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REGULAR ARTICLE

CROP RESPONSES TO INTERACTION BETWEEN PLANT GROWTH REGULATORS AND NUTRIENTS

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SUMMARY

In the present review a number of examples has been made to cover the aspects of interactions of phytohormones and nutrients in the growth and development of plants which include plant height, leaf area, leaf area index, dry weight, plant growth rate, relative growth rate, crop growth rate, net assimilation rate, carbon dioxide exchange rate, chlorophyll content, photosynthesis, photosynthetically active radiation, ethylene evolution, nitrate reductase activity, carbonic anhydrase activity, nutrient accumulation, nitrogen uptake efficiency, nitrogen use efficiency, nitrogen utilization efficiency, fertilizer use efficiency, productive use efficiency, nutrient use efficiency, seed yield, seed yield merit, seed N content, nitrogen yield merit, merit of genotype biological yield, biological yield, harvest index, oil yield, oil content, acid value, iodine value and saponification value. So the present study indicates that the process of growth and development in addition to the yield of plants is significantly affected by the phytohormones along with nutrients in both irrigated and non -irrigated conditions has been described in detail.

Key words: Plant hormones, Nutrients, Growth, Physiological, Biochemical, Nitrogen efficiency, Yield, Quality characteristics

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1. Introduction

History of civilization begins with the evolution of agrarian societies. The practice of agriculture is several thousand years old and practical discussions of crop production goes back to at least 2000 years ago, even then, agriculture faces many challenges worldwide. In many regions production needs to be expanded to provide food for growing population, while in others, current production levels have to be maintained while striving for the right balance between intensive agriculture and environmental concerns. The production of oilseeds in India is one of those areas which need to be addressed seriously. The languid production of oilseeds has converged the attentions of agricultural scientist to innovate and implement the improvised methods for boosting the yield, through proper nutrition, plant protection measures and high yielding varieties improved agronomic practices, maintaining internal hormonal balance and source-sink relationship. The traditional agricultural economy heavily relies on organic manure but could not meet the demands of rising populations and, therefore, greater efficiency in agriculture is required. In this, context, inorganic nutrients, which is concerned with acquisition of mineral elements from the soil, found to be immensely remarkable. The green revolution of India owes much to this form of nutrition. Now, when we are on the verge of entering into the era of Ever Green Revolution, the investigations regarding application of nutrients need to be thoughtfully considered, which has largely been ignored.

In this context, it may be emphasized that work carried out in relation to nutrient is voluminous and it is known that application of only few nutrients (viz., N, P and K) alter the availability and uptake of other nutrients, therefore a balanced fertilization is very important. Sulphur an important plant nutrient is generally not applied to the plants except in the case of application of phosphorus in the form of single super phosphate (SSP) or gypsum. But sulphur, a major component of oil and protein structure found to enhance both the yield and quality of oilseed crops (Pasricha *et al.,* 1988; Lakkineni and Abrol, 1992; Dubey *et al.,* 1994; Yadav *el al*., 1996). Along with proper nutrition, if plants are supplied with any other chemical, which can improve the yield then that will be an additional benefit for the farmers. One such group of chemicals is thought to be the plant growth regulators.

Plant growth regulators

A phytohormone or plant hormone may be defined as an organic substance other than a nutrient, active in very minute amounts which are formed in certain parts of the plant and which are usually translocated to other sites, where it evokes specific biochemical, physiological and/or morphological responses. Thus plant growth regulator is organic substances which in low concentration promotes, inhibits or modify growth and development, whereas growth inhibitor is an organic compound that retards growth generally. Hence, all hormones are plant growth substances i.e. natural plant products but opposite is not true. The precise location of synthesis of phytohormones is uncertain out actively growing leaves, fruits and developing seeds are thought to be the active sites of synthesis of phytohormones. However, it appears that all tissues have the potential to produce any of the phytohormones, which are transported via the xylem or phloem and by diffusion such as in the case of ethylene. They occur in plants as free and conjugated forms. The latter are conjugates of sugars, amino acids and possibly peptides. The free forms are generally considered to be biologically active, while conjugates are viewed as functioning in controlling levels of the more active free forms transport and storage. But phytohormones a major component of oil and protein structure found to enhance both the yield and quality of oilseed crops (Khan, 1996a; Khan, 1997; Khan *et al*., 1997 b; Khan, 1998; Khan *et al*., 2002 b; Lone *et al*., 2005; Mir *et al*., 2009 a). The plant hormones are extremely important agent in the integration of developmental activities. Environmental factors often exert inductive effects by evoking changes in hormone metabolism and distribution within the plant. Apart from it, they also regulate expression of the intrinsic genetic potential of plants. Generally mechanisms of action of phytohormones are poorly understood. However, several mechanisms or combinations may be operative. Control of genetic expression has been demonstrated for the phytohormones at both the transcriptional and translational levels. Also, hormones receptors and binding proteins have been identified on membrane surface that are specific for some phytohormones. The type and abundance of these proteins appear to be important in determining the sensitivity of the tissues' to differing concentrations and types of phytohormones, during development and changing environment.

Mineral nutrition

Mineral nutrition includes the supply, absorption, utilization of essential nutrients for growth and yield of crop plants. This is not known with certainty when humans first incorporated organic substances, manures or wood ashes as fertilizers in the soil to stimulate plant growth. However, it is documented that as early as 2500 B.C., humans recognized the richness and fertility of alluvial soils in valleys of the Tigris and Euphrates rivers (Hewitt, 1963; Tisdale *et al*., 1985). Early progress in the development of understanding of soil fertility and nutrition concept was slow, although the Greeks and Romans made significant contributions in the years 800 to 200 B.C. (Marschner, 1986; Westerman and Tucker, 1987). It was only to the credit of Justus Von Leibig (1803-1873) that the scattered information concerning the importance of mineral nutrients for plant growth was collected and summarized the mineral nutrition of plants and was established as a scientific discipline (Marschner, 1983). Plants contain small amounts of about more than hundred elements but only 17 elements are known to be essential (Epstein, 1972; Fageria, 1984; Salisbury and Ross, 1994). The exclusive requirements of inorganic nutrients in higher plants basically distinguish them from man, animals and a number of micro-organisms, which additionally need organic compounds.

Plants respond to environmental perturbations with a wide range of physiological and developmental adjustments. An adaptive change to variations in nutrient availability represents an important group of these metabolic responses, which often constitute the most stringent factors limiting plant distributions and productivity (Clarkson and Luttge, 1991). There are many instances which suggest that nutrients and growth regulators can interact in a variety of ways. Deficient and toxic leves of nutrients can affect the concentrations of specific hormones, and in turn, hormones have the capacity to direct the translocation and accumulation of nutrients in plants (Kuiper, 1988; Kuiper *et al*., 1989). Actually, the nutritional status of a plant in common with other environmental factors which influence its metabolism and growth can affect the synthesis and distribution of growth substances (Haru *et al*., 1982; Green, 1983). Contradictory reports were observed about the influence of growth regulators on absorption and transport of ions either directly, because of some interaction with membrances (Lea and Collins, 1979) or indirectly through effects on metabolism. Considering the complex interactions of plant hormones and the multiplicity of plant functions they control, the impact of nutrients on hormones is an important issue (Whenham *et al*, 1989; Thorsteninsson and Eliasson, 1990; Arshad and Frankenberger, 1991; Cao *et al*., 1993).

In the following pages, attempt has been made to cover the aspects of interactions of plant growth regulators with nutrients application.

2. Interaction effect on growth characteristics

Growth of the plant was found to be influenced by the interaaction of hormones and nutrients. Alvim (1960) reported that plant height of kidney bean (*Phaseolus vulgaris* L.) responded positively when urea was sprayed along with GA_3 spray, while urea alone was phohibitive. Enhancement with the applicantion of GA_3 and K was observed in sunflower (Dela Gaurdia and Benlloch, 1980), but the relative response to the GA_3 treatment decreased with increasing K levesl (Erdei and Dhakal, 1986). Retardation in the plant height of gobhi saraon (*Brassica napus* L.) by the foliar spray of CCC and ethrel at all the levels of nitrogen was noted and the reduction was more pronounced in the absence of nitrogen (Grewal *et al*., 1993). The flower number of different crops was found to be positively responsive towards exogenous application of growth substances (Morgan *et al*., 1983; Friends, 1985). It was observed that treatment with kinetin along with phosphorus enhanced the flower number of tomato (*Lycopersicon esculentum*. Mill), while marked decrease was noted in phosphorus deficient plants. Grewal and Gill (1986) reported that in a field grown paddy (*Oryza sativa* L.), leaf area index of the crop increased with the foliar spray of NAA (100 and 200 mg/l) and nitrogen (0, 60, 90 and 120 kg N/ha), while again Grewal *et al*. (1993) noted that in a field grown *Brassica napus* L. foliar spray of CCC (250 and 500 ppm) and ethrel (500, 1000 and 15000 ppm), in absence of N application considerably reduced the leaf area index of the crop. At 50 kg N/ha, 250 ppm CCC and 500 ppm ethrel the crop retained more LAI, whereas at 100 kg N/ha, 500 ppm CCC and 1000 ppm ethrel proved to be more beneficial. The findings are in close conformity with Bangal *et al*. (1982) and

Singh *et al*. (1987). A stimulative effect of GA_3 sprays was found for total dry weight, while urea did not show any effect on this (Alvim, 1960) in *Phaseolus vulgaris*. (Etherl spray (400 or 600 ppm) along with basal (45 or 60 kg/ha) and foliar application (0 or 10 kg/ha) of N increased leaf area index and dry mass of mustard (Khan, 1996). In various studies on mustard, Khan *et al*. (2000), Mir (2002), Mir *et al*. (2008 a), Mir *et al*. (2009 b,c), Lone *et al*. (2010) and Mir *et al*. (2010 a,b) reported that at 0 or 40 kg N/ha, ethrel did not produce any significant effect, but at basal 80 kg N/ha, ethrel affected growth parameters like plant height, leaf number, leaf area, LAI and total dry matter. Similar enhancement in leaf area index and dry mass of mustard was noted with GA_3 and N interaction in mustard (Khan e*t al*., 1996; Khan *et al*., 2002 a). Plant growth rate (PGR), relative growth rate (RGR), crop growth arte (CGR), and carbon dioxide exchange rate (CER) were increased by the application of 10^{-4} GA_3 at optimal level of nitrogen 80 kg N/ha (Khan *et al*., 2002 a). Exogenous application of CCC and mepiquat chloride enhanced the crop growth rate of groundunt (Jeyakumar and Thangraj, 1996). However, RGR was decreased by CCC application in *Plantgo major* (Dijksrtra and Kiuper, 1989). While 400 ppm of CCC exogenously applied enhanced CGR, RGR and NAR of *Brassica juncea* under non - irrigated conditions (Lone, 2001).

3. Interaction effect on physiological characteristics

a. Chlorophyll content

Chlorophyll content of plants was observed to be invariably influenced with the application of growth substances and supplementation of nutrients. When Palmer and Phillips (1963) applied IAA with nitrogen, an increase in the chlorophyll content of sunflower (*Helianthus annuus* L.) was noted. In 1991, Meyappan *et al*. noticed that combined application of NAA + Borax increased the total chlorophyll content of *Arachis hypogea* L. Grewal and Gill (1986) recorded an increase in chlorophyll content of paddy (*Oryza sativa* L.) in response to foliar application of NAA with nitrogen. Furthr Grewal *et al*. (1993) obsrved that cholorophyll content in *Brassica napus* was significantly improved when CCC (250 and 500 ppm) and ethrel (500 ppm) was applied in combination with 50 and 100 kg/N/ha. But conversely to this, Bashist (1988) recordd a prohibitive efect of GA_3 applicaion along with nitrate on chlorophyll content of sesame (*Sesamum indicum* L.)

b. Photosynthesis

Positive trend in photosynthetic activity of the groundnut was recorded in response to NAA and Borax application (Meyapan *et al*., 1991). While exposure of sesame seedlings to CCC and nitrate increased the photosynthetic activity (Bashist, 1990). Grewal *et al*. (1993) observed indirect evidence of improved photosynthetic activities by enhancing chlorophyll content and retaining higher LAI with nitrogen (50 and 100 kg/ha), spray of CCC (250 and 500 ppm) and ethrel (500 ppm). Interaction of GA_3 with N was found to enhance photosynthesis in mustard (Ansari, 1996; Khan *et al*., 1996; Khan *et al*., 1997 a). Ethrel spray (200 ppm) with N levels (0, 40, 80, and 120 kg/ha) showed positive effect on photosynthetic rate up to 80 kg N/ha in mustard (Khan *et al*., 2000; Lone, 2001; Mir, 2002; Khan, 2004 a,b; Khan *et al*., 2007; Mir *et al*., 2008 a; Mir *et al*., 2009 b; Lone *et al*., 2010; Mir *et al*., 2010 a,b).

c. Photosythetically active radiation

In a field grown paddy (*Oryza sativa* L.), Grewal and Gill (1986) obsrved that foliar application of NAA and nitrogen significantly enahnced the photosynthetically active radiaiton. Grewal and Kolar (1990) noted that increase in N (0, 50 and 100 kg/ha) helped the crop canopy to trap more radiation. CCC at 250 or 500 ppm and ethrel at 500 ppm further improved the radiation interception. However, in the absence of N application, all growth regulators treatment had negative effects on PAR interception of *Brassica juncea* L., further Grewal *et al*. (1993) reached to similar conclusion while working with *Brassica napus* L.

d. Ethylene evolution

The plant regulator ethrel at 200 µL/L along with basal basal 80 kg N/ha significantly increased the 1-aminocyclopropane-1-carboxylic acid (ACC) content, ACC -oxidase activity and ethylene production in leaves of *Brassica juncea* (Mir, 2002; Mir *et al*., 2008 b)

4. Interaction effect on biochemical characteristics

a. Nitrate reductase activity

Khan *et al*. (1996) reported impressive increase in the nitrate reductase activity (NRA) of mustard leaves in response to GA_3 application at optimal basal of nitrogen. At basal 80 kg N/ha, ethrel 200 µL/L significantly increased the nitrate reductase activity in leaves of *Brassica juncea* (Mir, 2002; Mir *et al*., 2008 a; Lone *et al*., 2010).

b. Carbonic anhydrase activity

Khan *et al*. (1996) reported that carbonic anhydrase (CA) activity were significantly increased by the application of GA_3 at optimal basal level of nitrogen.

c. Nutrient accumulation

Bostrack and Struckmeyer (1964) reported a negative trend in the uptake of potassium, when plants of soybean (*Glycine max*) grown with nitrogen (70, 210 and 630 mg/l) potassium (117.8, 235.6 and 1178 mg/l) and phosphorus (16, 32 and 160 mg/I) was sprayed with 50 mg/l) GA_3. In addition to this, kinetin induced preferential uptake of phosphorus, reported in corn (*Zea mays*) leaves by Muller and Leopold (1966). When Kannan and Mathew (1968) exposed bean (*Phaseolus vulgaris*) and maize (*Zea mays* L.) with GA_3 and TIBA (10^{-5} M), CC ($5x10^{-4}$ M), kinetin and AMO-1618 (10^{-4}M), differentaila pattern in the transport of iron was recorded Iron translocation was found to be more affected by Alar than by GA_3 or CCC. Bashist (1988) noted that gibberellic acid treatment markedly inhibited nitrate uptake in sesamum. Contradictory reports of translocation of potassium was noted, when Erdei and Dhakal (1988) treated winter wheat to different potassium status (0.01 to 10 mM) and phytohormones (NAA, BA, GA_3, ABA and ethrel). In low K^+ plants, GA_3, ethylene and ABA stimulated K^+ uptake. NAA and BA inhibited K^+ uptake. In high K^+ plants, the effects of GA_3, ethylene and ABA were similar to that in low K^+ uptake. However, BA and NAA had opposite effects stimulaing the K^+ uptake. A positive response of foliar spray for growth regulators (NAA, IAA and Resorcinol) on nitrogen uptake in pearl millet (*Pennisetum typhoides*) was noticed by Rangacharya and Bawankar (1991). In sunflower (*Helianthus annuus* L.) Reddy *et al*. (1996) found improvement in the uptake of nitrogen, phosphorus, potassium and sulphur with increase in levels of sulphur (0, 15, 30 and 45 kg/ha) and benzyladenine (0, 20, 40 and 60 ppm). In *Brassica juncea* increase in N uptake and NR activity has been reported (Khan *et al*., 1996) with GA_3 and N application and K uptake with ethrel and N application (Khan *et al*., 2000; Mir, 2002; Khan *et al*., 2007; Mi *et al*. 2009 b,c).

5. Interaction effect on nitrogen, fertilizer, productive and nutrient use efficiency characteristics

Mir (2002) reported impressive increase in the nitrogen uptake efficiency, nitrogen use efficiency and nitrogen utilization efficiency of mustard in response to ethrel application at basal 80 kg N/ha. Ethrel (200 pm) and cycocel (400 ppm) at 60 kg N/ha showed significant results on productive use efficiency and nitrogen use efficiency (Lone, 2001). Similarly nitrogen use efficiency, fertilizer use efficiency, productive use efficiency and nutrient use efficiency of mustard were significantly increased by GA_3 at optimal level of nitrogen 80 kg N/ha (Ansari, 1996; Khan and Samiullah, 1997 a; Khan *et al*., 2002 a).

6. Interaction effects on yield characteristics

a. Seed yield

Foliar spray of growth regulators (2-4-D, Atrataf, NAA and CCC) and urea at the time of flowering affected the grain weight per plant in *Cicer arientum* L. Significiant increase was observed in seed yield with the combined application of NAA (25 ppm) and urea (1%) (Bangal *et al*., 1982). In a field experiment, Zhukov and Reutov (1985) noted that complex application of calculated rates of fertilizers, 2-4-D and CCC resulted in an increase in grain yield of winter wheat (*Triticum aestivum* L.) The beneficial effect of foliar spray of NAA on the grain yield of paddy (*Oryza sativa* L.) under low level of N (0 and 60 kg/ha) was reported by Grewal and Gill (1986). This improvement was associated with increase in the number of ear-bearing shoots/plants, number of filled grains/panicle and grain weight. Sawan *et al*. (1988) observed nd enhancement in the seed yield of cotton (*Gossypium barbadense* L.) with the combined application of growth regulators (IAA, IBA and NAA) and increasing levels of N (72, 144 or 216 kg/ha) and phosphorus (36 or 72 kg P2O5/ha). Oil percentage was found to be influenced with the application of growth regulators and high P level, and followed an upward trend. In accordance with this, Uppar and Kulkarni (1989) were also able to produce highest seed yield of sunflower (*Helianthus annuus* L.), when nitrogen (120 kg/ha) was applied in combination with TIBA (250 ppm). Ramos *et al*. (1989) reported that, an early application of sulphur with foliar spray of ethephon on spring barley (*Hordeum vulgare* L.) brough about a remarable enhancement in the grain yield, without modifying the 1000 grain weight. In a field trials, Rangacharya and Bawankar (1991) noticed an increase in the grain yield of pearl millet (*Pennisetum typhoides*) with the application of NAA along with N (60 kg/ha) and P (30 kg/ha) application. Bergmann and Eckert (1990) conlcuded that sufficient nitrogen supply was an essential requirement for increasing the yield of rye and barley by mono ethanolamine (EA). A marked improvement in the grain yield of *Brassica napus* L. was observed when nitrogen was available at the rate of 50 kg/ha along with foliar spray of CCC (250 ppm) and ethrel (1500 ppm). The combined effect of growth regulators and nitrogen could not change the oil content. But application of nitrogen enhanced oil content significantly (Grewal *et al*., 1993). Significant increase in yield attributing parameters and seed yield has also been reported from author's laboratory in mustard crop. Ehtrel spray along with N increased pod number, seed number, 1000 seed weight, seed yield, seed yield merit, seed N content, nitrogen yield merit and merit of genotype under irrigated conditions (Khan, 1996 b; Mir, 2002; Mir *et al*., 2008 a) and under un-irrigated conditions (Khan *et al*., 2000; Lone, 2001; Mir, 2002; Mir *et al*., 2008 a; Mir *et al*., 2009 c; Lone *et al*., 2010). Similarly, GA_3 with N showed enhancement in yield (Khan *et al*., 1996) and GA_3 and N and P registered increase in yield and its attributing parameters (Ansari, 1996; Khan and Samiullah, 1997 b; Khan *et al*., 1997 a,b; Khan, *et al*., 1998; Khan *et al*., 1999).

b. Biological yield

Biological yield and merit of genotype were enhanced by ethrel at 80 kg N/ha in mustard under irrigated and non- irrigated conditions (Khan *et al*., 2000; Mir, 2002; Mir *et al*., 2009 c). Lone (2001) also reported that ethrel (200 ppm) and cycocel (400 ppm) at 60 kg N/ha showed significant results on biological yield. GA_3 at the optimal level of sulphur increased the biological yield (Mobin, 2001).

c. Harvest index

Exogenous application of ethrel (200 µL/L) along with basal 80 kg N/ha increased the harvest index in mustard (Khan *et al*., 2000; Mir, 2002; Mir *et al*., 2009 c). Cycocel (400 ppm) and ethrel (200 ppm) increased the harvest index at 60 kg N/ha (Lone, 2001).

d. Oil yield

Khan (1996), Khan *et al*. (2000), Lone (2001) and Mir (2002) reported impressive increase in the oil yield of mustard in response to ethrel and CCC application at basal 80 kg N/ha and 60 kg N/ha. Mobin (1999) also reported that the application of GA_3 along with sulphur increases the oil yield.

7. Interaction effect on quality characteristics

In an experiment on mustard (*Brassica juncea* L.) interaction effect on GA_3 and basal N and P levels on fatty acid composition was found non significant (Khan *et al*., 1997 b). Oil content, acid value, iodine value and saponification value were enhanced by ethrel

(200 μL/L) with nitrogen 80 kg N/ha and CCC (400 ppm) with 60 kg N/ha in mustard under irrigated and non -irrigated conditions (Lone, 2001; Mir, 2002).

8. Conclusions

This study highlights the pivotal role played by the plant growth regulators along with nutrients on plant growth and development by affecting various growth characteristics like: plant height, leaf area, leaf area index, dry weight, plant growth rate, relative growth rate, crop growth rate, net assimilation rate, carbon dioxide exchange rate; physiological characteristics like chlorophyll content, photosynthesis, photosynthetically active radiation, ethylene evolution; biochemical characteristics like nitrate reductase activity, carbonic anhydrase activity, nutrient accumulation; nitrogen efficiency characteristics like nitrogen uptake efficiency, nitrogen use efficiency, nitrogen utilization efficiency, fertilizer use efficiency, productive use efficiency, nutrient use efficiency in addition to yield characteristics like; pod number, seed number, 1000 seed weight and seed yield, seed yield merit, seed N content, nitrogen yield merit, merit of genotype, biological yield, harvest index, oil yield and quality characteristics like oil content, acid value, iodine value and saponification value.

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References

Alvim, P.D.T. (1960). Net assimilation rate and growth behavior of beans as affected by gibberellic acid urea and sugar sprays. *Plant Physiology* 35 (3): 285- 288.

Ansari, H.R. (1996). Effect of some phytohormones and NPK on growth and metabolism of mustard. Ph.D. thesis, Aligarh Muslim University, Aligarh, India.

Arshad, M., Frankenberger, Jr., W.T. (1991). Effects of soil properties and trace elements on ethylene production in soils. *Soil Science* 151: 377-386.

Bangal, D.B., Deshmukh, S.N and Patil, V.A. (1982). Note on the effect of growth regulators and urea on yield attibutes of gram (*Cicer arientinum*). *Legume Research* 5: 54-56.

Bashist, D.P. (1988). Effect of gibberellic acid on nitrate utilization in *Sesamum indicum* seedlings, Proc. *Indian Acadamy Science (Plant Sci.)* 98 (5): 419-424.

Bashist, D.P. (1990). Effect of growth retardant-(2- chloroethyl)- trimethyl ammonium chloride on NO_3 uptake and nitrate reductase activity in Sesamum seedlings. *Acta Botanica India* 18: 55-58.

Bergmann, H. and Eckert, H. (1990). Effect of monoethanolamine on growth and biomass formation of rye and barley. *Plant Growth Regulation* 9(1): 1-8.

Bostrock, M.J. and Struckmeyer, B.E. (1984). Effects of gibberellic acid on soybeans grown at different levels of nitrogen, potassium or phosphorus. *Bot. Gaz.* 125: 142-145.

Cao, Y.A., Glass, D.M. and Crawford, N.M. (1993). Ammonium inhibition of Arabidopsis root growth can be reversed by potassium and by auxin resistance mutations aux 1, axr 1 and axr 2. *Plant Physiology* 102: 983-989.

Clarkson, D.T. and Luttge, U. (1991). Mineral nutrition: Inducible and repressible nutrient transport systems. *Prog. Bot* 52:61-83.

De La Gaurdia, M.D. and Benlloch , M. (1980). Effect of potassium and gibberellic acid on stem growth of whole sunflower plants. *Physiologia Plantarum* 49: 443-448.

Dijkstra, P. and Kuiper, P.J.C. (1989). Effects of exogenenously applied growth regulators on shoot growth of inbred lines of *plantago major* differing in relative growth rate: differential response to gibberellic acid and 2- chloroethyle-trimethyle –ammonium chloride. *Physiologia plantarum* 77: 512-518.

Dubey, O.P., Sahu, T.R. and Garg, D.C. (1994). Response and economics in relation to nitrogen and sulphur in Indian mustard (*Brassica juncea*). *Indian Journal of Agronomy* 39: 49-53.

Epstein, E. (1972). Mineral nutrition of plants: principles and perspectives. Wiley, New York.

Erdei. L. and Dhakal. M.R. (1988). Effect of K status and phytoormone on k transport in wheat. *Plant Soil* 111: 171-175.

Fageria, N.K. (1984). Fertilization and mineral nutrition of rice. EMBRAPA-CNPAF/Editora Campus, Rio de Janerio.

Friend, D.J.C. (1985). Brassica. In: *CRC Handbook of Flowering*. pp. 48-77. A.H. Halery (Ed).CRC Press, Boca Raton, FL.

Green, J. (1983). The effect of potassium and calcium on cotyledon expansion and ethylene evolution induced by cytokinins. *Physiologia Plantarum* 57: 57-61.

Grewal, H.S. and Gill, H.S. (1986). Influence of NAA and N on the growth and yield of late planted paddy (Oryza sativa). *Journal of Agronomy and Crop Science* 106(1): 37-40.

Grewal, H.S. and Kolar, J.S. (1990). Response of *Brssica juncea* to chlorocholine chloride and ethrel sprays in association with nitrogen application. *Journal of Agricultural Sciences Cambrige* 114:87-91.

Grewal, H.S., Kolar, J.S., Cheema, S.S. and Singh, G. (1993). Studies on the use of growth regulators in relation to nitrogen for enhancing sink capacity and yield of gobhi sarson (*Brassica napus*). *Indian Journal of Plant Physiology* 36(1): 1-4.

Haru, K., Naito, K. and Suzuki, H. (1982). Differential effects on benzyladenine and potassium on DNA, RNA, protein and chlorophyll contents and expansion growth of detached cucumber cotyledone in the dark and light. *Physiiologia Plantarum* 55: 247-254.

Hewitt, E.J. (1963). The essential nutrient elements: requirements and interaction in plants. In: *Plant Physiology: A Treatise*. pp. 137-329. F.C. Steward (Ed.). Academic Press, New York.

Jeyakumar, P. and Thangraj, M. (1996). Effect of mepiquat chloride on certain physiological and yield characteristics of groundnut (*Arachis hypogea* L.). *Journal of Agronomy and Crop Science* 176 (3): 159-164.

Khan, N.A. (1996 a). Effect of gibberellic acid on carbonic anhydrase, photosynthesis, growth and yield of mustard. *Biologia Plantarum* 38: 145-147.

Khan, N.A. (1996 b). Response of mustard to ethrel spray and basal and foliar application of nitrogen. *Journal of Agronomy and Crop Science* 176: 331-334.

Khan, N.A. (1997). Evaluation of gibberellic acid for increasing yield efficiency of mustard cultivars. *Test of Agrochemicals and Cultivars* 18: 26-27.

Khan, N.A. (1998). Effect of ethrel spray on yield of mustard cultivars under non irrigated conditions. *Test of Agrochemicals and Cultivars* 19: 38-39.

Khan, N.A. (2004 a). Activity of 1-aminocyclopropane carboxylic acid synthase in two mustard (*Brassica juncea* L.) cultivars differing in photosynthetic capacity. *Photosynthetica* 42: 477-480.

Khan, N.A. (2004 b). An evaluation of the effects of exogenous ethephon, an ethylene releasing compound, on photosynthesis of mustard (*Brassica juncea*) cultivars that differ in photosynthetic capacity. *BMC Plant Biology* 4: Article No. 21.

Khan, N.A. and Samiullah (1997 a). Effect of gibberellic acid spray on fertilizer use efficiency, productive efficiency of fertilizers and nutrient use efficiency of mustard grown with basal N and P levels. National Seminar, Plant Physiology for Sustainable Agriculture, March, 19-21. pp 58.

Khan, N.A. and Samiullah (1997 b). Effect of gibberellic acid spray and basal nitrogen and phosphorous on productivity of mustard. National Seminar, Plant Physiology for Sustainable Agriculture, March, 19-21. pp 58.

Khan, N.A., Mobin, M. and Samiullah. (1997 a). Effect of gibberellic acid on morpho-physiology and yield of mustard grown with basal levels of N and P. Proceedings National Seminar, Plant Physiology for Sustainable Agriculture, March, 19-21. pp 67.

Khan, N.A., Ansari H.R. and Samiullah. (1997 b). Effect of gibberellic acid spray and basal nitrogen and phosphorus on productivity and fatty acid composition of rapeseed-mustard. *Journal of Agronomy and Crop Science* 179: 29-33.

Khan, N.A., Lone N.A. and Samiullah. (2000). Response of mustard to applied nitrogen in association with or without ethrel spray under non irrigated conditions. *Journal of Agronomy and Crop Science* 183: 1-4.

Khan, N.A., Ansari, H.R. and Mobin, M. (1996). Effect of gibberellic acid and nitrogen on carbonic anhydrase activity and mustard biomass. *Biologia Plantarum* 38: 601-603.

Khan, N.A., Ansari, H.R. and Samiullah. (1998). Effect of gibberellic acid spray during ontogeny of mustard on growth, nutrient uptake and yield characteristics. *Journal of Agronomy and Crop Science* 181: 61-63.

Khan, N.A., Ansari, H.R., Mobin, M. and Samiullah. (1999). Effect of gibberellic acid on morphophysiology and yield of mustard (*Brassica juncea* L.) grown with basal levels of nitrogen and phosphorus. In: *Plant Physiology of Sustainable Agriculture*. pp. 214-224. G.C. Srivastava, K. Singh and M. Pal (Eds.). Pointer Publishers, Jaipur, India.

Khan, N.A., Mir, M.R., Nazar, R. and Singh. S. (2007). The application of ethephon (an ethylene releaser) increases growth, photosynthesis and nitrogen accumulation in mustard (*Brassica juncea* L.) under high nitrogen levels. *Plant Biology* 54: 1435-1440.

Khan, N.A., Mir, R., Khan, M., Javid, S. and Samiullah. (2002 a). Effects of gibberellic acid spray on nitrogen yield efficiency of mustard grown with different nitrogen levels. *Plant Growth Regulation* 38: 243-247.

Khan, N.A., Ansari, H.R., Khan, M., Mir, R. and Samiullah. (2002 b). Effect of phytohormones on growth and yield of Indian mustard. *Indian Journal of Plant Physiology* 7(1): 75-78.

Kuiper, D. (1988). Growth responses of *Plantago major* L. ssp. *Pleiosperma* (pilger) to changes in mineral supply. *Plant Physiology* 87: 557-557.

Kuiper, D., Schuit, J. and Kuiper, P.J.C. (1989). Effects of internal and external cytokinin concentration on root growth and shoot to root ratio of *Plantago major* ssp. *Pleiosperma* at different nutrient conditions. pp. 183 -188. In: B.C. Loughman, O. Gasparikova, and J. Kolek (eds.), Structural and functional Aspects of Transport in Roots. Kluwer Academic Publishers, London.

Lakkineni, K.C. and Abrol, Y.P. (1992). Sulphur requirement of rapeseed – mustard, groundnut and wheat : a comperative assessment. *Journal of Agronomy and Crop Science* 169: 281-285.

Lea, E.JA. and Collins, J.C. (1979). The effect of the plant hormone abscissic acid on lipid bilayer membranes. *New Phytology* 82: 11-18.

Lone, N.A. (2001). Studies on effect of cycocel and ethrel in association with nitrogen on growth and metabolism of mustard under non-irrigated conditions. Ph.D. Thesis, Aligarh Muslim University, Aligarh, India.

Lone, N.A., Mir, M.R. and Khan, N.A. (2005). Effect of gibberellic acid on physiological attributes and yield of mustard (*Brassica juncea* L.). *Applied Biological Research* 7: 24-26.

Lone, N.A., Mir, M.R., Ashraf Bhat, M., Haleema Ashraf., Bhat, K. A., Rashid, R., Asma Hassan., Nasier Ahmad., Akhtar, S., Bhat, J.A. and Habib, M. (2010). Effect of ethrel and nitrogen on nitrate reductase activity, photosynthesis, biomass and yield of mustard (*Brassica juncea* L. Czern and Coss). *Recent Research in Science and Technology* 2(2): 25-26.

Marschner, H. (1983). General introduction to the mineral nutrition of plants. In: *Encyclopedia of Plant Physiology*. pp. 5-60. A. Lauchli and R.L. Bieleski (Eds). New Ser., vol. 15A. Springer-Verlag, New York.

Marschner, H. (1986). Mineral nutrition of higher plants. Academic Press, New York.

Meyyappan, M., Vaiyapuri, V. and Alagappan, R.M. (1991). Effects of plant growth regulators and micronutrients on chlorophyll content and Hill-activity in

Arachis hypogea L. var.VRI-I. Proc. Of Int nl. Conf. Pl. Physoil. Banaras Hindu Universtiy, India pp. 7-11.

Mir, M.R. (2002). Physiological significance of ethrel (2- chloroethyl phosphonic acid) and nitrogen in relation to growth and metabolism of mustard under irrigated and non- irrigated conditions. Ph. D. Thesis, Aligarh Muslim University, Aligarh, India.

Mir, M.R., Khan, N.A., Rather, G.H., Lone, N.A. and Subaya Basharat. (2008 a). Effect of nitrogen and ethrel on various physiological and yield attributes of mustard (*Brassica juncea* L.). *Applied Biological Research* 10: 1-5.

Mir, M.R., Khan, N.A., Rather, G.H., Lone, N.A. and Subaya Basharat. (2008 b). Effect of nitrogen and ethrel on ACC, ACC oxidase and ethylene production in mustard (*Brassica juncea* L.). *Applied Biological Research* 10: 47-50.

Mir, M.R., Lone, N.A and Khan, N.A. (2009 a). Impact of exogenouly applied ethephon on physiological and yield attributes of two mustard cultivars under rainfed conditions. *Applied Biological Research* 11: 44-46.

Mir, M.R., Lone, N. A., Khan, N. A., Singh, S. and Asma Hassan. (2009 b). Impact of ethrel and nitrogen on growth, leaf water content, potassium accumulation and dry mass of mustard. (*Brassica juncea* L). *SKUAST Journal of Research* 11: 187-192.

Mir, M. R., Khan, N. A., Lone, N. A., Payne, W.A., Mir, A. H., Asma Hassan and Viqar Ahmad.(2009 c). Effect of basal nitrogen application and foliar ethephon spray on morphophysiology and productivity of mustard (*Brassica juncea* L. Czern and Coss). *Applied Biological Research* 11: 60-65.

Mir, M.R., Khan, N. A., Ashraf Bhat, M., Lone, N. A., Rather, G.H., Razivi, S.M., Bhat, K.A., Singh, S. and Payne, W.A. (2010 a). Effect of ethrel spray on growth and photosynthetic characteristics of mustard (*Brassica juncea* L. Czern and Coss) cultivars. *International Journal of Current Research* 6: 22-26.

Mir, M.R., Khan, N. A., Bhat, M.A., Lone, N. A., Rather, G.H., Razivi, S.M., Bhat, K.A., Singh, S. and Payne, W.A. (2010 b). Effect of ethrel spray and nitrogen on growth, photosynthesis, carboxylation efficiency and water use efficiency of mustard (*Brassica juncea* L.). *International Journal of Current Research* 6: 45-52.

Mobin, M. (1999). Morphophysiology and productivity of mustard in relation to gibberellic acid and sulphur application. Ph. D. Thesis. Aligarh Muslim University, Aligarh, India.

Morgan, D.G., Kieller, D.R. and Prynne, A.O. (1983). Nitrogen, growth regulators and pod development in oilseed rape. In: *Interaction Between Nitrogen and Growth Regulators in Control of Plant Development*. M.B. Jackson, (Ed). British Plant Growth Regulator Group Monograph 9: 75-86.

Muller, K. and Leopold, A.C. (1996). The mechanism of kinetin induced transport in corn leaves. *Planta* 68: 186-205.

Palmer. J.H. and Philips, I.DJ. (1963). The effect of the terminal bud, indole acetic acid and nitrogen supply on the growth and orientation of the petiole of *Helianthus annuus*. *Physiologia Plantarum* 16: 573-584.

Pasricha, N.S., Aulakh, M.S., Bahl, G.S. and Baddesha, H.S. (1988). Fertilizer use research in oilseed crops. *Fertilizer News* 33: 15-22.

Ramos, J.M., Garcial de Moral, L.F., Molina-cano, J.L., Salamanca, P. and Roca de Togores, F. (1989). Effect of an early application of sulphur or ethephon as foliar sprays on the growth and yield of spring barley in a Mediterranean environment. *Journal of Agronomy and Crop Science* 163: 129-137.

Rangacharya, R.P. and Bawankar, P.R. (1991). Effect of growth regulators on nitrogen uptake yield and grain protein in pearl millet. *Annual Plant of Physiology* 5(2): 230-233.

Reddy, S.N., Singh, B.G. and Reddy, R.V. (1996). Effect of sulphur and benzyladenine on quality and nutrient uptake in sunflower. *Annuals of Plant Physiology* 10(2):166-170.

Salisbury, F.B. and Ross, C.W. (1994). *Plant Physiology. 4th ed*. Wadsworth Publishing Company, Belmont, C.A.

Singh, H., Chandra, S. and Jolly, R.S. (1987). Effect of growth regulators in relation to time of sowing and yield of soybean cultivars. *Annuals of Applied Biology* 3: 36-43.

Thorsteinsson, B. and Eliasson, L. (1990). Growth retardation induced by nutritional deficiency or abscisc acid in *Lemna gibba*: the relationship of growth rate and endogenous cytokinin content. *Plant Growth Regulation* 9: 171-181.

Tisdale, S.L., Nelson, W.L. and Beaton, J.D. (1985). Soil fertility – past and present. In: *Soil Fertility and Fertilizers*. pp. 5-18. 4th ed. Macmillan, New York.

Uppar. D.S. and Kulkarni, G.N. (1989). Effect of nitrogen and growth regulators on seeed yield and quality of sunflower. *Seed Research* 17: 113-117.

Westerman, R.L. and Tuker, T.C. (1987). Soil fertility concepts: past, present and future. In: *Future Developments in Soil Science Research*. pp. 171-179. Soil Sci Soc. Am., Madison, Wisconsin.

Whenham, R.J., Burn, I.G., Stone, D.A. and Fraser, R.S.S. (1989). Effect of nitrogen nutrition and water regime on abscisic acid, phaseic and dihydrophaseic acid metabolism in leaves of field grown kale (*Brassica oleracea*): Consequences for plant growth and crop yield. *Journal of Science Food and Agriculture* 49: 143-155.

Yadav, N.P.S., Singh, V. and Mehta, V.S. (1996). Effect of different levels and sources of sulphur on yield, quality and uptake of sulphur by sesame. *Journal of Oilseed Research* 13(1): 22-25.

Zhukov, Yu. and Reutov, A.V. (1985). Productivity of witer wheat during combined application of calculated rates of fertilizers, 2-4-D bad CCC. *IZV Tumiryazev S-Kh Akade* 0: 92-97.