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Manipulating Rice Planting Geometry and Nutrient Levels has an Effect on Brown Planthopper, *Nilaparvata lugens* (Stål) (Hemiptera: Delphacidae) Incidence

Ch. Muhammad Rafiq[1], Muhammad Rizwan[1]*, Bilal Atta[1], Arshed Makhdoom Sabir[1], Misbah Rizwan[2], Muhammad Arshad[3], Muhammad Zeeshan[3], Hamza Latif[3], Usama Bin Khalid[1], Shawaiz Iqbal[1]

[1]Rice Research Institute, Kala Shah Kaku, Punjab, Pakistan
[2]Department of Biology, Government College for Women, Emanabad, Gujranwala, Punjab, Pakistan
[3]Department of Entomology, University of Sargodha, 40100, Sargodha, Punjab, Pakistan

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Authors' Contribution
CMR, MR and BA conceived the idea. UBK, SI, MZ collected data for yield and yield attributes. MR, BA and HL collected data of *Nilaparvata lugens* incidence in field and fertilizer responsive development of *Nilaparvata* under lab conditions. CMR, MR, BA, MZ and MA analyzed the data. MR, BA, MR and MA wrote the draft. MR and MA writing review and editing.

Key words
***Nilaparvata lugens*, Population incidence, Planting geometry, Yield attributes, Nutrition impact, Fitness parameters**

ABSTRACT

Rice is best known as a staple food for half of the world's population. Brown planthopper, *Nilaparvata lugens* (Stål) (Hemiptera: Delphacidae) is a serious insect pest of rice crops throughout Asia. In case of a severe attack, the whole crop turns brown called 'hopperburn' and farmers face great yield losses. The experiments were performed to evaluate the planting geometry and nutritional effects on *N. lugens* abundance and yield attributes of the crop using susceptible rice (*var.* Basmati 515). Results indicated that planting geometries with more space (60 and 90 cm) after 12 lines with a uniform number of plants in each plot had less incidence of *N. lugens* as compared to narrow spaced (0 and 30 cm) geometries. More number of *N. lugens* nymphs (80.0-95.0 number/plant) were recorded with less spaced planting geometry as compared to higher spaced planting geometry (27.0-29.5 numbers/plant) during both years. With different planting geometry, no significant difference was recorded in the agronomic parameters except yield and 1000 grain weight. The highest yield was recorded in a plot with 90 cm path followed by 60, 30 and 0cm path, respectively. Towards different doses of nitrogen and phosphorus on *N. lugens*, the higher dose of nitrogen had a significant effect on *N. lugens* nymph survival, adult emergence and survival, while the phosphorus induced a non-significant effect. Therefore, in the absence of *N. lugens* resistant variety, ecological manipulation and nutrients availability could be a better strategy for short-term *N. lugens* management in organic rice production.

INTRODUCTION

The brown planthopper, *Nilaparvata lugens* (Stål) (Hemiptera: Delphacidae) is a very destructive insect pest of rice crop (Shah *et al*., 2019; Atta *et al*., 2020). Its first incidence was recorded on rice crop in Pakistan in 2013 and now it is well established in the Kallar tract of Punjab (Rizwan *et al*., 2019). The occurrences of *N. lugens* outbreaks in this region are more severe as compared to other regions of Punjab as this region is the hub of rice production. Thus, the problem of *N. lugens* outbreaks in the region has provoked more attention. *N. lugens* damages rice crop production in both a quantitative and qualitative way (Akhter *et al*., 2017). Nutrition management is being considered the most important practice in the agriculture industry. Further, insect biology and response are affected by ecological factors, such as temperature, humidity, moisture, morphology, and the nutritional quality of the plants (Fischer and Fiedler, 2000). Various studies have directed the importance of host plant quality on insect pests (Moon and Stiling, 2000; Altieri and Nicholls, 2003; Marazzi *et al*., 2004). Nitrogen induces lush green color in plants, increases succulence, and enhances the susceptibility to crop pests in general (Huberty and Denno, 2006; Lu and Heong, 2009). Higher nitrogen levels in plants support herbivorous insects through better survival rate, higher body weight, shorter developmental period, and higher fecundity rate (Fischer and Fiedler, 2000; Huberty and Denno, 2006). The effect of phosphorous on insect pests is poorly studied for its

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* Corresponding author: ranarizwanjabbar@yahoo.com
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fitness. However, it may impose severe consequences for the growth rate of consumers (Elser *et al*., 2000; Sterner and Elser, 2002). Phosphorous is an important component of energy molecules produced in plants such as ATPs, ADPs, and RNA synthesis. Hence, the availability of nitrogen and phosphorous is very much necessary for the growth and development of insects (Huberty and Denno, 2006).

Another important agronomic factor is the plant density that influences the microenvironment of the field and impacts the development and yield components of crops and attraction to insect pests. Increasing plant population density generally decreases the growth and yield per plant (Caliskan *et al*., 2007). The optimal plant population allows the interception of all photosynthetically active radiation (PAR) to contribute the highest yield. No further increase in yield can be made possible under the same conditions with more plant density (Duncan, 1986) because of a decline in radiation use efficiency (Purcell *et al*., 2002). For a specific cereal crop, optimum plant density may vary with the genotype and geographical location to attain the highest yield. Better light interception attributes to higher yield for narrow row planting (Board *et al*., 1992).

Population dynamics of insect pests are dependent upon various parameters that favor their survival rate, high fecundity, and faster development. The ecological fitness of an insect describes its role in the specific niche or ecosystem. It may vary depending upon how an individual or community interacts with their surroundings (Lu and Heong, 2009). Host plant plays a key role in the abundance of herbivorous insects by influencing their fitness and survival (Cook and Demo, 1994).

Information on the nutritional composition of rice plants and the plant diversity in the field is an important concern for the management of *N. lugens*.

The present study was conducted to evaluate: (i) the effect of manipulating planting geometries on population incidence of *N. lugens* along with the impact on plant population, plant height, and panicle length, number of filled and unfilled grains, 1000 grain weight, and crop yield under field conditions, and (ii) nitrogen and phosphorous on *N. lugens* nymph survival, adult emergence, and adult survival under controlled conditions.

MATERIALS AND METHODS

Nilaparvata lugens *culture*

N. lugens was reared under laboratory conditions on susceptible rice variety Basmati 515. Forty-five to sixty days old potted plants were cleaned with distilled water and leaf sheaths were detached. Adult pairs of *N. lugens* were released in wooden rearing cages (80 × 50 × 120 cm) containing potted plants for oviposition and removed after 48 h with the help of an aspirator. The plants were changed twice a week to provide sufficient food and ambient conditions for nymph survival and development. A sufficient population was maintained through this cycle to attain the required number of *N. lugens* for further experiments.

Effect of planting geometry on N. lugens *incidence and plant's agronomic characters*

The effect of planting geometry on the incidence of *N. lugens* was studied under field conditions on susceptible rice (*var.* Basmati 515). Rice nursery was sown during 1st week of June and 30 days old plants were transplanted on 1st week of July. The experiment was laid out in randomized complete block design. The field was divided into 3 plots and each plot was considered a block. All treatments were randomly assigned in each plot. Three plants were randomly selected from each plot to record the data. All recommended plant production operations were carried out as per protocol but no pesticide was used for plant protection purposes. The experiment was performed for two cropping seasons in 2018-19. The detail of planting geometry in different treatments is given in Figure 1. The population of *N. lugens* per plant was recorded from randomly selected plants to take an average number. Data were recorded on weekly basis for *N. lugens* population records till the physiological maturity of plants. Data for plant population (m^{-2}), plant height (cm), tiller per plant (Nos.), panicle length (cm), filled and unfilled grains per panicle, weight of filled grains (g), and 1000 grain weight (g) were recorded from selected plants. Yield (kg) per plot was recorded upon the harvesting of trial and then converted into mound per hectare.

Effect of nutrients on N. lugens *incidence*

Two-week-old rice seedlings (*var.* Basmati-515) were transplanted in pots (18cm high × 12cm diameter) and provided with three levels of nitrogen (0, 100, 200 kg N ha^{-1}), and phosphorous (0, 25, 50 kg P_2O_5 ha^{-1}) and combinations of these levels. The experiment was laid out in a completely randomized design and replicated five times considering each plant as a replication. Two and a half kg of dry soil was poured into each pot. The soil consisted of clay loam, with pH=7.5, organic matter C = 0.3-0.6%, N = 0.35 gkg^{-1}, available P = 1 gkg^{-1}, available Si = 0.11 gkg^{-1} and available K = 67.12 $mgkg^{-1}$ (Rizwan *et al*., 2021). The amount of fertilizer applied to each pot was calculated considering 1 ha of agriculture field contains 2×10^6 kg soil in its root zone (Asher *et al*., 2002). One-third of the nitrogen fertilizer and whole phosphorous (in the form of DAP) were mixed in the soil as basal application. The remaining 2/3 applied in splits when plants were 25 and 35 days old. These macronutrient treatments were tagged as N_0, N_{100}, N_{200} and P_0, P_{25} and P_{50}. Plants were placed under natural conditions and regular watering was carried out to allow ample growth of plants. The plants grown in pots with prescribed levels of nutrients were evaluated for *N. lugens* nymph and adult development rates. Thirty newly hatched 1st instar *N. lugens* nymphs were collected from laboratory culture and released in each treatment (45 days old plants). Data were collected daily for nymph survival and adult development and survival. Nymph survival was estimated by counting the total number of nymphs used and reached the adult stage. Nymph development was counted by the number of degree-days required to reach the adult stage by nymphs for each treatment. Seven pairs of newly developed adults from each nutrient level were introduced into 45 days old plants supplemented with the same level of nutrients. The number of enduring adults was noted on the 7th day.

Data analysis

The effect of plant geometry on all studied parameters was analyzed by one-way analysis of variance (ANOVA) and nutrition effect on *N. lugens* survival and development was analyzed by two-way ANOVA. Means were separated by using the least significant difference (LSD) test at a probability level of 5%. Data were analyzed by using SPSS 20.0 software.

RESULTS

Effect of planting geometry on N. lugens *incidence and plant's agronomic characters*

Incidence of *N. lugens* population among treatments was significant during 2018 ($F_{3, 35}$ = 216.93, $P < 0.05$) and 2019 ($F_{3, 35}$ = 216.93, $P < 0.05$). The least number of *N. lugens* (27.0-29.5 numbers/plant) was recorded in T_4 during 2018-19. However, the highest population of *N. lugens* (80.0-95.0number/plant) was recorded in T_1 and T_2 during both study years (Fig. 1). The yield per plot was also significantly affected by planting geometry during 2018 ($F_{3, 11}$= 17.55, P= 0.002) and 2019 ($F_{3, 11}$= 17.55, P= 0.002). The highest yield was recorded 35.0 to 36.7 quintal/ha in T_3 and T_4 during 2018 and 27.0 to 27.5 quintal/ha in 2019 (Fig. 3).

Planting geometry had no significant effect on plant population ($F_{3, 11}$= 1.83, $P > 0.05$), plant height ($F_{3, 11}$= 2.41, $P > 0.05$), number of filled gains ($F_{3, 11}$= 2.29, $P > 0.05$), and number of unfilled grains ($F_{3, 11}$= 1.06, $P > 0.05$) during 2018. Similar trend was found in 2019, as no significant effect of planting geometry was found on plant population ($F_{3, 11}$= 1.54, $P > 0.05$), plant height ($F_{3,11}$= 2.41, $P > 0.05$), number of filled gains ($F_{3,11}$= 2.29, $P > 0.05$), and number of unfilled grains ($F_{3,11}$= 1.06, $P > 0.05$). Further number of tillers per plant ($F_{3, 11}$= 1.12, $P > 0.05$), panicle length ($F_{3, 11}$= 4.27, $P > 0.05$), weight of filled grains ($F_{3, 11}$ = 0.72, $P > 0.05$), were not significantly affected by planting geometry during 2019 while, effect was significant on 1000 grain weight ($F_{3, 11}$= 21.05, P= 0.0014). The highest grains weight 26.9g/1000 grains were recorded in T_4 during 2018. During 2019, similar trend was found in which planting geometry did not affect significantly the number of tillers per plant ($F3_{,11}$= 1.12, $P > 0.05$), panicle length ($F_{3,11}$= 4.27, $P > 0.05$), weight of filled grains ($F_{3,11}$ = 0.72, $P > 0.05$), except 1000 grain weight ($F_{3,11}$ = 6.58, P = 0.0252). The grains weight was recorded highest 25.95 g/1000 grains in T_4 (Fig. 2).

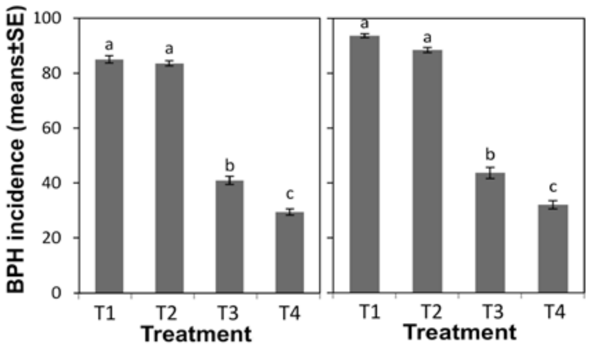

Fig. 1. Impact of manipulating planting geometries on *Nilaparvata lugens* incidence during 2018 and 2019. Means sharing similar letters are not significantly different at $P > 0.05$.

Effect of nutrients on N. lugens

A significant effect ($F_{2, 26}$= 589.47, $P < 0.05$) of nitrogen doses was found on *N. lugens*, effects of phosphorous ($F_{2, 26}$ = 0.21, $P > 0.05$), and their interactions ($F_{4, 26}$ = 1.68, $P > 0.05$) was not significant. There was a significant difference among nymph survival developed on different doses of nitrogen *i.e.*, 0, 100 and 200 Kg ha^{-1}. Nymph survival rate was higher (80.0-8.0%) when nitrogen dose was higher (N_{200}) with the combination of phosphorous. In the same way, nitrogen had a significant ($F_{2, 26}$= 70.55, $P < 0.05$) effect on the nymph development. Nymph duration decreased with the increase in nitrogen dose while phosphorous ($F_{2, 26}$= 0.73, $P > 0.05$) and nitrogen × phosphorous ($F_{4, 26}$ = 0.73, $P > 0.05$) showed no significant effect on the nymph developmental period. Nitrogen also showed a significant ($F_{2, 26}$= 164.26, $P < 0.05$) effect on the adult survival rate of *N. lugens* introduced to different treatments. The adult survival rate was improved significantly from 19.05% to 57.14% with N_0 to N_{200}, respectively. However, phosphorous ($F_{2,\ 26}$= 2.06, $P > 0.05$) and nitrogen×phosphorous interaction ($F_{4,\ 26}$ = 2.06, $P > 0.05$) induced a non-significant effect on the adult survival of *N. lugens* (Fig. 4).

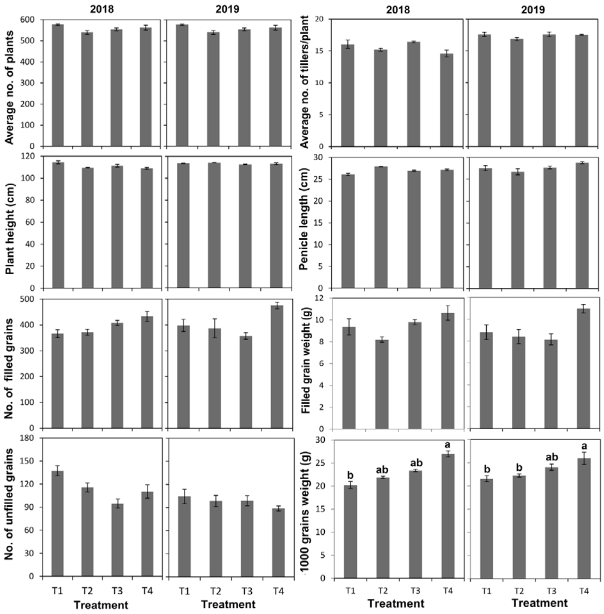

Fig. 2. Impact of manipulating planting geometries on agronomic parameters of Basmati-515 during 2018 and 2019. Bars without lettering shows non-significant ($P > 0.05$) difference among the treatments. Means sharing similar letter are also not significant at $P > 0.05$.

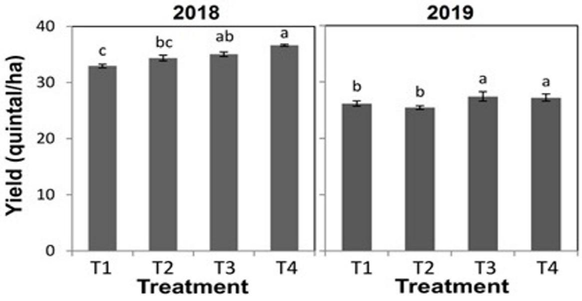

Fig. 3. Impact of manipulating planting geometries on yield of Basmati-515 during 2018 and 2019. Means sharing similar letters are not significantly different at $P > 0.05$.

DISCUSSION

The higher *N. lugens* population was recorded in less spaced geometries, while the plant population remained non-significant in all planting geometries. No significant difference was recorded in almost all agronomic parameters of the plants when planted at different geometries. Hence, the yield suffered more in less spaced planting methods than more spaced geometries under field conditions. Insect-plant interaction is an important component of integrated pest management (Speight *et al*., 2008). Teetes (1991) reported that transplanting dense seedling changes paddy plant canopy growth which resultantly generates a microclimatic environment that favors the *N. lugens* abundance. Prasad *et al*. (2003) have also reported that compact seedling plantations influence *N. lugens* prevalence positively. Our results support that dense transplantation of seedlings without an aeration path or space supports *N. lugens* development positively while having a significant effect on yield. Thus, dense transplantation needed to be avoided and discouraged. It creates a dense and bushy plant canopy, a situation, favorable for *N. lugens* growth, development, and multiplication. Differences in planting geometries at uniform plant populations differed significantly in grain yield. This illustrates that an optimum plant population with a higher path is important to obtain high grain yields.

Nitrogen doses achieved a significant increase in the survival rate of nymphs, reduced nymph duration, and improved adult survival rate, while phosphorous induced a non-significant effect. Nymphal survival rate almost doubled with nitrogen application (N_0 to N_{200}) from 45.56 to 84.44%. The developmental period of nymphs was also reduced from 14.56 days to 10.89 days. It means more number of generations in less time leads to more chances of crop failure. Adult survival was more than double with N_{200} application (52.38%) compared to N_0 application (23.81%). Throughout Asia, *N. lugens* is being considered the most serious sucking insect pest of rice crops. Nutrients availability persuades changes in the morphology and biochemistry of host plants that may be useful for survival and higher fitness of herbivores (Bernays, 1990). Nitrogen content is the most important component limiting

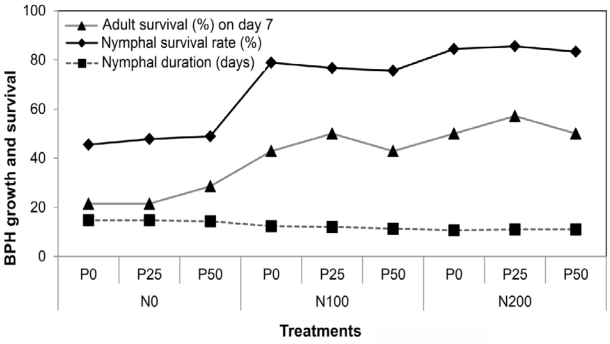

Fig. 4. Nymphal survival (%), duration (days) and adult survival (%) of *Nilaparvata lugens* after one week of fertilizer application under controlled conditions.

herbivores insect pests (Lu *et al*., 2007; Han *et al*., 2014; Oliveira *et al*., 2014). The survival rate of both nymph and adult stages of *N. lugens* was significantly higher on nitrogen-supplemented plants than nitrogen-deficient ones, and it was almost double for nymph and adult. However, phosphorous did not affect the *N. lugens* and the findings are following Rashid *et al*. (2017). This study endorses that nitrogen-supplemented rice plants enhanced the chances of *N. lugens* survival as reported in previous studies (Lu *et al*., 2004; Rashid *et al*., 2017). Nitrogen application to rice plants results in a significant increase in nitrogen and protein contents in plant sap (Rashid *et al*., 2016), from which insect could get more protein as sucking insect pests derives soluble protein and amino acids from their host plants for their maintenance (Slansky and Scriber, 1985). Moreover, nitrogen reduces the supplementation of silicon which makes plants less preferable for insect pests if accumulated in higher concentration and it lessens the accumulation of allelochemicals which could be noxious to insect pests (Sterner and Elser, 2002; Schoonhoven *et al*., 2005; Rashid *et al*., 2016; Ali *et al*., 2017). Previous studies reported that silicon could induce resistance to herbivores (Reynolds *et al*., 2009; Kvedaras *et al*., 2010; Han *et al*., 2015; Nikpay *et al*., 2015). In the present study, it is clear that N greatly affected *N. lugens* survival. Nitrogen also reduced the generation time for *N. lugens* development means that higher nitrogen application will reduce generation time and leads more generations in the same field enhancing the risks of hopper burn. It means *N. lugens* generation is positively correlated but nymph duration is negatively associated with nitrogen.

CONCLUSION

Fertilizer administration provides an alternate strategy for the management of *Nilaparvata lugens* as it provides a less conducive environment for its growth, development, survival, and propagation. On the other hand, planting geometry with more space and a uniform number of plant populations offers another tactic for *N. lugens* management and to obtain a higher yield. Both strategies could be applied for insect pest management to organic rice production.

Statement of conflict of interest

The authors have declared no conflict of interest.

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