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Plant Nutrition: A tool for the management of hemipteran insect-pests-A review

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ABSTRACT

Nutrition of plants has a substantial impact on the predisposition of plants to insect-pests. Regulated and balanced crop fertilization can be helpful in altering host plant susceptibility to sucking insect-pests. Hemipteran herbivores are sensitive to alteration in host plant nutrition. Primary pest defence of plants like biochemical, physical and mechanical properties can be enhanced by balanced fertilization with plant nutrients. All plant nutrients may affect plant health but two of them namely, nitrogen and potassium play a major role. The effect of other nutrients is less frequently mentioned. Most studies revealed that generally excessive use of nitrogen decreases crop resistance to pests whereas potassium increases the same. So, the agricultural practices like excessive, injudicious and unscientific use of fertilizers can result in nutrient imbalance and finally into increased attack of insect-pests. Careful consideration of present and future information on this topic can lead to better predictive capabilities in hemipteran insect-pest management.

Key words: Fertilizers, Hemipteran, Management, Plant nutrition, Sucking pests.

Integrated pest management is a decision support system for the selection and use of pest control tactics, singly or in harmoniously coordinated management strategy, based on cost/benefit analyses that take into account the impact on producers, society, and the environment (Kogan, 1998). It includes all approaches ranging from single component control methods to the most sophisticated and complex control method. Integrated pest management in agro-horticultural ecosystems needs the priority use of some unconventional methods including adequate inorganic fertilization (El-Zahi *et al.,* 2012). Increased nutrient application to the soil enhances plant growth and thus improves the yield of crops. However, improved vegetative growth can make the plant more attractive to pest attack and destruction by altering plant tissue's nutrient level (Baidoo and Mochiah, 2011; Gogi *et al.,* 2012).Soil nutrient management practices can significantly affect the susceptibility of crops to pests and do so without adversely affecting plant productivity (Phelan *et al.,* 1995; Rouhani *et al.,* 2012).

Nutrition concerns the chemicals required by organism for its growth, tissue maintenance, reproduction and necessary to maintain these functions. Besides carbon, hydrogen and oxygen, which plants obtain from carbon dioxide and water, 14 nutrients are recognized as essential *viz.*, primary macronutrients (nitrogen, phosphorus and potassium), secondary macronutrients (calcium, magnesium and sulphur) and micronutrients (iron, manganese, zinc, copper, boron, molybdenum, chlorine and nickel) for growth of plants. These elements are major composnents of amino acids, proteins, enzymes, nucleic acids, carbohydrates and lipids (Rattan and Goswami, 2009). Insects require amino acids for the production of proteins which are used for structural purposes, as enzymes for transport and storage and as receptor molecules. Some amino acids are involved in morphogenesis, cuticular sclerotization, visual pigment synthesis, neurotransmitters and also as an energy source. Carbohydrates are part of insect cuticle, used as fuel, many converted into fats for the production of amino acids. Lipids, like fatty acids, phospholipids and sterols are components of cell wall. Sterols are used in ecdysone synthesis. Some inorganic compounds like sodium, potassium, calcium, magnesium, chlorine and phosphate are major elements in the functioning of cells and are essential components of insect diet (Chapman, 2000). Though this subject has been dealt with in detail in respect of health of human beings, but is lagging behind in relation to plant health particularly the role of nutrients in resistance and tolerance in plants to insect-pests and diseases.

The relationship between plant nutrient content and insect populations has invoked the interest in the minds of ecologists for a long. Insects need multiple nutrients for their growth and development (Busch and Phelan 1999; Joern *et al.,* 2012). Understanding relationship between plant nutrition and pest reproductive potential is important for pest management in modern agro-ecosystems (Zarasvanda *et al.,* 2013). Fertilization practices may also affect crop tolerance

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to pests by affecting the growth pattern, the anatomy and morphology and particularly the chemical composition (Michaud and Charbonneau 1993). Amongst different group of insects, sucking insects show a much stronger response to crop fertilization (Balakrishnan *et al.,* 2007; Butler *et al.,* 2012).

Most sap-sucking insects belong to the order Hemiptera which use highly modified mouthparts consisting mandibles and maxillae enclosed in a slender flexible sheath known as the labium. The maxillae interdigitate to form two needle-like channels (stylets) which penetrate the parenchyma (e.g. some immature scale insects, many Heteroptera), the phloem (e.g. most aphids, mealybugs, soft scales, psyllids, leafhoppers and whiteflies), or the xylem (e.g. spittle bugs and cicadas) (Gullan and Cranston, 2010). Many species of plant feeding Hemiptera are considered serious agricultural and horticultural pests, whose desapping leads to wilting, distortion, or stunting of shoots. Apart from feeding, some also transmit plant viruses and other diseases and their sugary excreta (honeydew) leads to formation of black sooty moulds, which spoil leaves and fruits and can impair photosynthesis.In this article, effects of plant nutrition particularly primary macronutrients (with an emphasis on nitrogen, phosphorous and potassium) on hemipteran insect growth, development and abundance have been discussed.

Role of major nutrients in growth and development of plants and insects

Nitrogen: The nutrients have an important function in development process of insects. Nitrogen (N) is absorbed by the plant in the form of ammonium (NH_4^+) and nitrate (NO_3^-) and is used to synthesize amino acids, proteins and other complex nitrogenous compounds like chlorophyll. Adequate supply of nitrogen is associated with high photosynthetic activity, vigorous vegetative growth and a dark green colour of the leaves (Zafar *et al.,* 2010) as well as foliar nitrogen levels (Schutz *et al.,* 2008).

Amongst different nutrients, N is the most important element limiting growth of insects. Leaf nitrogen content is an appropriate indicator to assess quality of plants for many insects, as most of the herbivore insects generally prefer plants with high nitrogen content as their food. More application of nitrogen to plants changes the plant biochemistry that leads to high incidence of herbivorous insects, especially the homopterans (Jansson *et al.,* 1991; Slosser *et al.,* 1998; Bi *et al.,* 2001; Ge *et al.,* 2003; Firidin *et al.,* 2013). Application of nitrogenous fertilizer can normally increase herbivore feeding preference, food consumption, survival, growth, reproduction and population density by altering the nutritional levels in the plant tissues and significant reduction of host resistance against insect-herbivores (Cipollini *et al.,* 2002; Prudic *et al.,* 2005; Ortega-Arenas *et al.,* 2006; Zhong-xian *et al.,* 2007; Biswas *et al.,*2009). Fluctuation in the nitrate (NO_3^-) can increase susceptibility of plants to insect-pests as its excessive use decreases lignin concentration, which is a substance used by plants as a physical defence against various pests (Torres-Olivar*et al.,* 2014). An excessive N supply with unbalanced fertilization requires carbon (C) to metabolize it and this leaves little C from the Kreb's cycle for synthesis of secondary compounds, such as phenols and quinones. Phenolic compounds play an important role in the host/pest relationship, being the basis for many defence mechanisms. They act as phytoalexins or as precursors of lignin and suberin, which act as mechanical barriers in leaves and stems against insect-pest attack (Imas, 2013).

Phosphorous: Phosphorus (P) alters a variety of biochemical processes within plants due to its role in the metabolism of nucleotides, coenzymes and phospholipids (Clarke, 1982). It is central atom of phosphates which help in the formation of nucleic acids and high energy phosphate compounds like ATP.For phytophagous insects, phosphorus has not been considered as limiting as nitrogen. However, a few studies suggested that P can affect survivorship, fecundity, body size, oviposition preference, growth rate and population density. Its limitation can impose severe consequences for cellular function and ultimately the growth rate of consumers (Huberty and Denno, 2006).

Potassium: Potassium is a major plant nutrient accumulated by the roots and distributed throughout the plant. It is a key component of plant nutrition which significantly influences crop growth as well as infestations of some insects. K has fundamental roles in turgor generation, primary metabolism, and long-distance transport (Zorb *et al.,* 2014).

The role of K in mitigating crop damage due to insects has been well documented. It plays an important physiological role including build up of resistance to insect-pests. Adequate amounts of K have been reported to decrease the incidence of insect and mite damage considerably. Plants excessively supplied with N and little K have soft tissue with little resistance to sucking and chewing insects. The yellowish discoloration of plants suffering from K deficiency acts as a signal to attract aphids (Imas, 2013; Liu *et al.,* 2013). Whereas, high levels of potassium can enhance secondary compound metabolism, reduce carbohydrate accumulation, elimination of some amino acids, increase the silica content of leaves and plant damage from insect-pests (Baskaran *et al.,* 1985; Krauss, 2001; Facknath and Lalljee, 2005). A sufficient potassium supply tends to harden plant structures, including the aspects like stronger cuticle, stronger outer wall of epidermis, stronger cell walls, improved formation of sclerenchymatous tissues, lignification stimulated, silicification stimulated, thicker and harder stems. This hardening of plant structures is generally considered to improve mechanical resistance to feeding of insects especially sucking insects (Perrenoud, 1990).

Insect specific influences of major plant nutrients

Whiteflies: Jauset *et al.* (1998; 2000) observed nitrogen to affect feeding and oviposition site selection by greenhouse whitefly,*Trialeurodes vaporariorum* (Westwood)adults. The plants supplied with high nitrogen dose inhabited higher number of adults and the females laid more eggs on leaves of the plants with higher nitrogen and water content. They also observed increase in survival of immature stages with an increase in nitrogen dosage (Table 1). Ortega-Arenas *et al.*(2006) observed a significant increase innumber of eggs and nymphs of *T. vaporariorum*in gerbera with an increase in supply of nitrogen. Bi *et al.* (2001; 2003) investigated the impact of nitrogen fertilization on population dynamics and honeydew production by silverleaf whitefly, *Bemisia argentifolii* Bellows and Perring, on cotton plants and observed increase in number of both adult and immature whiteflies during population peaks with increased amounts of applied nitrogen. The effect of differentiates of N fertilizer at 50, 100, 150 and 200 kg N/ha, respectively, on the sucking insect pest complex of cotton studied by Ahmed *et al.* (2007) revealed highest N rate resulted in the highest mean population of whitefly, *Bemisia tabaci* Gennadius being 0.44; 1.49, 1.43 and 1.62 per leaf at 50, 100, 150 and 200 kg N/ha, respectively. Park *et al.* (2009) reported that the duration of developmental time is influenced by the nitrogen levels in *T. vaporariorum*. They observed the duration of eggs and nymphs to decrease with an increase in dose of nitrogen concentration from low (199 ppm) to medium (266 ppm) and high (395 ppm). They also found the honeydew production of nymphs to increase with decreasing nitrogen concentrations. Biswas *et al.* (2009) observed highest number of *B. tabaci*, per leaf at a higher dose of nitrogen and found a positive correlation between whitefly abundance level and nitrogen dose.

England *et al.*(2011) evaluated the influences of sustainable water-soluble fertilizer, a conventional water-soluble fertilizer, an alternation of these, a controlled-release fertilizer, and a clear water control on the life-history traits of *B. tabaci* biotype B reared on poinsettia (*Euphorbia pulcherrima*). The sustainable fertilizer produced plants with the highest concentration of amino acids. The relationship between total amino acids in phloem and survival was significant, with the highest survival at intermediate levels. Fecundity, however, was negatively correlated with total amino acid content of the host plant. Pang and Dong (2013) observed foliar application of amino acid to significantly promote tomato growth and resulted in increased plant height, leaf stentering and leaf area. Though application of phytonutrient also promoted plant growth but to a lesser degree than application of amino acid. Except for nitrogen and sugar, minerals and nutrient contents in tomato leaves varied with fertilizers treatments. Leaf content of phosphorus, protein and free amino acid was positively correlated with several tomato growth parameters, including plant height, leaf stentering, and leaf area. Whereas, potassium resulted in negative correlation with these parameters. The developmental duration of *B. tabaci* was longest on tomatoes treated with amino acid foliar fertilizer, followed by those treated with phytonutrient. Amino acid foliar fertilizer treated plants resulted in the nymphs with largest body size and higher adult female longevity and fecundity. However, the highest intrinsic rate of increase (r_m) of *B. tabaci* was resulted in plants treated with phytonutrient. Amino acid foliar fertilizer did not facilitated *B. tabaci* population growth.

Sudhakar *et al.*(1998) in brinjal observed significant reduction of population of all the sucking pests by changing the nutrient composition of the host plant by application of higher doses of potash. Feltrin *et al.* (2002) evaluated the infestation of *B. tabaci* (B biotype)on tomato plants fertilized with different sources of potassium namely, KCl + K_2SO_4 + K_2SiO_3; KCl + K_2SO_4; K_2SO_4 + KC1. They observed that different sources of potassium neither affect the *B. tabaci* B biotype infestation, nor the fruit yield and quality of the tomato fruits.

The influence of combination of three major phyto-nutrients (N, P and K) evaluated by El-Rafie (1999) on infestation of tomato with *B. tabaci* in Egypt revealed that plants treated with high levels of N resulted in increased number of *B. tabaci* and decreased yields. A mixture of moderate levels of nitrogen with potassium sulfate and phosphorous resulted in low population of *B. tabaci* and increased yields. El-Zahi *et al.* (2012) also investigated the influence of nitrogen, phosphorus and potassium fertilizers at recommended rates (66:30:24 kg/ha) on the population densities of *B. tabaci* infesting cotton plants and the results indicated that nitrogen fertilizer significantly enhanced the population density of the pest. Phosphorus fertilizer proved to be very effective in lowering its incidence. Plants fertilized with potassium either alone or in combinations with others were significantly infested with moderate numbers of *B. tabaci*. Plants treated with NPK in combination were infested with moderate population densities of the three insects and resulted in highest average number of squares and green bolls per cotton plant.

The micronutrients (non-chelated and chelated) in cotton crop were found not to affect the multiplication of whitefly, *B. tabaci* (Abro *et al.,*2004). Gogi *et al.* (2012) investigated the impact of nutrient management schedules involving different formulations of various nutrients (N, P, K, Zn, B and humus) on infestation of whitefly on non- Bt cotton cultivar. The results revealed that nutrients had significant effect on population of whitefly. Zn, B, N, P and K accumulatively demonstrated 83.6 per cent variation in the population of whitefly. Maximum role in population fluctuation of whitefly was played by nitrogen (80.62 %).

Table 1: Effect of plant nutrients on hemipteran insects-pests

Nutrient	Test species	Effect on insect		Reference(s)
		Whiteflies		
Nitrogen	*Trialeurodes vaporariorum*	Increased feeding, oviposition, distribution, immature survival, number of eggs and nymphs at higher N	+	Jauset *et al.*(1998;2000), Ortega-Arenas *et al.* (2006)
		Increase in honeydew production and decrease in duration of eggs and nymph duration with increase in N	+	Park *et al.* (2009)
	Bemisia argentifolii	Increased number of adults and immature with higher N levels	+	Bi *et al.* (2001; 2003)
	Bemisia tabaci	Increase in population with increase in N levels	+	Ahmed *et al.* (2007); Biswas *et al.* (2009); El-Rafie (1999); El-Zahi *et al.* (2012)
Potassium	*Bemisia tabaci*	Population reduction at higher doses of K	-	Sudhakar *et al.*1998
		No evident effect on population	0	Feltrin *et al.*(2002)
		Plants fertilized with K resulting in moderate population	-	El-Zahi *et al.* (2012)
Phosphorus	*Bemisia tabaci*	P application lowering the incidence	-	El-Zahi *et al.*(2012)
		Aphids		
Nitrogen	*Aphis gossypii*	N level enhanced weight size, colour, fecundity and distribution towards high N areas	+	Men*et al.*(2004); Chau *et al.*(2005)
		High N levels caused significantly lowest mean generation time and the highest finite rate of increase	+	Rostami *et al.*(2012)
	Brevicoryne brassicae	Higher levels of nitrogen fertilization cause an increase in the population	+	Kotlinski (2011)
	Hysteroneura setariae	Increased N resulted in increased survivorship,fecundity and rm	+	Jahn *et al.*(2005)
	Lipaphjs erysimi	Higher N increased the aphid population	+	Pandey (2010)
	Macrosiphum euphorbiae	Aphid performance was significantly lower on unfertilised plants with low N	+	Johanna and Barbara 2002
	Metopolophium dirhodum	Longevity was found unaffected, but its intrinsic rate of increase and fecundity increased at high N level	+	Alan (2012)
	Schizaphi graminum	High N caused higher net reproduction rate, doubling time, generation time and rm	+	Zarasvanda *et al.* (2013)
	Sipha flava	Population increased with increasing N levels	+	Miyasakaa *et al.* (2007)
	Sitobion avenae and *Rhopalosiphum padi*	Positive effect of Non the adult weight, Fecundity and longevity of both	+	Aqueel and Leather (2011)
Potassium	*Aphis craccivora*	Damage was lower at higher concentrations	-	Asiwe (2009)
	Aphis glycines	Greater intrinsic rate of population increase and net reproductive rate in the low K in comparison with the medium and high K treatments	-	Myers and Gratton (2006)
	Lipaphjs erysimi	Application of K reduced the population build up	-	Pandey (2010)
	Myzus persicae	Higher doses gave the least number of aphids per plant	-	Sarwar*et al.*(2011)
	Sipha flava	Population found to be unaffected by K fertilization.	0	Miyasakaa *et al.*(2007)
Phosphorus	*Lipaphjs erysimi*	Application of P reduced the population build up	-	Pandey (2010)
	Macrosiphum	P had a positive effect on several parameters of aphid performance.	+	Johanna and Barbara 2002
	Myzus persicae euphorbiae	Significantly higher infestation in treatments receiving P	+	Omar *et al.*(1993)
		Leafhoppers and plant hoppers		
Nitrogen	*Amrasca sp.*	An increase in numbers of jassids per leaf at higher N dosages	+	Ahmed *et al.* (2007); Biswas *et al.*(2009)
	Amrasca devastans	The highest N rate resulted in the highest per leaf mean population	+	Ahmed *et al.*(2007); Sta. Cruz *et al.*(2007); Razaq*et al.*(2014)
	Empoasca decipiens	An increase in population with increased rate of N	+	Ghorbani *et al.*(2010)
	Nilaparvata lugens	Higher population density at higher N	+	Zhong-xian *et al.*(2006); Dash *et al.*2007; Rashid *et al.*(2013)
	Sogatella furcifera	A positive correlation between nitrogen levels and incidence of *S. furcifera*	+	Kushwaha and Chand (1988)

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Phosphorus	*Empoascadolichi*	P reduced the population densities and damage	-	Shri Ram *et al.*1987, 1990
	Clavigralla sp., *Riptortus* sp., *Anoplocnemis*., *Mirperus* sp. and *Negara* sp.	Higher P levels reduced the population densities and damage	-	Pitan *et al.*2000
	Nilaparvata lugens	An increase in P contents showed a significant positive correlation	+	Dash *et al.*2007
		Phosphorus fertilization markedly increased the population growth	+	Rashid *et al.*(2013)
Potassium	*Nilaparvata lugens*	The lower K level in plants facilitated the fecundity	-	Liu *et al. et al.* 2013
		K content in foliage showed negative relationship	-	Dash *et al.*2007
		High K application decreased population build up and dry weight of BPH.	-	Rashid *et al.*(2013)
Sulphur	*Nilaparvata lugens*	Greater response with a lower incidence	-	Li *et al.*(2010); Dash *et al.* 2007
Zinc	*Nilaparvata lugens*	Zn content in foliage showed negative relationship	-	Dash *et al.*2007
		Psylla		
Nitrogen	*Cacopsylla pyricola*	Psylla populations were larger in the high N treatment.	+	Daugherty *et al.*(2007)
		Mealy bugs		
Nitrogen	*Saccharicoccus sacchari*	Survival and size increased with increasing N	+	Rae and Jones (1992)
	Planococcus citri	High N increased egg loads, size and decreased developmental time	+	Hogendorp *et al.*(2006)
	Planococcus ficus	N increased survival	+	Cocco *et al.*(2013)

+: Positive i.e. insect development or damage decreased;
- : Negative i.e. insect development or damage increased;
0: No effect i.e. insect development or damage unchanged

Aphids: Host plant quality is known to be an important fac-tor affecting aphid demography, survival, fecundity and life expectancy (Dixon 1987; Rostami *et al.,* 2012). Fertilization also influences the distribution and population dynamics of aphid pests seriously (Tan *et al.,* 2012). Morales *et al.* (2001) observed cornfields treated with organic fertilizer for at least two years hosted fewer aphids, *Rhopalosiphum maidis* than treated with synthetic fertilizer, which was attributable to high concentration and total content of foliar nitrogen in corn in the synthetic fertilizer treated plants.

Jahn *et al.* (2005) studied inter-generational effects of N fertilizer applications (0, 50, 100 and 150% of standard N fertilizer rates) to rice plants on rusty plum aphid, *Hysteroneura setariae* (Thomas). Second-generation aphids produced on plants having higher N levels had significantly higher survivorship, fecundity and intrinsic rate of increase (rm) regardless of the N treatment of plants that parents fed on, indicated that the effect of a high N diet was expressed in second generation of aphids (Table 1). Chau *et al.* (2005) established that population growth rate of *A. gossypii* on potted chrysanthemum plants increased with fertilization levels from 0 to 38 ppm N and reached a plateau from 38 to 488 ppm N. They also observed that aphids distributed themselves to high N level areas in the plant. More aphids were found in the apical and middle strata of the plants than the basal stratum, which had the lowest nitrogen content. The weight, size, colour and fecundity of aphid were also enhanced by the nitrogen level. Kotlinski (2011) found that higher levels of nitrogen fertilization can cause an increase in population of *Brevicoryne brassicae* on cabbage. The effect of nitrogen applications on *Sitobion avenae* and *Rhopalosiphum padi* in wheat plants was investigated by Aqueel and Leather (2011). They recorded a positive effect of N-fertilizer on the adult weight achieved by *S. avenae* and *R. padi*. Fecundity and longevity of both species were also positively correlated with N-fertilizer application. In *R. padi*, N-fertilizer reduced the time to reach maturity but not in *S. avenae*. Rostami *et al.* (2012) studied the effect of different nitrogen levels (0, 25, 50, 100 and 150%) on life table parameters of cotton aphid, *A. gossypii* reared on *Chrysanthemum indicum* Kitan. The intrinsic rate of increase and net reproductive rate ranged from 0.173 to 0.225 and 15.47 to 28.28, respectively, at different tested fertilizer levels. The aphids showed significantly lowest mean generation time and the highest finite rate of increase when fed on chrysanthemum fertilized at highest (150%) fertilizer level. Also, aphid fecundity and survival showed a positive correlation when the fertilizer concentration was increased. On the other hand, the highest life expectancy was obtained for the aphids fed on chrysanthemum with a lower (25%) nitrogen level. Alan (2012) observed that the longevity of cereal aphid, *Metopolophium dirhodum* remained unaffected by the level of fertilisation, but aphids' intrinsic rate of increase and fecundity increased with higher level. The influence of wheat nitrogen nutrition (0, 50, 100 and 150%

concentrations) on biology and life table of *Schizaphis graminum* was studied by Zarasvanda *et al.,* (2013) revealed that increase in nitrogen fertilisation resulted in increase insoluble nitrogen concentration in plants. Nitrogen had no effect on pre- and post-reproductive periods but significant effects were observed on reproduction period, adult longevity and fecundity. Aphids feeding on plants treated with higher fertilisation significantly had higher net reproductive rate, doubling time, generation time, finite rate of increase and the intrinsic rate of natural increase. Number of wingless aphids increased significantly with increase in fertilisation level.

A study conducted by Myers and Gratton (2006) on soybean aphid indicated that soil K availability and leaf K levels affect plant quality and may play an important role in soybean aphid population dynamics. A significantly greater intrinsic rate of population increase and net reproductive rate in the low K treatments in comparison with the medium and high K treatments was found. Walter and Difonzo (2007) also observed higher populations of soybean aphid in potassium deficient plants. Similar results were also found by Asiwe (2009) who evaluated the effects of four levels of phosphorus fertilizer application (0, 15, 30 and 45 kg P_2O_5 ha^{-1}) on *Aphis craccivora* population, damage and grain yield of cowpea in Nigeria. The results indicated that damage by *A. craccivora* was lower at 30 and 45 kg P_2O_5 ha^{-1} and consequently higher grain yields were obtained. Observations of Sarwar *et al.*(2011) are also in line with the above studies. They reported *Myzus persicae* to flourish more on canola, *Brassica napus* plants that were grown in soils without potassium. Whereas, at higher potassium nutrition levels least number of aphids per plant were obtained resulting in highest seed yield.

The population growth rate of the *Schizaphis graminum* was found to decrease in barley seedlings watered with nutrient solutions containing high doses of nitrate in a study conducted by Salas *et al.* (1990). Rosseto *et al.* (1997) evaluated the effect of fertilizers (various combinations of NPK) on *A. gossypii* infesting cotton and results revealed that number of aphids increased with fertilization and decreased in the absence of fertilizers. In studies undertaken by Johanna and Barbara (2002) on *Macrosiphum euphorbiae* on *Petunia axillarishybrida*in relation to plant nutrient levels and the ratio of nitrogen to potassium (N/K) revealed that not only the nutrient levels but the ratios are also important in influencing the aphid performance. Both P and K were associated with a short development time but a strong correlation between P and K content made it impossible to detect their relative importance. Aphid performance was significantly lower on unfertilised plants with low N content, suggesting a positive effect of N. However, a high N/K ratio did not increased aphid performance. Damage due to yellow sugarcane aphid, *Siphaflava* on *Pennisetum clandestinum* tended to increase with increasing N levels and remained unaffected by K fertilization. The fertilization with increasing N resulted in greater dry matter production of *Pennisetum clandestinum* but it also tended to increase the damage caused by its feeding (Miyasakaa *et al.,* 2007). Pandey (2010) evaluated effect of nitrogen, phosphorus and potash on *Lipaphis erysimi* population build-up and yield parameters in mustard and found that application of nitrogen alone or higher dosage of nitrogen increased aphid population while application of phosphorus and potash with or without combination of nitrogen reduced the population build up. Tan *et al.* (2012) investigated the effects of N and P on *Aphis gossypii* population density on Bt-cotton. Aphid density in cotton plants fertilized with 72 kg N /ha (84.2 aphids/plant) was found to be significantly higher than fertilized with 0 and 108 kg N /ha (36.7 and 47.8 aphids/plant). Compared to cotton plants treated with 23 and 69 kg P /ha, aphid density was higher (61.67 aphids/plant) in cotton plants treated with 46 kg P /ha.

Leafhoppers and plant hoppers: Kushwaha and Chand (1988) observed a positive correlation between nitrogen levels (60 to 180 kg/ha) and the incidence of *Sogatella furcifera* in rice (Table 1). Zhong-xian *et al.* (2006) also studied the effect of N fertilizer rates (200, 100 and 0 kg N/ ha) on the diversity of brown plant hoppers (BPH) and their natural enemies in rice and observed higher density of BPH in plots with higher N (200 kg /ha) at booting and milking stages. Sta.Cruz *et al.*(2007) also found a positive correlation of brown plant hopper damage with N concentration. Contrary to these, Men *et al.* (2004) found that leafhopper populations were not significantly influenced by nitrogen fertilizer applications. The effects of various rates of N fertilizer (50, 100, 150 and 200 kg/ha) on the sucking insect pest complex of cotton studied by Ahmed *et al.* (2007) revealed that increase in N rate resulted in elevated population levels of *Amrasca devastans*. An increase in numbers of jassids (*Amrasca sp.*) per leaf at higher N dosages was also observed by Biswas *et al.* (2009) in okra. Similar observations were recorded by Ghorbani *et al.* (2010) who found an increase in population of *Empoasca decipiens* (37.5%) with increased rate of nitrogen fertilizer from 100 to 200 kg/ha. Razaq *et al.* (2014) reported that *A. devastans* population increase significantly with increase in nitrogen level.

Some reports showed that the application of phosphorus reduced the population densities and damage of *Empoasca dolichi* (Shri Ram *et al.* 1987; 1990) and pod sucking bugs (Pitan *et al.,* 2000).Liu *et al.*(2013) indicated that the number of eggs laid by *Nilaparvata lugens* reared on the rice varied significantly with K concentration, which increased by 0.12 and 0.22 fold under 20 mg/L and 160 mg/ L K level, respectively compared to that of the control (40 mg/L) and decreasing by 0.57 fold under 0 mg/L K.

Effect of nitrogen, phosphorus and potassium fertilizers on the incidence of *A. devastans* studied on three cotton genotypes revealed that the pest population was significantly higher in plots without fertilizer than in those receiving fertilizer (Purohit and Deshpande 1991). In another study, Kavitharaghavan *et al.* (2006) observed the incidence of leaf hopper *A. devastans* to be comparatively less in the organics-applied aubergine plants than those on plants applied with NPK in the inorganic form. They also observed nymphal duration to prolong and low leaf hopper growth index in organics-applied treatments. Prasad *et al.* (2003) observed that N and K applied in 2 or 3 splits, significantly decreased the incidence of green leaf hopper (*N. virescens*) and earhead bug (*Leptocorisa acuta*), and increased the grain yield, compared to basal application of Nitrogen. Application of N and K both at 90 kg/ha resulted in low pest incidence and high grain yield. Also, a basal dressing of FYM along with the split application of N and K each at 90 kg/ha resulted in lowest pest incidence. An increase in N and P content in rice foliage showed a significant positive correlation with BPH while, K, Zn and sulphur content in foliage showed negative relationship (Dash *et al.,* 2007). Rashid *et al.* (2013) evaluated the consequences of N, P and K application on population build up and weight of *Nilaparvata lugens* in rice. Interactions demonstrated no significant effect on population growth and weight. However, interaction of N and P showed significant effect on population growth of BPH. Fertilization with nitrogen increased population and dry weight of BPH. Phosphorus fertilization markedly increased the population growth while high potassium application decreased population build up and dry weight of BPH.

The growth and developmental parameters, growth index and population build up of white backed planthopper (WBPH), *Sogatella furcifera* were found to be affected significantly by application of four micronutrients namely, Zn, Fe, Cu, and Mn in the form of their ulphate fertilizers on rice (Rath2006). Zn and Fe induced antibiosis effect on WBPH and reduction in nymphal survival and enhancement of nymphal duration were more pronounced. These treatments also favoured the production of more males, exhibiting lower growth index and population build up (Rath*et al.,* 2009).Dash and Mukherjee (2009) observed NPK @ 60:30:30 kg/ha supplemented with zinc sulphate @ 25 kg/ha as basal dose to harbour significantly low population of brown planthoppers than application of corresponding NPK dose alone without zinc sulphate. They also observed that higher NPK level (120:60:60 kg/ha) to result in highest hopper population among the nutrient levels tested.

Psylla: Daugherty *et al.* (2007) tested efficacy of nutrients against pear psylla (*Cacopsylla pyricola* Foerster). The pear trees receiving more N were taller, had longer total branches, a greater total number of leaves, and higher leaf nitrogen content. Psylla populations were also larger in high N treatment (Table 1). Rouhani *et al.* (2012) tested the impact of nitrogen (N), calcium (Ca) and zinc (Zn) fertilizers on common pistachio psylla, *Agonoscena pistaciae* in pistachio orchards. The highest measure of control on eggs was related to ZnCa and Zn while the least was related to NZn. The results also showed that the highest measure of pest control was related to Ca while the least was related to N and Zn.

Mealy bugs: Rae and Jones (1992) observed the influence of nitrogen applied to potted sugarcane on the survival and size attained at the onset of the oviposition period of immature *Saccharicoccus sacchari*. Survival of *S. sacchari* increased to a maximum at 320 mg/litre soluble nitrogen in sugarcane and decreased at higher levels, while size increased with increasing nitrogen over the whole range of concentration tested (Table 1). The effect of nitrogen concentration on the reproduction and development of citrus mealybug, *Planococcus citri*, studied by Hogendorp *et al.* (2006) on coleus, *Solenostemon scutellarioides* revealed that the citrus mealybug life history parameters were influenced by the applied nitrogen concentrations (ppm), leaf nitrogen concentration (%) and total moisture content (g). Citrus mealybug feeding on coleus, receiving high nitrogen fertilizer concentrations had the greatest egg loads, were larger in size, and had the shortest developmental times. Cocco *et al.* (2013) investigated the effects of different nitrogen fertilization regimes on female development of vine mealybug, *Planococcus ficus*, and the citrus mealybug, *Planococcus citri* on *Vitis vinifera*. The survival of *P. ficus* in unfertilized plants was lower than in those supplied with nitrogen. The development time of *P. ficus* on unfertilized grapevines was significantly longer than in all other treatments, while no differences were found on plants infested with *P. citri*. The nitrogen fertilization significantly affected development time, size and fecundity of *P. ficus*, while no differences were found on the survival and sex ratio.

Scale insect: A field trial was conducted by Siddappa *et al.* (2008) to record the incidence of scale insect in curry leaf supplying with the nutrition by organic and inorganic fertilizers. Increase in scale infestation was noticed with the corresponding increase in inorganic fertilizers. Application of only inorganic fertilizer at recommended dosage (RDF) enhanced the scale infestation followed by RDF with FYM. Fernandes *et al.* (2012) observed the elevated nitrogen and potassium levels in nutritional solutions led to increase in nymphs and adults of *Coccus viridis* in coffee plants. Potassium and nitrogen had both direct and indirect effects on it. The direct effect was because of the increase of the nitrogen content in the leaves. The indirect effect instead was because of reductions in the caffeine and chlorogenic acid contents in the leaves.

CONCLUSION

It can be concluded that amongst the plant nutrients discussed here, Nitrogen fertilization showed very clear and

significant effect on growth and development of all the Hemipteran insects. High N doses result in increased oviposition, abundance and survival of different species of whiteflies. Studies on different aphid species also revealed that high N level enhances weight, size, fecundity, finite rate of increase and low mean generation time. Also in other hemipterans like leafhoppers, plant hoppers, psyllids, mealybugs and scale insects a positive correlation between N level and population density, damage to plants, number of individuals, size, egg laying etc. has been observed.

Potassium, on the other hand has negative impact on growth and development of sucking pests. Higher K levels results in decline in population, incidence, intrinsic rate of population increase and net reproductive rate of aphids and whiteflies. So, the idea that higher levels of N fertilizers increase the number of pest and K is outstandingly important in conferring 'resistance' to pest attack finds great support.

Scanty information on role of Phosphorus and other macro and micronutrients on these aspects is available and efforts should be made to carry out these studies so that their roles in HPR to sucking pests become clear. The available information can be used in sucking pest management in crops by regulating plant nutrition. Plants, which are supplied with all necessary nutrients in a balanced manner, are shown to be more resistant to insect-pests. This lowers the need for particular pest control measures and also can be integrated with insect-pest management programmes.

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