1-Naphthaleneacetic acid in rice cultivation

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Rice is consumed by half of the world's population. It is a model monocotyledonous crop. In this communication, the effect of 1-naphthaleneacetic acid (NAA) on the growth, yield attributes and yield is elaborated. Results show that NAA, a synthetic auxin, when applied in spray influences the life cycle of rice via metabolic processes to manifest beneficially through translocating assimilates from source to sink, and hence the yield.

Keywords: 1-Naphthaleneacetic acid, plant growth regulators, rice cultivation, yield components.

1-NAPHTHALENEACETIC acid (NAA) is an aromatic acid. Naturally, it is insoluble in water; however, it is noted that it is soluble up to 380 ppm in water. It is a synthetic acid, but is similar to naturally occurring indoleacetic acid in its action on plants. Thus it is a synthetic plant hormone in the auxin family. Functions of NAA are stimulation of cell division, cell elongation, elongation of shoot, photosynthesis, RNA synthesis, membrane permeability and water uptake involved in many physiological processes like prevention of preharvest fruit drop, flower induction, fruit set, delayed senescence and prevention of bud sprouting, leaf chlorophyll content and increased yield in fruit crops. An exogenous application of naturally occurring or synthetic plant growth regulators affects endogenous hormonal pattern of the plant either by supplementation of sub-optimal levels or by interaction with their synthesis, translocation or inactivation of existing hormone levels.

The use of plant growth regulators in the field of agriculture has been commercialized in some advanced countries like Europe, USA and Japan. The current uses of different plant growth regulators are not only in high value horticultural crops but also to increase field crop yield directly either by increasing biological yield or the harvest index. NAA is a somatotrophin-like growth regulator in plants.

Auxins such as NAA have been used since a long time to improve fruit quantity and quality of many deciduous fruit trees. Antonio and Bettio[1] showed that application of NAA at the rate of 30 mg l^{-1} led to increase in fruit size and delay in harvesting period of peach CV. Diamante. Ruth *et al.*[2] studied the effect of synthetic auxins on fruit size of five cultivars of Japanese plum and found that application of 30 mg l^{-1} of NAA at the beginning of pit hardening caused an appreciable and significant increase in fruit size. Amiri *et al.*[3] showed that 400 mg l^{-1} of NAA application reduced the preharvest fruit drop, and an increase in fruit size was noticed in Satsuma mandarin. Application of NAA @ 400 ppm during the last week of April and first week of May to acheive maximum guava yield was suggested[4]. The effect of growth regulator NAA on fruit drop, yield and quality of mango cultivar Langra was noted with 200 ppm of the chemical[5]. Application of NAA significantly increased trigonelline and mucilage content of seed in fenugreek[6].

An increase in the number of pods and seeds per pod in grams was observed with 25 ppm NAA[7]. It was also noted that seed and pod weight increased with foliar application of 25–30 ppm NAA thrice at 5-days interval, beginning at flowering stage in chickpea[7]. Planofix (NAA) increased the number of pods per plant, dry pod yield and 100 seed weight in groundnut (40 and 50 days after sowing)[8]. Suty[9] reported that Rhodofix (NAA) at 3.4 g per ha increased the number of pods per plant, seeds per pod, 100 seed weight and yield of fababean. Bai *et al.*[10] applied eight foliar sprays of 25 mg l^{-1} NAA at 7 days intervals, which significantly increased the seed yield and yield components of *Vigna radiata*. The number of pods per plant was found to increase by spraying 40 mg l^{-1} NAA on groundnut once at either 45 days after sowing or twice at 45 and 55 days after sowing[11]. Merlo *et al.*[12] also reported that NAA application on soybean at flowering increased the number of branches per plant and average pod weight, but the latter application increased plant dry weight. It was found that 100 seeds weight increased with the foliar application of 20 mg l^{-1} NAA[13]. Deotale *et al.*[14] studied the effect of GA and NAA on growth parameters of soybean and obtained highest plant height, number of leaves per plant, number of branches per plant, leaf area, dry matter, days to maturity and seed yield with 100–400 mg l^{-1} NAA. Maximum number of seeds per pod and seed yield was obtained when NAA was applied 15 days after emergence stage[15].

Favourable influence of auxins such as NAA has been reported on invertase content of sugarcane[16,17]. In appropriate concentration NAA affects the growth and yield of a number of plants, viz. tomato[18], bitter gourd[19] and cowpea[20]. Planofix (NAA) had a significant effect on plant height, number of fruiting branches, volume of boll and yield of cotton[21]. NAA has been used for the enhancement of growth and yield of cereals[22]. Application of

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20 ppm of NAA showed better performance in enhancing the straw and grain yields of wheat cultivars[23]. Growth and yield parameters of rice were significantly promoted in response to various auxin levels[24]. Reports regarding the growth and yield aspects with NAA on cereal plants, including rice are available[25–27].

Influence on rice growth

A pot experiment showed that 100 and 200 ppm of NAA when sprayed, significantly increased the plant height at 60 DAS (days after sowing)[28]. In coarse rice IR-6 application of NAA showed that maximum plant height of 130 cm was attained at maturity, suggesting that plant height is enhanced by NAA[29]. Similar results were observed in rice variety Biser-2 (ref. 30). The highest plant height was observed due to 200 ppm NAA sprays in both varieties BRRIdhan-29 and BRRIdhan-50 during winter season in Bangladesh[31].

The effect of various concentrations of NAA on transplanted coarse rice was observed on plant height at maturity in Dara Ismail Khan, NWFP, Pakistan[29].

The number of leaves per plant was found to increase due to application of 100 ppm of NAA spray in BRRI-dhan-29 and varied significantly at 60 DAS[28]. There was an increasing trend of leaf area per plant due to application of 100 ppm in rice varieties. Chaudhuri *et al.*[26] observed a significant increase in total chlorophyll content in leaves of rice plants treated with NAA and its formulations, indicating possibly a delayed senescence of leaves.

In another experiment the number of tillers per plant was found to increase due to application of 100 ppm of NAA in BRRIdhan-29 and varied non-significantly[31]. Again, in a pot experiment the number of tillers per plant was found to increase by the application of 100 ppm of NAA in BRRIdhan-29 and varied significantly at 60 DAS[28]. It was noted that application of NAA significantly inhibited the growth of unproductive tillers and the elimination of unproductive tillers promoted the growth of productive tillers at the middle and late growth stages[32].

Root length, root volume and root weight (dry and fresh) were found to markedly increase using 100 ppm of NAA under flooded condition. Maximum root length, root volume and root weight (fresh and dry) was obtained from 100 ppm NAA. It was also observed that the combined application of NAA and flooded irrigation was more effective than the intermittent irrigation[33]. In plants, sprayed with NAA, the fresh and dry weight of the below soil mass (root) increased during and at the end of the rice vegetation[30]. Rice sprayed with 10 and 100 ppm NAA at tillering stage significantly increased root dry weight[34]. NAA is a widebroad somatotrophin-like growth regulator in plants. It produces significant effects in promoting development of pointed ends for the root system, resulting in more, straighter and thicker roots.

Chaudhuri *et al.*[26] observed that NAA enhanced the total dry matter production at harvest in two varieties of rice, CV. Jaya and Mahsuri. Total dry matter was found to increase up to harvest by the application of both 100 and 200 ppm of NAA in the variety BRRIdhan-29, whereas in BRRIdhan-50 total dry matter also increased at 15 and 30 days after spraying and the variation was non-significant[28]. Sarker *et al.*[33] noted that high plant dry weight was obtained from 100 ppm NAA. With the applied concentration of NAA, the fresh and dry weight of total above soil mass (stem, leaf and panicle) showed increase only 15 days after treatment following a trend to decrease, especially at the end of the vegetation[30]. Chaudhuri *et al.*[26] noted that crop growth rate at peak tillering stage of growth was significantly high because of application of NAA in both the rice varieties, Jaya and Mahsuri. It was observed that relative growth rate was maximum at the early stage of growth and then declined gradually. Relative growth rate was significantly higher during 0–15 and 45–60 DAS in the rice variety BRRIdhan-29. Net assimilation rate (NAR) was non-significantly affected and found to increase during 15–30 days after spraying following application of 100 and 200 ppm NAA in BRRI-dhan-29, but 200 ppm only in BRRI dhan-50. Also, 100 ppm NAA produced better stimulation[29]. Similar beneficial effects of auxins on growth parameters of rice have been reported in the literature[25,35].

Auxin precursor is generated via the shikimate pathway to biosynthesize auxin in the plastids; then it is believed to be located in the cytosol. Auxin degradation and conjugation is possible with amino acids and sugars, and remains in storage for subsequent hydrolysis and is used for plant growth and development.

NAA is a high-efficiency auxin-like plant growth regulator. When applied in low concentrations as foliar spray on plants, it is transported basipetaly downward slowly to initiate adventitious roots and better root activities[36], thus enhancing nutrient uptake. It also improves cell elongation and cell division[37] and thus growth is enhanced. In small concentrations, it delays senescence. Hence, crop growth is found to increase significantly.

Influence on yield components

It has been reported that panicles/m^2 had enhanced significantly by the application of NAA when sprayed at panicle initiation stage[26]. In an experiment with NAA and phosphorus application in field conditions it was observed that productive tillers had increased significantly by the application of NAA[38]. In a pot experiment, the rice variety Biser-2 showed that productive tillers had increased significantly by the application of NAA[30]. Liu *et al.*[32] noted that 1000 mg l^{-1} of NAA application promoted the development of heavy panicles in rice. Data revealed that in a NAA and irrigation experiment in field with rice (IR-6), NAA and 75 cm of irrigation produced the highest number of panicles. In a pot experiment, Jahan and Golam Adam[28] observed that the number of effective tillers per plant in BRRI dhan-29 increased due to 100 ppm of NAA. However, Chaudhuri *et al.*[26] observed no appreciable difference in panicles per hill in rice varieties Jaya and Mahsuri due to application of NAA at the rate 30 ppm. In transplanted coarse rice IR-6, the highest number of panicles ($328/m^2$) was reported by the application of NAA.

It was noted that the number of grains per panicle in BRRIdhan-29 increased following application of both 100 and 200 ppm of NAA[31]. In another experiment with NAA and irrigation regimes, it was observed that application of NAA significantly increased the number of grains per panicle[39]. Chaudhuri *et al.*[26] also observed significant increase in the number of grains per panicle in Jaya and Mashuri with the application of NAA in spray. Different concentrations of NAA caused significant changes in grains per panicle during 15 and 30 days after treatment and at the end of the rice harvest[30] Golam Adam and Jahan[31] observed that the number of grains per panicle increased in BRRIdhan-29 following both 100 and 200 ppm of NAA application, whereas it decreased in BRRIdhan-50.

Application of NAA increased the percentage of filled grains in rice variety IR-6 alone or in combination with phosphorus or irrigation[29,38,39]. In Biser-2 rice, NAA applied at tillering stage increased the fertile grains in the main panicle[30]. It was also observed that filled grains per panicle increased in BRRIdhan-29 using 100 and 200 ppm of NAA[31]. Also, 1000 grain weight which is associated with the mobilization and translocation of assimilates from plant parts to developing grains after flowering showed an increase when NAA was sprayed at different stages of growth. The maximum beneficial effect was noted when sprayed at panicle initiation stage. In IR-6, 1000 grain weight was observed to be 20.76–21.03 g. Similar beneficial effects were noted in an experiment of NAA spray in combination with phosphorus as well as different levels of irrigation[29,38,39]. Chaudhuri *et al.*[26] observed slight increase in 1000 grain weight in the rice variety Jaya, but a significant increase in 1000 grain weight in the rice variety Mahsuri due to application of NAA.

As mentioned earlier, application of NAA in low concentration enhances growth, thus creating a significantly high source strength. A high sink potential is also formed and accelerated translocation of assimilates from source to sink enhances the manifestation of yield components in association with extended grain filling period.

Influence on yield

Yield is the cumulative result of manifestation of yield components. An experiment conducted to study the effects of NAA and three irrigation frequencies on root growth and yield of BRRIdhan-28 showed that maximum yield was from 100 ppm of NAA along with flooded irrigation[33]. In Pakistan, during 2004–05, experiments carried out in field conditions with application of NAA alone or in combination with phosphorus or irrigation, increased significantly the yield of rice variety IR-6 (refs 29, 38, 39). In rice variety Biser-2, rice production was enhanced by the application of NAA[30]. Liu *et al.*[32] reported that the grain yield of rice increased when NAA was sprayed at 1000 mg l^{-1}. Due to the application of 100 and 200 ppm of NAA as foliar spray, grain yield per plant increased by 27.67% and 6.85% respectively, in BRRIdhan-29 though not statistically significant. However, in BRRIdhan-50 grain yield per plant decreased by 26.54% with 100 ppm and 27.67% with 200 ppm of NAA as foliar spray. Also, 100 ppm of NAA appeared more beneficial[32]. Bakhsh *et al.*[38] noted a better harvest index value in rice variety IR-6 due to application of NAA as foliar spray. Chaudhuri *et al.*[26] observed that the yield of rice varieties, viz. Jaya and Mahsuri had significantly enhanced by the application of NAA, irrespective of the time of application. Thus, it is apparent that the effect of auxins is cumulative in nature leading to increase in most of the growth and yield attributes; and hence the ultimate gain in grain yield is significant[40]. According to Rhodes and Ashworth[41], the metabolism of auxins and growth promoters generates the energy-rich phosphate and precursors of metabolic processes, which may be the factors in the initiation of enhanced growth processes. The increased growth and delayed senescence in turn, favoured increase in yield as most of the assimilates were translocated from the source to the sink under a stimulated environment. As the growth of the plants and the yield components are effectively enhanced, the resultant effect of yield had significantly improved. However, the effect is prominent in case of long-duration rice varieties as the slow movement of NAA takes sufficient time to activate the system.

Influence on major nutrient uptake

An experiment was conducted to find the responses of two rice varieties to NAA application as spray on nitrogen, phosphorus and potassium uptake by straw and root at three different stages and NPK concentrations in grains. Uptake of nitrogen, phosphorus and potassium was recorded higher at the tillering stage and harvest in general. However, nitrogen, phosphorus and potassium concentrations in grains were favourably influenced by 200 ppm NAA in both varieties, viz. BRRI dhan-29 and BRRI dhan-50, except potassium concentration in BRRIdhan-29. BRRIdhan-29 showed comparatively more positive response to NAA than BRRI dhan-50 (ref. 42). Thus NAA influences root growth effectively, creating a potential gradient for further uptake of nutrients.

Conclusions

Keeping the above in consideration, it may be inferred that application of NAA has the following effects: (i) Efficient root activities which improve nutrient uptake for better growth of rice plant; (ii) Improves growth parameters effectively; (iii) Most of the yield attributing factors are enhanced; (iv) Significant increase in grain yield; (v) Delayed senescence to improve mobilization of assimilates from source to sink.

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