helped in the data analysis. SKN provided technical support.

Compliance with ethical standards

Conflict of interest: The authors do not have any conflict of interest to declare.

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