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# Effect of mineral nutrients, seed treatment and foliar fungicides on spot blotch (*Bipolaris sorokiniana*) severity and agronomic performance of wheat (*Triticum aestivum*) in hot-humid environment of eastern Gangetic plain in India

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ABSTRACT

Spot blotch disease [*Bipolaris sorokiniana* (Sacc.)] is one of the most serious biotic constraint affecting wheat production in India. The effect of balanced macro- and micro-fertilization, fungicidal seed treatment and foliar fungicides either individually or in combination were assessed for their impact on spot blotch severity, grain yield, and other yield attributing characters during 2012-13 and 2013-14. Average maximum temperature (27.0°C) and high relative humidity (>90%) in February and March during both the years favoured disease development and spread. *In vitro* analysis of untreated pre-sown seeds using a blotter paper test revealed 19.2% and 32.5% seed infection with *B. sorokiniana* during 2012-13 and 2013-14, respectively. At the end of each cropping season, seed infection in harvested seed lots ranged from 5-6% in treatments with a combination of balanced fertility, seed treatment and foliar fungicide, 13% following two sprays of propiconazole, and 71% in control treatment. Application of balanced nutrition alone reduced AUDPC by 37% and increased grain yield up to 26%. However, the combined influence of balanced nutrition, carboxin + thiram seed treatment and two foliar sprays of propiconazole resulted in a 99% reduction in AUDPC values with 60% higher grain yield (6.30 t/ha), 45% higher TKW (41.33 g) and significant increase in other yield attributes. The current study illustrates the role of a combination of crop and disease management practices in the control of spot blotch and improving the agronomic performance of wheat in eastern plains of India.

**Key words:** AUDPC, *Bipolaris sorokiniana,* Integrated crop management, Spot blotch, Wheat

Spot blotch disease caused by *Bipolaris sorokiniana* (Sacc.) Shoem has emerged as one of the most destructive pathogen of wheat in warmer humid areas of the world. Spot blotch severity has also been reported to increase with nutrient deficiency, soil moisture stress, crop growth stages, susceptible cultivars along with high temperature and humidity (Regmi *et al.* 2002, Sharma and Duveiller 2006). These stresses are more commonly encountered in the Indo-Gangetic plains of eastern India, especially in rice-wheat cropping systems (Duveiller 2004). Globally, more than 25 mha wheat is affected by spot blotch. However, in India alone, around 13.5 mha of wheat production is affected by this disease and most of this is under the intensive rice-wheat cropping systems (Aggarwal 2011, Duveiller *et al*. 2005b) of the north-eastern plain zone. Worldwide, spot blotch is responsible for substantial losses varying from 20-100% in grain yield and 0.1%-18% in thousand kernel weight in commercial and experimental fields (Duveiller *et al*. 2005b, Aggarwal 2011). Host resistance, chemical treatments and cultural and agronomic practices such as sanitation, spacing and balanced fertilization are priority practices applied for the management of spot blotch disease in wheat. Potash, boron, zinc and manganese deficiencies enhance spot blotch severity in wheat plants (Marschner 1995, Sharma *et al.* 2006). Spot blotch pathogen is both seed and air borne (Aggarwal 2011). Given the role of seed-borne inoculum, seed treatment fungicides can provide good protection of germinating seeds, improves crop stand and reduced seedling infection (Duveiller *et al.* 2005b, Poudyal *et al.* 2005, Sharma *et al.* 2005). Although pesticide usage should be minimized, foliar application of fungicides remains a useful approach for the management of this disease in warmer wheat growing regions of South Asia (Sharma and Duveiller 2006, Poudyal *et al.* 2005). Highly adopted and leading cultivars of wheat show substantial reduction in grain yield due to this pathogen (Duveiller *et al.* 2005a). The present study was undertaken to assess the impact of balanced fertilization, application of macro and micronutrients and rationalized use of fungicides as seed treatment and need based spray both individually and in combination on

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integrated management of spot blotch disease and their effect on grain yield and other yield attributing characters in wheat (*Triticum aestivum* L.).

## MATERIALS AND METHODS

The study was conducted in rice (*Oryza sativa* L.) wheat cropping sequence plots at IARI Regional Station, Bihar (25°59'N, 85°40'E, 52 m AMSL) (India) during the 2012-13 and 2013-14 wheat growing seasons. The soil type at the experimental site was calcareous clay in texture with pH (8.1), low in organic carbon, available nitrogen, potash, boron, sulphur and intermediate in zinc and phosphorous. The field experiment was seeded on 30th November of each year using the spot blotch susceptible cultivar, HUW 234 with plots (5.0 × 2.0 $m^2$) arranged in RBD with three replications. The following 15 treatment combinations of macro and micronutrients, seed treatments, and foliar spray(s) of different fungicides: $T_1$: seed treatment (ST) with carboxin (37.5%) + thiram (37.5%) (Vitavax power®) (@ 2.5 g/kg seed), $T_2$: $T_1$ + one foliar spray (FS) with propiconazole (Tilt®, 25% EC) @ 0.1% at the time of initiation of disease on Flag - 1 leaf, $T_3$: $T_1$ + two FS of propiconazole (@ 0.1%) at the time of initiation of disease on Flag - 1 leaf followed by second spray at 20 days interval (DI), $T_4$: no ST and only 01 FS of propiconazole, $T_5$: only two FS of propiconazole, $T_6$: ST with tebuconazole (Raxil®, 2% DS) @ 1.5 g/kg seed, $T_7$: $T_6$ + one FS of tebuconazole (Folicur®, 250 EC) 0.1% at the time of initiation of disease on Flag - 1 leaf, $T_8$: $T_6$ + two FS of tebuconazole 0.1% at the time of initiation of disease on Flag - 1 leaf followed by second spray at 20 DI, $T_9$: only one FS of tebuconazole, $T_{10}$: two foliar sprays of tebuconazole, $T_{11}$: N: $P_2O_5$: $K_2O$ (120: 60: 40 kg/ha) + Zn: S: B (5: 30:1.0 kg/ha) + ST with carboxin + thiram (@2.5 g/kg seed) + two FS of propiconazole (@ 0.1%), $T_{12}$: N: $P_2O_5$: $K_2O$ (120: 60: 40 kg/ha) + Zn: S: B (5: 30:1.0 kg/ha) + ST with carboxin + thiram (@ 2.5 g/kg seed) + one FS of propiconazole (@ 0.1%), $T_{13}$: N: $P_2O_5$: $K_2O$ (120: 60: 40 kg/ha) + Zn: S: B (5: 30:1.0 kg/ha), $T_{14}$: N: $P_2O_5$: $K_2O$ (120: 60: 40 kg/ha) and $T_{15}$: N: $P_2O_5$ (120: 60 kg/ha).

### *Observations and data analysis*

Germination count data and the number of infected seedlings were counted at 20 DAS in a one square meter area in each test plot. Disease severity was recorded by visually assessing the per cent diseased leaf area three times at 10 days intervals from each plot. The area under the disease progress curve (AUDPC) was calculated using percent severity estimations corresponding to the three ratings. Yield attributes including number of effective tillers/$m^2$, plant height (cm), spike length (cm), grains/spike, grain yield (t/ha) and harvest index were measured. The data of two years were statistically analyzed using an analysis of variance to determine the least significant difference at 5% probability level ($P<0.05$), and the differences in means were evaluated by Fisher's least significant difference to compare the results.

## RESULTS AND DISCUSSION

Spot blotch disease severity was recorded very high on susceptible wheat cultivar HUW 234 covering more than 90% of plant area. The average minimum (13.8°C) and maximum (27.8°C) temperature of February and March months at Pusa (Bihar) during 2012-13 were comparatively higher than 2013-14. Relative humidity (>90%) was higher in 2012-13 than 2013-14 during most of the wheat growing seasons. Higher precipitation in first week of March, 2014 and more number of cloudy and foggy days during winter months along with less solar radiation during 2013-14 was associated with higher disease severity and decreased grain yield.

### *Seed incubation test under in vitro conditions*

The analysis of untreated seed samples revealed 19.2 and 32.5% seed infection with *B. sorokiniana* in seed used for planting in 2012-13 and 2013-14, respectively. Germination tests of pre-sown seeds showed 95.83 and 96.42% germination during both years, respectively, indicating that the levels of *B. sorokiniana* observed in seeds did not significantly influence the germination in subsequent season. Similarly, Poudyal *et al.* (2005) also corroborated the findings that different levels of seed infections do not affect the germination in wheat. Higher number of infected seedlings/$m^2$ (5.8-7.6) was recorded from plots sown with untreated seed as compared to plots sown with fungicidal treated seeds. This signifies the role of seedborne inoculum in causation of seedling blight. However, no correlation was observed between the frequency of *B. sorokiniana* isolated from pre-sown seeds and number of infected seedlings.

### *Effect of different treatments on seed germination, plant stand and seedling blight*

Seed treatment with carboxin + thiram ($T_1$, $T_2$ and $T_3$) resulted higher germination and low seedling blight/$m^2$ in field as compared with control during both the years. Though, seed treatments with tebuconazole ($T_6$, $T_7$ and $T_8$) were almost equally effective in germination and seedling emergence, but they did not reduce seedling blight in field compared to carboxin + thiram seed treatments. Integrated treatments, including seed treatment with carboxin + thiram with basal application of macro and micronutrients plus foliar spray(s) of propiconazole, resulted in the highest pooled mean germination (98.19 and 97.72%) and initial plant stand/$m^2$ [328.06 ($T_{11}$) and 321.84 ($T_{12}$)] along with the lowest number of infected seedlings/$m^2$ [1.50 ($T_{11}$) and 2.17 ($T_{12}$)] in the field, suggesting positive effect of combined treatments on seed germination, plant stand and control of infected seedling emergence. Since, disease symptoms start early in seedling stage (Duveiller *et al.* 2005a) and in view of significant effect of fungicide seed treatments with carboxin + thiram on seed germination, plant establishment and number of infected seedling/$m^2$, this option should be considered for better crop management. The results of present investigation are also in agreement with those of Meisner *et al.* (1994) and Poudyal *et al.* (2005)

who reported that wheat seed treatment with Vitavax® 200 increased seedling emergence, plant establishment and reduced seedling infections.

*Effect of fungicide spray on AUDPC, agronomic traits and seed infection*

The fungicide protected conditions ($T_2$-$T_5$ and $T_7$-$T_{10}$) resulted higher increase in mean yield (26-44%), TKW (24-35%), grains/spike (20-42%), effective tillers/m$^2$ (33-60%) over control ($T_{15}$) (Table 1 and 2). Reduction in AUDPC in 2012-13 (87-98%) due to fungicides spray(s) ($T_2$-$T_{10}$) was higher as compared to 2013-14 (86-96%) (Table 1 and 2). The difference observed in both the years may be ascribed partly due to environmental conditions and spot blotch severity. The unusual rain during grain filling period in first week of March, 2013-14 lays more stress on unprotected treatments including control. The treated plots were less affected as compared to untreated and control, showing the viability of treatments and their combinations to be performed under stress conditions. Some difference in per cent increase in yield, TKW and spot blotch severity due to environmental conditions have been reported by Poudyal *et al.* (2005). Higher decrease in mean value for AUDPC (91-97%) and increase in grain yield (34-44%) were observed in propiconazole sprayed plots ($T_2$-$T_5$) as against tebuconazole sprayed plots ($T_7$-$T_{10}$) where decrease in mean value for AUDPC (87-95%) and increase in grain yield (25-41%) were lower proving better performance of propiconazole in disease control. The two sprays of both fungicides either propiconazole ($T_3$ and $T_5$) or tebuconazole ($T_8$ and $T_{10}$) individually or in combination with seed treatments resulted in significant decrease in AUDPC and associated increase in grain yield and its attributes over single spray of either of the fungicides and control (Table 1 and 2). The increase in grain yield, TKW and in other yield attributing factors was observed under fungicides protected condition and was in agreement with the results of other reports (Sharma and Duveiller 2006, Duveiller *et al.* 2005b) where emphasis was given on three or more sprays of propiconazole, epoxiconazole, tebuconazole for better control of spot blotch disease in wheat. Significantly better response of one spray of propiconazole plus seed treatment with carboxin + thiram ($T_2$) was obtained as it resulted in higher increase in mean grain yield (5.41 tonnes/ha, 37%) and decrease in AUDPC value (64.81, 94%) compared to control where 3.95 tonnes/ha grain yield and AUDPC value of 1042.18 was recorded. The decrease in grain infection due to fungicide sprays was higher with mean values ranging from 13-38% as compared to control (71%) (Table 3).

*Effect of balanced fertilization and integrated treatments on disease and agronomic traits*

Application of NPK ($T_{14}$) reduced the mean AUPDC by 14%, grain infection by 23% and increases the grain yield by 7% over the control during 2012-13 and 2013-14. Where N and P were only applied to imitate the stress condition for higher spot blotch severity, the results indicated the role of potassium in yield enhancement along with reduction in spot blotch severity. The findings of the present investigation are in agreement with earlier findings of Regmi *et al.* (2002), Sharma and Duveiller (2006) and Sharma *et al.* (2005, 2006), who reported that potassium application significantly decreased the spot blotch severity, seed infection and increased grain yield in wheat. The soil of the experimental plot was deficit in available K and its application decreased spot blotch severity and increased grain yield and its attributes under fungicide protected and non protected conditions during both the years, suggesting the combined negative effect of spot blotch disease and potassium deficiency on grain yield losses. Results of the present investigation corroborated the earlier reports that the soils in eastern plains of India/South Asia under rice-wheat cropping system require K application to sustain wheat yields (Regmi *et al.* 2002, Sharma *et al.* 2005, 2006). Balanced application of macro and micronutrients (N, P, K, Zn, S and B) in combination ($T_{13}$) showed significant increase in mean grain yield (26%), spike length (8%) TKW (9%), grains/spike (12%), tillers/m$^2$ (14.91%) along with 37% decrease in disease severity over the control (Table 1, 2 and 3). The data also revealed that balanced fertilization ($T_{13}$) increased grain yield and its attributes equivalent to single spray of tebuconazole ($T_9$) (Table 1 and 2). This indicated that macro and micronutrients consistently helped in reducing spot blotch severity, along with direct effect on increasing the grain yield and its attributes. Therefore, the results of this investigation presents a concurred evidence of macro and micronutrients mediated yield enhancement in wheat crop through spot blotch management in warmer regions of South Asia. The results also showed the highest AUDPC mean value (1042) and lower grain yield (3.95 tonnes/ha) and other agronomic traits in control plot under low fertility stressed conditions where only N and P were applied. This confirms the previous findings that nonspecific hemibiotrophic pathogens causing foliar blight are highly influenced by nutrient management practices and thereby disease severity along with yield losses may be aggravated when the crop is under stress (Regmi *et al.* 2002, Sharma and Duveiller 2006, Duveiller *et al.* 2005b, Sharma *et al.* 2006). However, application of macro and micronutrients (N, P, K, Zn, S and B) plus seed treatment with carboxin + thiram and two foliar sprays of propiconazole ($T_{11}$) resulted in the lowest mean value for grain infection (5%), AUDPC (12.35) along with 98% reduction in disease severity over the control. This treatment significantly increased the average grain yield by 60% (6.30 tonnes/ha), TKW by 45% (41.33 g), number of tillers by 66% (456/m$^2$ ), spike length by 46% (11.95 cm), number of grains/spike by 53% (48.39), plant height by 10% (109.41 cm), harvest index by 42.97%, net return/ha was ₹ 91620 and net B: C ratio was 1: 2.66 as compared to control in both years where the lowest average seed yield (3.95 tonnes/ha) and its attributes were obtained. The combined treatments brought the coherence of integrated disease management

Table 1 Effect of different treatments on yield attributes of wheat cultivar, HUW234

| Treatment | No. of tillers/m$^2$ | | Pooled mean | Plant height (cm) | | Pooled mean | Spike length (cm) | | Pooled mean | No. of grains/spike | | Pooled mean |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 2012-13 | 2013-14 | | 2012-13 | 2013-14 | | 2012-13 | 2013-14 | | 2012-13 | 2013-14 | |
| $T_1$ | 355.74$^{EF*}$ | 352.81$^{HI}$ | 354.28$^{F}$ | 101.24$^{D}$ | 100.78$^{BCD}$ | 101.01$^{DEF}$ | 9.57$^{FGH}$ | 9.25$^{GHI}$ | 9.41$^{GHI}$ | 37.87$^{F}$ | 36.61$^{FGH}$ | 37.24$^{H}$ |
| $T_2$ | 408.69$^{CD}$ | 401.54$^{DEF}$ | 405.12$^{CD}$ | 103.96$^{BCD}$ | 102.83$^{BCD}$ | 103.40$^{CDE}$ | 10.97$^{ABCD}$ | 10.85$^{BCDE}$ | 10.91$^{BCDE}$ | 43.58$^{CD}$ | 41.52$^{CD}$ | 42.55$^{DE}$ |
| $T_3$ | 447.33$^{AB}$ | 434.78$^{ABC}$ | 441.06$^{AB}$ | 106.20$^{ABC}$ | 105.03$^{AB}$ | 105.62$^{BC}$ | 11.52$^{AB}$ | 11.31$^{ABC}$ | 11.42$^{ABC}$ | 45.27$^{B}$ | 44.62$^{B}$ | 44.95$^{B}$ |
| $T_4$ | 395.12$^{D}$ | 389.50$^{EF}$ | 392.31$^{D}$ | 102.68$^{CD}$ | 101.92$^{BCD}$ | 102.30$^{CDEF}$ | 10.32$^{CDEF}$ | 10.22$^{DEFG}$ | 10.27$^{DEFG}$ | 41.15$^{E}$ | 39.93$^{DE}$ | 40.54$^{FG}$ |
| $T_5$ | 422.41$^{BC}$ | 412.86$^{CDE}$ | 417.64$^{BC}$ | 104.17$^{BCD}$ | 102.98$^{BCD}$ | 103.58$^{CDE}$ | 11.28$^{ABC}$ | 11.02$^{ABCD}$ | 11.15$^{ABCD}$ | 43.86$^{BCD}$ | 43.05$^{BC}$ | 43.46$^{CD}$ |
| $T_6$ | 346.11$^{F}$ | 331.49$^{IJ}$ | 338.80$^{FG}$ | 101.19$^{D}$ | 100.61$^{CD}$ | 100.90$^{DEF}$ | 9.12$^{GHI}$ | 8.89$^{HIJ}$ | 9.01$^{HIJ}$ | 35.92$^{G}$ | 35.83$^{GH}$ | 35.88$^{I}$ |
| $T_7$ | 382.65$^{DE}$ | 379.23$^{FG}$ | 380.94$^{DE}$ | 102.10$^{CD}$ | 101.71$^{BCD}$ | 101.91$^{DEF}$ | 10.11$^{DEFG}$ | 9.96$^{EFG}$ | 10.04$^{EFG}$ | 40.79$^{E}$ | 38.45$^{EF}$ | 39.62$^{G}$ |
| $T_8$ | 438.52$^{AB}$ | 426.16$^{BCD}$ | 432.34$^{AB}$ | 104.67$^{BCD}$ | 103.34$^{BC}$ | 104.01$^{CD}$ | 11.43$^{AB}$ | 11.18$^{ABCD}$ | 11.31$^{ABC}$ | 44.39$^{BC}$ | 43.15$^{BC}$ | 43.77$^{BC}$ |
| $T_9$ | 367.04$^{EF}$ | 360.28$^{GH}$ | 363.66$^{EF}$ | 101.84$^{CD}$ | 101.40$^{BCD}$ | 101.62$^{DEF}$ | 9.87$^{EFGH}$ | 9.63$^{FGH}$ | 9.75$^{FGH}$ | 38.83$^{F}$ | 37.69$^{FG}$ | 38.26$^{H}$ |
| $T_{10}$ | 397.79$^{CD}$ | 393.67$^{EF}$ | 395.73$^{CD}$ | 103.46$^{CD}$ | 102.79$^{BCD}$ | 103.13$^{CDE}$ | 10.68$^{BCDE}$ | 10.47$^{CDEF}$ | 10.58$^{CDEF}$ | 42.74$^{D}$ | 40.64$^{D}$ | 41.69$^{EF}$ |
| $T_{11}$ | 459.74$^{A}$ | 452.37$^{A}$ | 456.06$^{A}$ | 109.72$^{A}$ | 109.11$^{A}$ | 109.41$^{A}$ | 11.97$^{A}$ | 11.92$^{A}$ | 11.95$^{A}$ | 49.08$^{A}$ | 47.69$^{A}$ | 48.39$^{A}$ |
| $T_{12}$ | 454.58$^{A}$ | 449.82$^{AB}$ | 452.20$^{A}$ | 108.49$^{AB}$ | 107.91$^{A}$ | 108.20$^{AB}$ | 11.83$^{A}$ | 11.75$^{AB}$ | 11.79$^{AB}$ | 48.43$^{A}$ | 47.28$^{A}$ | 47.86$^{A}$ |
| $T_{13}$ | 317.87$^{G}$ | 312.64$^{J}$ | 315.26$^{G}$ | 101.57$^{CD}$ | 101.31$^{BCD}$ | 101.44$^{DEF}$ | 9.20$^{GHI}$ | 8.56$^{IJ}$ | 8.88$^{HIJ}$ | 36.14$^{G}$ | 34.71$^{H}$ | 35.43$^{I}$ |
| $T_{14}$ | 283.66$^{H}$ | 276.23$^{K}$ | 279.95$^{H}$ | 100.66$^{D}$ | 100.13$^{CD}$ | 100.40$^{EF}$ | 9.00$^{HI}$ | 8.23$^{IJ}$ | 8.62$^{IJ}$ | 33.43$^{H}$ | 31.54$^{I}$ | 32.64$^{J}$ |
| $T_{15}$ | 279.30$^{H}$ | 270.41$^{K}$ | 274.86$^{H}$ | 100.16$^{D}$ | 99.50$^{D}$ | 99.83$^{F}$ | 8.21$^{I}$ | 8.14$^{J}$ | 8.18$^{J}$ | 32.19$^{H}$ | 31.10$^{I}$ | 31.65$^{J}$ |
| SE(d) | 13.155 | 12.056 | 12.232 | 2.358 | 2.082 | 1.654 | 0.537 | 0.501 | 0.477 | 0.706 | 0.966 | 0.594 |
| LSD (P=0.05) | 26.947 | 24.696 | 25.057 | 4.8311 | 4.2643 | 3.3884 | 1.0991 | 1.0262 | 0.9771 | 1.4458 | 1.9788 | 1.2174 |

*Mean with at least one letter common is not statistically significant using Fisher's least significant difference.

Table 2 Effect of different treatments on yield attributes and yield of wheat cultivar HUW 234

| Treatment | Physiological maturity (days) | | Pooled mean | TKW (g) | | Pooled mean | Yield (t/ha) | | Pooled mean | Harvest Index (%) | | Pooled mean |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 2012-13 | 2013-14 | | 2012-13 | 2013-14 | | 2012-13 | 2013-14 | | 2012-13 | 2013-14 | |
| $T_1$ | $115.33^{EF*}$ | $114.33^{GHI}$ | $114.83^{FGH}$ | $32.73^{F}$ | $32.24^{F}$ | $32.49^{H}$ | $4.78^{G}$ | $4.67^{H}$ | $4.73^{I}$ | $41.23^{CDE}$ | $41.02^{DEF}$ | $41.12^{EFG}$ |
| $T_2$ | $119.67^{BCD}$ | $118.33^{CDE}$ | $119.00^{BCD}$ | $38.68^{BC}$ | $37.12^{C}$ | $37.90^{CD}$ | $5.43^{CD}$ | $5.38^{CD}$ | $5.41^{DE}$ | $42.69^{AB}$ | $42.60^{ABC}$ | $42.65^{AB}$ |
| $T_3$ | $121.33^{ABC}$ | $20.67^{AB}$ | $121.00^{AB}$ | $39.29^{B}$ | $38.15^{B}$ | $38.72^{B}$ | $5.71^{B}$ | $5.64^{B}$ | $5.67^{B}$ | $42.88^{A}$ | $42.84^{ABC}$ | $42.86^{AB}$ |
| $T_4$ | $119.33^{CD}$ | $17.00^{DEF}$ | $118.17^{CDE}$ | $37.48^{D}$ | $36.77^{C}$ | $37.13^{E}$ | $5.32^{DE}$ | $5.23^{DE}$ | $5.27^{EF}$ | $42.48^{AB}$ | $42.27^{ABCD}$ | $42.38^{ABCD}$ |
| $T_5$ | $121.00^{ABC}$ | $0.00^{ABC}$ | $120.50^{AB}$ | $39.02^{B}$ | $37.25^{BC}$ | $38.14^{BCD}$ | $5.52^{BCD}$ | $5.47^{BC}$ | $5.50^{CD}$ | $42.77^{A}$ | $42.70^{ABC}$ | $42.73^{AB}$ |
| $T_6$ | $114.67^{EF}$ | $113.00^{HI}$ | $113.83^{GH}$ | $31.63^{G}$ | $30.81^{G}$ | $31.22^{I}$ | $4.66^{G}$ | $4.51^{H}$ | $4.58^{I}$ | $40.74^{DE}$ | $40.56^{EF}$ | $40.65^{FG}$ |
| $T_7$ | $118.67^{CD}$ | $116.67^{EF}$ | $117.67^{DE}$ | $36.95^{D}$ | $35.79^{D}$ | $36.37^{F}$ | $5.18^{EF}$ | $5.11^{EF}$ | $5.14^{FG}$ | $41.97^{ABC}$ | $41.86^{ABCDE}$ | $41.91^{BCDE}$ |
| $T_8$ | $120.33^{ABC}$ | $9.67^{ABC}$ | $120.00^{ABC}$ | $39.11^{B}$ | $37.52^{BC}$ | $38.32^{BC}$ | $5.62^{BC}$ | $5.58^{B}$ | $5.60^{BC}$ | $42.83^{A}$ | $42.79^{ABC}$ | $42.81^{AB}$ |
| $T_9$ | $117.33^{DE}$ | $116.00^{FG}$ | $116.67^{EF}$ | $36.24^{E}$ | $34.71^{E}$ | $35.48^{G}$ | $5.02^{F}$ | $4.92^{FG}$ | $4.97^{GH}$ | $41.61^{BCD}$ | $41.33^{CDEF}$ | $41.47^{DEF}$ |
| $T_{10}$ | $20.00^{ABCD}$ | $19.00^{BCD}$ | $119.50^{BCD}$ | $38.17^{C}$ | $36.95^{C}$ | $37.56^{DE}$ | $5.39^{DE}$ | $5.30^{CDE}$ | $5.34^{DE}$ | $42.53^{AB}$ | $42.33^{ABCD}$ | $42.43^{ABC}$ |
| $T_{11}$ | $122.67^{A}$ | $121.67^{A}$ | $122.17^{A}$ | $41.87^{A}$ | $40.79^{A}$ | $41.33^{A}$ | $6.34^{A}$ | $6.27^{A}$ | $6.30^{A}$ | $43.01^{A}$ | $42.93^{A}$ | $42.97^{A}$ |
| $T_{12}$ | $122.33^{AB}$ | $121.33^{A}$ | $121.83^{A}$ | $41.38^{A}$ | $40.51^{A}$ | $40.95^{A}$ | $6.23^{A}$ | $6.16^{A}$ | $6.19^{A}$ | $42.91^{A}$ | $42.87^{AB}$ | $42.89^{A}$ |
| $T_{13}$ | $115.67^{EF}$ | $115.00^{FGH}$ | $115.33^{FG}$ | $31.47^{G}$ | $30.56^{G}$ | $31.02^{I}$ | $5.04^{F}$ | $4.89^{G}$ | $4.96^{H}$ | $41.62^{BCD}$ | $41.38^{BCDEF}$ | $41.50^{CDEF}$ |
| $T_{14}$ | $113.67^{F}$ | $113.00^{HI}$ | $113.33^{GH}$ | $30.76^{H}$ | $29.59^{H}$ | $30.18^{J}$ | $4.32^{H}$ | $4.12^{I}$ | $4.22^{J}$ | $40.65^{DE}$ | $40.12^{FG}$ | $40.38^{GH}$ |
| $T_{15}$ | $113.33^{F}$ | $112.33^{I}$ | $112.83^{H}$ | $29.16^{I}$ | $28.00^{I}$ | $28.58^{K}$ | $4.02^{I}$ | $3.88^{J}$ | $3.95^{K}$ | $40.33^{E}$ | $40.07^{G}$ | $40.20^{H}$ |
| SE(d) | 1.375 | 1.138 | 1.061 | 0.335 | 0.461 | 0.304 | 0.111 | 0.096 | 0.083 | 0.555 | 0.743 | 0.461 |
| LSD (P=0.05) | 2.8168 | 2.3313 | 2.1743 | 0.6861 | 0.9439 | 0.6234 | 0.2268 | 0.196 | 0.1708 | 1.1369 | 1.5211 | 0.9451 |

* Mean with at least one letter common is not statistically significant using Fisher's least significant difference.

Table 3 Effect of different treatments on AUDPC, grain infection (%), net return (₹/ha) and B: C ratio

| Treatment | AUDPC | | Pooled mean | Grain infection (%) | | Pooled mean | Net return (₹/ha) | | Pooled mean | B: C ratio | | Pooled mean |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 2012-13 | 2013-14 | | 2012-13 | 2013-14 | | 2012-13 | 2013-14 | | 2012-13 | 2013-14 | |
| $T_1$ | 580.25$^{C*}$ | 705.76$^{C}$ | 643.00$^{C}$ | 41.50$^{C}$ | 44.08$^{C}$ | 42.79$^{C}$ | 65969.00$^{FG*}$ | 66984.83$^{H}$ | 66476.92$^{HI}$ | 2.33$^{EF}$ | 2.26$^{F}$ | 2.30$^{F}$ |
| $T_2$ | 59.67$^{DE}$ | 69.96$^{DEF}$ | 64.81$^{DEFG}$ | 21.67$^{E}$ | 29.75$^{EF}$ | 25.71$^{GH}$ | 76506.33$^{BC}$ | 78402.03$^{CDE}$ | 77454.18$^{CDE}$ | 2.64$^{AB}$ | 2.54$^{BCD}$ | 2.59$^{BC}$ |
| $T_3$ | 30.86$^{E}$ | 37.04$^{EF}$ | 33.95$^{EFG}$ | 11.92$^{F}$ | 14.58$^{GH}$ | 13.25$^{I}$ | 80366.6$^{B}$ | 82311.0$^{B}$ | 81338.87$^{B}$ | 2.68$^{A}$ | 2.59$^{AB}$ | 2.64$^{AB}$ |
| $T_4$ | 84.36$^{DE}$ | 88.48$^{DEF}$ | 86.42$^{DEF}$ | 23.75$^{E}$ | 33.67$^{E}$ | 28.71$^{FG}$ | 74847.00$^{CD}$ | 76274.43$^{EF}$ | 75560.72$^{EF}$ | 2.63$^{AB}$ | 2.52$^{BCD}$ | 2.58$^{BC}$ |
| $T_5$ | 49.38$^{DE}$ | 51.44$^{EF}$ | 50.41$^{EFG}$ | 12.33$^{F}$ | 16.25$^{G}$ | 14.29$^{I}$ | 77793.00$^{BC}$ | 79738.07$^{BCD}$ | 78765.53$^{BCD}$ | 2.66$^{A}$ | 2.57$^{ABC}$ | 2.62$^{AB}$ |
| $T_6$ | 625.51$^{C}$ | 722.22$^{C}$ | 673.87$^{C}$ | 40.75$^{C}$ | 46.75$^{C}$ | 43.75$^{C}$ | 64351.00$^{G}$ | 64652.87$^{H}$ | 64501.93$^{I}$ | 2.30$^{EF}$ | 2.21$^{F}$ | 2.26$^{F}$ |
| $T_7$ | 90.53$^{DE}$ | 100.82$^{DE}$ | 95.68$^{DE}$ | 32.50$^{D}$ | 35.25$^{DE}$ | 33.88$^{DE}$ | 71997.00$^{DE}$ | 74277.27$^{FG}$ | 73137.13$^{FG}$ | 2.48$^{CD}$ | 2.45$^{DE}$ | 2.47$^{DE}$ |
| $T_8$ | 41.15$^{DE}$ | 45.27$^{EF}$ | 43.21$^{EFG}$ | 19.58$^{E}$ | 26.83$^{F}$ | 23.21$^{H}$ | 78665.6$^{BC}$ | 80852.0$^{BC}$ | 79758.87$^{BC}$ | 2.61$^{ABC}$ | 2.53$^{BCD}$ | 2.57$^{BCD}$ |
| $T_9$ | 127.57$^{D}$ | 141.97$^{D}$ | 134.77$^{D}$ | 36.08$^{CD}$ | 40.42$^{CD}$ | 38.25$^{D}$ | 69773.00$^{EF}$ | 71488.60$^{G}$ | 70630.80$^{G}$ | 2.43$^{DE}$ | 2.38$^{E}$ | 2.41$^{E}$ |
| $T_{10}$ | 72.02$^{DE}$ | 82.30$^{DEF}$ | 77.16$^{DEFG}$ | 20.83$^{E}$ | 31.92$^{EF}$ | 26.38$^{GH}$ | 74838.00$^{CD}$ | 76927.40$^{DEF}$ | 75882.70$^{DEF}$ | 2.52$^{BCD}$ | 2.49$^{CDE}$ | 2.50$^{CDE}$ |
| $T_{11}$ | 10.29$^{E}$ | 14.40$^{F}$ | 12.35$^{G}$ | 4.25$^{G}$ | 6.33$^{I}$ | 5.29$^{J}$ | 89456.0$^{A}$ | 91620.2$^{A}$ | 90538.12$^{A}$ | 2.70$^{A}$ | 2.61$^{AB}$ | 2.66$^{AB}$ |
| $T_{12}$ | 18.52$^{E}$ | 32.92$^{EF}$ | 25.72$^{FG}$ | 5.50$^{FG}$ | 8.42$^{HI}$ | 6.96$^{J}$ | 88341.6$^{A}$ | 90682.5$^{A}$ | 89512.08$^{A}$ | 2.74$^{A}$ | 2.66$^{A}$ | 2.70$^{A}$ |
| $T_{13}$ | 600.82$^{C}$ | 709.87$^{C}$ | 655.34$^{C}$ | 31.42$^{D}$ | 33.33$^{EF}$ | 32.38$^{EF}$ | 68126.67$^{EFG}$ | 66846.90$^{H}$ | 67486.78$^{H}$ | 2.22$^{FG}$ | 1.98$^{G}$ | 2.10$^{G}$ |
| $T_{14}$ | 862.14$^{B}$ | 921.81$^{B}$ | 891.97$^{B}$ | 49.42$^{B}$ | 58.50$^{B}$ | 53.96$^{B}$ | 58046.67$^{H}$ | 57161.97$^{I}$ | 57604.32$^{J}$ | 2.09$^{G}$ | 1.97$^{G}$ | 2.03$^{G}$ |
| $T_{15}$ | 1000.00$^{A}$ | 1084.36$^{A}$ | 1042.18$^{A}$ | 64.50$^{A}$ | 76.67$^{A}$ | 70.58$^{A}$ | 52755.33$^{I}$ | 51827.20$^{J}$ | 52291.26$^{K}$ | 1.94$^{H}$ | 1.82$^{H}$ | 1.88$^{H}$ |
| SE(d) | 42.359 | 38.733 | 32.729 | 3.436 | 3.237 | 2.204 | 1945.753 | 1565.263 | 1449.368 | 0.068 | 0.052 | 0.050 |
| LSD (P=0.05) | 86.768 | 79.342 | 67.042 | 7.0381 | 6.6301 | 4.5137 | 3985.7 | 3206.3 | 2968.9 | 0.1386 | 0.1075 | 0.1026 |

* Mean with at least one letter common is not statistically significant using Fisher's least significant difference.

practices for reduction of spot blotch disease and seed infections along with enhanced plant growth, grain yield and its attributes. Similarly, balanced fertilization plus seed treatment and single foliar spray of propiconazole ($T_{12}$) also decreased grain infections (90%), AUDPC (97%), along with increase in average grain yield (57%), TKW (43%), tillers (65%), spike length (44%), grains/spike (51%), plant height (8%), harvest index (40.20%), net return (₹ 89512 ) and net B: C ratio (1: 2.70) over the control. The treatment, $T_{12}$ was statistically at par with the treatment, $T_{11}$, whereas, it was significantly higher than control ($T_{15}$) in terms of net return, B: C ratio and associated increase in grain yield (Table 1, 2, 3). Therefore, it would be more cost effective to apply only one fungicide spray along with nutrients' combinations at the time of initiation of disease on penultimate (flag -1 or 2) leaves. The integration of various management practices like, balanced fertilization, seed treatment and fungicidal spray(s) in a unified way under present investigation seems to be first report of its kind for the management of spot blotch disease and exploitation of production potential of wheat in warmer areas of Indian subcontinent. Associated increase in grain yield was always higher along with low disease severity under balanced soil nutrition plus fungicidal protected conditions ($T_{11}$, $T_{12}$) as compared to low fertilized and unprotected conditions ($T_{15}$) where higher disease severity and low grain yield were observed (Table 1, 2, 3). This elucidated that spot blotch caused associated grain yield losses under balanced fertilization ($T_{13}$) and nutrient stress conditions ($T_{15}$). Much higher yield losses were noticed under soil nutrients stress conditions ($T_{15}$) compared to balanced nutrients ($T_{13}$). The lower grain yield (3.95 tonnes/ha) in N and P fertilized control plot ($T_{15}$) compared to higher grain yield (4.96 tonnes/ha) in balanced fertilization treatment and other treatments suggested that the disease had more yield losses under nutrient stress conditions. The balanced fertilization prolongs the canopy's stay green character and fungicide application(s) delays the loss of green leaf area due to spot blotch pathogen. Hence, the plant leaves, especially the flag leaf, can photosynthesize for longer period and wheat crop remain green activated for longer period in the field. This is clearly evidenced by more number of days for physiological maturity (121-122 days) along with higher yield and other agronomic traits under balanced fertilization and fungicide protected conditions ($T_{11}$ and $T_{12}$) compared to control (113 days). These results are in conformity with the observations reported earlier by Duveiller *et al.* (2005b), Simoglou and Dordas (2006) who described similar delay in loss of green leaf area in wheat crop while controlling foliar blight and tan spot disease through application of mineral nutrients and fungicides. The present study emphasized the rationalized use of fungicides in combination with other integrated approaches for the management of wheat spot blotch disease under field conditions. It also supported the concept that the effect of nonspecific foliar diseases can be reduced through optimum crop husbandry and good soil fertility management (Sharma *et al.* 2005, 2006). Single spray of propiconazole at the time of initiation of disease in penultimate leaves in combination with seed treatment and balanced fertilization proved cost effective and highly remunerative among all treatment in the study. The finding of this study underlines the importance of integrated crop and disease management practices in minimizing the spot blotch mediated yield losses to wheat crop in hot humid wheat growing environment of South Asia.

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