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Establishment of Mineral Nutritional Requirement for Some Important Medicinal and Aromatic Plants in Climatic Conditions of Northern India

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ABSTRACT

Exploiting the healing power of plants has been a human practice since prehistoric times. To meet the ever-increasing demand of medicinal plants, cultivation of these plants on scientific principles is the only solution. Mineral nutrients are indispensable for the growth and development of plants as their deficiency limits crop production significantly. Like other plants, medicinal plants also require mineral elements for their growth and development. However, all species do not require the same complement of minerals in the same amounts; in fact, the differences between species are much less variable than those between the amounts of specific minerals within a single species. With a view of improving yield and quality (active constituents) of medicinal and aromatic plants (MAPs), the mineral nutritional requirement of several MAPs in an Indian climate was calculated. The work was conducted in pots as well as in the field, supplying graded levels of the nutrients to the soil along with proper controls. This review provides information regarding the optimum requirement of N, P and K in Indian climatic conditions for the following MAPs: *Anethum sowa*, *Cichorium intybus*, *Curcuma Longa*, *Cymbopogon flexuosus*, *Datura innoxia*, *Foeniculum vulgare*, *Lallemantia royleana*, *Linum usitatissimum*, *Mentha arvensis*, *Nigella sativa*, *Plantago ovata*, *Solanum nigrum*, *Tigonella foenum-graecum*, *Withania somnifera* and *Zingiber officinale*.

Keywords: active constituents, enzymes activities, MAPs, mineral nutrients, quality, yield

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INTRODUCTION

By the dramatic advancement in conventional medicine established so far, it is clear that herbal medicines offer an unparalleled opportunity to relieve disease symptoms and save lives. Cultivation of these plants on scientific lines is a major source of continued and authentic supply of the medicinal plant products. As true for other crop plants, mineral nutrients are indispensable for the growth and development of the MAPs because they limit the crop production directly if not supplied in appropriate amounts and proportions (Wallace and Wallace 2003). There are 20 essential elements reported till date (MMAK; **Fig. 1**) that are essential for plant growth and development. The research work on the N, P and K requirement of the MAPs was started several decades ago at the Botany Department, Aligarh Muslim University, Aligarh (India). The concerted efforts carried out in this regard revealed that the mineral nutrients applied either basally or through leaves, not only improved the growth and yield of the MAPs, but also proved a potential tool to obtain the herbal production of desired quality.

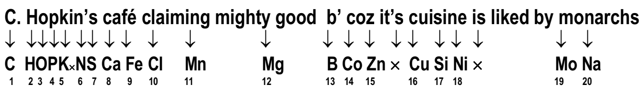

Fig. 1 A mnemonic to memorize 20 essential elements for plants.

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Invited Review

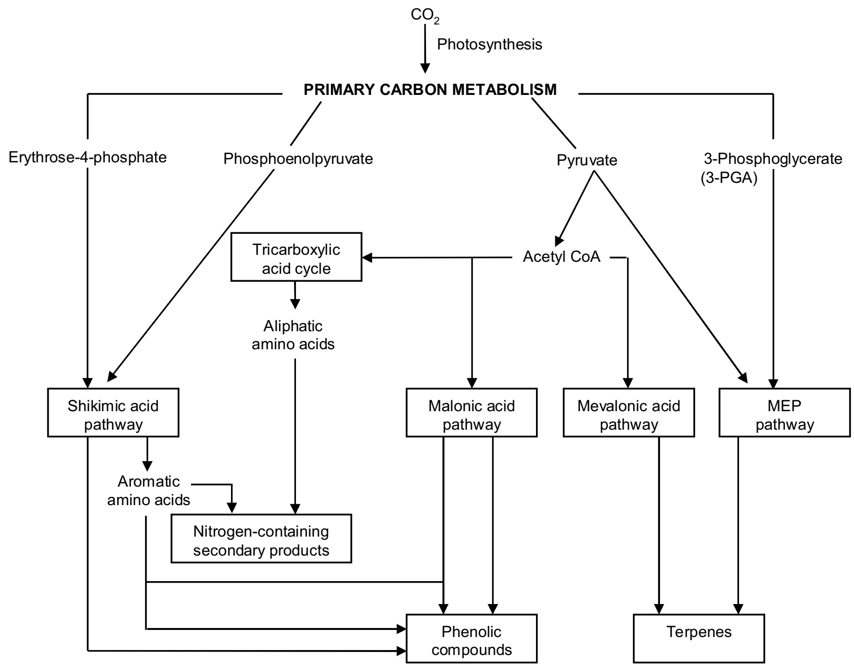

Fig. 2 Major pathways of secondary-metabolite biosynthesis and their interrelationships with primary metabolism. Based on and modified from **Taiz L, Zeiger E** (2006) *Plant Physiology* (4th Edn), Sinauer Associates, Inc., Publishers, USA, 700 pp

Medicinal plants produce diverse assortment of organic constituents (**Fig. 2**). Since the earlier time, herbs have been appreciated for their pain relieving and healing abilities and people still rely on the curative properties of plants in about 75% of the human ailments. Over centuries, people around the world have developed their own traditions to make sense of medicinal plants and their uses. Many of the thousands of species, growing throughout the world, have medicinal uses; they contain active constituent that have healing action on the body (Robbers *et al.* 1996). They are used both as raw herbs and as herbal products/conventional medicines in order to combat illness and support the body's defense system to regain good health. However, the herbal medicines, available in the market, do not have desired quality. Even authenticity of herb-products is doubtful for various reasons. One of the best alternatives to this situation is the cultivation of these plants on scientific lines. This will not only augment the yield and quality of the MAPs, but also will ensure their steady supply in the market. Therefore, it is essential to undertake systematic studies regarding the mineral/fertilizer requirements of the MAPs, at least of those whose supply is not keeping pace with their increasing demand (Handa and Kaul 1996; ICAR 2002; Farooqi and Sreeramu 2003). There are sixty-plus factors that can limit crop production; however, soil fertility (mineral nutrients requirement) is top-leading factor after the water-demand of crop plants (Wallace and Wallace 2003). Mineral nutritional requirement of the macro-elements is an important aspect of plant-production as these elements are required in the synthesis of cell structural units (e.g. carbon in cellulose), incorporation in organic molecules (e.g. magnesium incorporation in chlorophyll), activation of enzymes (e.g. utilization of Mg^{++} ions in glucose degradation in cellular respiration) and balancing the osmotic potential of the cells (e.g. use of K^+ ions in guard cells for stomatal functioning). Foliar application of nutrients (the application of nutrient-solutions on plants and their subsequent absorption by the plant parts, especially by the leaves) is an alternative method for the administration of fertilizers (Boynton 1954; Wittwer and Teubner 1959). This nutrient-feeding technique has also been applied on medicinal plants (Khan 1986; Khan *et al.* 1987; Husain 1988; Khan 1988; Khan *et al.* 1992, 1999). However, literature on the foliar fertilization of the MAPs is meager. Work done at Aligarh regarding soil-applied and/or foliage-applied nutrients on the MAPs has been discussed in this review (**Table 1**), employing the following plants.

Black nightshade or *mako* (*Solanum nigrum* L.)

The medicinal use of black nightshade or *mako* (*Solanum nigrum* L.; Family Solanacae) is recommended as a cardiac tonic and as alterative, diuretic, sedative, expectorant, cathartic and anodyne agent. The decoction of its leaves is used in dropsy, chronic enlargement of liver and jaundice. The extract of entire plant is also prescribed in chronic skin diseases, blood-spitting, piles, inflammation of kidney and bladder and gonorrhea. Berries of the plants are alterative and diuretic along with their use in fevers, diarrhea and heart diseases. Berries contain a steroidal alkaloid, solasodine (Bradley *et al.* 1978; Schilling *et al.* 1992; Edmonds and Chweya 1997), which is commercially used as a precursor for the production of complex steroidal compounds used in contraceptive pills (Everist 1981). In order to work out the optimum requirement of nitrogen (N) and phosphorus (P) and to explore the effect of interaction of the two nutrients, three pot experiments were conducted in the natural environment of the net house.

Experiment 1 was conducted to work out the dose of N required for optimum vegetative and reproductive growth, and to explore the effect of N on leaf-N, -P and -K content, fruit-yield and -solasodine content (Khan 1986; Khan *et al.* 1995). N (as urea) was applied at 0, 0.45, 0.90, 1.35, 1.80 and 2.25 g/pot, each pot carrying 3.5 kg of soil. Seeds were planted in pots and plant samples were drawn at fortnight intervals for recording growth and yield parameters. In addition, fruit-solasodine content and leaf-N, -P and -K contents were also estimated at each sampling date. Application of N influenced all the parameters studied. In general, 1.80 g N/pot was the optimal N dose. In addition, fruit-solasodine was significantly correlated with leaf-N at different growth stages (r = 0.706, 0.622 and 0.670) (Afaq *et al.* 1985; Khan *et al.* 1997).

In Experiment 2, the effect of P was studied on the vegetative and reproductive growth of *S. nigrum* (Khan 1986; Khan *et al.* 2000). P (as single superphosphate) was applied at 0, 0.15, 0.30, 0.45, 0.60 and 0.75 g P/pot, each pot carrying 3.5 kg of soil. P significantly influenced most parameters, with 0.45 g P/pot proving optimal, in general. It was suggested that the fruits should be harvested between 160-190 days after sowing (DAS), preferably at 175 DAS, for maximum fruit-yield and solasodine production. Most

Table 1 A list of the effects of macro nutrient elements on the active constituents and quality attributes of selected medicinal plants studied in Indian climate (Aligarh).

Common name	Botanical name	Macro nutrients	Phytochemicals / active constituents	Quality attributes	Mode of experiment	Reference
Black nightshade	*Solanum nigrum*	N applied P applied	Solasodine content	-	Pot experiment Pot experiment	Khan 1986; Khan *et al.* (1995), Khan *et al.* (1991, 2000)
Black Psyllium	*Lallemantia royleana*	P applied	-	See-swelling factor	Field experiment	Khan *et al.* (1999)
Chicory	*Cichorium intybus*	N applied	-	-	Field experiment	Wasiuddin *et al.* (1979)
Datura	*Datura innoxia*	P applied N and P applied	Alkaloids content Alkaloids content	-	Field experiment Pot experiment	Afaq *et al.* (1978) Nasir (2009)
Dill	*Anethum sowa*	N and P applied	Carvone content	Essential oil content	Field experiment	Khan *et al.* (1991)
Fennel	*Foeniculum vulgare*	N and P applied	Anethole, fenchone camphene and d-fenchone), methyl chavicol	Essential oil content	Field experiment	Khan *et al.* (1992, 1999)
Fenugreek	*Tigonella foenum-graecum*	N and P applied	-	-	Field and pot experiments	Azam (2002)
Ginger	*Zingiber officinale*	N and P applied; Triacontanol	-	Rhizome carbohydrate and protein contents	Pot experiment	Singh (2008) Singh *et al.* (2012)
Kalonji	*Nigella sativa*	N applied	-	-	Field experiment	Khan 1991
Lemongrass	*Cymbopogon flexuosus*	N applied	Citral content	Oil content	Field experiment	Samiullah *et al.* (1988)
Linseed	*Linum usitatissimum*	P applied N applied N applied	oil content oil content oil content	iodine value iodine value iodine value	Field experiment	Mohammad (1989) Mohammad (1994) Mohammad *et al.* (1999)
Mint	*Mentha*	N and P applied	oil content	-	Pot experiment	Hashmi (2004)
Psyllium	*Plantago ovata*	N and P applied	-	See-swelling factor	Field and pot experiments	Azam (2002)
Turmeric	*Curcuma longa*	N and P applied	Curcumin content	Rhizome carbohydrate and protein contents	Pot experiment	Singh (2008)
Withania	*Withania somnifera*	N and P applied	Total alkaloids content	Leaf-protein content	Pot experiment	Nasir (2009)

of the parameters were consistently correlated with leaf-P content positively. The correlation between leaf-P content and fruit yield was highly significant (r = 0.888) at 40 DAS and between leaf-P content and solasodine yield at 175 DAS, suggesting timely corrective measures to be taken, using leaf-P content. Thus, if low leaf-P content is noted at 40 DAS, corrective measures like foliar application or top dressing with P may be adopted to increase the leaf-P content and, thereby, to ensure maximum yield and solasodine content of fruit at harvest.

Experiment 3 was conducted to study the individual and combined effects of N and P on different parameters (as measured in earlier two experiments). N was applied at 0.90 (control), 1.35, 1.80 and 2.25 g N/pot, while P was applied at 0.30 (control), 0.38, 0.45 and 0.53 g P/pot as basal dressing at the time of sowing. Samples were collected at harvest (175 DAS) (Khan *et al.* 1991). Application of 1.35 g N and 0.38 g P/pot was optimum N-P combination for almost all the characteristics studied. Compared with the control (0.90 g N and 0.38 g P/pot), number of fruits was increased by 35.4%, fresh weight by 27.6%, dry weight by 39.3%, fruit-solasodine content by 25.0% and solasodine yield by 76.6% as a result of application of 1.35 g N and 0.38 g P/pot. It was concluded that *Solanum nigrum* might be grown successfully in pot culture using 1.35 g of N (3.0 g of urea) and 0.38 g of P (5.0 g of monocalcium superphosphate)/pot.

Chicory or *kasni* (*Cichorium intybus* L.)

Although considered as weed, chicory or *kasni* (*Cichorium intybus* L.; Family Asteraceae) is cultivated for its food uses. It is eaten roasted and ground roots can be used as a substitute for coffee or an additive. Chicory has a long history of herbal use and is especially of great value for its tonic affect upon the liver and digestive tract. The root can be used fresh or dried; it is best harvested in the autumn. The leaves are harvested as the plant comes to flower, and the dried leaves may be stored for a later use. It is of little use in modern herbalism, though it is often used as part of the diet. The root and the leaves are added as ingredients in appetizer, cholagogue, depurative, digestive, diuretic, hypoglycemic, laxative and tonic preparations. The roots are more active medicinally. A decoction of chicory roots has proved beneficial for the treatment of jaundice, liver enlargement, gout and rheumatism. Decoction of the freshly harvested plant is used for treating gravel. The root extracts have experimentally proved to slow down and weaken the heart (pulse) rate; hence, the plant extract is administered for heart irregularities (Duke and Ayensu 1985; Foster and Duke 1990; The Wealth of India 1992; Petrovic *et al.* 2004; Mares *et al.* 2005; Nandagopal and Ranjitha Kumari 2007; Atta-ur-Rahman *et al.* 2008; Wang and Cui 2011).

Owing to so many important uses, a field trial was conducted on chicory to study the effect of five doses of basal N (0, 30, 60, 90, and 120 kg N/ha) (Wasiuddin *et al.* 1979). Shoot and root yields were studied at two stages during the crop span. Most of the growth and yield characteristics were affected significantly by N treatments, of which 90 kg N/ha proved optimum; whereas, the control (no application of N) gave the lowest values. However, the important productivity attributes, *viz.* fresh and dry weights of root, were maximally improved at 60 kg N/ha.

Datura or *dhatura* (*Datura innoxia* Mill.)

Leaves and flowering tops of datura or *dhatura* (*Datura innoxia* Mill.; Family Solanaceae) have narcotic and antispasmodic properties. It is a source of scopolamine alkaloid that is used as a pre-anesthetic agent in surgery, childbirth and ophthalmological treatments (Chopra *et al.* 1986; Duke 1992; The Wealth of India 1992). Afaq *et al.* (1978) studied the effect of different levels of P on the growth parameters and alkaloid content of *D. innoxia*. They concluded that the plant height as well as number of branches, fresh and dry weights and alkaloid content of leaves were significantly increased as a result of P levels (30, 60 and 90 kg P_2O_5/ha applied as monocalcium superphosphate) in comparison with the control. 90 kg P_2O_5/ha proved the best P dose for all the parameters studied. Rajgopal (1993), who also worked in the Botany Department, AMU, Aligarh, reported the enhancement in the physio-morphological parameters of datura as result of vitamin B and C application.

A pot experiment was carried out by Nasir (2009) to find out the optimum dose of basal N for datura. N was applied at 0 (control), 15, 30, 45 and 90 mg N/kg soil (N_0, N_{30}, N_{60} and N_{90}, respectively) at 45 DAS. The crop was assessed in terms of growth attributes (shoot and root lengths per plant, leaf area per plant, shoot and root fresh weight per plant and shoot and root dry weights per plant), biochemical parameters (total chlorophyll (Chl) and carotenoids contents, leaf-N, -P and -K contents and activities of nitrate reductase (NR) and carbonic anhydrase (CA), seed-yield, yield attributes (capsules/plant, seeds/capsule, and 100-seed weight), and quality characteristics (total alkaloid content/plant). Level N_{60} proved the best among the doses of N tested for most of the growth, biochemical, yield and quality parameters; however, carotenoids content, P content, seeds/capsule and 100-seed weight were not significantly affected by N application. Treatment N_{60} significantly increased the seed-yield and total alkaloid content by 22.8% at harvest (at 210 DAS) and 11.1% at 120 DAS compared to the control.

Another experiment was also conducted by Nasir (2009), aiming at establishing the optimum basal dose of P for datura. P was applied at five levels, *viz*. 0 (control), 20, 30, 40 and 50 mg P/kg soil (P_0, P_{20}, P_{30}, P_{40} and P_{50}, respectively) applied at 45 DAS. The parameters studied and sampling stages, at which the data were recorded, were the same as stated above. Of the P levels applied, P_{40} proved optimum for all the growth, biochemical, yield and quality parameters studied, except carotenoids content, number of seeds/capsule and 100-seed weight that were not affected by the P levels significantly. Treatment P_{40} enhanced seed-yield by 22.7% at harvest (210 DAS) and total alkaloid content by 17.2% at 120 DAS, as compared to the control.

Nasir (2009) also carried out a pot experiment to find out the best combination of N and P in respect with the optimum concentration of triacontanol (TRIA) spray ($10^{-6.5}$ M) as determined in an earlier experiment. Four basal combinations of N and P, *viz*. 0 kg N + 0 kg P/ha (N_0P_0), $N_{30}P_{13}$, $N_{45}P_{26}$ and $N_{60}P_{40}$ were applied at 45 DAS, respectively. The plants were subjected to six fortnightly sprays of $10^{-6.5}$ M of TRIA. The treatments were designated as (i) N_0P_0 + $10^{-6.5}$ M (ii) $N_{30}P_{13}$ + $10^{-6.5}$ M (iii) $N_{45}P_{26}$ + $10^{-6.5}$ M and $N_{60}P_{40}$ + $10^{-6.5}$ M. The crop performance was assessed in terms of growth and biochemical parameters, yield characteristics and quality parameters. Of the four NP+TRIA treatments, $N_{60}P_{40}$ + $10^{-6.5}$ M proved the best one that enhanced all the growth, biochemical, yield and quality parameters, except carotenoids content, number of seeds per capsule and 100-seed weight, which were not affected by the treatments significantly. In addition, $N_{60}P_{40}$ + $10^{-6.5}$ M resulted in increased seed-yield (20.2%) and total alkaloid content (27.1%) over the control.

Dill or *soya* (*Anethum sowa* L.)

Dill or soya (*Anethum sowa* L.; Family Apiaceae) is a popular condiment. Its fruits are used as carminative, aromatic, stimulant and diuretic in indigenous system of medicine. Fruit-oil of soya is an important constituent of gripe water. The emulsion of the fruit-oil in water is useful in flatulence, colic pains, vomiting and hiccups. The chief oil-constituent of dill is carvone, a cyclic terpene ketone, which is very important pharmaceutically (Kirtikar and Basu 1975; Chopra *et al.* 1986; Singh *et al.* 2005; Yazdanparast and Bahramikia 2008). In order to work out the optimum mineral-nutrient requirement of dill, the following two experiments were performed at Aligarh.

Experiment 1 was conducted in the field to study the effect of four levels each of N (0, 40, 80 and 120 kg N/ha) and P (0, 15, 30 and 45 kg/P ha) applied in all possible combinations. The source of N and P was urea and single superphosphate, respectively. Six parameters, namely, fresh weight of shoot/plant, dry weight of shoot/plant, number of branches/plant, number of umbels/plant and number of umbellets/umbel, were noted at vegetative and reproductive stages. Besides, hectoliter weight and total yield of fruit were noted at harvest. Various N and P treatments had significant effect on the parameters studied. 80 kg N and 30 kg P/ha, applied individually, proved optimum for most of the parameters studied at all the growth stages. Combined application of N and P (N-P interaction) resulted in much more pronounced enhancement in the parameters studied (Afaq *et al.* 1984).

Experiment 2 was also conducted in the field on dill to work out whether foliar application of N and P nutrients could be economically feasible for improving plant yield and oil quality of dill. In this experiment, N and P were applied on the foliage alone as well as in combination, using the following treatment-scheme: Control (water spray; F_w), 20 kg N/ha (FN_{20}), 2 kg P/ha (FP_2) and 20 kg N + 2 kg P/ha ($FN_{20}P_2$). The scheme of basal N and P treatments was as follows: 80 kg N + 30 kg P/ha ($BN_{80}P_{30}$), 53 kg N + 20 kg P/ha ($BN_{53}P_{20}$) and 40 kg N + 15 kg P/ha ($BN_{40}P_{15}$). A uniform basal dose of 30 kg K/ha was also applied. The nutrient-spray was carried out at flowering stage. Among the basal doses, $BN_{80}P_{30}$ proved optimum for yield parameters. However, $BN_{40}P_{15}$ proved the best for essential oil and carvone contents. Among the spray treatments, $FN_{20}P_2$ gave maximum values for yield characteristics, but no single spray treatment proved optimum for quality characteristics. Regarding interaction effects, $BN_{53}P_{20} \times FN_{20}P_2$ proved the best for yield parameters and $BN_{40}P_{15} \times FP_2$ gave maximum values for essential oil and carvone content (Khan *et al.* 1991).

Fennel or *saunf* (*Foeniculum vulgare* Mill.)

Fennel or *saunf* (*Foeniculum vulgare* Mill.; Family Apiaceae) is used as a laxative, stomachic and carminative remedy. It is a stimulant for adults and is also used in prevention of colic in the infants. The leaves are reported to possess diuretic properties against hookworms. Both oil and fruits are recommended for eye diseases, burning sensation in the body, fever, thirst, wounds, dysentery and leprosy. An infusion of fruits in boiling water is employed as an enema for infants. Its fruits are used to increase lacteal secretions in women and to stimulate sweating. Fruits of fennel bear two pharmaceutically important compounds, anethole and fenchone. The fruits also contain iodine, vitamin A, thiamine, riboflavin, niacin and ascorbic acid in minute quantities (The Wealth of India 1992; Abed 2007; Agarwal *et al.* 2008; Kaur and Arora 2010). Due to the aforesaid importance of fennel, a good deal of work was conducted at Aligarh on the basal as well as foliar application of mineral fertilizers with regard to yield and quality of the plant. The detail of the work done is as follows.

Influence of three basal levels of N, P and K (0, 60 and 90 kg/ha, each of N, P_2O_5 and K_2O) was studied on growth characteristics (at 110 and 130 DAS) and yield (at harvest) of fennel (Experiment 1). Considering main effects, 90 kg N, 60 kg P_2O_5 and 90 kg K_2O/ha proved the best. Fruit yield was maximal in plants receiving 90 kg N or 90 kg P_2O_5/ha, whereas 60 as well as 90 kg K_2O/ha proved equally good. As a result of application of 90 kg each of N, P_2O_5 and K_2O/ha, the highest fruit yield was attained. These results were confirmed by a field experiment (Experiment 2), in which the effect of seven basal combinations of N and P_2O_5 (i.e. N_0P_0, $N_{90}P_{60}$, $N_{90}P_{90}$, $N_{90}P_{120}$, $N_{120}P_{60}$, $N_{120}P_{60}$ and $N_{120}P_{60}$) was explored on growth and yield attributes of fennel. Compared to control (N_0P_0), the N and P treatments enhanced shoot length, number of branches, fresh and dry weights and number of umbels/plant. Number of umbellets per umbel and fruit yield/plant also recorded significant in-

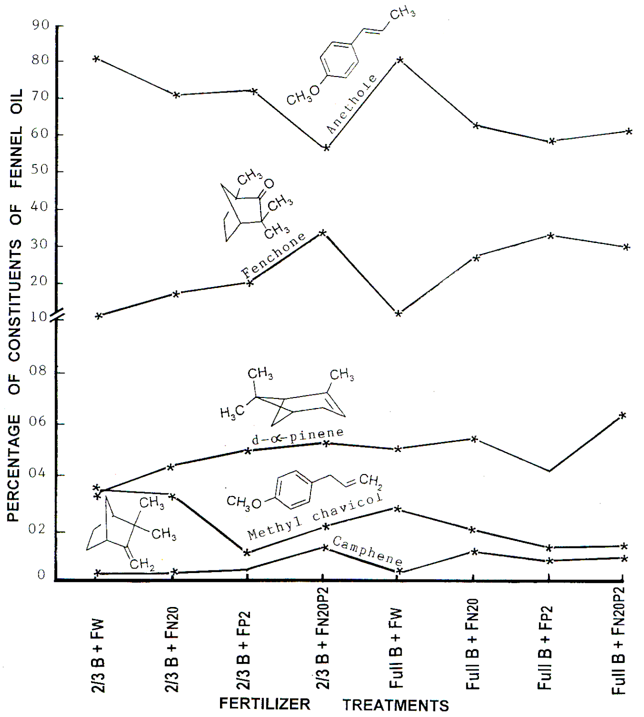

Fig. 3 Changes in essential oil constituents of fennel (*Foeniculum vulgare* Mill.) as influenced by N and P levels applied through soil and foliage. Anethole and methyl chavicol, being similar in structure, showed similar trends. Likewise, fenchone and camphene, belonging to the same group, resulted in similar trends. The figure indicates that the synthesis of anethole was at the expense of fenchone and *vice-versa*. However, d-α-pinene, having different structure showed a different trend. Thus the desired fennel oil constituent may be obtained by different types, levels and mode of mineral nutrition application to the crop. Unpublished.

crease over the control. Finally, it was confirmed that the treatment $N_{90}P_{60}$ (90 kg N + 60 kg P_2O_5/ha) was optimum for growth as well as yield attributes of fennel (Afridi *et al.* 1983, 1987).

One more field trial was conducted on fennel (Experiment 3) using the optimal basal dose of N, P and K [($N_{90}P_{40}K_{50}$); 90 kg P_2O_5/ha = 40 kg P/ha], brought out by the two field trials conducted on fennel as mentioned above, in order to work out whether supplemental foliar sprays of N and P solutions could further enhance the growth, yield and quality of fennel. The scheme of foliar N and P treatments was as follows: water spray (control), 20 kg N/ha, 2 kg P/ha or 20 kg N + 2 kg P/ha. The foliar treatments were applied with two basal fertilizer levels, *viz*., 90 kg N + 40 P/ha (optimal dose) and 60 kg N + 27 kg P/ha (sub-optimal dose). A basal dose of 50 kg K/ha was applied uniformly. Foliar spray was applied at the flowering stage (120 DAS). The essential oil of fennel was determined by GLC using SE-30 column. The optimal basal dose gave better results than did the sub-optimal one. Spray of 20 kg N + 2 kg P/ha proved optimum. This spray proved more effective at sub-optimal than at optimal basal dose. The percentage of anethole (but not of fenchone) in the essential oil was significantly higher in plants grown with the sub-optimal basal dose of N and P. On the other hand, foliar application of N, P and N + P decreased the anethole content of essential oil and increased that of fenchone significantly. Hence, it was suggested that foliar feeding might be employed in order to improve essential oil of fennel for perfumery and confectionary industries (Khan *et al.* 1992).

A correlation study between N-P treatments and different components of fennel essential oil was carried out on the basis of Experiment 3 (different components of fennel essential oil as affected by nutrient treatments are shown in **Fig. 3**). Camphene and d-fenchone (bicyclic terpenes), showed common trend (r = 0.87), with their contents being maximum with $FN_{20}P_2$ at both the basal levels (**Fig. 3**). Methyl chavicol and anethole (phenolic ethers) exhibited parallel trend (r = 0.56), with the control giving comparatively a higher values at both basal levels. However, there was a negative correlation between anethole and d-fenchone (r = -0.99), suggesting that the synthesis of the one was at the expense of the other. The trend of d-α-pinene was different and its content was maximal at $FN_{20}P_2$ regardless of basal levels. It was concluded that suitable combinations of basal and foliar N and P nutrients could be exploited to ensure higher seed-yield and improved component of essential oil of fennel (Khan *et al.* 1999).

Black cumin or *kalonji* (*Nigella sativa* L.)

Black cumin or *kalonji* (*Nigella sativa* L.; Family Ranunculaceae) is an important medicinal plant. The seeds are used for flavouring the pickles and marmalades. The seeds have carminative, stimulant, diuretic, emmenagogue, galactagouge properties and are used in treatment of mild cases of puerperal fever (Chatterjee and Pakrashi 1991; Khan *et al.* 1999). The extracts of seeds have shown anticancerous activity and proved much effective against Dalton's lymphoma ascites cells (Salomi *et al.* 1989; Ramadan and Moersel 2002; Ramadan 2007). The oil of *N. sativa* contains secondary plant products, *viz*. carvone, d-limonene, cymene and nigellone. Keeping these merits of *N. sativa* in mind, a field experiment was conducted to study the effect of three basal N doses, *viz*. 40, 80 and 120 kg N/ha, on growth and yield parameters (plant height, branch number, fresh weight, dry weight, number of flowers/plant, number of capsules/plant, number of seeds/capsule, hectoliter weight and seed-yield). 80 kg of N/ha proved the best for seed-yield as well as for yield characteristics. However, the effect of N application was not significant on growth parameters (Khan 1991).

Lemongrass or *izkhar* (*Cymbopogon flexuosus*)

Lemongrass or *izkhar* (*Cymbopogon flexuosus*; Family Poaceae) is one of the medicinally important essential oil bearing plants. The essential oil of lemongrass is rich in citral which is mainly used as a basic raw material for the manufacture of many aromatic compounds in pharmaceutical, perfumery and cosmetic industries (The Wealth of India 1992; Sharma *et al.* 2009). Experiment 1 was conducted in the field on lemongrass in connection with boosting up the essential oil yield and citral content, giving emphasis on leaf-N, -P and -K contents. The effect of eight levels each of N (150, 200, 250, 300, 350, 400, 450 and 500 kg N/ha) and P (0, 25, 50, 75, 100, 125, 150 and 175 kg P_2O_5/ha) was studied on leaf-N, -P and -K content of lemongrass (*C. flexuosus*), exercising three cuts during the research tenure. Applied N had a positive effect on leaf-N concentration at all the three cuts; while, leaf-K was significantly increased at the first and second cut only. Treatment with N_{200} (200 kg N/ha) at first and third cut and N_{250} (250 kg N/ha) at second cut resulted in maximum leaf-N content. The highest leaf-K content was recorded due to N_{300} (300 kg N/ha) at first cut and due to N_{500} (500 kg N/ha) at second cut. The effect of applied P on N, P and K content of leaves was significant at all the three cuts. The contents of the three nutrients (N, P and K) were increased appreciably up to P_{150} (150 kg P/ha) at first and third cut and up to P_{125} (125 kg P/ha) at second cut. It was concluded that leaf-N, -P and -K contents might be used as tools for assessing the N and P requirement of lemongrass (Samiullah *et al.* 1984).

Experiment 2 was also conducted in the field on lemongrass. The experiment was aimed at investigating the effect of basal application of eight doses of N (150, 200, 250, 300, 350, 400, 450 and 500 kg N/ha) on height of culms, number of leaves, weight of fresh and dry plants, herbage yield, content and yield of essential oil and citral content of oil. There were carried out three harvests at 120, 180 and 240 days after planting. The extraction of the oil from leaves was accomplished through steam distillation using Clevenger's apparatus. For estimation of citral content, gas chromatography was used. The pooled data of three cuts revealed that the effect of N application was significant on all the characteristics studied. It was inferred that N application benefited growth, yield and quality of lemongrass. Application of 300 kg N/ha proved the best for most parameters including essential oil and citral content (Samiullah *et al.* 1988).

Linseed or *alsi* (*Linum usitatissimum* L.)

Seeds of linseed or *alsi* (*Linum usitatissimum* L.; Family Linaceae), an important industrial crop, are used for the extraction of oil and the stem is used for the fibres. About 80% of linseed oil is used in oil industry and the remaining 20% is used for edible purpose (Verma *et al.* 2005). The stem fibre is used in the manufacture of canvas, coating, durries, shirting and strong twines. Its good quality fibre is used for linen production. The woody portion of stem, left after the removal of fibre, is a source of paper manufacture (Samba Murty and Subrahmanyam 1989). Besides, the seeds are useful in the treatment of gonorrhea, respiratory diseases, the diseases of genitor unitary organs, nephritis and cystitis. It is also useful in the treatment of colds, coughs, sore chest, and in throat and pulmonary ailments (Kirtikar and Basu 1987; Thompson *et al.* 2005; Chen *et al.* 2006; Pan *et al*. 2009).

Experiment 1 was conducted in the field to study the effect of five levels of P (0, 50,100,150 and 200 kg P_20_5/ha), applied basally as single superphosphate, on the yield of linseed var. LIK745. At the time of sowing, a uniform dose each of N (100 kg N/ha) and potassium (K) (25 kg K_2O/ha) was applied in the form of urea and muriate of potash, respectively. Application of P increased all the yield characteristics significantly. Among the P doses applied, P_{150} (150 kg P_2O_5/ha) proved the optimum one, enhancing the number of capsules/plant from 7.85 (in control) to 14.85. However, the number and weight of seeds/capsule were maximal in P_{200} (200 kg P_2O_5/ha). It was recommended that 150 kg P_2O_5/ha (or 68 kg P/ha) might be economical P dose for linseed cultivation (Samiullah *et al.* 1982).

Experiment 2 was conducted in the field on linseed (var. 'LHS-1') to work out the effect of basal application of P levels (10, 15, and 20 kg P/ha) in conjunction with supplemental application of P (0, 1, 2, and 3 kg P/ha) through foliage. Basal P was applied at the time of sowing as single dose, while foliar spray of P was carried out in two equal splits at 70 and 90 DAS. In addition, 100 kg N/ha was applied to the soil uniformly at the time of sowing. Number of capsules/plant, number of seeds/capsule, hectoliter weight, seed-yield, content and yield of oil, and iodine value of oil were studied at harvest. The P treatments affected all the parameters significantly. 15 kg P/ha as basal dressing and 1 kg P/ha as foliar spray proved the optimum basal and foliar dose of P, respectively. The two P doses (basal and foliar), applied together also gave the highest values for most of the parameters studied. Such a combined application of P (P_{basal} + P_{foliar}) gave 11.6% more seed-yield and 14.6% more oil yield compared with the control (grown with basal P applied at 15 kg P/ha + water spray) (Mohammad 1989).

Experiment 3 was also conducted in the field on linseed (var. 'LHS-1'), applying four levels of basal N (25, 50, 75 and 100 kg N/ha) and three levels of foliar N (0, 10 and 20 kg N/ha). Except number of seeds/capsule, P application affected all the yield and quality parameters significantly. Of the four basal P levels, 50 kg N/ha proved optimum for most characters, while 10 kg N/ha brought out to be the best foliar treatment of P. The interaction 50 kg basal N/ha × 10 kg foliar N/ha resulted in maximum yield of linseed (Mohammad 1994).

Experiment 4 was also conducted in the field employing four newly released varieties of linseed, *viz*. 'Garima;, 'Mukta', 'Neelam' and 'Shubhra', to study the effect of five levels of basal N (0, 30, 60, 90 and 120 kg N/ha) on growth and yield attributes. Effect of interaction between N dose and cultivar (N × cv) was significant on many parameters including seed-yield. Application of 90 kg N/ha on 'Neelam' and 'Shubhra' cultivars gave the highest values for all the parameters studied (Mohammad *et al.* 1999).

Mint or *podina* (*Mentha arvensis* L.)

The plant mint or *podina* (*Mentha arvensis* L.; Family Lamiaceae) is of immense medicinal properties. It is used as stimulant, tonic, vermifuge, anti-spasmodic, diaphoretic, stomachic, carminative, antiviral, antifungal, antibacterial and choleretic agent. Japanese mint is primarily grown for methanol content extracted from its essential oil. The mint oil has wide application in pharmaceutical, therapeutic, agrochemical and flavor-products industries all over the world (The Wealth of India 1992; Tassou *et al*. 2004). Apart from menthol, mint oil contains many valuable terpenes and other minor constituents. Menthol has refreshing aroma and cooling effect; in addition, it has stimulating and antiseptic properties that has promoted its wide-spread medicinal uses like those in inhalers, ointments, pain balms, cough syrups, cough lozenges tablets and in many other health-care formulations. Moreover, the oil is directly used as flavoring agent and is an ingredient in several medicinal preparations (Misra *et al.* 2000; Akram *et al.* 2011).

Six pot experiments were conducted on Japanese mint, employing various basal N and P levels. 90 kg N/ha applied with 30 kg P/ha proved the best for most of the growth, physiological and yield attributes of the crop. Using PGRs gibberellic acid (GA_3) and kinetin (Kn) along with basal N and P application, it was worked out that the best combination of N + P + phytohormones was 90 kg of basal N/ha + 30 kg of basal P/ha + foliar application of 10^{-4} M of GA_3 for maximum growth and productivity of mint (Hashmi 2004).

Psyllium or *isubgol* (*Plantago ovata* Forsk.)

Isubgol or *isubgol* (*Plantago ovata* Forsk.; Family Plantaginaceae) is widely used for its mucilaginous seed and its husk. It is known to grow well in Sind (Pakistan). The husk and seeds are laxative and have proved very effective for chronic dysentery, habitual constipation and diarrhea (Dastur 1977; Tewari *et al.* 2001; Meyers 2008).

Experiment 1 was a field experiment conducted to study the effect of (1) 20 and 40 kg of basal P/ha (BP) supplemented with foliar spray (FS) of water (control) and that of 1, 2 or 4 kg P/ha, and (2) 20 kg BP/ha supplemented with top-dressing (T) of 10 or 20 kg P/ha on growth and yield attributes of isubgol. All the treatments received a uniform basal dressing of 20 kg/ha each of N and K at the time of sowing. Treatment BP_{20} + FS_2 improved the seed-yield by 74% compared with BP_{40} + water spray. In addition to seed-yield, the treatment also improved the seed quality together with a saving of 18 kg P/ha (Husain and Khan 2000).

Experiment 2 was conducted in pots as well as in field in order to investigate the effect of best combination of soil-applied N and P on agricultural performance of isubgol. Out of several N-P combinations, $N_{60}P_{30}$ (60 kg N + 30 kg P/ha) proved the best fertilizer dressing for growth and other physiological parameters as well as for yield and quality attributes. It was the first report of its kind in respect with the effect of N and P application on such a large number of physiological parameters regarding this medicinally important plant. In Experiment 3, it was further confirmed that if 200 mg/L of gibberellic acid is sprayed on the foliage of the plant at flowering stage together with a basal dose of $N_{50}P_{25}$ (50 kg N + 25 kg P/ha), the productivity of the isubgol could be maximized successfully (Azam 2002).

Black Psyllium or *tukhm-e-balanga* (*Lallemantia royleana* Benth.)

Black Psyllium or *tukhm-e-balanga* (*Lallemantia royleana* Benth.; Family Lamiaceae) is used for chronic constipation and for softening stools in conditions such as hemorrhoids, cracks in the skin around the anus (anal fissures), surgery on the rectum, and pregnancy (Gupta 1982; Kirtikar and Basu 1987; Davidson *et al*. 1996; Wolever *et al.* 1999). It is also used for diarrhea, dysentery, irritable bowel syndrome (IBS), reducing high cholesterol, and treating cancer. In India, psyllium husk is used to make "Gulab Sat Isabgol", a medicinal product of psyllium. Psyllium mucilage is also used as a natural dietary fiber for animals (Modi *et al.* 1974; Mathur *et al.* 1990; WHO 1999; Rahimi *et al*. 2011).

A field experiment was conducted on Black Psyllium to determine whether foliar application of P (at 60 DAS) at 0, 1, 2 and 4 kg P/ha (F_w, FP_1, FP_2 and FP_4, respectively) or top-dressing of 10 and 20 kg P/ha (TP_{10} and TP_{20}, respectively) could improve the growth, yield and quality of the crop. A uniform basal dose of 20 kg/ha each of N and K was applied at sowing. P was applied basally at 40 kg P/ha (recommended P dose) in control 1 ($BP_{40} + F_w$) and at 20 kg P/ha in the remaining treatments, including the control 2 ($BP_{20} + F_w$); both the controls were sprayed with de-ionized water. At full bloom stage, the plants were examined for length of root, fresh weight of root, dry weight of root, length of shoot, fresh weight of shoot, dry weight of shoot, number of branches/plant, and number of buds/branch. At harvest, the seed-yield, biological yield and seed-swelling factor were recorded. Most of the vegetative parameters were generally improved by $BP_{20} + FP_2$, $BP_{20} + Fp_4$ and $BP_{20} + TP_{10}$. Yield characters and seed-swelling factor fetched maximum value due to $BP_{20} + FP_2$ and $BP_{20} + FP_4$. It was concluded that foliar spray of only 2 kg P/ha on plants, supplied with half of the recommended P dose at sowing, might be optimum, saving the phosphatic fertilizer significantly (Khan *et al.* 1999).

Withania or *ashwagandha* (*Withania somnifera* L.)

Withania or *ashwagandha* (*Withania somnifera* L.; Family Solanaceae) is a medicinal plant grown in different parts of India, including Aligarh. It is locally known as Ashwagandha. The leaves and roots of the plant are used for the treatment of rheumatoid arthritis, cough, dropsy, female disorders, ulcers and scabies (Chopra *et al.* 1958; Kirtikar and Basu 1975; Mishra *et al.* 2000; Mirjalili *et al.* 2009; Ahmad *et al.* 2010; Singh *et al.* 2010; Ven Murthy *et al.* 2010; Nasreen and Radha 2011).

In Experiment 1, the effect of four levels of N (0, 30, 60 and 90 kg/ha) was investigated on physio-morphological parameters of withania, conducting a pot experiment at the Department of Botany, A.M.U., Aligarh. All the doses of N proved effective in enhancing the parameters studied. However, 90 kg N/ha resulted in maximum growth, Chl content, NR activity, leaf-protein content and leaf-N content as compared to other N doses (Singh *et al.* 2005).

Experiment 2 was also conducted on withania in order to explore the effect of P application on the growth attributes and contents of Chl and carotenoids. Four basal doses of P (0, 20, 40 and 60 kg P_2O_5/ha) were applied at the time of sowing. Sampling was done at 120 DAS. Values of all the parameters were significantly increased due to basal application of P as compared to the control. Among the P treatments, 60 kg P_2O_5/ha proved the best for all the parameters studied. Fresh weight, dry weight, number of leaves, dry weight of leaves and leaf area/plant were significantly increased by 25.31, 46.30, 31.44, 28.11 and 21.28%, respectively due to 60 kg P_2O_5/ha. In addition, 60 kg P_2O_5/ha increased total Chl and carotenoids contents by 15.50 and 17.00%, respectively, over the control. It was concluded that 60 kg P_2O_5/ha was the best P dose for the growth attributes as well as for total Chl and carotenoids contents of the crop (Singh and Naeem 2004).

Nasir (2009) conducted a pot experiment to find out the requirement of basal N for withania. N was applied at 45 DAS at the rate of 0 (control), 15, 30 and 45 mg N/kg soil (designated as N_0, N_{30}, N_{60} and N_{90}, (i.e. equivalent to 0, 30, 60 and 90 kg N/ha) respectively). The crop was assessed in terms of growth parameters (shoot and root length/plant, leaf area/plant and weights of fresh and dry shoot and root/plant), biochemical parameters (total Chl and carotenoids contents, leaf-N, -P and -K contents, and activities of NR and CA), seed-yield, yield attributes (berries/plant, seeds/berry, 100-seed weight, and root yield) and quality characteristics (total alkaloid content). The growth, biochemical and quality parameters were studied at 60, 120 and 180 DAS, respectively. Yield characteristics were studied at harvest (210 DAS). N_{45} proved the optimum N rate that gave maximum values for most of the growth, biochemical, yield and quality parameters. Contrarily, the carotenoids content and leaf-P content, at all the stages of growth, while number of seeds/berry and 100-seed weight at harvest, were not significantly affected by N rates. Application of N_{45} increased seed-yield and total alkaloid contents by 23.5% at harvest (210 DAS) and by 17.3% at 120 DAS compared to the control. The highest root-yield was attained due to N_{30}.

Nasir (2009) conducted another pot experiment*,* aiming at establishing the optimum basal dose of P for withania. P was applied at 45 DAS at the rate of 0 (control), 6.5, 13 and 20 mg P/kg soil (designated as P_0, P_{13}, P_{26} and P_{40}, (i.e. equivalent to 0, 13, 26 and 40 kg P/ha, respectively). The parameters studied and the sampling stages were the same as stated above. The application of P improved most of the parameters except carotenoids content, number of seeds per berry and 100-seed weight. Out of four P basal levels, P_{26} proved the best for all the growth, biochemical, yield and quality parameters studied. Treatment P_{26} increased the seed-yield by 23.0% at 210 DAS and total alkaloid content by 15.3% at 120 DAS, as compared to the control. The root yield was also improved by 22.2% compared to the control.

Nasir (2009) also carried out a pot experiment to find out the best combination of N and P in respect with the optimum concentration of TRIA spray ($10^{-6.5}$ M) as determined in an earlier experiment. Four basal combinations of N and P, *viz*. 0 kg N + 0 kg P/ha (N_0P_0), $N_{30}P_{13}$, $N_{45}P_{26}$ and $N_{60}P_{40}$ were applied at 45 DAS. The plants were subjected to six fortnightly sprays of $10^{-6.5}$ M of TRIA. The treatments were designated as (i) $N_0P_0 + 10^{-6.5}$ M (ii) $N_{30}P_{13} + 10^{-6.5}$ M (iii) $N_{45}P_{26} + 10^{-6.5}$ M and $N_{60}P_{40} + 10^{-6.5}$ M. The crop performance was assessed in terms of growth and biochemical parameters, yield characteristics and quality parameters. Of the four treatments, $N_{45}P_{26} + 10^{-6.5}$ M of TRIA proved the best that enhanced all the growth, biochemical, yield and quality parameters, except carotenoid content, seeds/berry and 100-seed weight, which were not affected by the aforementioned treatments. The application of $N_{45}P_{26} + 10^{-6.5}$ M of TRIA significantly increased seed and root yield and total alkaloid content over the control.

Ginger or *adrak* (*Zingiber officinale* Rosc.)

Ginger or *adrak* (*Zingiber officinale* Rosc.; Family Zingiberaceae) is valued in medicine as a carminative and stimulant of the gastrointestinal tract. It is an important antioxidative, antitumorigenic, antimicrobial and antiviral agent (Akoachere *et al.* 2002; Ippoushi *et al*. 2003; Borrelli *et al.* 2004; Ghaly *et al*. 2009; Malu *et al*. 2009; Choudhury *et al*. 2010; Rehman *et al*. 2011). Ginger is used both in fresh and dried forms. Dry ginger is the raw material for ginger powder, essential oil and oleoresins. Essential oil and oleoresin represent the aroma and flavour of ginger, respectively, and thus determine the quality of ginger.

Singh (2008) conducted a pot experiment on ginger to study the effect of five basal levels of N, *viz*. 0 (control), 40, 80, 120 and 160 kg N/ha, on growth characteristics (plant height, number of leaves/plant, number of tillers/plant, leaf length and breadth and shoot fresh weight, rhizome fresh weight, shoot dry weight and rhizome dry weight), biochemical parameters (Chl content, leaf-N, -P and -K contents, rhizome-N, -P and -K contents, and the contents of seed-carbohydrate and -protein) and yield attributes (primary fingers/plant, secondary fingers/plant and rhizome yield/plant) of ginger. A recommended basal dose of P and K (22 kg P and 42 kg K/ha) was also applied uniformly at the time of sowing. The growth and biochemical parameters were studied at 120 and 180 DAS while the yield attributes were recorded at harvest (240 DAP). It was concluded that application of N might successfully enhance most of the characteristics studied, with 120 kg N/ha giving the highest values.

Singh (2008) conducted another pot experiment on ginger, aiming at exploring the optimum dose of basal P out of five P levels, *viz.* 0 (control), 10, 20, 30 and 40 kg P/ha for growth and development of ginger. A uniform dose of N (120 kg N/ha) and the recommended dose of K (42 kg K/ha) was also applied basally. Application of P significantly increased most of the attributes studied, with 30 kg P/ha resulting in the highest values.

Singh (2008) conducted yet another pot experiment on ginger to study the effect of five levels of foliar spray of TRIA, *viz.* 0 (control; deionized water), $10^{-7.0}$, $10^{-6.5}$, $10^{-6.0}$ and $10^{-5.5}$ M on the performance of ginger grown with a uniform basal dose of N and P (120 kg N + 30 kg P/ha) as determined from previous experiment together with the recommended basal dose of K (42 kg K/ha) so as to establish the best foliar-spray dose of TRIA. The performance of the crop was studied in terms of growth characteristics, biochemical parameters and yield and quality attributes. The spray of TRIA at $10^{-6.0}$ M improved most of the characters, with $10^{-6.0}$ M of TRIA registering the maximum values.

Turmeric or *haldi* (*Curcuma longa* L.)

Turmeric or *haldi* (*Curcuma longa* L.; Family Zingiberaceae) is also a medicinal plant. It is extensively used in Ayurveda, Unani and Siddha medicines as a home remedy for various diseases (Ammon and Wahl 1991; Eigner and Scholz 1999). It is used as a household remedy as anti-inflammatory, antiseptic and anti-irritant in the form of thin paste on skin. Curcumin, the main yellow bioactive component of turmeric has been shown to have a wide spectrum of biological actions (Araújo and Leon 2001; Luthra *et al.* 2001; Shukla *et al*. 2002; Chattopadhyay *et al*. 2004; Sunilson *et al*. 2009; Naz *et al*. 2010; Seo *et al*. 2011). Turmeric has also been found to possess hepatoprotective and hepatotoxic activity (Deshpande *et al*. 1998).

Singh (2008) conducted a pot experiment to find out the optimum basal dose of N for *Curcuma longa*. N was applied at 0 (control), 30, 60, 90 and 120 kg N/ha. The crop performance was adjudged in terms of growth characteristics (plant height, number of leaves/plant, number of tillers/ plant, leaf length and breadth/plant, shoot fresh weight, rhizome fresh weight, shoot dry weight and rhizome dry weight/plant), biochemical parameters (Chl content, leaf-N, -P and -K contents, rhizome-N, -P and -K contents, and carbohydrate and protein contents), yield attributes (primary and secondary fingers/plant and rhizome yield/plant) and quality parameters (curcumin content). The crop also received a uniform recommended basal dose of P and K (13 kg P and 50 kg K/ha). Growth characteristics and biochemical and quality parameters were studied at 120 and 180 DAS while yield attributes were recorded at harvest (240 DAP). Application of N resulted in enhanced values for most of the parameters, with 90 kg N/ha proving optimum.

Another pot experiment was conducted by Singh (2008) to establish the optimum basal dose of P for turmeric. P was applied at 0 (control), 15, 30, 45 and 60 kg P kg/ha. Recommended basal dose of N and K (90 kg N and 50 kg K/ha) was also applied uniformly. The crop response was assessed on the same parameters as studied above. Application of P enhanced most of the characteristics studied, with 40 kg P/ha proving the best.

Yet another pot experiment was conducted on turmeric to investigate the effect of five foliar spray of TRIA, *viz.* 0 (control; deionized water), $10^{-7.0}$, $10^{-6.5}$, $10^{-6.0}$ and $10^{-5.5}$ M on the same parameters studied as above in order to select the best TRIA concentration. The crop also received a uniform recommended basal dose of N, P and K (90 kg N, 45 kg P and 50 kg K/ha). Application of TRIA improved values for most parameters, with $10^{-6.0}$ M giving the highest values (Singh 2008).

CONCLUSIONS

Each essential nutrient element plays a specific role (sometimes in combination with one or more nutrient elements) in plant growth and metabolism. However, N, P and K are considered separately as they are removed by most of the crops in relatively much larger quantities. N has a pronounced influence on plant growth and development and, hence, all the economically important medicinal crops have recommended N rates for optimal yield. Applying N in excess of the plant requirements may increase chances of N losses to the environment; therefore, proper application of N fertilizer (and that of other mineral nutrients) is important for nutrient management. The growth, yield and quality (active constituents) of the medicinal plants may be significantly stimulated by N, P and K application as the threshold quantities of these macronutrients might activate the enzymes required in different metabolic processes. N can also affect the phytonutrient contents in plants (Chenard *et al.* 2005). According to Mozafar (1993), N fertilization increased, decreased, or had no effect on vitamin and carotene contents of several vegetable species. Thus, the replenishment of the nutrient elements through their external application is imperative for healthy crop growth and profitable economical returns. In most of the studies presented in this review, the macronutrients (N, P and K) resulted in augmentation of growth and productivity of various medicinal plants. Hence, the recommended fertilizer dose might be used for their maximum production. On the other hand, the percent content of the active constituents might be either increased or decreased in response to application of these macronutrients. Because of the reported contradictions of N rate on plant quality, fertilization studies to determine optimal yield should also address chemical quality factors (Hochmuth *et al.* 1999). In such a situation, one has to decide the type, level, and mode of fertilizer application (soil or foliar application) for the optimum output of the desired active constituent. The circumstances may be very different in developed countries where often heavily fertilized plants are produced and consumed as compared with the developing countries where plants are often grown with no or sub-optimal fertilizer doses.

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