

Nitrogen and Potassium Fertility Impacts on Aggregate Sheath Spot Disease and Yields of Rice

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Abstract : Aggregate sheath spot (AgSS), a disease caused by *Rhizoctonia oryzae-sativae*, is one of the major rice (*Oryza sativa* L.) diseases in California. A three year study was initiated in 1998 to evaluate the effect of nitrogen (N) and potassium (K) fertility on the severity of AgSS. A field with a history of AgSS was divided in two: in one the straw was incorporated and in the other the straw was removed. Rice was fertilized annually with five rates of N ranging from 0 to 200 kg ha⁻¹ (main plot) and six rates of K ranging from 0 to 125 kg ha⁻¹ (sub-plot). Soil K levels in both fields declined over time and by the third year, soil K was below the critical level of 60 µg K g⁻¹ soil in both fields. There was a grain yield response to K fertilizer in all 3 years in the field where straw was removed and in the third year when straw was incorporated. Where there was a significant response to K fertilization, yields increased by 560 kg ha⁻¹. In all fields and years there was a significant yield response to N fertilizer. AgSS severity decreased with increasing N and K fertilizer rates and leaf N and K concentrations at panicle initiation. Furthermore, the leaf N concentration required for maximum rice yields was lower than the leaf N concentration which resulted in the lowest severity of AgSS.

Key words : Nitrogen, Nutrient-disease interaction, Potassium, *Rhizoctonia oryzae-sativae*, Rice.

Aggregate sheath spot (AgSS), caused by *Rhizoctonia oryzae-sativae* (Sawada) Mordue [syn. *Ceratobasidium oryzae-sativae* P. S. Gunnell & R. K. Webster] is a common disease of rice world wide. It has been reported in Asia (Taheri et al., 2007), Australia (Lanoiselet et al., 2005a), the Middle East (Rahimian, 1989), South America (Cedeno et al., 1998) and the US (Gunnell and Webster, 1984). In California, where rice is grown on over 200,000 ha, it has been observed since the late 1960's and is one of the prevalent rice diseases (Gunnell and Webster, 1984). All cultivars currently grown in California are somewhat susceptible to aggregate sheath spot (Miller and Webster, 2001). Research in Australia has shown that AgSS can result in yield declines of up to 20% (Lanoiselet et al., 2005b). Initially, AgSS lesions appear on the lower leaf sheaths at the water line following infection from *R. oryzae-sativae* sclerotia floating on the water. The disease progresses to the upper leaf sheaths and, under favorable conditions, can spread to the flag leaf and cause yield loss by reducing photosynthetic area.

In California, due to the Rice Straw Burning Reduction Act of 1991 (AB-1378), which mandated the phase down of rice straw burning in California's Sacramento Valley, most growers incorporate the straw following harvest. This change in straw management is likely to have an impact on AgSS incidence and severity. *R. oryzae-sativae* can over winter in the soil

or on straw debris regardless of whether the straw is incorporated or left on the surface (Lanoiselet et al., 2005a); however, Miller and Webster (2001) reported that methods which remove the straw significantly reduced sclerotia compared to when straw was retained in the field. While the effects of straw management have been studied, Miller and Webster (2001) suggested that further research is needed to identify other cultural practices that lead to a reduction of disease incidence and development.

Nitrogen and K management are both known to affect plant diseases. In addition to fertilizer management, soil N and K fertility is affected by straw management (Eagle et al., 2000; Linquist et al., 2006). Nitrogen fertilizer applications do not favor the development of AgSS (Gunnell and Webster, 1985) and may even decrease its incidence (Williams and Smith, 2001). With respect to K, there is strong evidence of the positive benefits of good K fertility management on disease resistance, including that to AgSS (Williams and Smith, 2001). Evidence has clearly shown the positive residual impact of straw incorporation on the K fertility status of agricultural soils (Cox and Uribe, 1992; Allison et al., 1997; Wihardjaka et al., 1999; Dierolf and Yost, 2000). In particular, straw management plays a critical role in the K fertility status of rice soils since it contains about 80% of the above ground plant K (Dobermann et al.,

Table 1. Soil properties at the onset of the experiment in two adjacent fields with differing winter straw management practices.

Field	pH	Total N (%)	Total C (%)	CEC (meq 100 g ⁻¹)	Sand (%)	Silt (%)	Clay (%)
Straw removed	4.9	0.09	1.17	12.7	30	47	23
Straw incorporated	4.9	0.09	1.18	12.8	33	46	22

1996, 1998; Dobermann and Fairhurst, 2000) and its removal has been cited as the major culprit of K deficiencies in irrigated rice fields throughout Asia (De Datta, 1981; Gill and Kamprath, 1990; Dobermann et al., 1998). Potassium deficiency are a potential problem in all intensive irrigated rice systems and is common on coarse textured soils, where rice straw is removed and where there is little K in irrigation water (Dobermann et al., 1996). In California rice systems K deficiency is not widespread, and primarily occurs on low CEC alluvial terrace soils along the eastern portion of the Sacramento Valley (Williams and Smith, 2001). The objective of this study was to evaluate the effect of N and K fertility management on rice yields and AgSS severity.

Materials and Methods

1. Field experiment

Two field experiments were conducted in the Sacramento Valley near Marysville, California, in a field with a history of AgSS. The experiment was initiated in the Fall of 1998 and ended in the Fall of 2001. The soil is classified as a San Joaquin loam (fine, mixed, thermic Abruptic Durixeralf) with a clay content of 23% and has been historically K deficient (Table 1). The field had been in continuous commercial rice production for over 40 years prior to the initiation of the experiment. Straw had been burned until the early 1990's. Thereafter, straw was incorporated annually in the fall after harvest followed by winter flooding. Grower fertilizer application rates varied annually but ranged from 135–160 kg N ha⁻¹, 20–30 kg P ha⁻¹ and 45–70 kg K ha⁻¹.

In the fall of 1998, a single field was divided into two separate 3 ha fields. A levee divided the two fields, although, water could still move between the fields. The only difference in management between the two fields was the straw management: each fall it was either incorporated or removed. When incorporated, straw was cut approximately 10 cm above the ground, chopped and disked followed by winter flooding. When removed, the straw was mowed to a height of about 10 cm, windrowed, and baled followed by winter flooding. Each field had an identical experiment with treatments replicated four times and laid out as a split-plot design with five N rates (0, 50, 100, 150, 200 kg ha⁻¹ N) as main plot treatments and six K rates (0, 21, 42, 63, 83, 104 kg K ha⁻¹) as the subplot treatments. All the N fertilizer was applied in a single dose as (NH₄)₂

SO₄ using a fertilizer applicator (Clampco, San Juan Baptista, CA) and buried 5 to 10 cm under the soil surface before flooding. The K fertilizer was applied as KCl and broadcast by hand prior to N application to allow for fertilizer incorporation with the fertilizer applicator. Triple-super-phosphate was broadcast by hand prior to N application for each experimental plot at the rate of 50 kg P ha⁻¹ across all treatments to ensure that P was not limiting. Individual sub-plot size was 3.05×7.62 m. In the first and third year, the field was flooded and seeded within two days after fertilization. In the second year of the experiment, flooding and seeding took place 2.5 weeks after fertilization due to rain, which prevented final field operations before flooding could occur. The rice variety M 202 was used each year and seeded by air. Plots remained continuously flooded until two to three weeks prior to harvest when the fields were drained.

In each year the experiments were established in a different area within the field to the previous year's experiment. No K fertilizer was applied to the area of each field not used for the current year's experiment; however, N and P fertilizers were applied at the conventional rate.

Each year before applying fertilizer, soil samples (0–20 cm) were collected from each main plot. Soils were air-dried and extracted for exchangeable K using 1 M NH₄OAC method and analysis was determined by inductively coupled plasma mass spectrometry (ELAN 6000, Perkin Elmer) (Sparks, 1996).

At panicle initiation (PI), 40 of the most recently developed leaves were sampled from each sub-plot for N and K analysis. At crop maturity, a 19 m² portion in the middle of each plot was harvested using a small plot combine harvester (SWECO, Sutter, CA). The PI leaf and harvest grain and straw samples were dried at 60 °C to a constant weight and ground to 0.5 mm using a Wiley Mill. The PI leaf N content was determined by dry combustion using a Carlo Erba CNS analyzer (Carlo Erba, Milan, Italy) and the PI leaf K content was determined by extraction with 2% acetic acid followed by analysis using ICP (ELAN 6000, Perkin Elmer) (Miller, 1998). Grain yields are reported at 14% moisture.

AgSS ratings were determined in both fields in the following treatments: 0, 100, and 200 kg N ha⁻¹ with 0, 42, and 83 kg K ha⁻¹ with the exception of the third year when the 0, 63, and 104 kg K ha⁻¹ sub-plots were sampled. The rating was done three weeks before harvest on 40 stems, randomly selected from each plot.

Table 2. Analysis of variance results (P value) for the grain yield and aggregate sheath spot (AgSS) ratings in relation to N and K fertilizer management for each year (years 1, 2 and 3 correspond to 1999, 2000 and 2001, respectively).

Field	Fertility variable	Year 1	Year 2	Year 3
Grain yield				
Straw removed	N	0.0000	0.0000	0.0000
	K	0.0014	0.0000	0.0039
	NxK	0.5166	0.1156	0.2151
Straw incorporated	N	0.0000	0.0000	0.0000
	K	0.6857	0.1070	0.0044
	NxK	0.7760	0.5034	0.8480
AgSS ratings				
Straw removed	N	0.0003	0.0014	0.0021
	K	0.0984	0.2038	0.0010
	NxK	0.1805	0.6962	0.0688
Straw incorporated	N	0.0035	0.0006	0.0002
	K	0.5579	0.9582	0.0047
	NxK	0.4560	0.5115	0.6874

The rating system was based on the observance of AgSS lesions on the leaf sheaths. Webster (2005) describes AgSS symptoms and disease progression as follows: sclerotia, which over winter in residue or soil, float to the surface when the field is flooded infecting plants at the water line. Infections first appear as oval lesions with grayish-green to straw-colored centers surrounded by a distinct brown margin. Lesions expand and progress up the plant as it matures during the season. In some cases it causes culm rot or infects the panicle rachis, resulting in sterile florets and partially filled panicles. In severe cases the panicle does not emerge from the boot. Consequently, the severity of the disease can be rated by how far up the plant it is by the end of the season. The rating system used here evaluated the top four leaf sheaths (including the flag leaf) and determined severity as follows: 4=top four leaf sheaths infected; 3=three lower leaf sheaths infected, flag leaf sheath not infected; 2=two lower leaf sheaths infected; 1=the lowest leaf sheath infected; 0=no AgSS lesions on the top four leaf sheaths. All ratings were performed in the field immediately after sampling.

2. Statistical analysis

For each field and year, a separate ANOVA was conducted with SAS using the model for a split-plot design. Since the interaction between N and K fertility treatments on grain yields and AgSS ratings were not significant, regression analysis was conducted to determine the effect of N and K fertility rates on grain yields and AgSS ratings. Treatment effects were considered significant at a $P < 0.05$ level of probability.

Results and Discussion

The application of N and K fertilizer significantly

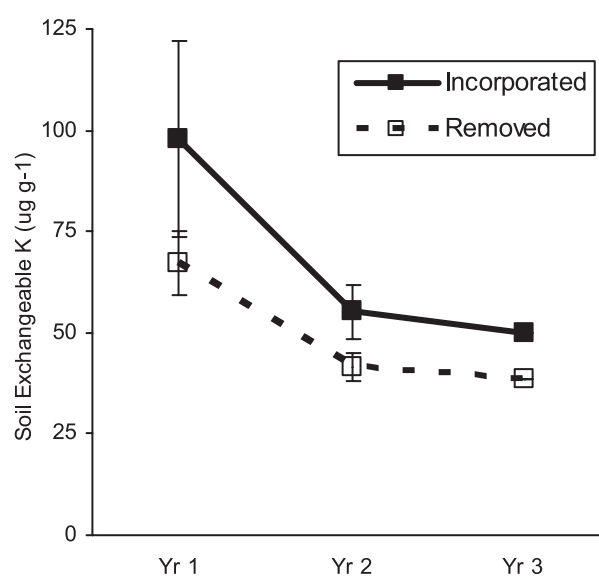


Fig. 1. Preplant soil exchangeable K in the straw incorporated and straw removed fields. Error bars represent one standard deviation and are not available for Yr 3.

increased grain yields in both fields in at least one of the three years (Table 2). Since the interaction between N and K fertility was not significant, the response of grain yield to N and K fertilization are reported and discussed separately.

1. Soil K

Available soil K decreased over time and by the third year extractable soil K levels were below the critical level of $60 \mu\text{g K g}^{-1}$ soil (De Datta and Mikkelsen, 1985) in both fields (Fig. 1). Available soil K was higher in the straw incorporated field as has been observed

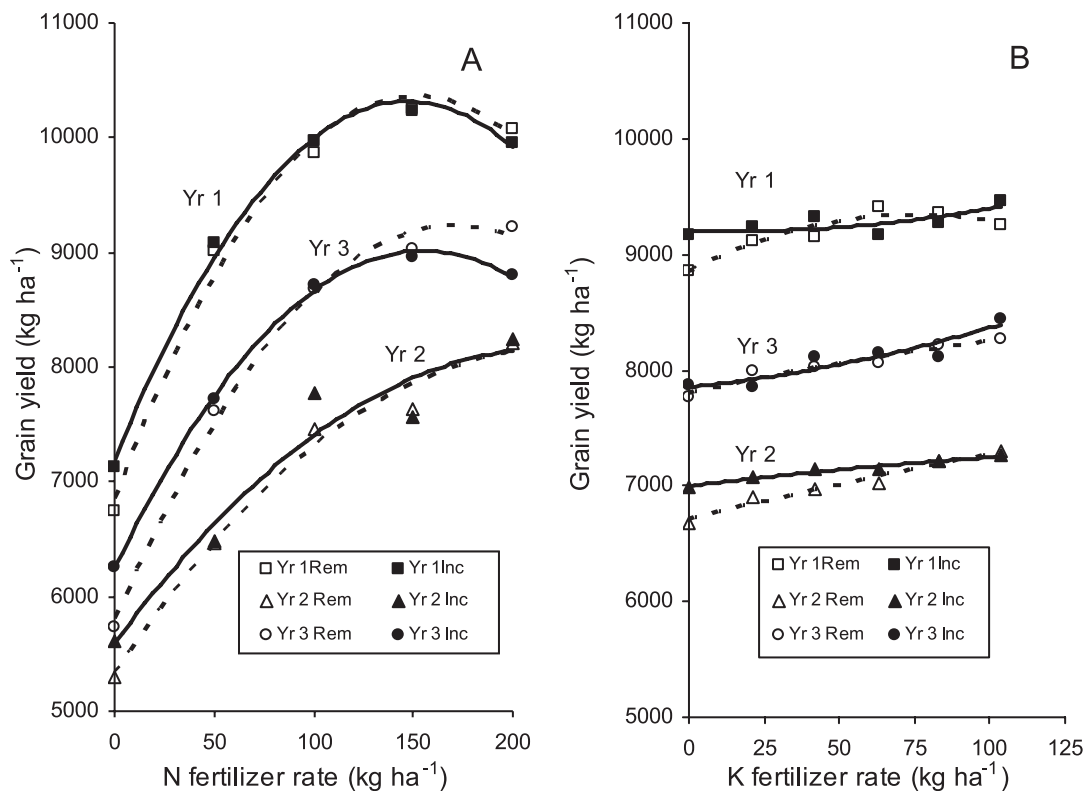


Fig. 2. Grain yield response to N (A) and K (B) fertilizer for both field sites in each year. The N data presented are the means across all K rates and the K data are the means across all N rates.

elsewhere (Hoagland and Martin, 1950; Karanthans and Wells, 1990; Dobermann et al., 1996; Prasad et al., 1999; Singh et al., 2004). It is unusual that soil K declined at similar rates in both fields; certainly, one would expect that it to decline more rapidly in the field where straw was removed. Mature rice straw contains approximately 80% of the aboveground plant K and is 1.5 to 2.0% K; rice grain on the other hand has a K concentration of 0.22 to 0.31% (Dobermann and Fairhurst, 2000). Assuming a harvest index of 0.5, a grain yield of 9 Mg ha⁻¹, a straw K content of 1.75%, and a grain K content of 0.26%, the total K in the grain and straw is 23 and 158 kg K ha⁻¹, respectively. As the crop was harvested at 10 cm above ground level, about 85% of the straw was removed, equal to 134 kg K ha⁻¹. Therefore, the annual removal of K was 23 and 157 kg K ha⁻¹ in the straw incorporated and removed field, respectively. We can not fully explain why soil K values declined at similar rates between fields but it is likely to be a combination of the following factors. First, field variability with respect to soil K; since the straw treatments were not replicated it was not possible to account for such variability in our experiment. Second, soils in the two fields differed and thus reacted differently to K inputs and/or soil K extraction. This is unlikely as the experimental site was initially a single field that was managed similarly for the past 40 years and the two experiments were only separated by 20 m

and soil characteristics of the two fields were similar (Table 1). Third, the low CEC of this soil suggests that it is limited in its capacity to retain exchangeable K and it is possible that K could be lost through leaching or surface water run-off. Bakker and Jenkins (2003) reported that the K concentration of straw left in the field over the winter dropped from an average of 1.4% to 0.2%. This suggests that K leaches from rice straw during the rainy winter period and may be exported from the field in runoff water. Although data was not collected on water outflow during the winter, the normal practice for this field was to establish deep and continuous flow of water. While this may account for a portion of the K that is lost, it is unlikely that much was lost this way because the straw was incorporated into the soil before flooding. Finally, K fixation is a possibility as other Sierra Nevada alluvial soils (as is this soil) have been shown to have a high K fixation potential (Murashkina et al., 2007).

2. Grain yield response to K fertilizer

There was not a grain yield response to K fertilization in the first year when straw was incorporated, however, as available soil K declined over time, a significant yield response developed by year 3 (Table 2 and Fig. 2). There was a significant grain response to K fertilizer in all years in the straw removed field (Table 2 and Fig. 2), with grain yields increasing by 560 kg ha⁻¹, on average,

as K fertilizer increased from 0 to 104 kg K ha⁻¹. Results from this study confirm findings by De Datta and Mikkelsen (1985) who reported a critical soil K value of 60 µg K g⁻¹ soil. In this study, when the soil K level was 67 µg K g⁻¹ soil or below, there was a significant grain yield response to K fertilizer (Fig. 3). The single exception was in year 2 when straw was incorporated and the soil K value was 57 µg K g⁻¹ soil.

3. Grain yield response to N fertilizer

In both fields there was a large grain yield response

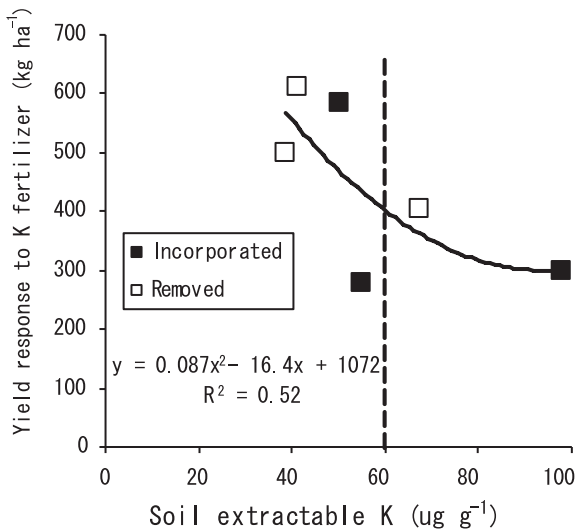


Fig. 3. Grain yield response of rice to K fertilizer as a function of soil extractable K in fields where straw was either incorporated or removed. The vertical dashed line represents the critical extractable K concentration of 60 µg g⁻¹. Grain yield responses to K of less than 300 kg ha⁻¹ were not significant.

to N fertilizer. In the zero N plots, grain yield in the straw removed field was on average 400 kg ha⁻¹ lower than where straw was incorporated. Other studies have also reported that straw incorporation increases available soil N and rice yield (Sistani et al., 1998; Eagle et al., 2000; Linquist et al., 2006). Maximum yields between sites were similar, with the highest yield recorded in year 1 (>10 Mg ha⁻¹), followed by year 3 (>9 Mg ha⁻¹) and year 2 (>8 Mg ha⁻¹). The yield response curves to N varied between years. In year 1 and 3 maximum yields were obtained with 150 kg N ha⁻¹, in contrast to 200 kg N ha⁻¹ in year 2. In year 2, rice was not sown for 2.5 weeks after the application of N and K fertilizers due to rainfall. This would have allowed for nitrification of the fertilizer N, making it susceptible to denitrification losses when the fields were flooded for planting (Buresh and De Datta, 1991).

4. Aggregate sheath spot effects on yield

The severity of AgSS was similar in both fields with the different straw management practices. The effect of straw management practices on AgSS can not be made from this study because straw management treatments were not replicated. Furthermore, *R. oryzae-sativae* floats on the water surface (Miller and Webster, 2001) and may have moved from one field to the other in this study since the fields were hydrologically connected. Miller and Webster (2001) reported that methods which remove the straw, including baling and burning, reduced sclerotia significantly compared to when straw was incorporated into the soil. However, *R. oryzae-sativae* can over winter as mycelium or sclerotia in the soil or on straw debris regardless of whether the straw is incorporated or left on the surface (Lanoiselet

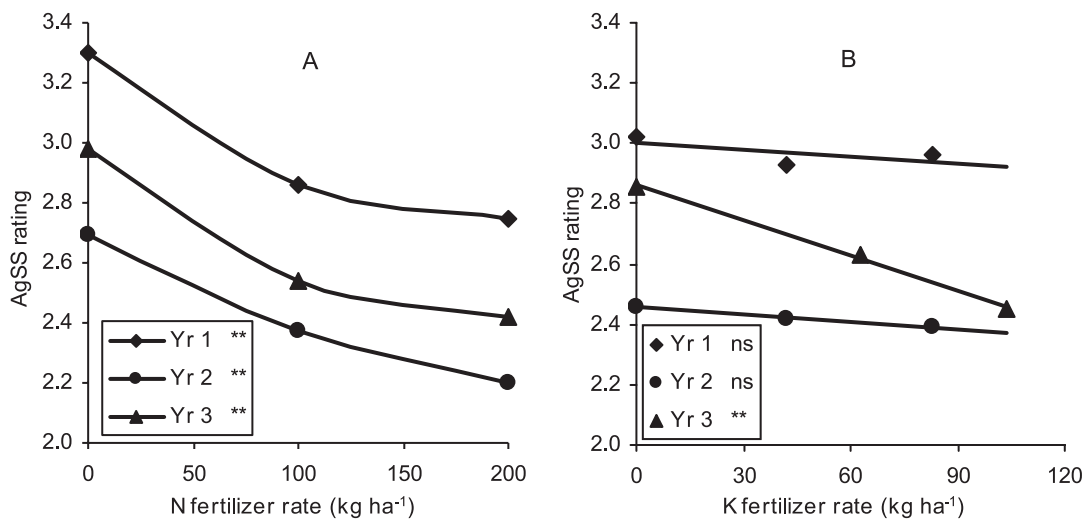


Fig. 4. Aggregate sheath spot (AgSS) rating response to N (A) and K (B) fertilizer. The responses was similar between the straw burned and incorporated field, so data were combined for analysis. The N response curve uses data that are averaged across all K rates and the K response curve uses data that are averaged across all N rates. ** indicates significance at the 0.01 probability level based on the combined ANOVA.

et al., 2005a).

Both N and K fertility influenced the severity of AgSS (Table 2 and Fig. 4). Nitrogen fertility had the largest effect on AgSS and the response was significant in every year. Averaged across fields and years, the AgSS ratings decreased from 2.99 to 2.46 as N rates increased from 0 to 200 kg N ha⁻¹ (Fig. 4). Gunnell and Webster (1984) also found that the overall severity of AgSS was most pronounced at lower N levels.

In each year there was a significant relationship between mid-season plant N concentration and AgSS such that as N concentration increased, the severity of AgSS decreased (Fig. 5). However, there was not a “critical” N concentration at which AgSS severity was minimized; in years 1 and 3 it was 3.9% and in year 2 it was 2.8%. As plant N concentration increased above that required for maximum grain yield, AgSS severity decreased. In year 1 and 3, where a yield plateau was achieved in response to N fertilization, the optimal leaf N concentration at panicle initiation for maximum yield was 3.2% (data not shown) in contrast to 3.9% (Fig. 5) required for the lowest AgSS ratings. This finding concurs with that of Williams and Smith (2001) who reported a significant decrease in the incidence of AgSS in rice when 210 kg N ha⁻¹ was applied compared

to 164 kg N ha⁻¹, which was required for maximum grain yields. The finding that a reduction of a fungal disease requires a higher N-fertilizer rate than what is required for maximum grain yield is different from what is commonly observed for some of the other rice leaf sheath diseases. Kannaiyan and Prasad (1979) found that by increasing the amount of N fertilizer, the severity of sheath blight (caused by *R. solani* Kuhn) increased. Yu et al. (1976) also found that sheath blight was more severe at higher N fertilizer rates. However, they found that the occurrence of the disease was not due to increased foliar N concentration but to increased relative humidity at the high N fertilizer levels—a factor contributing to the severity and spread of other diseases as well. Since AgSS decreased with increasing N fertilizer rates in our study, relative humidity within the rice canopy may have little effect on the growth and spread of AgSS. The question is then “why do higher N rates suppress the severity of AgSS?” One possibility is that the vertical movement of *R. oryzae-sativae* up the rice stem is slow and higher N rates allow the crop to grow faster than the spread of AgSS up the stem. This hypothesis is supported by findings that semi-dwarf cultivars are more vulnerable to AgSS than tall cultivars (Gunnell and Webster, 1984). Taller cultivars have faster growth rates than the semi-dwarfs, possibly allowing them to outgrow the spread of AgSS.

While increasing N fertilizer rates above that required for maximum yields reduces AgSS, this practice is not recommended because high N fertilizer rates can result in the spread of other fungal diseases. For example, Williams and Smith (2001) found in the same study where they reported a decrease in AgSS with high N fertilizer rates, that stem rot (*Sclerotium oryzae* Cattaneo) increased with increasing N rates. In another study, Keim and Webster (1974) found that stem rot severity increased with increasing foliar N concentration.

The effect of K on AgSS ratings were only significant in year 3 when soil K values were at their lowest in both fields (Table 2 and Fig. 4). In year 3, AgSS ratings decreased from 2.85 with no K fertilizer to 2.45 with 104 kg K ha⁻¹. The effect of mid-season leaf K concentration on AgSS ratings were confounded

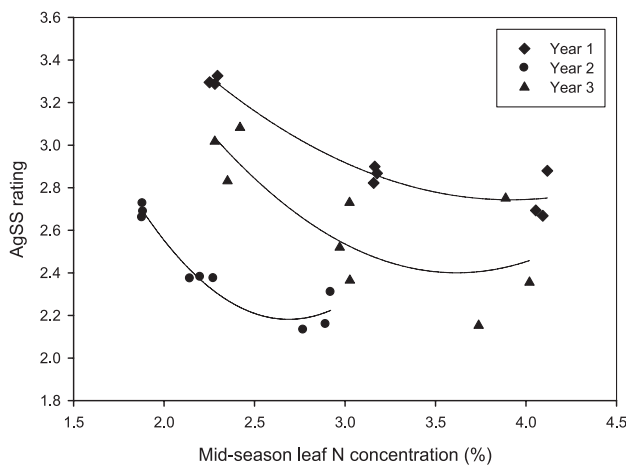


Fig. 5. The effect of midseason (panicle initiation) leaf N concentration on aggregate sheath spot (AgSS) ratings in each year under different straw management practices.

Table 3. Analysis of variance results (P value) for panicle initiation leaf K concentration in relation to N and K fertilizer management for each year (years 1, 2 and 3 correspond to 1999, 2000 and 2001, respectively).

Field	Fertility variable	Year 1	Year 2	Year 3
Straw removed	N	0.0003	0.0001	0.0000
	K	0.0000	0.0000	0.0000
	NxK	0.0030	0.5393	0.6672
Straw incorporated	N	0.1435	0.0020	0.0097
	K	0.0002	0.0000	0.0000
	NxK	0.3121	0.6853	0.7015

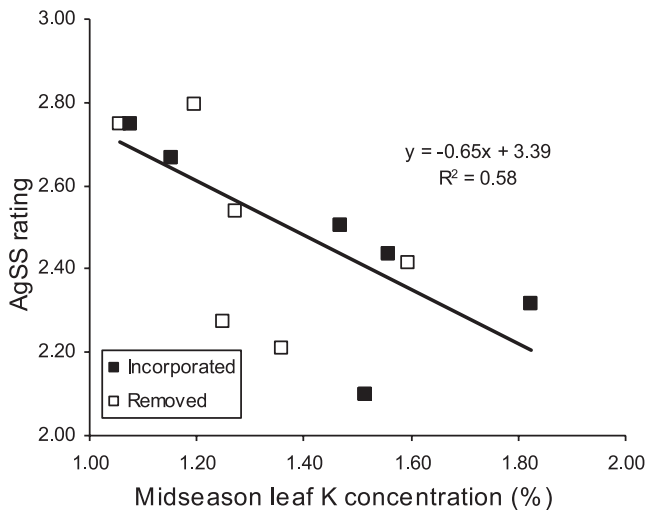


Fig. 6. The effect of midseason (panicle initiation) leaf K concentration on aggregate sheath spot (AgSS) ratings in year 3 under different straw management practices. The regression line is for both straw management practices. Data from the 0N plots were removed from the analysis due to the confounding effects of N treatment on leaf K concentration.

because of the highly significant effect of N fertility on K concentration (Table 3). Midseason leaf K concentration in the low N fertilizer treatments was high (1.79%) relative to treatments where adequate N fertilizer was applied (1.36%) (data not shown). Removing the zero N rate from the analysis and only using the 100 and 200 kg N ha⁻¹ rates, the effect of K fertility is apparent. As panicle initiation leaf K concentration increased from 1.05 to 1.8% the AgSS rating decreases from 2.7 to 2.2 (Fig. 6). These results corroborate those findings of Williams and Smith (2001) who found AgSS incidence to decrease significantly in response to increased K uptake and midseason leaf K concentration.

Conclusions

AgSS was affected directly by N and K fertility management practices. In the third year of the study, when soil K levels were lowest, K fertilizer applications resulted in a significant decrease in AgSS. Nitrogen management had the largest effect on AgSS severity and, unlike a number of other rice diseases, AgSS severity decreased with increasing N fertility levels. Moreover, as N fertility levels increased above what is required for maximum yields, AgSS continued to decrease. What is the significance of our findings in terms of fertility management? First, if the soil extractable K is low, K fertilizer should be applied which may improve yields and decrease the severity of AgSS. Second, it is not recommended to over fertilize with N in order to reduce AgSS because over fertilization can increase the severity of other fungal leaf sheath diseases and result in crop lodging and

reduced yield. Rather, N fertilizer should be applied with the goal of achieving optimal yields as opposed to maximum yields.

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