



Effects of nitrogen supply on defensive changes in maize against biotic stressors

S.D. BAMBORIYA¹, SHIVA DHAR², P.K. UPADHYAY³, ANCHAL DASS⁴, SUMITRA DEVI BAMBORIYA⁵,
KAMAL GARG⁶ AND R.P. MEENA⁷

ICAR-Indian Agricultural Research Institute, New Delhi 110 012

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ABSTRACT

The maize yield potential is constrained by a diverse range of biotic and abiotic factors, ultimately leading to diminished crop yield, and quality. Nitrogen (N)-an indispensable fertilizer element is known to exert an influence on incidence and severity of these biotic stresses. This paper describes the effect of various levels of N application and contrasting maize genotypes on weed infestation, maydis leaf blight (MLB) and fall armyworm (FAW) incidence in maize. The field experiment was carried out at ICAR-Indian Agricultural Research Institute, New Delhi during two consecutive years (2021 and 2022). Treatments comprising 6 maize genotypes (PJHM 1, PC 4, DKC 9167, PMH 13, AH 4271 and Pusa Vivek QPM 9-I) and seven N levels (0, 40, 80, 120, 160, 200 and 240 kg N/ha) were arranged in a factorial randomized complete block design. Results showed that genotypes with profuse growth, greater leaf area and higher light interception (PJHM 1, DKC 9167 and PMH 13) had minimum weed incidence and may be considered as a key element of integrated weed management in smallholder agriculture. Disease severity in PV QPM 9-I (5.3) was higher than all other genotypes while least in AH 4271 (2.7). The maximum and minimum pest incidence was observed in PJHM 1 (4.9 and 5.6,) and PV QPM 9-I (2.1 and 2.4), respectively. In general, the total (-9.4%) and broad-leaf weed density (-26.4%) reduced with increasing use of nitrogenous fertilizers, while the application of lower N rates reduced the prevalence of narrow-leaf weeds (34.2%). The early leaf senescence and poor photosynthetic rate at lower rates of N application decreased the plants immunity against MLB disease. Oppositely, the increased succulency at higher N doses led to severe FAW incidence in maize over control. Therefore, the study demonstrates that planting of competitive/resistant genotypes and use of 160 kg N/ha resulted in relatively less overall burden of biotic stressors on maize crop.

Key words: Corn, Fall armyworm, Maydis Leaf blight, Nitrogen, Plant health, Weed

Maize (*Zea mays* L.) an essential cereal and multipurpose species in the Poaceae family, is widely used for food, fuel, and industrial applications to make a number of products including maize starch, dextrose, syrup, and flakes (Singh *et al.*, 2022). Its biological plasticity allows to thrive well in a variety of climatic and soil conditions and, therefore, grown under diverse agro-ecologies untouched by other cereals. Maize is the only cereal crop gifted with the highest yield potential, and genetic diversity. It is becoming a popular crop in India due to its potential use in ethanol production. It is India's third-largest basic food crop in terms of output and acreage, after rice and wheat. Maize is grown on 9.86 million hectares area in India, contributing 31.5 million tonnes produce (DES, 2021). How-

ever, the prevalence of various biotic stresses like disease, insect-pest and weeds has become a potential yield limiting factor in many maize growing regions across the country. Among various biotic constraint, interference from weeds is a major threat to maize productivity. Maize is quite vulnerable to weed competition mainly at early crop growth stages. In maize crop, the potential yield losses due to weeds can range from 51 to 100%, in the absence of effective weed control strategies (Ghosh *et al.*, 2020). Of the 61 main diseases affecting maize, maydis leaf blight (MLB) is the most important foliar disease in most of the maize growing belts in the world. This massive foliar disease is caused by ascomyceteous fungus *Cochliobolus heterostrophus* (Drechs.), a necrotrophic plant pathogen that kills leaf tissues and may result in 70% yield losses in susceptible genotypes of maize (Manjunatha *et al.*, 2019). Fall army worm (FAW), *Spodoptera frugiperda* (J. E. Smit) has emerged as the most devastating pest of maize in the recent years (Sharanabasappa *et al.*, 2018). Under severe infection, this voracious pest may cause up to 100%

¹Corresponding author's Email: sbamboriya93@gmail.com

¹Scientist, ICAR-Indian Institute of Maize Research, Ludhiana, Punjab 141 004; ²Principal Scientist, ³Scientist, ⁴Principal Scientist, ^{6,7}Ph.D. Scholar, ICAR-Indian Agricultural Research Institute, New Delhi 110 012; ⁵Assistant professor, Rajasthan Agricultural Research Institute, Durgapura, Jaipur 302 018, Rajasthan

yield loss in corn, if control measures are adopted (Sharanabasappa *et al.*, 2018).

Nitrogen stands as a prominent nutrient that significantly influences plant metabolism, development, and physiology (Kumar *et al.*, 2022). It is intricately linked to fundamental plant processes, such as photosynthesis, amino acid synthesis, and the tricarboxylic acid cycle. It is crucial nutrient for maize since it improves the vegetative growth, leaf area, leaf production, chlorophyll content, photosynthesis, yield and overall quality (Bamboriya *et al.*, 2023). The dose and source of N influence the diversity, density and proliferation and community structure of crop-associated weeds (Ghosh *et al.*, 2020). Sub-optimal application of N may favor certain weed species and therefore, increase the herbicide demand (Jha *et al.*, 2017). The N alters plants ability to respond to biotic stressor, including attacks from herbivores as it can induce changes in host plant is morphology, biochemistry, physiology and microclimate (Aydogdu and Boyraz, 2011). In general, N poses a negative effect on plant's physical defence mechanism and secretion of anti-pathogen phytoalexins and also regulates the plant ability to bounce back from biotic stresses. Nitrogen is also known to affect the plants nutrition and therefore, nutritional supply to herbivores. Hence, a field study was conducted to study the impact of N fertilizer on plant biotic stresses in diverse genotypes of maize crop. We hypothesize that optimizing N dose for different genotypes will significantly improve the crop resistance against biotic stresses in maize.

MATERIALS AND METHODS

Field experiments were conducted over two consecutive years (2021 and 2022) at ICAR-Indian Agriculture Research Institute, New Delhi, India (28° 38'23" N and 77° 09'27" E). The experimental site is situated a in semi-arid and subtropical climate, with extremes of both cold and heat. The minimum and maximum temperature during the

kharif season was 17.0 and 38.2°C during 2021 and 18.6 and 38.8° C during 2022, respectively. The total rainfall received during the *kharif* season of 2021 and 2022 was 1256 and 821 mm, respectively. The mean relative humidity (RH) was 78.1% and 74.2% during 2021 and 2022, respectively. Soil of the experimental site was sandy loam in texture, low in organic C (0.44 %) and available N (185 kg/ha) content, medium in available phosphorus (12.8 kg P/ha) and available potassium (205 kg K/ha), non-saline (0.65 dS/m EC) and slightly alkaline in chemical reaction (7.7 pH).

The factorial experiment was laid-out in a randomized complete block design (RCBD) and replicated twice. The treatments consisted of six genotypes of maize (PJHM 1, PC 4, DKC 9164, PMH 13, APH 4271 and PV QPM 9-I) and seven N levels (0, 40, 80, 120, 160, 200 and 240 kg N/ha). Genotypes with contrasting nature (differing in maturity, yield potential and N response) were chosen for the experimental purpose (Table 1). Maize genotypes were planted on 15th and 9th July during 2021 and 2022, respectively. The seeds were sown at 5 cm depth following row-to-row spacing of 60 cm and plant-to-plant spacing of 20 cm. In order to protect the crop from seed and soil borne diseases, seeds were treated with carbendazim 50 WP @ 3 g/kg seed. Recommended dose of P (80 kg P₂O₅/ha) and K (60 kg K₂O/ha) were applied before planting of the crops through single-superphosphate and muriate of potash, respectively. The N was applied through urea in three equal splits at sowing, 30 and 45 DAS. For weed control, atrazine @ 750 g/ha was used as pre-emergence herbicide. Two to three irrigations were applied to maize as per crop need. The FAW (*Spodoptera frugiperda*) was controlled by repeated spray of emamectin benzoate @ 200 g/ha.

The leaf area index (LAI) for each treatment was measured using leaf area meter (Model LICOR 3000, USA). The SS1 SunScan plant canopy analyzer was used to quantify photosynthetically active radiation (PAR) interception

Table 1. Characteristics of the maize genotypes

Genotype	Type	Maturity group	Yield potential	N responsiveness
PJHM 1	Dual purpose hybrid	Medium-maturity (90-95 days)	High yielding (6.5 t/ha)	Extremely receptive to fertilizer N and can show positive N response up to 200 kg N/ha
PC 4	Composite variety	Early maturity (89-90) days	Low yield potential (4.5 t/ha)	Performs better under low input and moisture stress conditions
DKC 9164	Hybrid	Late maturity (105-110 days)	High yielding (6.5 t/ha)	-
PMH 13	Hybrid	Medium maturity (97 days)	High yielding (5.9 t/ha)	-
APH 4271	Advanced hybrid	Medium maturity (90-95 days)	High yielding (6.4 t/ha)	-
PV QPM 9-I	Pro-vitamin-A rich maize hybrid	Extra early maturity (75-80 days)	Yield potential (5.5 t/ha)	-

at silking. The measurement of the chlorophyll and carotenoid content was done by acetone method. The photosynthetic rate was measured at silking stage using Infrared Gas Analyzer (LI6400). A 0.25 m² quadrat was randomly placed between the central rows of each plot to measure the weed density and species composition of the weeds at 50 DAS. Weed species were recognized and counted and the data were subjected to square root transformation $\{\sqrt{(x+0.5)}\}$. The MLB diseases severity was visually estimated using for rating scale. The scale consisted of 9 categories designated by numerals 1 to 9. Scale 1 represents nil infection, 2 indicates light infection, 3–4 represents slight infection, 5 indicates moderate infection, 6–7 represents heavy infection and 8–9 indicates very heavy infection. Ten randomly selected plants/plot were evaluated for MLB and degree of infection was assigned to each plant. The average of the ten plants was computed and expressed between 1 to 9. The Davis scale was used to estimate the FAW damage on the maize leaves. Ten plants/plot were randomly chosen at knee-high stage and 0–9 score was assigned to each plant. Zero score indicates no harm, 1–4 represents moderate damage, 5–7 represents medium damage, and 8–9 represents significant damage. By averaging all of the ten sampled plants, the average damage score per plot was calculated.

Data were statistically analysed using the “Analysis of Variance Technique” with SAS 9.3 software. Least significant difference (LSD) values at the 5% level of probability were used to compare the treatments.

RESULTS AND DISCUSSIONS

Growth and physiological parameters

The growth and physiological parameters of plant depend on the type of genotype. The LAI and photosynthetic radiation interception were maximum in PHM 13, DKC 9164 and PJHM 1 (Table 2). The genotypic difference in PAR interception might be caused by potential variations in genotype’s leaf area and leaf orientation. Chlorophyll content and photosynthetic rate were substantially higher in PJHM 1, PMH 13 and AH 4271. PV QPM 9-I registered the lowest value of these growth and physiological parameters. Significant genotype variability in chlorophyll content, and PAR interception were also reported earlier by Chikoye *et al.* (2008).

The data revealed that when N levels increased from 0 to 240 kg N/ha, the LAI, intercepted PAR, chlorophyll content and photosynthetic rate consistently increased. The lowest total values of all these parameters were found in control with no N. The reduced LAI and intercepted PAR at unfertilized plots might be owing to the hampered leaves production and reduced leaf size as a result of poor plant growth under severe N stress. The primary cause of low chlorophyll values and photosynthetic rate in the absence of N is the breakdown of proteins and plastids, which slows down or stops chlorophyll synthesis (Choudhary and Behra, 2020).

Weed dynamics

During the maize cropping season, the major weeds

Table 2. Plant growth and physiological parameters of maize as affected by genotype and N levels at silking stage during 2021 and 2022

Treatment	LAI		Intercepted PAR (%)		Chlorophyll content (mg/g of fresh leaf)		Photosynthetic rate (μmole CO ₂ /m ² / sec)	
	2021	2022	2021	2022	2021	2022	2021	2022
<i>Genotype (G)</i>								
‘PJHM 1’	3.79	3.85	59.8	61.6	1.12	1.03	32.6	33.7
‘PC 4’	3.77	3.83	52.6	55.4	1.02	0.96	27.1	27.3
‘DKC 9164’	3.83	3.94	60.3	62.3	1.06	1.02	29.2	30.4
‘PMH 13’	3.85	3.96	61.6	62.6	1.07	1.04	30.0	29.8
‘AH 4271’	3.73	3.79	58.3	61.3	1.10	1.02	31.3	32.2
‘PV QPM 9-I’	2.84	2.94	46.5	47.3	0.98	0.94	23.5	25.2
CD (P=0.05)	0.24	0.13	1.8	2.9	0.06	0.07	1.7	1.8
<i>Nitrogen level (N) (kg/ha)</i>								
0	2.51	2.58	44.4	48.3	0.70	0.55	22.8	24.2
40	3.06	3.14	51.1	53.7	0.86	0.73	24.4	26.2
80	3.44	3.52	55.0	57.4	0.97	0.89	27.3	28.1
120	3.89	3.97	56.8	59.1	1.13	1.09	29.8	30.0
160	4.02	4.09	61.1	61.0	1.19	1.17	31.3	32.2
200	4.19	4.26	63.1	63.6	1.27	1.27	32.8	33.5
240	4.34	4.41	64.3	65.8	1.32	1.32	34.1	34.3
CD (P=0.05)	0.26	0.14	1.9	3.1	0.06	0.07	1.9	1.9
Interaction (G×N)	NS	*	*	*	*	NS	*	*

LAI- leaf area index; PAR- photosynthetically active radiation

were *Cyperus rotundus*, *Phyllanthus niruri*, *Convolvulus arvensis*, *Dactyloctenium aegyptium*, *Digitaria sanguinalis*, *Amaranthus viridis* and *Eragrostis tenella*. The structure of the genotype canopy has been observed to influence the weed density. Among the genotypes, the grassy weed density was in the order of PV QPM 9-I > AH 4271 = PMH 13 = DKC 9164 = PJHM 1 > PC 4 while a different trend was observed for broad-leaf weeds (PC 4 > PV QPM 9-I > AH 4271 > PMH 13 > DKC 9164 > PJHM 1). Sedges counts did not differ significantly among the genotypes (Table 3). Total weed density was 9.7–12.1 % lower with genotypes having higher LAI and intercepted PAR (PJHM 1, DKC 9164 and PMH 13) (Table 3), indicating that these genotypes were more competitive than weeds and may be a key element of integrated weed management in smallholder agriculture. The short stature and poor vegetative growth of PV QPM 9-I led to maximum weed density (8.56 and 9.16 weeds/m²). The LAI serves as a valuable tool in forecasting crop losses caused by weeds and is crucial for understanding crop-weed competition dynamics. Earlier Jha *et al.* (2017) also reported that a crop having a denser canopy (high LAI) can diminish weed competitiveness by limiting the amount of light available for weed growth and development. The correlation analysis also showed that LAI ($r=-0.59$) and intercepted PAR ($r=-0.73$) of maize was negatively related with total weed density.

The rates of N applications significantly affected the grassy, broad-leaf and total weed density over control. Population density of grassy weeds (53.4%) was positively related with N levels. Moreover, grassy weeds are more

competitive for applied N due to their greater N absorption efficiency, hence, they preferred N fertilized environment. In contrast, N application had negative effect on broad-leaf weeds as their higher count (up to 35.9 %) was observed in control plot as compared to 240 kg N/ha. Sedges density increased with N application up to 200 kg N/ha and declined thereafter. Total weed count was significantly reduced (-9.4%) with N fertilization over control mainly due to enhanced leaf area and greater PAR absorption at higher N levels.

MLB disease severity

The MLB was the only corn disease seen in the experimental plots. Disease development and severity of MLB was highly dependent on prevailing weather conditions. The incidence of MLB was observed during first year only when higher atmospheric humidity (>75%) and moderate temperature (17 to 38.2 °C) favoured sporulation, and lesion expansion (Manjunatha *et al.*, 2019). During the second year of the study, weather conditions (RH < 75 and low temperature) were not favourable for the disease incidence to appear.

Disease resistance frequently differs among plant species, as various genotypes showcased distinct patterns of chemical and physical defensive mechanisms. Among the tested varieties, 'PV QPM 9-I' was found most susceptible to MLB disease with the highest MLB disease scale (5.3) (Fig. 1). Conversely, 'AH 4271' displayed the lowest MLB disease scale (2.7), signifying that this particular genotype curtailed pathogen multiplication, thereby showcasing

Table 3. Weed density as affected by genotypes and N levels in maize during 2021 and 2022.

Treatment	Weed density (Number/m ²) at 50 DAS							
	Grassy weeds		Sedges		Broad- leaf weeds		Total weeds	
	2021	2022	2021	2022	2021	2022	2021	2022
<i>Genotype (G)</i>								
'PJHM 1'	4.78	5.13	2.25	2.64	5.09	5.90	7.53	8.26
'PC 4'	4.57	5.03	1.83	2.22	6.91	7.17	8.45	9.06
'DKC 9164'	4.82	4.81	2.17	2.56	5.39	5.85	7.56	8.03
'PMH 13'	4.77	5.15	2.10	2.51	5.81	5.90	7.53	8.24
'AH 4271'	4.82	5.19	2.15	2.53	6.69	6.88	8.35	9.00
'PV QPM 9-I'	5.26	5.58	1.98	2.37	6.84	6.87	8.56	9.16
CD (P=0.05)	0.3	0.25	ns	ns	0.3	0.24	0.22	0.26
<i>Nitrogen level (N) (kg/ha)</i>								
0	3.62	3.86	2.37	2.92	7.06	7.66	8.48	9.03
40	4.30	4.52	2.50	2.83	6.72	7.15	8.39	8.88
80	4.46	4.98	2.33	2.68	6.46	6.82	8.15	8.84
120	5.05	5.36	2.09	2.57	6.28	6.24	7.94	8.58
160	5.34	5.64	1.87	2.12	5.67	5.96	7.80	8.44
200	5.49	5.79	1.72	2.18	5.36	5.66	7.63	8.34
240	5.59	5.88	1.67	2.00	5.30	5.53	7.58	8.28
CD (P=0.05)	0.3	0.27	0.34	0.37	0.3	0.26	0.24	0.28
Interaction (G×N)	*	NS	NS	NS	NS	*	*	NS

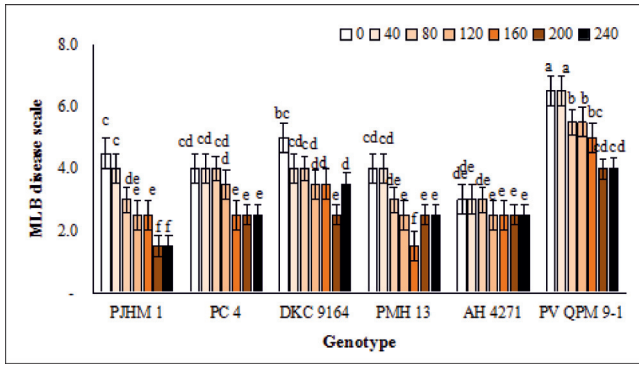


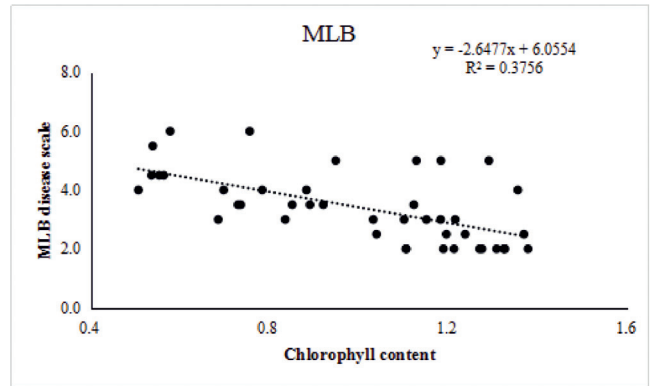
Fig. 1. Interaction effect of genotypes and N levels on MLB disease scale in maize during 2021. Error bars show standard error.

relative resistance to the disease. Manjunatha *et al.* (2019) reported that resistant maize genotypes had greater hairs on leaf and comparatively lesser stomatal openings over susceptible genotypes.

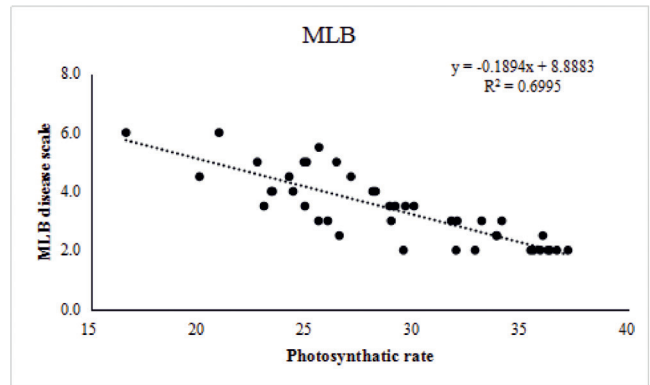
In addition to being a crucial nutrient for crop growth and yield, N has also been recognized to have a direct impact on the infection and severity of diseases (Aydogdu and Boyraz, 2011). The present study confirmed the positive effect of optimum N supply on maize defense mechanism against MLB, in which application of 160-200 kg N/ha resulted into least disease infection. The disease was more severe when N was not applied (4.2) or more than 160-200 kg N/ha was applied (3.2). Plants cultivated under N starved conditions, have poor defense mechanism against the pathogen (Aydogdu and Boyraz, 2011). We observed a negative correlation between leaf photosynthesis rate and chlorophyll content with MLB (Fig. 2). The *Cochliobolus heterostrophus* (Drechs.) is an necrotrophic/semi saprophytes facultative parasite that prefers senescing leaf or produce harmful chemicals to destroy leaf tissue. Hence, the reduced chlorophyll and increased rate of senescence at N starved condition increased the disease susceptibility with low N application. Contrarily, the improved metabolic activities like photosynthetic rate and chlorophyll production (Table 2) and reduced leaf senescence at high N levels might have increased the resistance towards the facultative parasite (Manjunatha *et al.*, 2019). On the other hand, N abundance might have increased plant succulence and reduced the cell wall thickness which make the plant more susceptible to pathogens (Aydogdu and Boyraz, 2011).

Pest incidence

The FAW is a major pest that feeds on maize crop. Significant effect of genotypes and N levels was observed on FAW infestation (Fig. 3). The average FAW damage score was 3.5 to 4.0 during 2021 and 2022, respectively. Geno-



(a)



(b)

Fig. 2. Correlation between MLB disease scale and chlorophyll content (a) and photosynthetic rate (b) in maize during 2021.

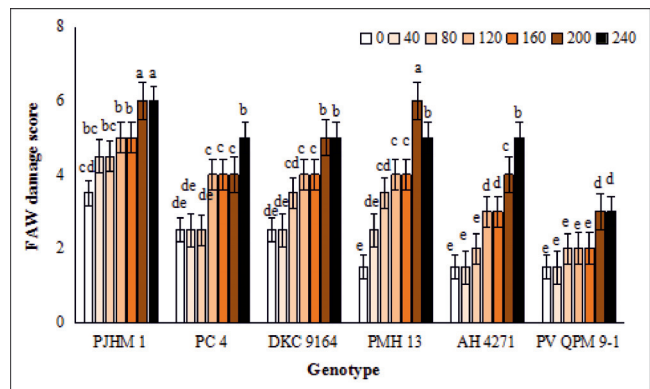


Fig. 3. Interaction effect of genotypes and N levels on FAW incidence in maize (mean of two years). Error bars show standard error (P=0.05).

type PJHM 1 had the highest FAW damage score (4.9 and 5.6) while, PV QPM 9-I had the lowest damage score (2.1 and 2.4). The observed resistance of maize genotypes to FAW could be due to increased defense protein, greater amino acid and glucose content, and jasmonic acid accumulation (Wang *et al.*, 2022). Leaf physical characteristics like leaf toughness and cuticle structure might have been the reason for increased resistance of PV

QPM 9-I against FAW.

The plant's ability to defend against pests is significantly influenced by environmental factors, including N fertilization (Wang *et al.*, 2022). Increased rates of N application from 0 kg to 200 kg N/ha increased the FAW damage in maize and the damage score remained relatively constant at 200–240 kg N/ha. The lowest level of N fertilization (0 kg/ha) reduced FAW damage by 50% as compared to the highest level (240 kg N/ha). Ample N availability in maize led to a significant rise in leaf area, N and protein content which improved leaf quality. As a result, leaf-chewing *S. exigua* larvae displayed a preference for feeding on high-N maize. Earlier, Wang *et al.* (2022) also found that excess N application increases soluble amino acids, soluble protein and soluble sugar consequently, attracted FAW larvae to feed on maize leaves.

Weeds, diseases and pests jointly stand as a key yield limiting factor for maize. Genotypes AH 4271, PJHM 1 and PMH 13 showed relatively higher resistance to MLB, while PV QPM 9-I had slight tolerance to the FAW, should be promoted. Crop grown without N or with sub-optimal doses of N were more vulnerable to severe weed infestation as well as leaf blight attack. Oppositely, over application of N led to heavy infestation of fall army worm. Therefore, cultivation of competitive/resistant varieties using optimal N application could be a cost-effective and eco-friendly approach for biotic stress management in maize.

REFERENCES

- Aydogdu, M. and Boyraz, N. 2011. Effects of nitrogen and organic fertilization on corn smut (*Ustilago maydis* (DC) Corda.). *African Journal of Agricultural Research* **6**(19): 4,539–4,543.
- Bamboriya, S.D., Dhar, S., Upadhyay, P.K., Dass, A., Meena, R.P. and Garg, K. 2023. Evaluation of maize (*Zea mays*) genotypes under different nitrogen levels in a Trans-Gangetic Plains region. *Indian Journal of Agronomy* **68**(4): 368–372.
- Chikoye, D., Lum, A.F., Abaidoo, R., Menkir, A., Kamara, A., Ekeleme, F. and Sanginga, N. 2008. Response of corn genotypes to weed interference and nitrogen in Nigeria. *Weed Science* **56**(3): 424–433.
- Choudhary, R.L. and Behera, U.K. 2020. Effect of conservation agriculture and nitrogen management on root architecture and soil properties in maize–wheat cropping system. *Journal of Soil and Water Conservation* **19**(3): 261–270.
- Department of Economics and Statistics (DES). 2021. Agricultural Statistics at a Glance.
- Ghosh, D., Brahmachari, K., Brestic, M., Ondrisik, P., Hossain, A., Skalicky, M., Sarkar, S., Moulick, D., Dinda, N.K. and Das, A. 2020. Integrated weed and nutrient management improve yield, nutrient uptake and economics of maize in the rice-maize cropping system of Eastern India. *Agronomy* **10**: 1906. <https://doi.org/10.3390/agronomy10121906>.
- Jha, P., Kumar, V., Godara, R. and Chauhan, B. 2017. Weed management using crop competition in the United States: A review. *Crop Protection* **95**: 31–37.
- Kumar, V., Dhyani, B.P., Shahi, U.P., Kumar, S., Kumar, A. and Singh, A., 2022. Effect of nitrogen schedule and management on yield of late-sown wheat (*Triticum aestivum*) in rice–wheat system. *Indian Journal of Agronomy* **67**(2): 144–147. <https://doi.org/10.59797/ija.v67i2.104>
- Manjunatha, C., Gogoi, R., Singh, B., Jeevan, B., Rai, S.N. and Singh, P.K. 2019. Phenotypic and physiological characterization of maize inbred lines resistant and susceptible to maydis leaf blight. *Indian Phytopathology*. <https://doi.org/10.1007/s42360-019-00117-w>
- Sharanabasappa, S.D., Kallelshwaraswamy, C.M., Asokan, R., Swamy, H.M.M., Maruthi, M.S. and Pavithra, HB. 2018. First report of the fall armyworm, *Spodoptera frugiperda* (JE Smith) (Lepidoptera: Noctuidae), an alien invasive pest on maize in India. *Pest Management in Horticulture Ecosystems* **24**(1): 23–29.
- Singh, B., Mundra, S.L. and Kaushik, M.K. 2022. Effect of nutrient management and plant density on productivity of QPM hybrids of maize (*Zea mays*). *Indian Journal of Agronomy* **67**(1): 26–29. <https://doi.org/10.59797/ija.v67i1.80>
- Wang, W., Wang, X., Liao, H., Feng, Y., Guo, Y., Shu, Y. and Wang, J. 2022. Effects of nitrogen supply on induced defense in maize (*Zea mays*) against fall armyworm (*Spodoptera frugiperda*). *International Journal of Molecular Sciences* **23**(18): 10,457.