Project Title: Potassium Responses in Rice Fields as Affected By Straw Management Practices

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STATEMENT OF OBJECTIVE

The average concentration of K in rice straw is around 1.4% but can range from as low as 0.6% and as high as 1.8%. The amount of straw removed by baling is often around 7,000 kg ha-' and the amount of K removed in the straw in Californian rice fields can exceed 100 kg ha'. When straw is removed on a continual basis, this management practice will have a pronounced effect on the available K levels in the soil. Some preliminary data gathered from the long-term straw rotation studies at the Rice Experiment Station showed that the extractable K levels in the soil in the top 15 cm declined significantly to less than 60 µg K g' soil when straw was baled for three years.

A limited number of trials were conducted to determine rice grain yield response to K fertilizer as affected by various straw management practices. Under eight different straw management practices grain yield showed a linear positive response to K fertilizer application: grain yield was 9,000 kg ha' when no fertilizer was applied and increased to 11,000 kg ha' following the application of 135 kg K20 ha'. As the response was linear, the highest amount of K20 applied was not sufficient to meet all the K demand of the rice crop. The extractable K level at this site was 70 ppm (approximately 55-65 kg ha' of available K), which is considered to be slightly the critical K level in rice soil. The amount of extractable K was significantly correlated with the %K in the straw, which was significantly correlated with rice yield.

Furthermore, the concentration of K in the leaf tissue (sampled in July) increased significantly when rice straw was not removed from the field and the highest grain yield occurred when was straw was incorporated in the soil. These data strongly suggest that baling, and possibly burning, rice straw may require higher K fertilizer inputs in order to sustain yield. It would also suggest that the current soil K test may also not adequately reflect plant available K.

Another interesting observation in these studies was how K interacts with N and affects the N use efficiency of rice. A comparison of the amount of N required to produce a ton of grain was made between two sites with different levels of available (extractable) soil K. One site had high available K levels (370 µg K g' soil) whereas the other site had a low extractable K level (70 µg K g' soil) and showed a strong yield response to K application. The N requirement was 16 kg ha' when there was not a K limitation but doubled to 31 kg ha^{-1} at the site where K was deficient. The N requirement is defined as the amount of N in kg ha' that has to be available to the crop to produce a ton of grain. The N requirement is determined using the following formula:

Obviously, the rice production system with sufficient soil K was much more efficient in using available N to produce a ton of rice grain compared to the system when K was limited. The interaction between K availability and N requirement is remarkable and requires further attention.

Adequate K levels in the soil have also been shown to reduce the occurrence of diseases. For example, adequate levels of plant available K reduces the occurrence of aggregate sheath spot and rice stem rot diseases. By reducing the occurrence or the severity of diseases, the N requirement will decline and less N has to be available to produce a ton of grain.

Based on the above , the following objectives are formulated:

1. Re-evaluate the effect of K fertilization response of rice yield and its interaction with N.
2. Determine how adequate levels of available K affect the occurrence of rice diseases.
3. Reassess the accuracy of the soil K test on predicting plant available K.

The experimental design will include different levels of K fertilizer application under different levels of N. In response to the mandatory reduction of rice straw burning, new straw management practices are being tested by the rice farmers. Therefore, the K trials for this project will be conducted on sites where straw has been baled for a number of years and compared to sites where straw has been incorporated for a number of years.

The soil test currently used to determine plant available K levels will be re-examined. Soil with different clay and soil organic matter content will be collected from sites across the Sacramento Valley. Rice will be grown under controlled condition and the extractable soil K level correlated with the K content in leaves during the growing period. Different extractants will be used to test for soil available K.

The ultimate goal of the proposed experiment is to readjust K fertilization recommendations once we have determined how K fertilization affects the use of N when rice straw is removed versus incorporated. We believe adequate levels of K are required for optimal N fertilizer use efficiency and that incorporating rice straw will enhance the plant utilization efficiency of both K and N.

EXECUTIVE SUMMARY

A three-year study was carried out in several rice fields throughout the Sacramento Valley of California. The majority of the field research performed for this project was located at Mathews Farms near Marysville, California. Each year, many agronomic aspects of rice production were investigated by comparing the straw management techniques of incorporation and removal in two large 120-plot experiments. The major conclusions resulted from the investigation are:

Straw incorporation:

- recycles in excess of 100 kg K ha -1 to the subsequent crop
- increases the accumulation of total plant N
- does not decrease grain yield
- increases overall soil fertility to overcome a marginal soil K deficiency
- increases straw yield without a corresponding increase in grain yield leading to a reduced harvest index
- lowers the N requirement and therefore fertilizer costs
- very likely decreases the severity of aggregate sheath spot

The 1 molar ammonium acetate extraction method:

- was determined to be an excellent predictor of soil K deficiency, rice grain yield, and aggregate sheath spot severity.

WORK DESCRIPTION

Task 1: Re-evaluate the effect of K fertilization response of rice yield and its interaction with N.

The work for this task was performed at Mathews Farms.

Subtask 1.1:

A field at Mathew's Farm near Marysville, CA that has historically shown a K deficiency from straw removal activities was selected for this portion of the study. The soil at Mathews Farms is classified as a San Joaquin loam (Fine, mixed, Thermic Abruptic Durixeralf) that has been historically K deficient, and an application of 50 to 75 kg K ha' is needed for optimum grain production. The soil contains approximately 20% clay (USDA, 1998). At Mathews Farm, rice straw is typically incorporated in the fall after harvest by chopping followed by disking and usually flooding (Table 1). For this study straw was baled and removed from a 3-ha portion of the experimental field in the fall of 1998, 1999, and 2000. The field is flooded during the summer growing season, drained for harvest, flooded again during the winter for approximately 4 to 5 months, and finally drained for seedbed preparation in the spring (Table 1).

Table 1. Annual field operation schedule at Mathews Farm experimental site.

Season	Straw Incorporated Treatment	Straw Removed Treatment
Fall	Drain, Harvest, Chop, Disc, Flood	Drain, Harvest, Mow, Windrow, Bale, Flood
Winter	Flooding Continued	Flooding Continued
Spring	Drain, Chisel (2x), Disc, Landplane, Fertilize, Corrugated Roll, Flood, Seed (M-202 variety by air)	Drain, Chisel (2x), Disc, Landplane, Fertilize, Corrugated Roll, Flood, Seed (M-202 variety by air)
Summer	Flooding Continued	Flooding Continued

In the first and third years, the field was flooded and seeded several days after fertilization. In the second year of the experiment, flooding and seeding took place 2.5 weeks after the fertilization.

Subtask 1.2:

Two adjacent **sites** were selected, each approximately 3 ha in size. In the fall of 1998, 1999, and 2000 the straw was chopped (approximately 10 cm above the ground) and disked into the soil followed by flooding at one 3 ha experimental site, and was mowed, windrowed, and baled at the other site. Each site had a factorial experiment replicated 4 times and laid out as a split plot design with N as the main plot treatment and K as the subplot treatment. Five rates of N (0, 50, 100, 150, and 200 kg ha 1) as $(NH_4)_2SO_4$ were applied to 3.1 x 7.6 in plots using a fertilizer applicator (Clampco, San Juan Baptista, CA). Six rates of K (0, 25, 50, 75, 100, and 125 kg ha 1) as KCl were broadcast by hand prior to N application to allow for fertilizer incorporation with the Clampco apparatus. Triple superphosphate was also broadcast by hand prior to N application for each experimental plot at the rate of 112 kg ha 1. To avoid compounding years of fertilization rates, the location of the second and third year's factorial experiments was relocated adjacent to the previous year's factorial experiment site inside the large 3 ha experimental site. Due to space limitations on the Mathews site the straw incorporated and straw removed experiments during the third year of the experiment were located approximately 150m apart. During the first two years of the study, the straw removed and straw incorporated experiments were located approximately 20m apart.

The experimental **sites** underwent the field operations as displayed in Table 1.

Harvest Grain and Straw Yield and Nitrogen Content

At crop maturity, the middle of each plot (2.5 in x 7.6 m) was harvested using a small plot combine harvester (SWECO, Sutter, CA) that ground the entire plant, separated the grain and straw, and provided separate whole-plot mass values for the grain and straw. Representative subsamples of the grain (approximately 300 g) and straw (approximately 150 g) were taken and dried to constant mass at 60°C and ground to 0.5 mm using a Wiley Mill. Grain and straw yield, corrected to 14% moisture, were calculated for each treatment.

A field error was detected subsequent to the last day of harvest during the third year of the study. The scale used to determine the straw yield mass had been malfunctioning during the collection of the final three straw removed replicates (90 plots). However, the scale was operating properly during the straw yield harvest of the first straw removed replicate collected on the previous day. Because the grain yield for all straw removed treatments had been collected without error, the harvest index of the first replicate was used to calculate the straw yields for the corresponding treatments of the final three straw removed replicates.

The total N content of the grain and straw was determined by combustion using a Carlo Erba CNS analyzer.

Nitrogen Requirement and Nitrogen Fertilizer Use Efficiency

The N Requirement is defined here as the amount of N (kg ha 1) that has to be available to the crop to produce a ton of grain (Fiez et al., 1995). The method for calculating N requirement and determining grain yield is as follows:

[Nfert + Nseeding + Nmin - Nharvest] I grain yield (ton)

where,
Nfert = the amount of applied fertilizer-N (kg ha-1)
Nseeding = the amount of soil N (NH4 and NO3-) available at the time of seeding (kg ha-1)
Nmin = N made available following net mineralization of the SOM (kg ha 1)
Nharvest = amount of available soil N (NH4+ and NO3-) at the time of harvest (kg ha)

Immediately before seeding and immediately following harvest, representative soil cores (0-15 cm) were taken in all the treatments that were not fertilized with N where 75 kg K ha -1 was applied. These samples were refrigerated and extracted under field moisture conditions with 1 M KCl for available N (NH4+and NO3-) and analyzed on a continuous flow analyzer (Lachet, Coolum Beach, Queensland, Australia) (Sparks, 1996). Subsamples of the field condition soil samples were collected and corrected for moisture content by determining for oven dry weight after a 24-hour incubation at 105°C. Net N mineralization of the SOM was calculated by determining the total plant N uptake in the treatments that were not fertilized with N but received 75 kg K ha t.

The N fertilizer use efficiency, similar to N use efficiency (Sowers et al., 1994; Fiez et al., 1995) was calculated for a given treatment by using the following formula:

[N uptake+N - N$_{\text{min}}$] / Nfert

where,

N uptake+N = kg N in harvest grain and straw that were fertilized with N
Nmin = N made available following net mineralization of the SOM (kg ha 1)
Nfert = the amount of applied fertilizer-N (kg ha 1)

Statistical Analysis

The statistical analyses were conducted using PROC GLM analysis on SAS (Version 7) software (SAS, 1989). The replicate means of the dependent variables (i.e. midseason N and K content, grain and straw yield, harvest index, harvest grain and straw content, N Requirement, and N fertilizer use efficiency) were modeled against the class variables of the N and K application rates to test for significant differences in the responses of these dependent variables to fertilization. Comparisons for the dependent variables listed above were determined where straw was removed or incorporated separately for each year, as the subplot treatments of straw removal and incorporation were not randomized.

Subtask 1.3:

Midseason Plant Nitrogen and Potassium Contents

Each year, during the panicle initiation growth stage, 40 most recently developed leaf samples were taken from each treatment from both experiments. These samples were taken from all sides of a given treatment to be representative without damaging the stand growth. Samples were dried to constant mass at 60°C and ground to 0.5 mm using a Wiley Mill. The midseason plant N content was determined by dry combustion using a Carlo Erba CNS analyzer. The midseason plant K content was determined by extraction with 2% acetic acid followed by analysis using ICP (Miller, 1998).

Task 2: Determine how adequate levels of available K affect the occurrence of rice diseases.

This **portion** of the **project was also carried out at Mathew's Farm near** Marysville, CA.

Subtask 2.1:

The N (5 rates) by K (6 rates) factorial design and management practices are previously described in detail. Each year, a total of 36 3.1 x 7.6 in plots were used where straw was removed or soil incorporated. Plots fertilized with 0, 100, and 200 kg N ha' were sampled for aggregate sheath spot (AgSS) and rice stem rot.

For each growing season, three weeks before harvest 40 representative whole **stems** from each experimental treatment were rated for AgSS. Each plant was rated according to the following **scale** (for AgSS): 0 = no presence of AgSS; 0<1 = AgSS lesions below the third healthy leaf (counting from the top of the plant); 1 = three healthy leaves on stem, lesions below the third leaf; 2 = two healthy leaves on stem, **lesions** below the second leaf; 3 = one healthy leaf on stem, **lesions** below the first leaf (flag leaf); 4 = all leaves dead. Decimals (0.1 to 0.9 added on to each integer rating) were equal to the portion of stem circumference affected by uppermost **lesions** located on stem between leaves. For example, one healthy leaf with the uppermost AgSS lesion encircling half of the stem's circumference below this first leaf (flag leaf) would receive a rating of 2.5. All ratings were performed in the field immediately after sampling. The experimental treatments were also analyzed for the presence of rice stem rot during all years of the experiment.

Statistical Analysis

Statistical analysis was performed using the PROC GLM procedure in SAS (SAS Inst., 1989). The AgSS severity rating (dependent variable) was analyzed against N application, K application, and N by K application interactions (independent variables) separately in the experiment where straw was incorporated or removed. The straw incorporated and straw removed experimental results could not be compared statistically as the straw management treatments are not randomized within the factorial design of the N and K application rates.

Task 3: Reassess the accuracy of the soil K test on predicting plant available K.

Subtask 3.1:

Five rice growing locations representing four different **soil series** were used for this portion of the experiment. Two separate three-year experiments, which constituted the bulk of the research for this project, were located at Mathews Farms near Marysville, CA. Two separate one-year experiments were located at Josiassen Farms located near Oroville, CA. Lastly, two one-year experiments were located at McPherrin Farms and two different fields of LaMalfa Farms also located near Oroville, CA. The soil series for each of the locations are listed in Table 2.

Table 2. Description of the soil series for the initial Task 3 experimental locations.

Location	Soil Series
Mathews	San Joaquin loam (Fine, mixed, Thermic Abruptic Durixeralf)
Josiassen	Neerdobe clay (Fine, mixed, superactive, thermic Xeric Duraquert)
LaMalfa #5	Neerdobe clay (Fine, mixed, superactive, thermic Xeric Duraquert)
Lamalfa # 13	Rocklin fine sandy loam (Fine-loamy, mixed, thermic, Typic Durixeralf)
McPherrin	Stockton clay (Fine, smectitic, thermic Xeric Epiaquerts)

Subtask 3.2:

During the initial year of the study, 15 random **soil samples** (approximately 150 g) were collected before fertilization from each experimental site listed in Table 2. Soils were air-dried and extracted for exchangeable K using 0.25, 0.50, 0.75, and 1 M NH_4OAc, 0.1 M H_2SO_4, and 1.0 M HNO_3 and analyzed with ICP technology (Sparks, 1996).

Pursuant to a work change described in a previous report, only the Mathews and Josiassen sites were utilized during the second year of the experiment. The soil samples at Mathews Farm were collected in the same manner as the previous year. At Josiassen Farms, 100 soil samples were collected randomly from two **separate** transects (50 samples per transect). Samples from both sites were analyzed for exchangeable K using only the 1.0 M NH_4OAc method and coupled with ICP technology. However, the Josiassen samples were also analyzed for exchangeable Ca, Mg, and Na using the 1.0 M NH_4OAc extraction method and ICP technology. The experimental site at Mathews Farms was the only location utilized during the final year of the study. The analysis for exchangeable K was performed in the **same manner** as the second year.

Subtask 3.3:

Each year, 20 (except for Mathews Farms as described in Subtask 1.3) most recently developed leaf samples were collected at each pre-fertilization soil sample site during the panicle initiation growth stage. Samples were dried to constant mass at 60°C and ground to 0.5 mm using a Wiley Mill. The midseason plant N content was determined by dry combustion using a Carlo Erba CNS analyzer. The midseason plant K content was determined by extraction with 2% acetic acid followed by analysis using ICP technology (Miller, 1998).

Subtask 3.4:

Grain yield at all experimental sites during each year of the study was determined as described in Subtask 1.2.

Statistical Analysis

Correlations between pre-fertilization available soil K, available soil K content, midseason plant K content, and grain yield were carried out using Microsoft Excel software (Microsoft, Redmond, WA).

RESULTS

Task 1

Midseason N and K

During all three growing seasons, the application of N significantly (P<0.0001) increased the midseason plant N content (Fig. 1). The midseason plant N content as affected by N application was the highest during the first year of the experiment, ranging from 2.27% with no N applied and approximately 4.10% with 200 kg N ha' applied with no discernable difference arising from straw management (Fig. 1-A). The midseason plant N content as affected by N application was the lowest during the second year ranging from 1.77% with no N applied to 2.69% with 200 kg N ha' with straw incorporation, and rising to 1.96% with no N applied to 2.95% with 200 kg N ha' under straw removal (Fig. 1-B). During the second year, the midseason plant N content under straw removal was consistently higher than the midseason plant N content with straw incorporation for all levels of N application.

The application of K had no effect on the midseason plant N content throughout the experiment (Fig. 2). However, during the second year the midseason plant N content under straw removal was approximately 0.25% higher than the midseason plant N content under straw incorporation for all rates of K application while no corresponding differences were found during the first year (Fig. 2-B). During the third year the midseason plant N content under straw incorporation was approximately 0.25% higher than the midseason plant N content under straw removal for all rates of K application (Fig. 2-C).

During all three years of the experiment, the application of N significantly (P=0.05 to P<0.0001) decreased the midseason plant K content (Fig. 3). The midseason plant K content as affected by N application was higher under straw incorporation when compared to straw removal under all levels of N application during the first two years. However, in the third year of the study, the midseason plant K content was slightly higher under straw removal when compared to straw incorporation. During the first year of the experiment midseason plant K content decreased from 1.37% with no N applied to 1.12% with 200 kg N ha' applied under straw removal, and from 1.62% with no N applied to 1.47% with 200 kg N ha' with the incorporation of straw (Fig. 3-A). The midseason plant K content as affected by N application was lower during the second year ranging from 1.24% with no N applied to 0.81 % with 200 kg N ha"' under straw removal, and rising to 1.36% with no N applied to 1.06% with 200 kg N ha' under straw incorporation (Fig. 3-B). In the final year the midseason plant K content decreased from 1.85% with no N applied to 1.34% with 200 kg N ha"' when straw was removed and from 1.72% with no N applied to 1.27% with the application of 200 kg N ha' when straw was incorporated (Fig. 3-C).

The application of K significantly (P=0.007 to P<0.0001) increased the midseason plant K content during all years of the experiment (Fig. 4). Also, straw incorporation increased the midseason plant K content when compared to straw removal under all rates of K application during the first two years of the experiment. However, this difference in midseason plant K content due to straw incorporation decreased in the second year when compared to the first year. During the first year, the midseason plant K content increased from 1.42% with no K applied to 1.65% with 125 kg K ha -1 applied under straw incorporation, and from 1.08% with no K applied to 1.38% with 125 kg K ha-1 applied under straw removal (Fig. 4-A). During the second year, the midseason plant K content increased from 1.15% with no K applied to 1.36% with the application of 125 kg K ha -1 under straw incorporation, and from 0.91 % with no K applied to 1.21 % with 125 kg K ha -1 applied under straw removal (Fig. 4-B). During the third year similar increases were observed with increasing rates of K, however, the midseason plant K content was slightly higher under straw removal when compared to straw incorporation (Fig. 4-C).

Grain and Straw Yield

The application of N significantly (P<0.0001) increased **grain** yield throughout the duration of the experiment (Fig. 5). There was no difference **in grain** yield with N application due to straw management practices in any year except where no N was applied (zero N). In the first year zero N treatments, the grain yield was 7,128 kg ha' when straw was incorporated and 6,745 kg ha -1 when straw was removed (Fig. 5-A). During the first year, grain yield increased to approximately 10,000 kg ha i with 100 kg N ha' applied and no further increase was observed through the 2 highest N rates regardless of straw management (Fig. 5-A). The grain yields in the zero N treatments during the second year were 5,607 kg ha -1 and 5,295 kg ha -1 under straw incorporation and straw removal, respectively (Fig. 5-B). However, during the second year, the grain yields increased steadily through all N rates to approximately 8,200 kg ha -1 at 200 kg N ha -1 under straw incorporation and straw removal (Fig. 5-B). The slope remained positive through all rates of N indicating potential **grain** yield response with addition N application. In the third year zero N treatments, the grain yield was 6,248 kg ha -1 when straw was incorporated and 5,735 kg ha' when straw was removed (Fig. 5-C). During the third year, grain yield increased to 8,716 kg ha -1 with 100 kg N ha -1 applied and no further **increase** was observed through the 2 highest N rates when straw was incorporated (Fig. 5-C). However, under straw removal grain yield showed an **increasing** trend through all rates of N as well as a higher overall grain yield when compared to straw incorporation (Fig. 5-C). The highest grain yield during the first year was 10,257 kg ha -1 with the application of 150 kg N ha' under straw removal (Fig. 5-A). The highest **grain** yield during the second year was considerably lower at 8,247 kg ha' with 200 kg N ha' applied under straw incorporation (Fig. 5-B). During the final year of the experiment, the highest grain yield was 9,217 kg ha' when straw was removed and 200 kg N ha' was applied (Fig. 5-C).

There was no observed grain yield response to the application of K when straw was incorporated in the first two years of the experiment (Fig. 6). However, in the third year of the experiment, there was a significant (P=0.0009) **increase** in grain yield with the application of K when straw was incorporated (Fig. 6-C). With the removal of straw, a significant grain yield response to K application during year 1 (P=0.013), year 2 (P=0.0008), and year 3 (P=0.0053) of the experiment was observed (Fig. 6). During the first year of the experiment, grain yield remained near 9,200 kg ha' through all rates of K application in the straw incorporated sites and with straw removal increased from 8,858 kg ha' with no K applied **rising** to 9,401 kg ha' with 75 kg K ha', slightly decreasing thereafter at the highest K rates (Fig. 6-A). In the second year of the experiment grain yield following straw incorporation remained around 7,000 to 7,200 kg ha' while grain yield under straw removal increased from 6685 kg K ha-1 with no K applied to 7298 kg ha -1 with 125 kg K ha -1 applied (Fig. 6-B). In the final year of the experiment grain yield increased from 7,862 kg ha -1 with no K applied to 8,448 kg ha -1 with the application of 125 kg K ha -1 when straw was incorporated and from 7,768 kg ha -1 with no K applied to 8,268 kg ha -1 with the application of 125 kg K ha -1 when straw was removed (Fig. 6-C).

The application of N significantly ($P<0.0001$) increased straw yield during all years under both straw management practices (Fig. 7). During all years straw yield was higher under all rates of N application when straw was incorporated compared to straw removal, except when 50 kg N ha -1 was applied in the second year where straw yield was identical for both straw management practices (Fig. 7-B). However, the effect of straw management on straw yield was more pronounced during the first and third years than in the second year. Straw incorporation during the first year of the experiment produced a straw yield of 5981 kg ha -1 with no N applied, rose sharply to 11,441 kg ha-1 with 150 kg N ha 1, and decreased to 10,932 kg ha-1 with 200 kg N ha -1 (Fig. 7-A). When straw was removed during the first year, the straw yield was 4,993 kg ha -1 in the zero N treatments (almost 1,000 kg ha -1 lower than the straw yield of the straw incorporated treatments) and increased to approximately 10,600 kg ha -1 where it leveled off between the 150 and 200 kg N ha -1 application rates (Fig. 7-A).

In the second year straw yield increased sharply from 4,709 kg ha -1 in the zero N treatments to 9,957 kg ha-1 where 200 kg N ha -1 was applied when straw was incorporated (Fig. 7-B). This positive and significant trend in the straw yield of the second year of straw incorporation indicates a further increase in straw yield with N application exceeding 200 kg N ha -1 (Fig. 7-B). Under straw removal during the second year straw yield increased from 4,179 kg ha -1 with 0 kg N ha-1 added to approximately 9,900 kg ha -1 where it leveled off between 150 and 200 kg N ha -1 added (Fig. 7-B). There was no difference between straw management practices during the third year when no N was applied (Fig. 7-C). There was also no observed increase in straw yield with N application above the rate of 100 kg ha 1 during the third year regardless of the straw management practice utilized (Fig. 7-C). Overall, in the third year straw yield increased from 7,528 kg ha-1 with no N added to 11,574 kg ha-1 with the application of 200 kg ha -1 when straw was incorporated and from 7,562 kg ha 1 with no N added to 10,453 kg ha -1 with the application of 200 kg ha 1 under straw removal.

Straw yield was not significantly affected by K application in the first and third years of the experiment (Figs . 8). The straw yield under straw incorporation was approximately 1,000 kg ha" higher than the straw yield when straw was removed for all rates of K addition during the first and third years of the experiment (Fig. 8). During the first year, straw yield steadily rose from 9,232 kg ha -1 when no K was added to 9,708 kg ha -1 when 125 kg K ha -1 was added when straw was incorporated (Fig. 8-A). Also in the first year, straw yield increased from 8,189 kg ha 1 with no K added to 8,817 kg ha -1 when 125 kg K ha -1 was added when straw was removed. During the third year of the experiment straw yield remained constant through all rates of K application at approximately 10,500 kg ha' when straw was incorporated and 9,500 kg ha -1 when straw was removed (Fig 8-C).

As in the first and third years of the experiment, straw yield in the second year under straw incorporation was considerably higher than straw yield under straw removal following K addition. However, the difference between straw yield due to straw management practices was not as apparent (Fig. 8-B). Straw yield in the incorporated plots consistently increased from 7,295 kg ha' with no K addition to 8,183 kg ha' with the addition of 125 kg K ha' during the second year, but this rise was not significant (Fig 8-A). In contrast to when straw was removed in the first year, there was a significant (P=0.0097) increase in straw yield due to K addition in the second year as straw yield rose from 6,752 kg ha' with the addition of 0 kg K ha' to 7,700 kg ha' when 125 kg K ha' was added (Fig. 8-B).

Harvest Index

Harvest index is defined as the grain weight divided by the total plant weight multiplied by 100 (in kg ha' corrected to 14% H2O). Harvest index was higher under straw removal than straw incorporation for all values of N and K application, except for 50 kg ha' in the second year (Figs. 5-10). The higher harvest index under straw removal can be attributed to straw management practices not affecting grain yield while straw yield increased with straw incorporation when compared to straw removal during both years of the experiment (Figs. 5-10).

The application of N significantly (P<0.0001) decreased the harvest index during the first two years of the experiment when straw was incorporated and removed. In the first year, the harvest index decreased from 57.9% in the zero N treatments to 48.7% with the application of 200 kg N ha"' under straw removal (Fig. 9-A). Also in the first year, the harvest index decreased from 54.4% in the zero N treatments to 47.8% following the application of 200 kg N ha' when straw was incorporated (Fig. 9-A). During the second year, the harvest index decreased from 55.9% in the zero N treatments to 46.0% following the application of 150 kg N ha' and then rose to 48.3% when 200 kg N ha' was applied and the straw removed (Fig. 9-B). A similar trend was found during the second year when straw was incorporated as the harvest index decreased from 54.4% in the zero N treatments to 44.8% with the application of 150 kg N ha', increasing to 48.3% when 200 kg N ha-' was applied (Fig. 9-B). No consistent trend with N application was observed in the harvest index for either straw treatment in the third year of the experiment (Fig. 9-C). However, the harvest index was approximately 3% higher under straw removal when compared to straw incorporation for all N application rates except for the zero N treatments (Fig 9-C).

The application of K did not significantly affect the harvest index during the first two years of the experiment (Fig. 10). During the first year, the harvest index was approximately 52% for all rates of K in the straw removed experiment and 50% for all rates of K when straw was incorporated (Fig. 10-A). During the second year, the harvest index was approximately 50% for all rates of K in the straw removed experiment and slightly but consistently decreased from 49.7% with no K applied to 47.9% with the application of 125 kg K ha' under straw incorporation (Fig 10-B). The application of K also did not significantly affect the harvest index when straw was removed during the third year (Fig. 10-C). However, there was a significant increase (P=0.0482) in harvest index from approximately 43.5% for the lowest four K rates to 45.3% with the application of 125 kg ha"' when straw was incorporated during the third year of the experiment (Fig. 10-C).

Harvest Grain and Straw N Content

When compared to straw incorporation, straw removal led to an increase in the harvest grain N content for all rates of N and K application during the first two years of the experiment (except for the addition of 50 kg N ha -1 in the second year) (Figs. 11 and 12). However, the incorporation of straw led to a higher harvest grain N content for all rates of N and K (except 100 kg K ha') in the third year of the experiment (Figs. 11-C and 12-C). The application of N resulted in a significant (P=0.03 to P<0.0001) increase in harvest grain N content during all years of the experiment under both straw management practices (Fig. 11).

During the first year, the harvest grain N content increased from 1.06% when no N was applied to 1.40% with the addition of 200 kg N ha' when straw was removed and increased from 1.12% when no N fertilizer was applied to 1.48% with the addition of 200 kg N ha' when straw was incorporated (Fig. 11-A). In the second year, the harvest grain N content decreased from 1.44% in the zero N treatments to 1.24% when 50 kg N ha' was applied and then steadily increased to 1.65% when 200 kg N ha' was applied in the straw removed plots (Fig. 11-B). The harvest grain N content in the second year when straw was incorporated increased from 1.13% when no N fertilizer was applied to 1.40% when 200 kg N ha' was applied. The harvest grain N content was considerably higher in the three highest N rates of the second year's experiment compared to the first year when straw was removed with no corresponding results found in the straw incorporated experiment (Fig. 11). During the third year, the harvest grain N content increased from 0.93% when no N was applied to 1.5 1% with the addition of 200 kg N ha' when straw was incorporated and increased from 0.90% when no N fertilizer was applied to 1.44% with the addition of 200 kg N ha' when straw was removed (Fig. 11-C).

Throughout the experiment, K application did not significantly affect the harvest grain N content whether straw was incorporated or removed (Fig. 12). In the first year under straw removal, the harvest grain N content slightly but inconsistently increased from 1.23% when no K was applied to 1.30% with the application of 125 kg K ha-1 and remained near 1.20% for all rates of K application when straw was incorporated (Fig. 12-A). In the second year, the harvest grain N content values when straw was removed were sporadic, ranging from 1.35% to 1.50% with no clear trend corresponding to the rate of K application (Fig. 12-B). In the second year, the harvest grain N content values when straw was incorporated ranged from 1.25% to 1.30% for all rates of K application. Interestingly, the harvest grain N content was higher for all rates of K application and straw management practices in the second year of the experiment when compared to the first year (Fig. 12). In the third year, the harvest grain N content slightly but inconsistently decreased from 1.14% when no K was applied to 1.10% with the application of 125 kg K ha' under straw removal and from 1.23% when no K was applied to 1.17% with the application of 125 kg K ha' (Fig. 12-C).

The application of N fertilizer significantly (P<0.0001) affected the harvest straw N content during all three years when straw was incorporated or removed (Fig. 13). During the first year, the harvest straw N content was similar for all N rates for both straw management practices, except for the application rate of 200 kg N ha', where the harvest straw N content was higher where straw was removed (0.94%) compared to straw incorporation (0.89%) (Fig. 13-A). In this first year, the harvest straw N content rose from approximately 0.60% where no N fertilizer was applied to 0.83% with the application of 150 kg N ha' when straw was incorporated and removed (Fig. 13-A).

In the second year, the harvest straw N content increased from 0.51 % without N application to 0.74% with the application of 200 kg N ha -1 when straw was removed (Fig. 13-B). In the second year when straw was incorporated, the harvest straw N content decreased from 0.55% without N application to 0.50% when 50 kg N ha' was applied and then steadily increased to 0.69% when 200 kg N ha -1 was applied (Fig. 13-B). In the first two years, the harvest straw N content was higher with the highest N rates under straw removal compared to the straw incorporation. Also, the harvest straw N content was considerably lower for all straw management practices and rates of N application in the second year compared to the first year (Fig. 13).

During the third year, the harvest straw N content was higher under straw incorporation for all N rates except for the application rate of 200 kg N ha', where the harvest straw N content was 0.45% when straw was removed and incorporated (Fig.13-A). In the third year, the harvest straw N content rose from approximately 0.45% where no N fertilizer was applied to 0.88% with the application of 200 kg N ha' when straw was incorporated and from 0.42% when no N was added to 0.77% when 200 kg N ha"' was applied under straw removal (Fig. 13-C).

The application of K had no significant effect on the harvest straw N content during the first year whether straw was incorporated or removed (Fig. 14). The harvest straw N content varied between 0.70% and 0.73% for all rates of K application in the first year's straw incorporated experiment with no apparent trend (Fig. 14-A). The harvest straw N content decreased slightly from 0.73% with no K applied to 0.71% with 125 kg K ha' added in the first year's straw removed experiment (Fig. 14-A).

In the second year, the harvest straw N content significantly (P<0.0001) decreased when straw was removed with no corresponding decrease or significance when straw was incorporated with K application (Fig. 14-B). When straw was removed, the harvest straw N content steadily decreased from 0.64% when no K was applied to 0.55% when 125 kg K ha' was added in the second year (Fig. 14-B). When straw was incorporated, the harvest straw N content varied erratically from 0.55% to 0.58% with the various levels of K application (Fig. 14-B). Overall, the harvest straw N content was considerably lower in the second year compared to the first year whether straw was incorporated or removed (Fig. 14). In the third year, the harvest straw N content decreased slightly and inconsistently from 0.63% to 0.59% when straw was incorporated (Fig. 14-C). When straw was removed in the third year there were significant (P=0.0342) differences between the K application rates but no consistent trend was observed (Fig. 14-C).

N Requirement

The N requirement [defined previously], significantly (P<0.0001) increased for all rates of N application and straw management practices for both years (Fig. 15). In the first year, the N requirement when straw was removed was slightly higher at the 50, 100, and 150 kg N ha' rates (19.3, 22.6, and 26.5 kg N ton' grain, respectively), compared to when straw was incorporated at the same rates (18.6, 21.9, and 26.2 kg N ton"' grain, respectively) (Fig. 15-A). However, the N requirement at the 200 kg N ha' application rate was similar during the first year whether straw was incorporated or removed (Fig. 15-A).

A different scenario was observed during the second year as the N requirements for all rates of N application when straw was removed were higher than when straw was incorporated (Fig. 15-B). In this second year, the N requirements rose from 25.9 kg N ton -1 grain with no N added to 38.6 kg N ton-1 grain when 200 kg N ha -1 was added when straw was removed and increased from 23.8 kg N ton -1 grain with no N added to 36.5 kg N ton"' grain when 200 kg N ha-1 was applied when straw was incorporated (Fig. 15-B). Overall, the N requirements when straw was incorporated or removed were considerably higher in the second year compared to the first year for all rates of N application (Fig. 15). The N Requirement significantly (P<0.0001) increased from approximately 16 kg N ton-1 grain to 36 kg N ton-' grain for all rates of N application under both straw management practices in the third year of the experiment (Fig. 15-C).

The application of K significantly decreased the N requirements when straw was removed in the first (P=0.014) and second (P=0.0005) years with no corresponding significance when straw was removed in the third year (Fig. 16). The application of K did not affect the N requirement when straw was removed in any year of the experiment (Fig. 16). During the first year, the N requirements when straw was removed and K was applied at 0, 25, and 50 kg K ha -1 (26.0, 25.3, and 25.3 kg N ton-' grain, respectively) were slightly higher than the N requirements (25.0, 24.5, and 24.5 kg N ton-' grain, respectively) of the corresponding rates under straw incorporation (Fig. 16-A). However, the N requirements when straw was incorporated and removed were similar (24.5 kg N ton -1 grain) when 75, 100, and 125 kg K ha -1 were applied (Fig. 16-A).

During the second year, the N requirements for all rates of K application were considerably higher when straw was removed compared to straw incorporation (Fig. 16-B). The N requirement significantly (P=0.0005) decreased with increasing K application from 33.8 kg N ton -1 grain with no K applied to 30.8 kg N ton -1 grain when 125 kg K ha-1 was applied in the second year's straw removed experiment (Fig. 16-B). In contrast to the sporadic data from the first year when straw was incorporated, in the second year under straw incorporation, the N requirement slightly decreased with increasing K application from 30.7 kg N ton-' grain with no K applied to 29.5 kg N ton -1 grain when 125 kg K ha -1 (Fig. 16-B). The N requirement was considerably higher in the second year when straw was incorporated and removed for all rates of K application when compared to the corresponding treatments of the first year (Fig. 16). During the third year of the experiment the N requirement remained near 26 kg N ton -1 grain for all rates of K application under both straw management practices (Fig. 16-C).

Nitrogen Fertilizer Use Efficiency

The application of N fertilizer did not affect the N fertilizer use efficiency during the first year of the study whether straw was removed or incorporated (Fig. 17-A). A significant (P=0.06) increase in N fertilizer use efficiency with N application was observed when straw was removed in the second year of the study and with the incorporation of straw in the third year of the study (Fig. 17). There was no significant affect on N fertilizer use efficiency resulting from the application of K fertilizer during any year of the study (Fig. 18). The average N fertilizer use efficiency value across all rates of N and K application when straw was incorporated and removed for the first and third years was approximately 70% while the N fertilizer use efficiency average in the second year was considerably lower at approximately 45% (Figs. 17 and 18).

Task 2

Aggregate Sheath Spot and Nitrogen

During all growing seasons, all rates of N application for both straw incorporation and straw removal significantly decreased the severity of AgSS (Fig. 21). During the initial year of the study AgSS was rated at approximately 3.3 at 0 kg ha' of applied N and significantly decreased (P<0.0001) to approximately 2.9 with the application of 200 kg N ha' for both straw incorporated and straw removed treatments.

During the second year of the study AgSS severity was rated at 2.82 at 0 kg ha' of applied N and significantly decreased (P=0.0025) to 2.43 with the application of 200 kg N ha' under straw removal (Fig 19). With straw incorporation, the second year's AgSS severity ratings were 2.57 at 0 kg ha' of applied N significantly decreasing (P<0.0001) to 1.97 with the application of 200 kg N ha'. As with applied K, the AgSS severity rating was higher under straw removal when compared to straw incorporation for all rates of applied N in the second year of the experiment.

During the third year of the study AgSS severity was rated at 2.84 at 0 kg ha' of applied N and significantly decreased (P<0.0001) to 2.43 with the application of 200 kg N ha' under straw removal. With straw incorporation, the third year's AgSS severity ratings were 3.11 at 0 kg ha' of applied N significantly decreasing (P<0.0001) to 2.41 with the application of 200 kg N ha'.

Aggregate Sheath Spot, Straw Management, and K

The application of K had no significant effect on the severity of AgSS in the first two years of the experiment despite the presence of a K deficiency (Figs. 6 and 20). There was a significant (P=0.0012 and P=0.0009) decrease in the severity AgSS during the third year of the study with the application of K when straw was incorporated as well as removed (Fig. 20).

During the first and third years of the study, it appears straw management had no effect on the severity of AgSS as both the straw incorporated and straw removed treatments had an AgSS rating of approximately 3 at all rates of applied K (Fig. 20). However, straw incorporation substantially decreased the severity of AgSS when compared to straw removal in the second year of the experiment at all rates of applied K. In the second year of the study the average AgSS severity rating under straw removal was 2.60 compared to 2.25 for the straw incorporated treatments. Compared to the first year, the overall severity of AgSS decreased in the second year (Fig. 20). In the third year, the severity of AgSS decreased from a rating of 2.94 with no K added to 2.48 with an application of 125 kg K ha' when straw was removed and 2.76 with no K added to 2.42 with an application of 125 kg K ha' when straw was incorporated (Fig. 20-C).

Rice Stem Rot

No evidence of Rice Stem Rot was found on any of the treatments analyzed in the **study.**

Task 3

As displayed in Tables 3 and 4, the pre-fertilization available soil K was well above the recommended 60 µg K g-1 soil for the McPherrin, LaMalfa (both sites), and Josiassen (both years). As a result, there was no relationship between pre-fertilization available soil K, midseason plant K, and grain yield for these experimental sites (R2<0.05 for all comparisons). Therefore the objectives for this task were completed using the data collected from the Mathews Farms experimental site.

Pre-fertilization Available Soil K Concentration

The pre-fertilization available soil K concentration, as determined by the 1 M neutral NH4OAC extraction method, decreased over time and varied under the different straw management practices. The highest pre-fertilization available soil K concentration was found after the first year of straw incorporation at 97.8 µg K g' soil with the first year of straw removal treatment yielding a pre-fertilization available soil K concentration of 67.2 µg K g' (Table 5). Following 2 seasons of straw incorporation, the pre-fertilization available soil K concentration was 55.1 µg K g' (Table 5). The lowest pre-fertilization available soil K concentration was determined following two years of straw removal at 41.4 µg K g-1 (Table 5). Following 3 seasons of straw incorporation, the pre-fertilization available soil K concentration was 50.0 µg K g-1 (Table 5). The lowest pre-fertilization available soil K concentration was determined following two years of straw removal at 38.6 µg K g' (Table 5).

Available Soil K, Midseason Plant K Content, and Grain Yield

Available soil K content was determined by adding the amount of K applied (in µg K g' soil) for each level of K application to the pre-fertilization available soil K content. The midseason plant K content data utilized in this section are reported in Figure 4. The grain yield data utilized in this section are reported in Figure 6.

Throughout the study, as pre-fertilization available soil K content decreased, the R2 value between midseason plant K content and grain yield increased (Table 5; Fig. 19). The study's highest pre-fertilization available soil K content value (97.8 µg K g' soil) in the first year's incorporated experiment had the study's lowest R2 value (0.46) between the midseason plant K content and grain yield data of the same experiment (Table 5). The study's second lowest pre-fertilization available soil K content (41.4 µg K g' soil) in the second year's removed experiment had the study's highest R2 value (0.99) between the midseason plant K content and grain yield data of the same experiment (Table 5).

5B-1 NE
5B-2 SW
5B-3 NW
5B-4 SE

0.75M NH_4OAc

Table 4. The interrelationship between pre -fertilization available soil K, midseason plant K, and grain yield at Josiassen Farms, CA.

Sample	Pre-fertilization Available soil K (ug K g-1 soil)	Midseason Plant K (%)	Grain Yield (kg ha)	Sample	Pre-fertilization Available soil K (ug K g-1 soil)	Midseason Plant K (%)	Grain Yield (kg ha)
1	209.8	1.50	3880	51	205.3	1.53	3060
2	162.3	1.49	4680	52	151.7	1.97	3620
3	147.2	1.45	2960	53	184.7	1.78	2900
4	139.7	1.30	3520	54	138.4	1.93	2820
5	123.9	1.48	2800	55	156.2	1.96	2100
6	141.6	1.34	3020	56	160.4	1.82	2740
7	143.7	1.23	2560	57	134.0	2.36	2040
8	130.0	1.49	2660	58	152.7	1.72	2480
9	133.2	1.33	2060	59	136.3	1.97	1800
10	133.1	1.44	2400	60	147.0	2.46	2220
11	145.8	1.50	2900	61	142.1	1.96	2720
12	138.8	1.52	2220	62	133.9	1.85	2220
13	156.6	1.28	2760	63	136.7	1.53	2760
14	144.4	1.44	2320	64	162.1	1.51	2560
15	161.3	1.52	2980	65	184.1	1.65	2540
16	150.6	1.45	2960	66	115.0	1.73	2660
17	122.1	1.45	2920	67	109.7	1.84	2080
18	126.2	1.58	2660	68	99.6	1.74	2880
19	133.8	1.59	2160	69	136.8	1.51	2500
20	132.8	1.53	2320	70	100.1	1.50	2180
21	135.2	1.44	2720	71	137.0	1.74	2420
22	109.6	1.63	3160	72	109.6	1.60	3640
23	133.2	1.58	2440	73	95.1	1.49	2920
24	147.4	1.91	1760	74	120.7	1.52	1840
25	142.0	1.64	2620	75	115.7	1.62	3420
26	132.2	1.43	2880	76	92.7	1.60	3400
27	104.9	1.46	3160	77	115.0	1.60	3240
28	118.3	1.57	2440	78	138.3	1.67	2820
29	145.2	1.41	2420	79	133.4	1.66	3580
30	109.5	1.57	2300	80	115.6	1.60	3980
31	130.2	1.44	3320	81	139.3	1.53	4040
32	148.4	1.60	2180	82	126.8	1.51	2720
33	129.9	1.65	2420	83	123.4	1.76	2640
34	122.5	1.36	2300	84	109.0	1.75	2300
35	125.9	1.48	2360	85	107.0	1.89	1800
36	109.3	1.59	1920	86	107.0	1.81	1340
37	113.0	1.50	1940	87	99.7	1.97	1480
38	108.9	1.61	1940	88	123.7	1.99	1780
39	145.2	1.68	2220	89	97.0	1.61	1600
40	146.3	1.58	2480	90	114.6	1.86	2300
41	137.8	1.55	2780	91	112.1	1.87	1760
42	97.2	1.71	1960	92	96.8	1.72	1800
43	123.1	1.75	1260	93	101.4	1.69	2960
44	146.3	1.63	2440	94	162.7	1.67	3700
45	131.1	1.75	2760	95	142.1	1.48	3460
46	127.9	1.75	2520	96	133.8	1.86	2420
47	135.3	1.59	2900	97	132.7	1.73	4020
48	140.6	1.60	4040	98	137.7	1.61	4840
49	100.5	1.65	6160	99	153.5	1.51	6100
50	142.4	1.50	6760	100	165.0	1.42	5380

Table 5. Interrelationships between pre-fertilization available soil K content, available soil K content, midseason plant K content, and grain yield under different straw management practices at Mathew's Farms.

Year	Straw Management Practice	Pre-fertilization available soil K content (μg K g' soil)	R2 Value for: Midseason plant K content (%) and grain yield (kg ha')	R2 Value for: Available soil K content (kg K g' soil) and grain yield (kg ha')
1	Incorporated	97.8	0.39	0.44
1	Removed	67.2	0.74	0.87
2	Incorporated	55.1	0.87	0.96
2	Removed	41.4	0.99	0.96
3	Incorporated	50.0	0.62	0.84
3	Removed	38.6	0.86	0.93

Data from both years also exhibited an indirectly proportional trend between pre-fertilization available soil K content and the R2 value between available soil K content and grain yield (Table 5; Fig. 19). The highest pre-fertilization available soil K content value (97.8 μg K g' soil) in the first year when straw was incorporated had the lowest R2 value (0.44) between the available soil K content and grain yield data of the same experiment (Table 5; Fig. 19). The second lowest pre-fertilization available soil K content (41.4 μg K g' soil) in the second year when straw was removed had the study's highest R2 value (0.96) between the available soil K content and grain yield data of the same experiment. However, there was little difference the R2 value (0.96) of the second year when straw was incorporated for the same parameters (Table 5).

All data discussed in this section are summarized in Tables A-1 through A-6 at the end of this report.

DISCUSSION

Pre-fertilization Available Soil K **Concentration**

The pre-fertilization available soil K concentration was approximately 45%, 33%, and 30% higher after each year of straw incorporation, respectively, when compared to straw removal (Table 5, Fig. 21). The increase of available soil K upon the incorporation of crop residue is well established (Hoagland and Martin, 1950; Karanthansis and Wells, 1990; Prasad et al., 1999). However, in a recent study, a decrease in the pre-fertilization available soil K concentration was observed in the second year whether straw was incorporated or removed, which likely indicates substantial K removal with the harvesting of the rice grain. This decrease in the pre-fertilization available soil K content was also observed in this study under both straw management practices and could also be due to spatial variability resulting from relocating the two experiments to different sites between each year of the study. It has been reported that rice can be considered K deficient when available soil K concentrations drop below 60 μg K g-1 soil (De Datta and Mikkelson, 1985). Using this standard, straw incorporation alone cannot recycle enough K to keep the available soil K concentration above deficient levels because the pre-fertilization available soil K concentration after two years of incorporation was below 60 μg K g 1 soil. Nonetheless, the release of K during rice straw decomposition returned large amounts of K to the soil and was utilized by the subsequent crop. Approximately 138 kg K ha -1 was recycled with the incorporation of straw at approximately 9,200 kg ha-1 (average straw yield across all N rates) following the first year, assuming the straw contained 1.5% K (Fig. 8-A). Approximately 112 kg K ha-1 was recycled with the incorporation of straw at approximately 7,500 kg ha -1 (average straw yield across all N rates) following the second year, assuming the straw contained 1.5% K (Fig. 8-B). Approximately 159 kg K ha 1 was recycled with the incorporation of straw at approximately 10,600 kg ha -1 (average straw yield across all N rates) following the third year, assuming the straw contained 1.5% K (Fig. 8-B). The amount of recycled K with straw incorporation exceeded the recommended K rate of 100 kg ha 1 for all years of the experiment. This would indicate that rice straw incorporation has the potential to provide sufficient K for optimal rice grain yields if the prescribed K fertilization levels are correct.

Preseason Available Soil K Content, K Application, Midseason K and N Contents, Grain Yield, Straw Yield, and Harvest Index

The results indicate midseason plant N content, midseason plant K content, straw yield and grain yield were related to the amount of available soil K concentration. In the second year, the midseason plant N content was higher when straw was removed (versus incorporated). No consistent differences in midseason plant N content between straw management practices were detected during the first and third years of the experiment (Figs. 1 and 2). The decrease in midseason plant N content following straw incorporation in the second year indicates that N immobilization could possibly have retarded N uptake. When N immobilization occurs in rice soils it is often only for a short period immediately following the incorporation of high C:N ratio straw (Rao and Mikkelson, 1976; Prasad, 1999). Rao and Mikkelson (1976) suggested a 15 to 30 day incubation period to allow for straw decomposition to occur. At the experimental site, the straw was incorporated in the fall with sufficient incubation time for straw to decompose before spring seeding. Therefore, immobilization of N occurring after this incubation period seems improbable. In addition, N immobilization would result in lower available soil N and decreased grain yield in the zero N plots when straw was incorporated. However, throughout the study grain yields were higher in the zero N treatments when straw was incorporated. This indicates increased available N in the system with added straw, suggesting an increase in the net N mineralization rather than N immobilization (Figs. 5 through 8).

The increase in midseason plant N content following straw removal is possibly the result of a K deficiency that became more apparent during the second year. The pre-fertilization available soil K concentration decreased each year of the study for both straw management practices (Table 5, Figure 21). Research has shown that K deficiency promotes 02 uptake that results in an accumulation of nitrogenous compounds and increased plant respiration (Fujiwara, 1965). During the first two years of the study, midseason plant K content was lower when straw was removed compared to incorporated indicating the inability of the rice crop to accumulate adequate K (Figs. 3 and 4). Finally, a response to K addition was observed for the grain yield during all three years when straw was removed (Fig. 6). The straw yield during the second year showed a response to K application when straw was removed but no corresponding response was observed in the third year (Fig. 8). No response to K application was observed in the grain or straw yield during the first two years of the experiment when straw was incorporated (Figs. 6 and 8). Crops will show a response to K addition only when the soil K supply is lower than required for optimal plant growth. In summary, the higher midseason plant N content when straw was removed in the second year can possibly be attributed to an accumulation of N in nitrogenous compounds resulting from a low-available soil K concentration-induced K deficiency that increased in severity over time. This K deficiency could have been exacerbated by N application, prompting plant growth that significantly diluted the midseason plant K content during both years of the experiment when straw was incorporated and removed (Fig. 3). Although, this K deficiency was overcome with adequate K and N fertilization continued straw removal could result in more severe yield-limiting K deficiencies.

However, during the third year of the study the midseason plant N and K contents when straw was incorporated and removed were not consistent with the trends that developed in the first two years (Figs. 1-4). The distance between the straw removed and straw incorporated experiments (as detailed in the Work Description) introduced field variability that could have confounded the midseason plant tissue data. Throughout the study, the observed differences in midseason plant tissue content between straw management practices were very small, usually less than 0.25%. Therefore, it is also possible that there are no differences in midseason plant N and K content resulting from alternative straw management practices.

An interesting discovery was made in the second year when straw was removed and a grain yield response to K addition only up to 100 kg K ha-1 was observed (Fig. 6). The midseason plant K content, as determined at panicle initiation was 1.09% when 75 kg K ha -1 was applied and 1.18% when 100 kg K ha-1 was applied (Fig. 4). This indicates a sufficient midseason plant K content level somewhere between 1.09% and 1.18%, which is slightly lower than the current adequate midseason plant K content guideline of 1.2% (Hill, 1992).

Straw management did not consistently affect grain yield except where no N was applied (Figs. 5 and 6). An increase in grain yield with no N application coupled with straw incorporation occurred after 3 seasons of rice straw incorporation in a similar rice straw management study in California (Eagle et al., 2000). Decreased yields under straw incorporation when no N was applied have been reported (Azam et al., 1991; Verma and Bhagat, 1992). This decrease in yield was the result of N immobilization from a recently incorporated crop that was not allowed time for decomposition (Azam et al., 1991; Verma and Bhagat, 1992). The increase in grain yield observed in this study following only one year of straw incorporation when no N was applied seems to indicate minimal N immobilization (Fig. 5). The immediate grain yield response under straw incorporation occurred because the N dynamics of the rice cropping system has been stabilized to a straw incorporated management system (since approximately 1993) with the removal of straw being an aberration that resulted in a yield decrease when no N was applied. The increase in grain yield observed in this study when straw was incorporated in the zero N treatments can be attributed to increased available soil N from straw decomposition (Ponnamperuma, 1984; Eagle et al., 2001; 2002; Bird et al., 2001; 2002). However, no significant differences in grain yields between straw practices were observed with the application of N in all years of the experiment (Fig. 5). This study's increase in available soil N following straw incorporation led to increased N accumulation without a corresponding increase in grain yield has been observed in a similar rice straw management study in California when N was applied (Eagle et al., 2000; 2001).

Throughout the experiment, grain yield was consistently controlled by the addition of nutrients (Figs. 5 and 6). The addition of N significantly affected grain yield all three years of the experiment under both straw management practices (Fig. 5). A significant grain yield response to K was consistently observed when pre-fertilization available soil K levels dropped below 55 μg K g^{-1} soil, as was the case during the second and third year when straw was removed and in the third year when straw was incorporated (Table 5, Figs. 6 and 21). However, a significant grain yield response was also observed in the first year under straw removal when the pre-fertilization available soil K content was 67.2 μg K g1 soil while no corresponding response was observed in the second year under straw incorporation with an available soil K content of 55.1 μg K g 1 soil (Fig. 6). This suggests that straw incorporation can increase soil fertility to potentially nullify a marginal K deficiency. However, the experimental design was not able to detect the benefit that straw incorporation provided to the marginally K deficient rice crop. In addition, a very high correlation between pre-fertilization available soil K and grain yield was observed at a pre-fertilization available soil K content of 67.2 μg K g-1 and below (Table 5, Fig. 21). Therefore the previously established soil available K deficiency level of 60 μg K g^{-1} should be revised for some marginally K deficient soils when straw is removed.

The incorporation of straw led to increased straw yield, and because grain yield was not affected by straw management, to a lower harvest index (Figs. 7 and 8). The increase in straw production without an increase in grain production would suggest that the crop did not use the additional nutrients that become available following straw incorporation for grain production. A high harvest index is indicative of mineral deficiency because more nutrients will be allocated to the grain in nutrient-stressed plants as a survival mechanism (Adachi et al., 1997). This concept is displayed in this study as the harvest index remained higher when straw was removed for all rates of N except in the second year where the harvest indices between straw practices were similar with the application of 50 kg N ha' and in the zero N treatment of the third year (Fig. 9). A nutrient imbalance that resulted from the previously described K deficiency likely led to the allocation of existing nutrients to the grain, causing higher harvest indices when straw was removed (Figs. 9 and 10). In a greenhouse study, straw yield increased after one year of straw incorporation (applied at 10 ton ha') and both straw yield and grain yield increased after two years of straw incorporation (Adachi et al., 1997). Further studies are required to be conducted to better understand this phenomenon in an effort to increase the grain yield (and not the straw yield) with proper physiological utilization of the additional nutrients added with residue incorporation.

Soil K status, harvest grain and straw N content, N requirement and N fertilizer use efficiency

A higher harvest grain N content was observed during the first two years of the study with straw removal when compared to straw incorporation (Figs. 11 and 12). Also, the harvest straw N content was similar or higher for all levels of N and K applied when straw was removed (versus incorporated) during all years of the study (Figs. 13 and 14). As previously discussed, nutrient stressed crops allocate a higher concentration of nutrients to the grain, as is the case here concerning N. More evidence for the previously described K deficiency when straw was removed is displayed by the significant decrease in harvest straw N content when K was applied in the second and third years of the study (Fig. 14). A recent study in California showed significantly higher N uptake in rice when straw was retained compared to straw removal with the majority of the additional N accumulation in the straw (Eagle et al., 2000). In the study by Eagle et al. (2000) the rice crop was not severely stressed for other nutrients, in contrast to this study. The allocation of nutrients was not reapportioned to the grain from the straw, and a lower harvest index resulted from increased N uptake. A similar study in rice displayed an increasing harvest index when rice plants were stressed for N (Adachi et al., 1997). This correlates well with another study where the harvest index decreased with N addition when yields were already maximized (Borrell et al., 1997). The increased N uptake in this study occurred when straw was removed, compared to straw incorporation, and possibly resulted from an accumulation of nitrogenous compounds with increasing respiration rates due to a K deficiency. Because the rice was stressed for K when straw was removed, it allocated this excess N to the grain, resulting in a higher harvest index with increased N uptake.

However, during the third year of the study the harvest grain N contents when straw was incorporated and removed were not consistent with the trends that developed in the first two years of the study (Figs. 11 and 12). As with the midseason plant tissue contents, the distance between the straw removed and straw incorporated experiments (as detailed in the Work Description) introduced field variability that could have confounded the midseason plant tissue data. The observed differences in midseason plant tissue content between straw management practices were very small, less than 0.1 % in the first and third years. Therefore, it is also possible that there are no differences in the harvest plant N content resulting from alternative straw management practices.

Despite the increased concentration of N in the grain when straw was removed during the first two years of the study (in response to a K deficiency), the grain yield was the same whether straw was incorporated or removed with respect to all rates of N application (Figs. 5, 11, 12, 13, and 14). This led to a higher N requirement with straw removal when compared to straw incorporation during the first two years of the experiment and a slightly higher N requirement in the third year with the application of 150 and 200 kg N ha -1 (Figs. 15 and 16). Straw incorporation in California has led to increased N accumulation without a corresponding increase in grain yield which resulted in a lower N fertilizer use efficiency compared to straw burning (Eagle et al., 2000; 2001). Eagle et al. (2000; 2001) concluded straw incorporation constituted a fertilizer reduction of at least 12 kg N ha 1. It can be inferred from Eagle et al. (2000; 2001) that the N requirement was higher following straw incorporation. This contrasts the higher N requirement when straw was removed in this study. Further investigation is required to account for this discrepancy between these similar rice straw management studies.

The higher N requirement when straw was removed became more apparent in the second year and coincided with lower pre-fertilization available soil K concentration levels existing in the second year of the study (Table 1, Figs. 15 and 16). The application of K when straw was removed was followed by a significant decrease in the N requirement (Fig. 16). Another benefit of incorporating straw is that no corresponding decrease in N requirement was observed following K application and straw incorporation in any year of the study (Fig. 16). This translates into lower required N fertilization rates following straw incorporation. It is likely this decreased requirement for N fertilization with straw incorporation is not solely due to the addition of K. Incorporation of rice straw has been shown to supply trace nutrients, N, P, and S and improve the soil physical, chemical, and microbiological properties (Xie and Hasegawa, 1985).

Substantially increased N requirements and decreased N fertilizer use efficiencies were observed in the second year of the study (Figs. 15, 16,17, and 18). As previously mentioned, there was a 2.5-week lag time between fertilization and flooding in the second year of the study while flooding occurred just several days after fertilization in the first year. This provides evidence that a portion of the N applied in the second year may have been lost through nitrification, followed by denitrification, due to this lag time.

It is very common for N fertilizer use efficiency to decrease with the addition of N fertilizer. However, in this study the addition of N fertilizer did not drastically change the N fertilizer use efficiency except for when straw was removed in the second year of the study. This suggests limited deleterious environmental effects typical with the higher N applications required for optimal grain yields because the rice crop appears to be very efficient at taking up inorganic N compounds before they are lost from the rice agroecosystem.

The NH4OAc test and plant K availability

Exchangeable K data collected using the 1 M NH4OAc method proved to be an excellent predictor of midseason plant K content and grain yield when K deficiencies became prevalent in the second year (Table 5, Fig. 21). However, measuring the pre-fertilization available soil K concentration using the 1 M NH4OAc method could not predict responses to K fertilizer application in the first year following straw removal. Grain yield and straw yield significantly responded to K fertilizer addition when there was a pre-fertilization available soil K concentration of 67.2 μg g ' in the first year, while neither the grain yield nor the straw yield responded to K application in the second year when straw was incorporated and there was a pre-fertilization available soil K concentration of 55.1 μg g' (Table 5). This indicates that the incorporation of straw provided nutrients and/or improved soil physical properties that were beneficial to the overall grain yield but were undetectable by the NH4OAc test. It cannot be concluded from this study that the NH4OAc test cannot be used on soils where straw is incorporated. The NH4OAc test accurately predicted crop responses to various levels of K addition when pre-fertilization available soil K concentrations were below 60 μg K g' soil when straw was removed as well as incorporated (Fig. 21). This corroborates the critical level of 60 μg K g' soil for rice as determined in previous studies but suggests a slightly higher critical soil K concentration is possible for some soils, especially when straw is incorporated (De Datta and Mikkelson, 1985).

The high correlation between pre-fertilization available soil K concentration (plus added fertilizer K) in predicting grain yield as soil K levels decreased indicates that no measurable amount of K fixation occurred in this study (Fig. 19). Moreover, the high correlations between the grain yield and available soil K concentration indicate that it is unlikely significant K losses occurred through leaching (Table 5, Fig. 21). Studies in the Philippines have shown that K additions from irrigation water often compensate for any K losses occurring as a result of leaching (Dobermann et al., 1998). Therefore, the K deficiency observed in this study was likely derived from a low K supplying capacity of the soil minerals. The 1 M NH4OAc test appropriately predicted plant available K despite the drastic change in soil conditions upon flooding and the wet-dry cycle, both of which have shown to drastically effect the plant available soil K concentrations (Attoe, 1946; Addiscott and Johnston, 1975; Phillips and Greenway, 1998). It can be concluded from this study that the 1 M NH4OAc measurement of pre-fertilization available soil K concentration can be successfully utilized to determine K fertilization recommendations in rice soils that have similar characteristics as the San Joaquin loam and have pre-fertilization available soil K concentration levels below 60 μg K g' soil.

Aggregate Sheath Spot and Nitrogen

The application of N significantly decreased the severity of AgSS during all years of both experiments (Fig. 21). Moreover, the severity of AgSS continued to decrease up to the maximum amounts of N application. This indicates that N application continues to decrease the severity of AgSS even after yields have reached maximum yield. These data corroborate well with Gunnell and Webster (1984) who concluded that the overall severity of AgSS was most pronounced at lower N levels. A decrease in the incidence of AgSS with increasing organic N applications as vetch was observed in an unpublished 1994 University of California Cooperative Extension study. Also, a recent study on a California rice soil has shown a significant decrease in the incidence of AgSS with 210 kg N ha -1 compared to 164 kg N ha -1 (Williams and Smith, 2001). It appears from these experiments that an increase in plant N concentration from N fertilizer application increases the resistance of rice to AgSS infection.

Aggregate Sheath Spot, Straw Management, and K

The significant effect of K fertilization reducing AgSS severity indicates a possible critical available soil K level for AgSS resistance of 50 µg K g 1 soil (Table 5, Figs. 20 and 21). This result corroborates a recent study on a K deficient California rice soil that found AgSS incidence to marginally but significantly decrease in response to increased K uptake with fertilizer K addition (Williams and Smith, 2001). The midseason plant K content (at panicle initiation) was below the recommended 1.2% (i) under low levels of K application in the first and third years when straw was removed as well as in the third year when straw was incorporated, (ii) under low levels of K application in the second year when straw was incorporated, and (iii) under all levels of K application except 125 kg ha -1 in the second year when straw was removed (Fig. 4). These midseason plant K deficiencies correlated with yield responses to K application where straw was removed (Fig. 6). Because K was not at sufficiently high concentrations for maximum yields in both years when straw was removed, it is likely that K would have been at insufficient levels for adequate AgSS resistance as well. Because AgSS severity was not significantly affected by any midseason plant K concentration in the study, it is likely that an adequate plant K concentration existed for optimal AgSS resistance during the first two years of the study. The pre-fertilization available soil K content was 41.4 µg K g 1 soil in the second year of the study when straw was removed, which is less than the potential critical available soil K level for AgSS resistance of 50 µg K g-1 soil determined from the third year results of this study. The pre-fertilization available soil K content was less than 41.4 µg K g'1 when straw was removed in the third year, but more than 41.4 µg K g 1 when straw was incorporated in the third year. This again suggests benefits, in this case AgSS resistance, resulting from the incorporation of straw that may be attributed to increased organic N mineralization.

Aggregate Sheath Spot and Straw Management

Compared to two years of straw removal, two years of repeated straw incorporation reduced the severity of AgSS (Fig. 21). It should be noted here that the overall severity of AgSS decreased in the second year compared to the first year regardless of straw management practice (Fig. 21). This is likely due to overall lower yields observed in the second year (Figs. 5 through 8) indicating less AgSS development. These trends did not continue in the third year of the study where there were no discernable differences in AgSS severity except in the zero N and zero K treatments where AgSS severity was slightly higher when straw was incorporated. The third year results concerning AgSS severity could again be suspect due to the distance between the straw removed and straw incorporated experiments. It is very likely that field variability in the severity of AgSS was present, especially due to the fact that the straw removed plots were very close to a levy while the straw incorporated plots were not.

The increased AgSS severity observed when straw was removed in the first two years is possibly explained by a combination of two factors. First, the nutrient imbalance caused by the K deficiency when straw was removed may provide favorable conditions for the AgSS fungus to flourish in rice. Nutrient imbalance is a determining factor in the infection severity of a large number of diseases (Huber and Amy, 1985). However, no decrease in AgSS severity was observed upon K addition (Fig. 21). Therefore, it is possible that the remaining stubble resulting from straw removal enables the efficient infection of the subsequent rice crop by *Rhizoctonia oryzae-sativae.* In contrast, the fall incorporation of rice straw reduces the AgSS severity of the subsequent crop compared to straw removal. These results conflict with current management guidelines that ask for removal of AgSS-infected rice straw (Gunnell and Webster, 1992). These seemingly conflicting data can be explained by the typical field operations associated with straw management practices in California where the major initial *Rhizoctonia oryzae-sativae* infection is located on the rice plant below the water line (Table 1). The practice of straw removal entails mowing the rice plant at the water line in the fall. The remaining stubble is then disked underground during spring field operations. On the other hand, straw incorporation calls for fall incorporation before winter flooding, leaving the rice straw in full contact with the soil and the *Rhizoctonia oryzae-sativae* in competition with the indigenous microbial populations for survival. Therefore, straw removal favors the survival and subsequent crop infection of *Rhizoctonia oryzae-sativae* when compared to straw incorporation. The effect of straw incorporation on subsequent crop diseases is not consistent. When compared to burning, the incorporation of winter wheat straw has been shown to increase the number of some *Fusarium* spp. (Bateman et al., 1998). In a wheat cropping system, eyespot and sharp eyespot was shown to be significantly less severe under straw incorporation when compared to burning (Prew et al., 1995).

CONCLUSIONS AND PROJECT EVALUATION

California rice farmers have been forced by legislation to utilize a straw management practice alternative to the traditional burning. At this point in time farmers can either incorporate the straw into their soil or remove it off-site. It is much more cost effective to incorporate rice straw as there are no baling and transportation costs inherent with straw removal. However, many farmers have expressed a hesitation to incorporate rice straw as they feel their yields will be reduced as a result of weed and disease pressure.

This three-year study has produced evidence for a multitude of benefits resulting from the incorporation of rice straw. The incorporation of straw in a Californian rice field clearly increased plant K availability. Grain yield and straw yield responses to K fertilization only occurred when straw was removed, indicating sufficient K fertility resulting from the incorporation of straw. A K deficiency led to an increased accumulation of N in the midseason plant and grain content when straw was removed. The K deficiency also led to decreased midseason plant K content when straw was removed. The grain yield was similar whether straw was incorporated or removed. However, the incorporation of straw led to increased straw yield, and because grain yield was not affected, to a lower harvest index. Because the increased uptake of N did not lead to a higher grain yield, a higher N requirement became evident following straw removal. Therefore, the incorporation of rice straw reduces the rates of K and N fertilizer application needed for optimal crop growth. However, the midseason plant K content did significantly increase with K application when straw was incorporated and removed. This uptake of K following K fertilization and straw incorporation indicates a possible hidden hunger for K that could manifest if this study was continued. The NH4OAc test accurately predicted crop responses to various levels of K addition when pre-fertilization available soil K concentrations were below 60 µg K g-1 soil and AgSS severity. The incorporation of straw was shown to provide nutrients and/or improve soil physical properties that were beneficial to the overall grain yield but undetectable by the NH4OAc test. It cannot be concluded from this study that the NH4OAc test cannot be used on soils where straw is incorporated. It can be concluded that K fertilizer application along with straw incorporation would be preferred for long-term K sustainability of this California rice cropping system.

OUTREACH ACTIVITIES SUMMARY

Soil Science Society of America/American Society of Agronomy National Meeting
Minneapolis, **Minnesota**
November, 2000

University of California Cooperative Extension, Rice Winter Meetings
5 Locations throughout California
Winter, 2000

Fertilizer Research and Education Program Meeting
Tulare, CA
February, 2001

University of California Cooperative Extension, Rice Winter Meetings
5 Locations throughout California
Winter, 2000

Soil Science Society of America/American Society of America **National Meeting**
Charlotte, North Carolina
November, 2001

University of California, Davis
"Potassium and nitrogen responses in California rice fields as affected by straw management practices."
Master's Thesis authored by Eric Byous
Spring, 2001

University of California, Davis
"N and K dynamics as affected by straw management practices in a California rice field."
Master's Thesis authored by Grace Jones
To be completed Spring, 2003

Two papers are currently being prepared for publication in the Agronomy Journal.

FIGURES

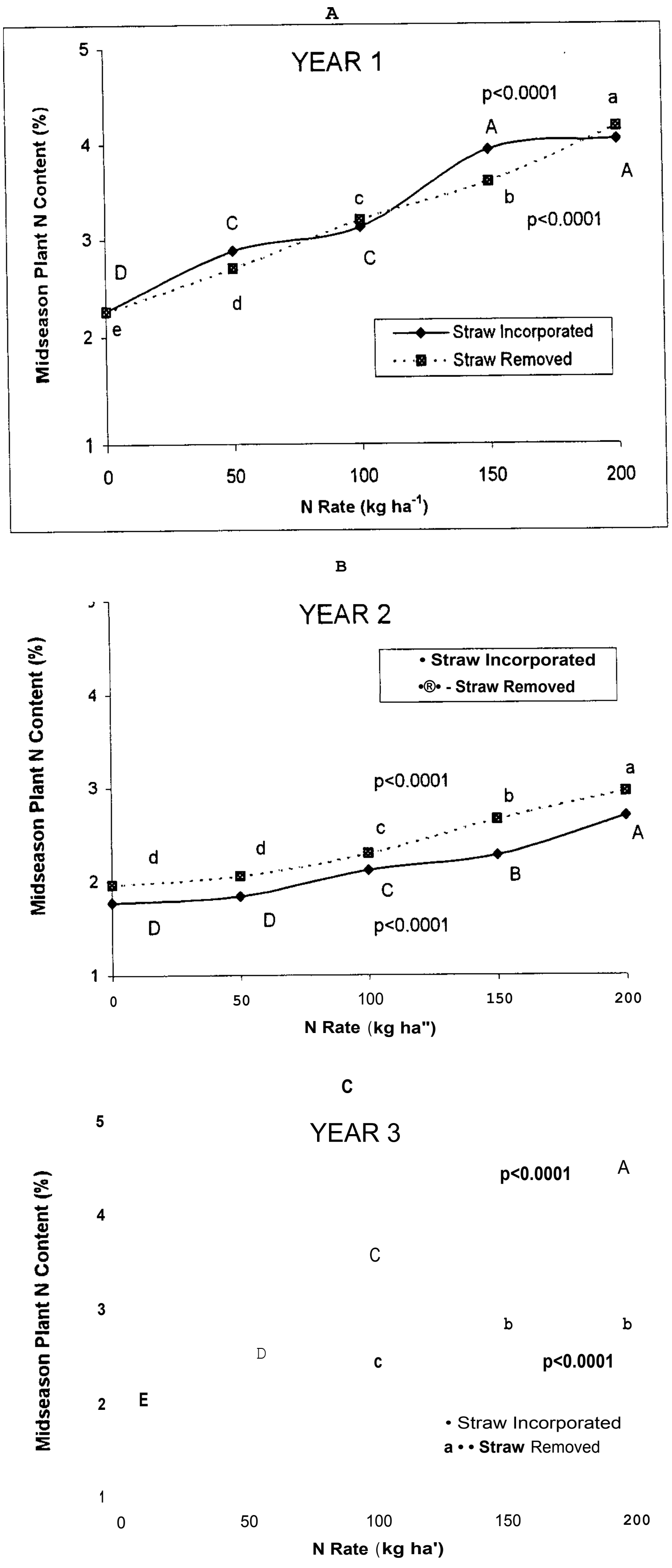

Figure 1. Midseason plant N content as affected by N rate and straw management. Upper and lower case letters represent statistical t grouping of the data where straw was incorporated and removed, respectively.

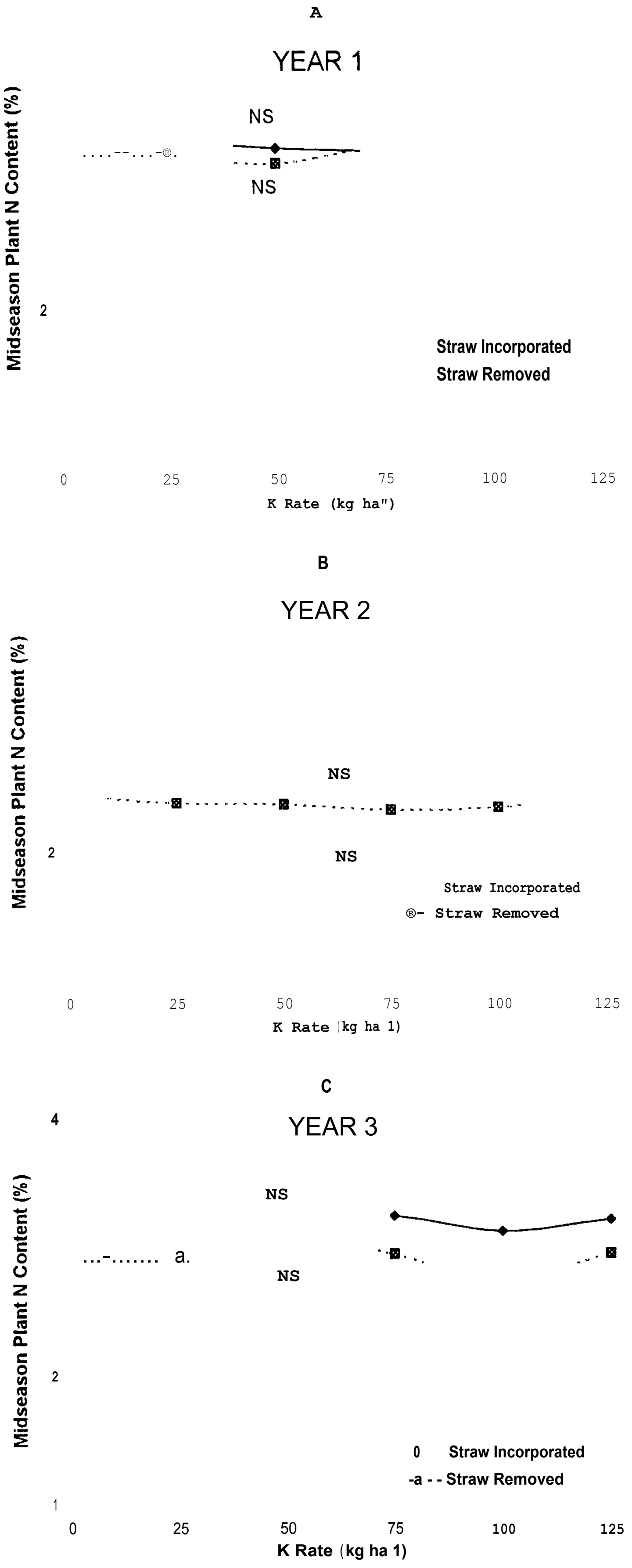

Figure 2. Midseason plant N content as affected by K rate and straw management.
NS - Not Significant

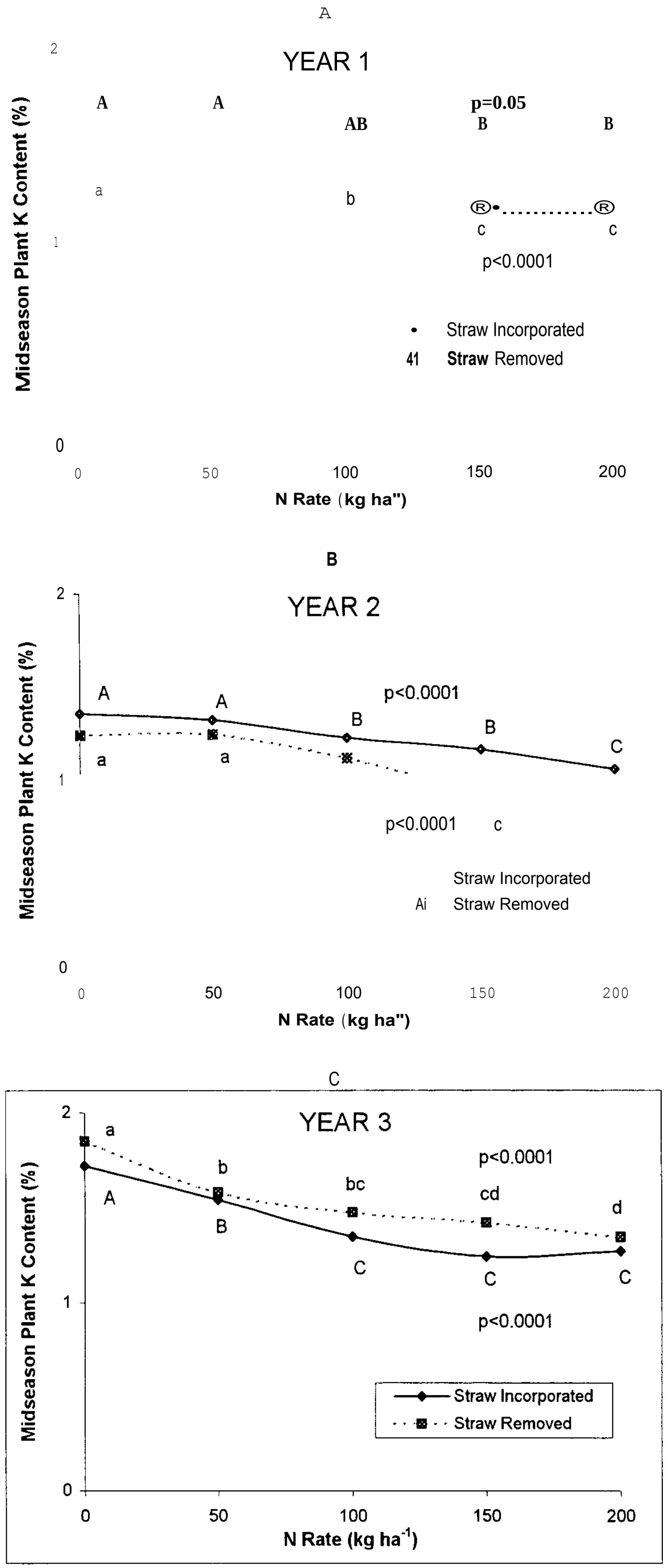

Figure 3. Midseason plant K content as affected by N rate and straw management. Upper and lower case letters represent statistical t grouping of the data where straw was incorporated and removed, respectively.

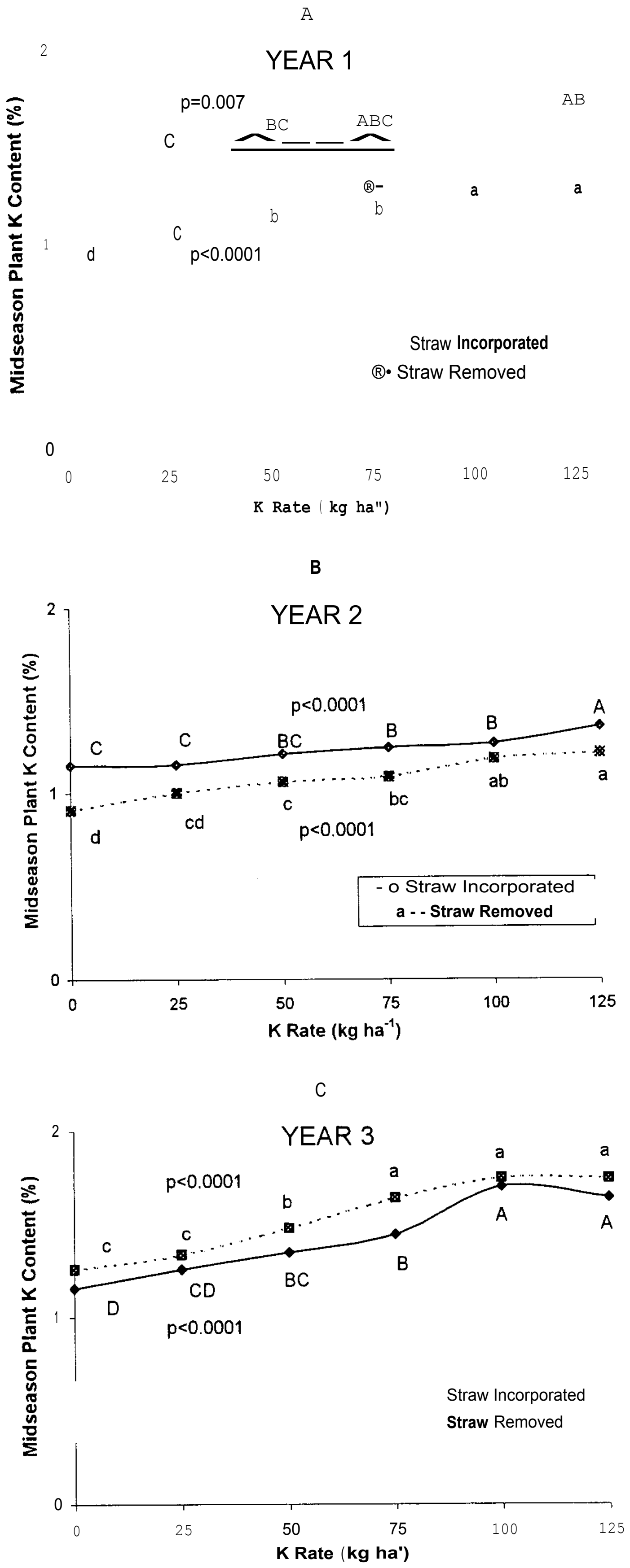

Figure 4. Midseason plant K content as affected by K rate and straw management. Upper and lower case letters represent statistical t grouping of the data where straw was incorporated and removed, respectively.

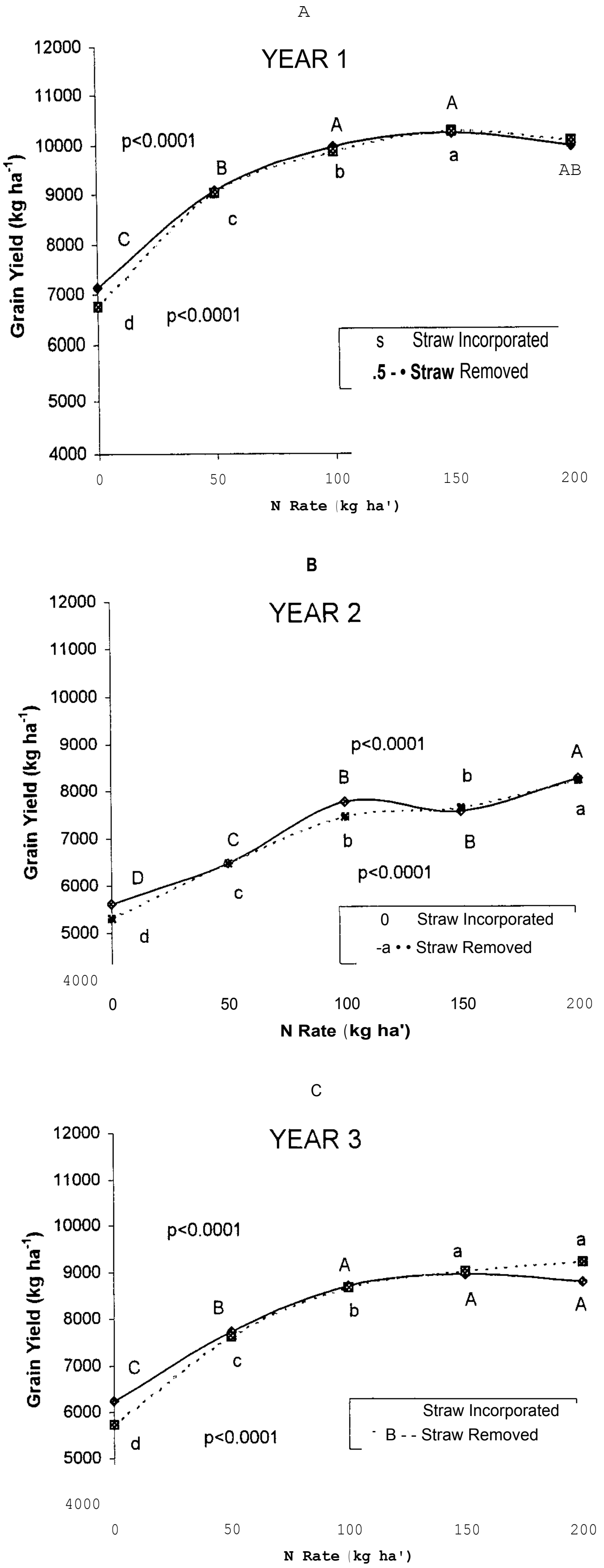

Figure 5. Grain yield as affected by N rate and straw management. Upper and lower case letters represent statistical t grouping of the data where straw was removed and incorporated, respectively.

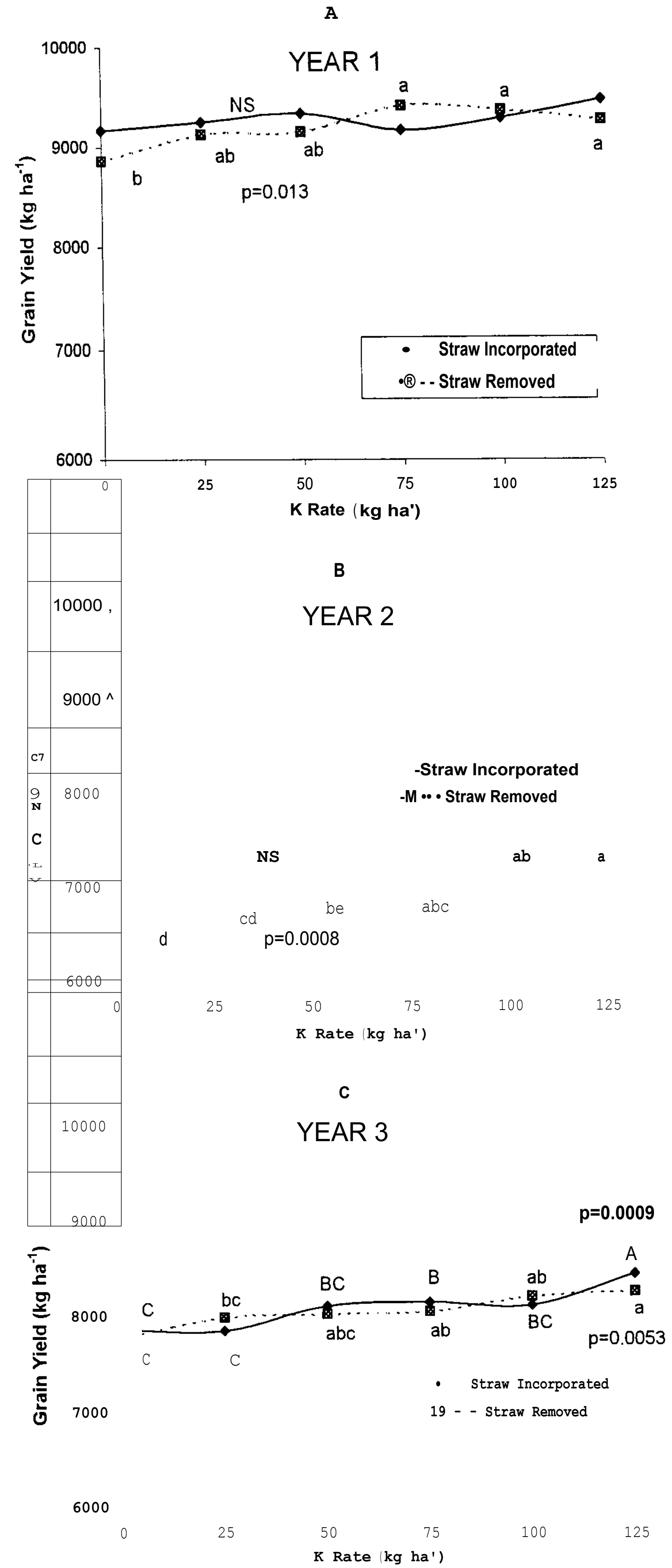

Figure 6. Grain yield as affected by K rate and straw management. Upper and lower case letters represent statistical t grouping of the data where straw was incorporated and removed, respectively.
NS - Not Significant

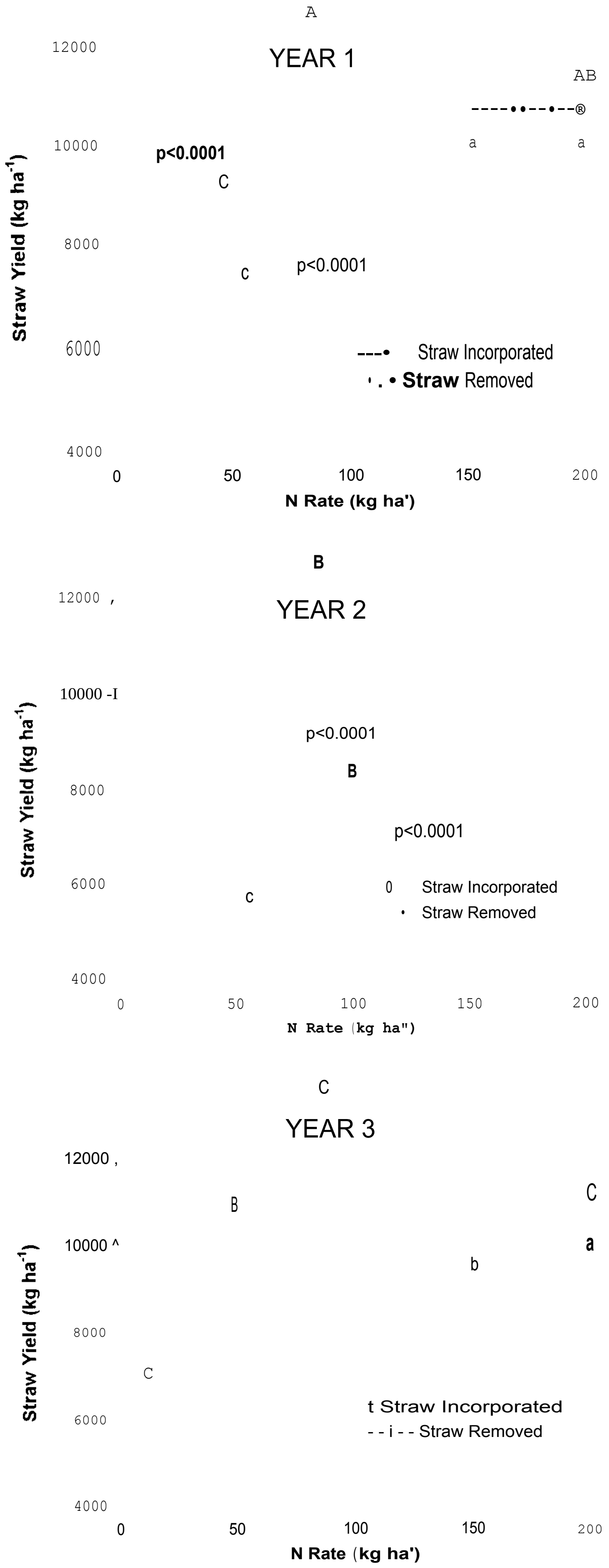

Figure 7. **Straw yield as affected by N rate and straw management.** Upper **and lower case letters represent statistical t grouping of the data where straw was incorporated and removed, respectively.**

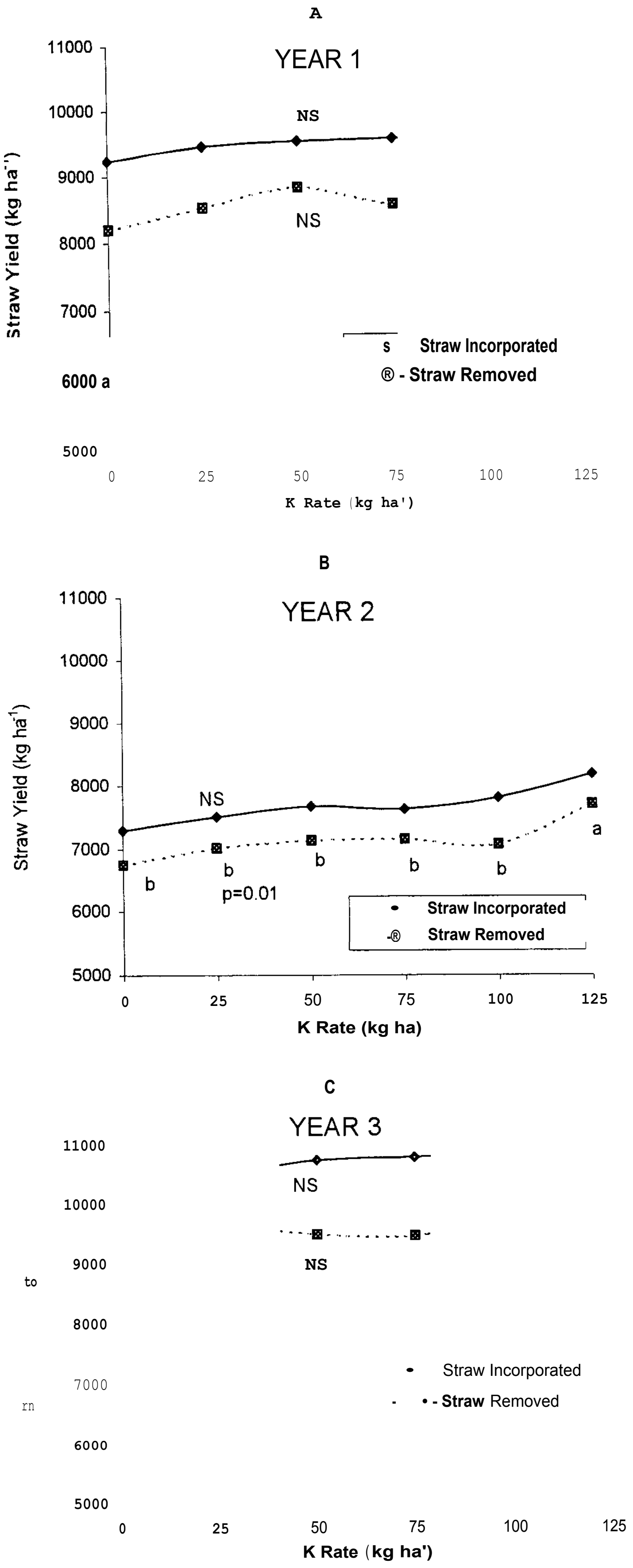

Figure 8. Straw yield as affected by K rate and straw management. Upper and lower case letters represent statistical t grouping of the data where straw was incorporated and removed, respectively. NS- Not Significant

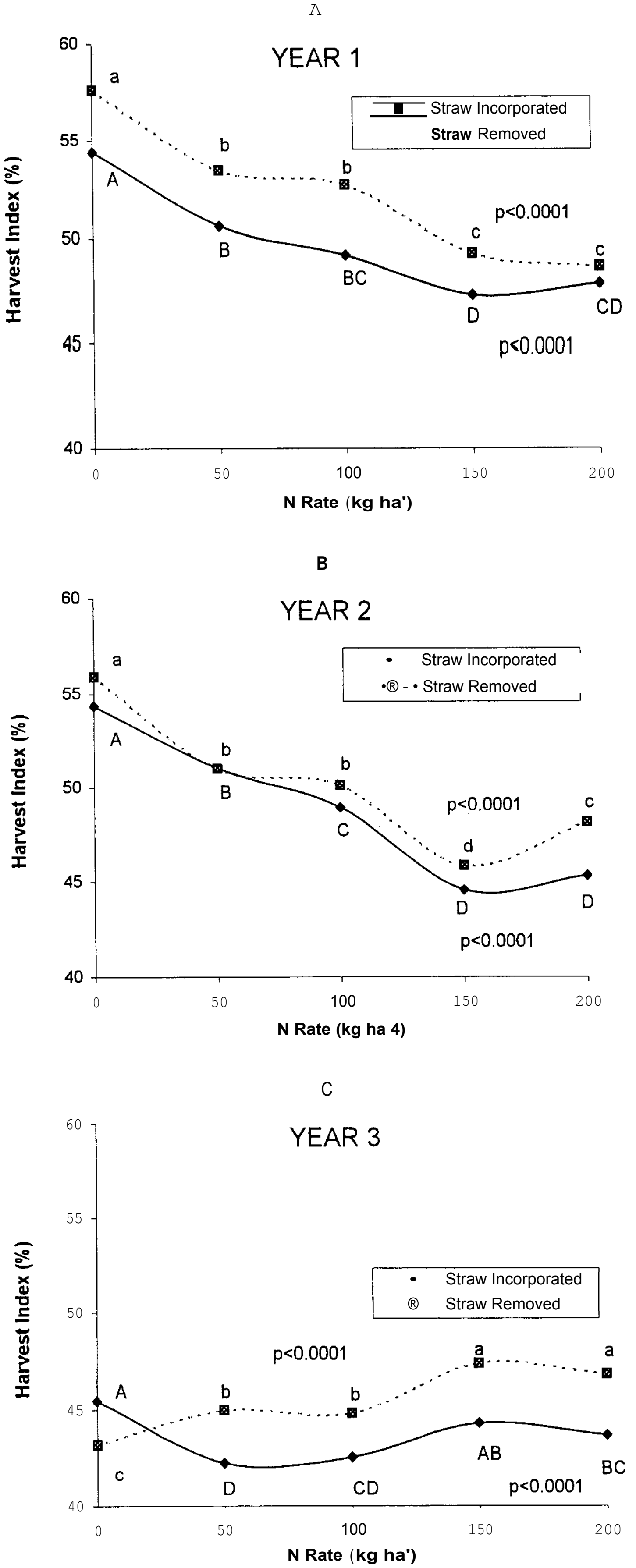

Figure 9. Harvest index as affected by N rate and straw management. Upper and lower case letters represent statistical t grouping of the data where straw was incorporated and removed, respectively.

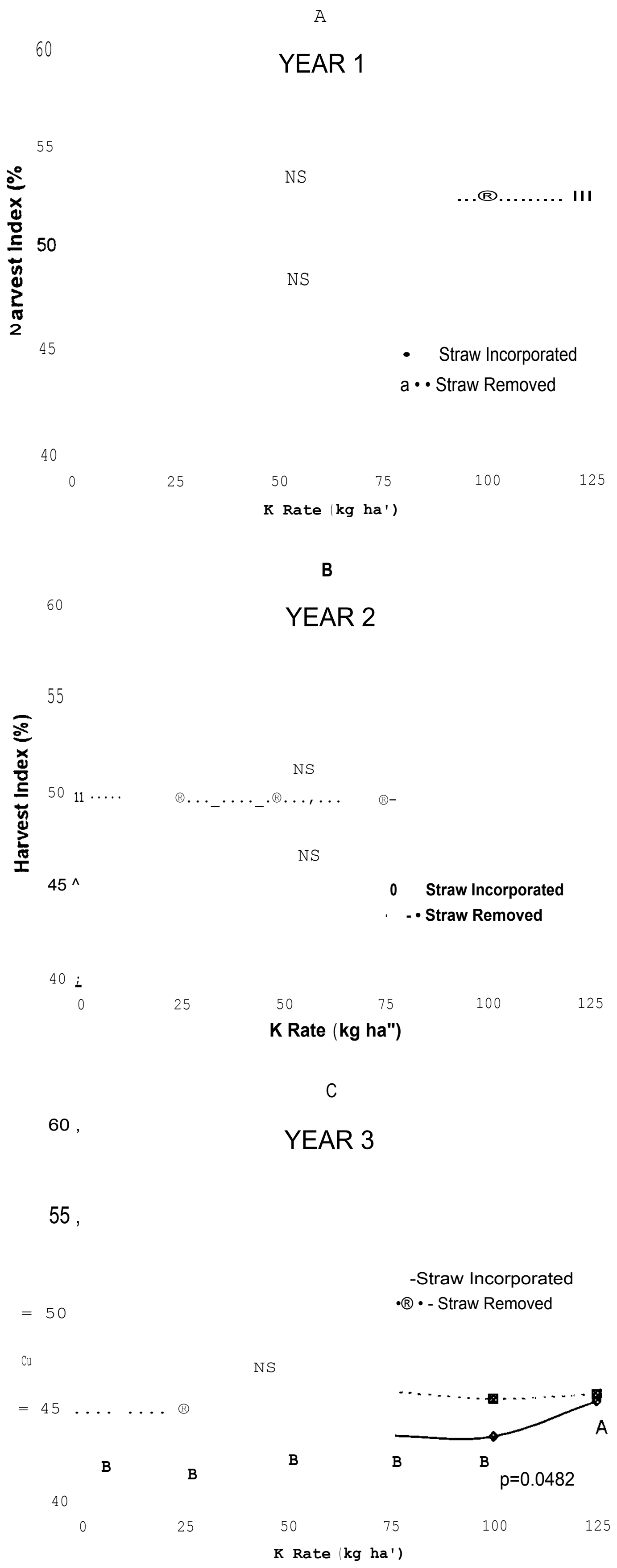

Figure 10. Harvest index as affected by K rate and straw management. Upper and lower case letters represent **statistical** t grouping of the data where straw was incorporated and removed, respectively.
NS - Not Significant

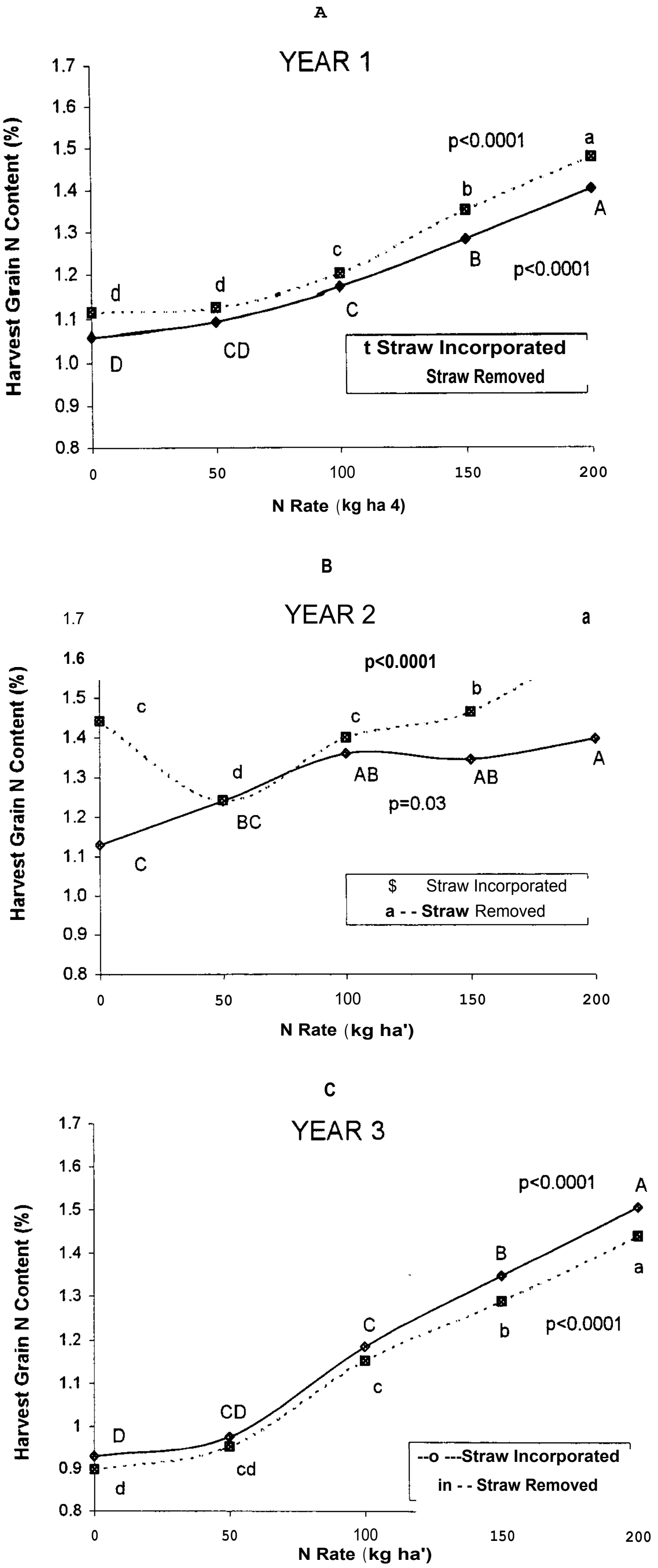

Figure 11. Harvest grain N content as affected by N rate and straw management. Upper and lower case letters represent statistical t grouping of the data where straw was incorporated and removed, respectively. NS - Not Significant

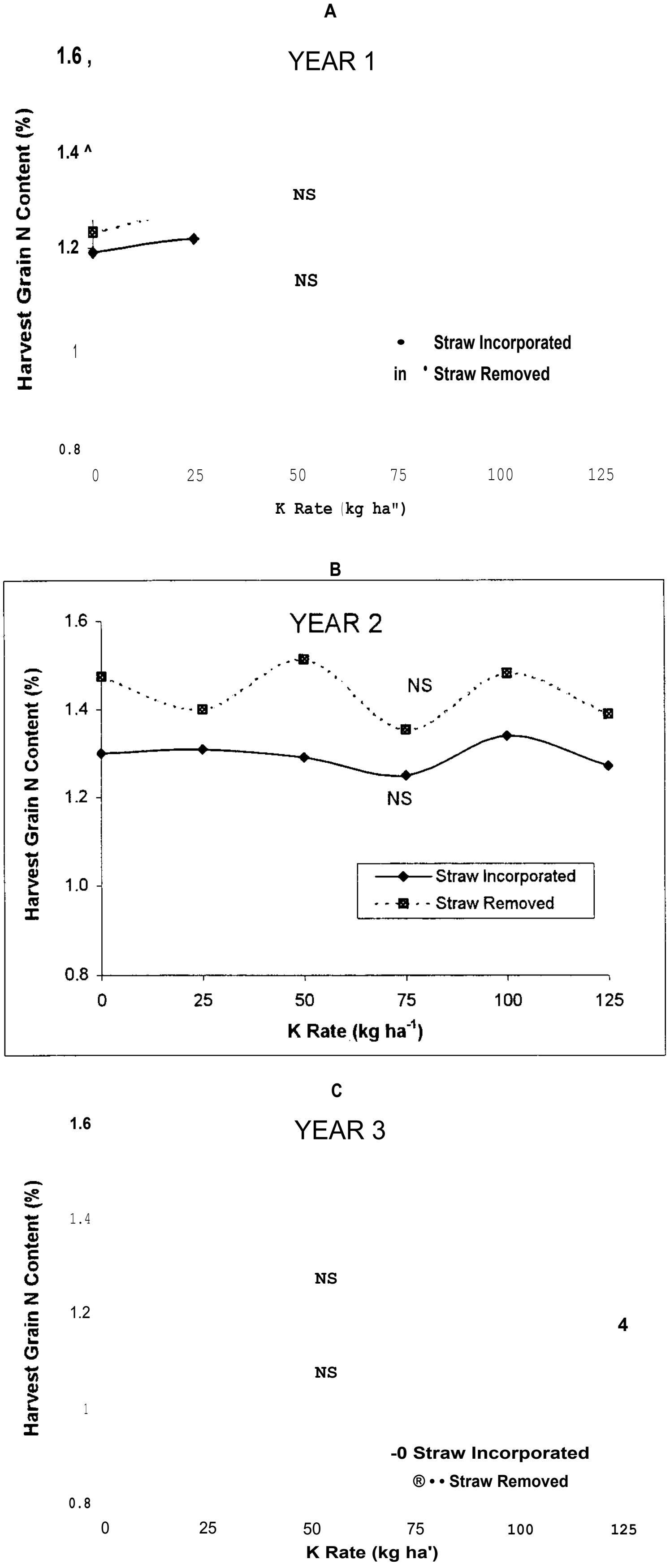

Figure 12. Harvest grain N content as affected by K rate and straw management. Upper and lower case letters represent statistical t grouping of the data where straw was incorporated and removed, respectively. NS - Not Significant

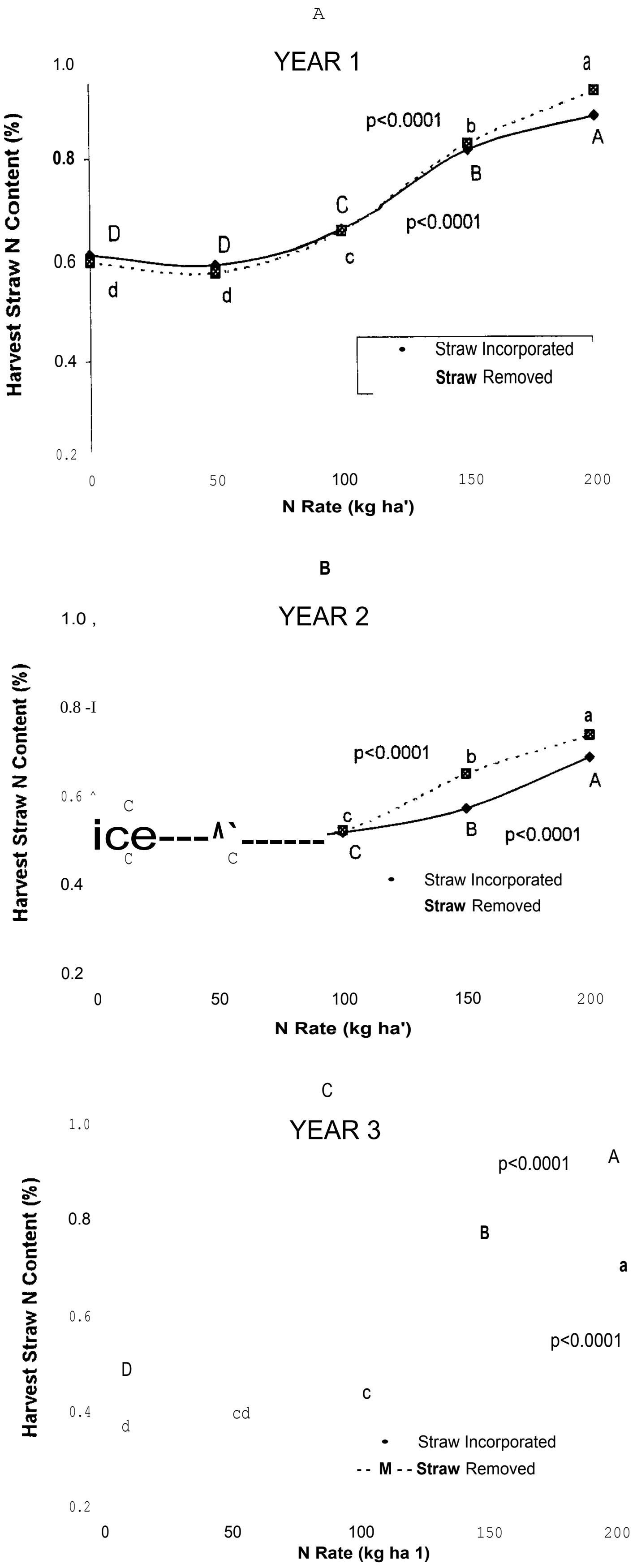

Figure 13. Harvest straw N content as affected by N rate and straw management. Upper and lower case letters represent **statistical** t grouping of the data where straw was incorporated and removed, respectively. NS - Not Significant

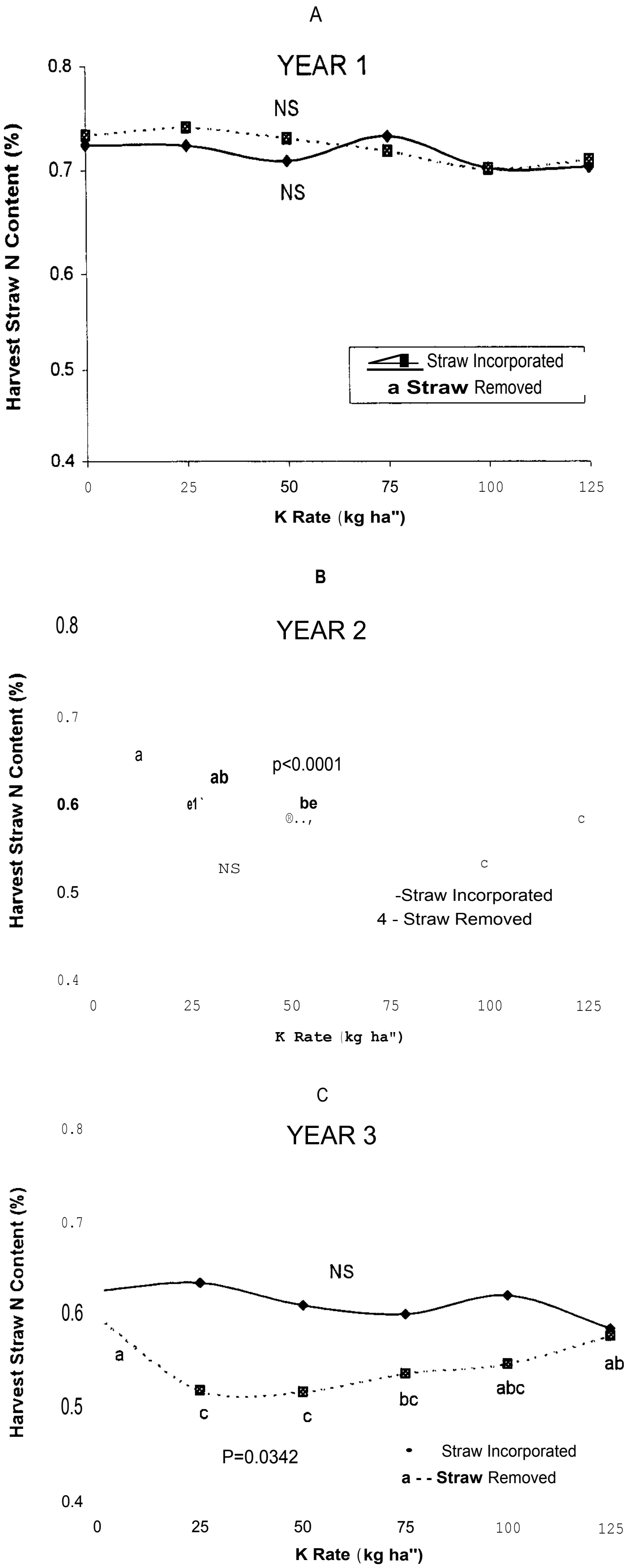

Figure 14. Harvest straw N content as affected by K rate and straw management. Upper and lower case letters represent statistical t grouping of the data where straw was incorporated and removed, respectively. NS - Not Significant

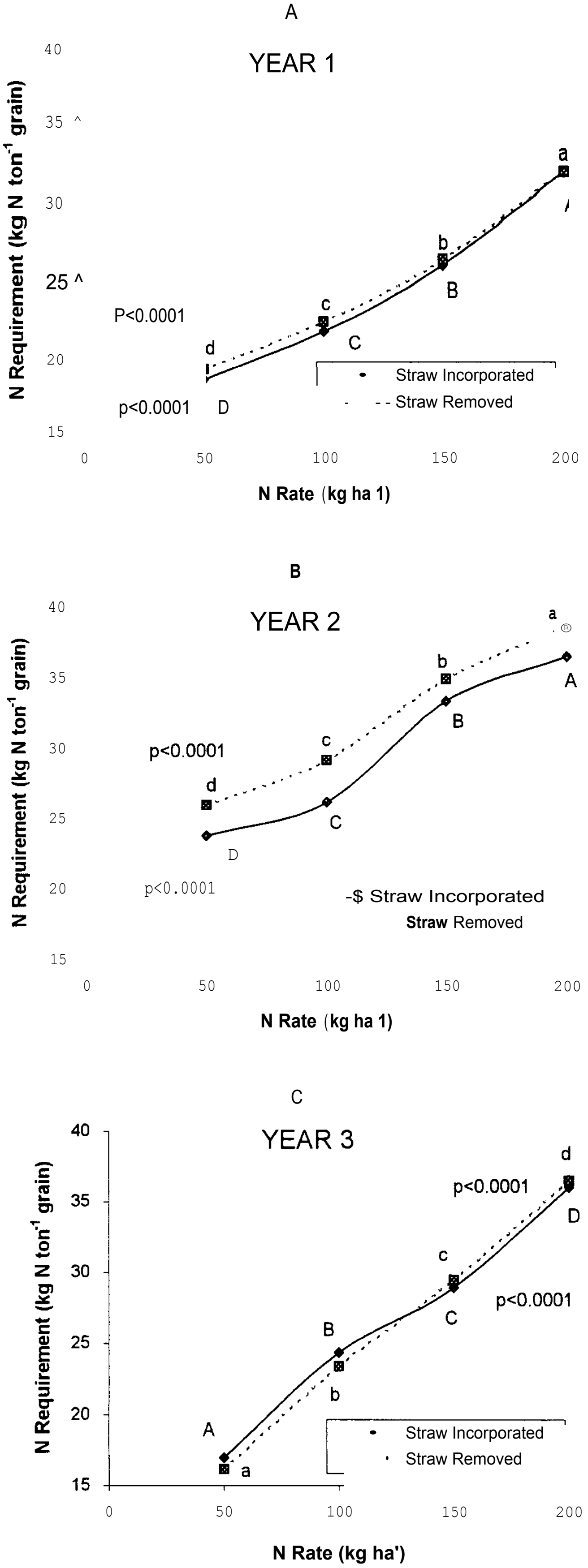

Figure 15. N requirement as affected by N rate and straw management. Upper and lower case letters represent statistical t grouping of the data where straw was incorporated and removed, respectively.

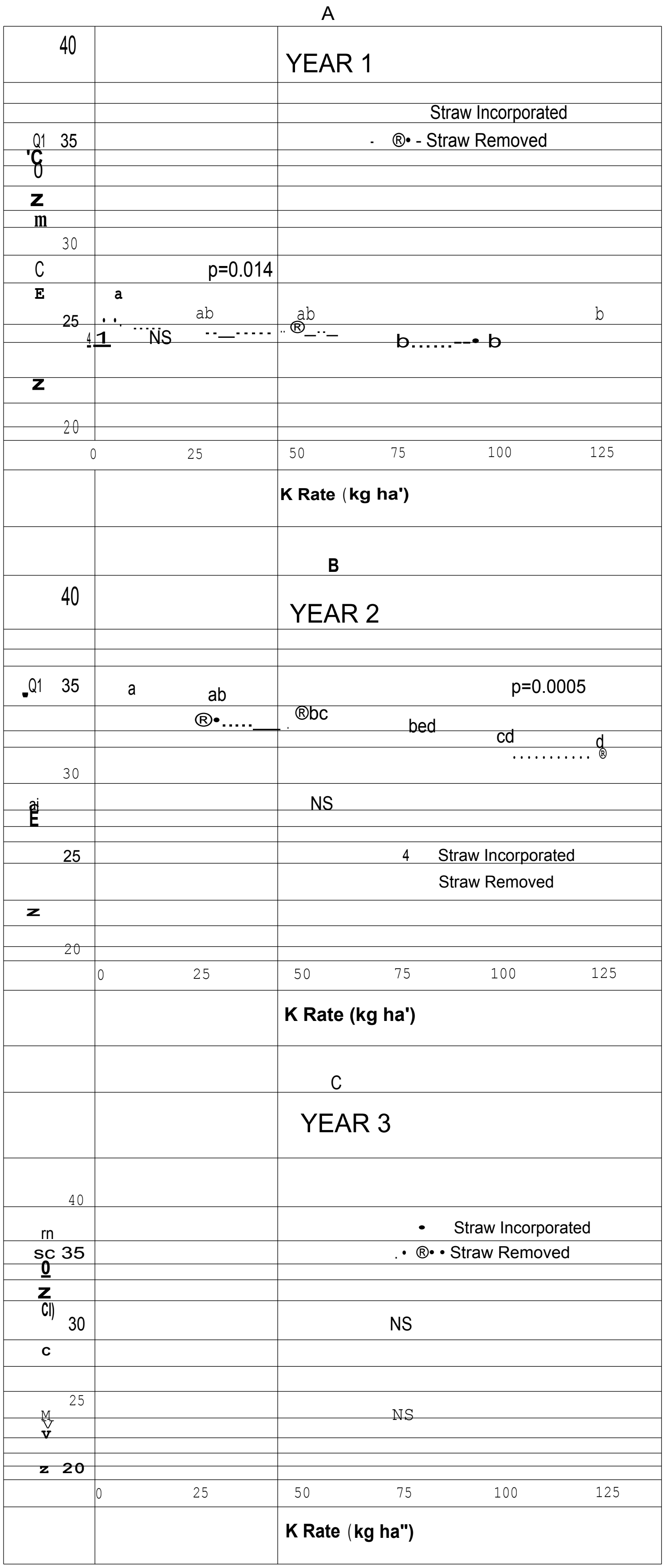

Figure 16. N requirement as affected by K rate and straw management. Upper and lower case letters represent statistical t grouping of the data where straw was incorporated and removed, respectively.

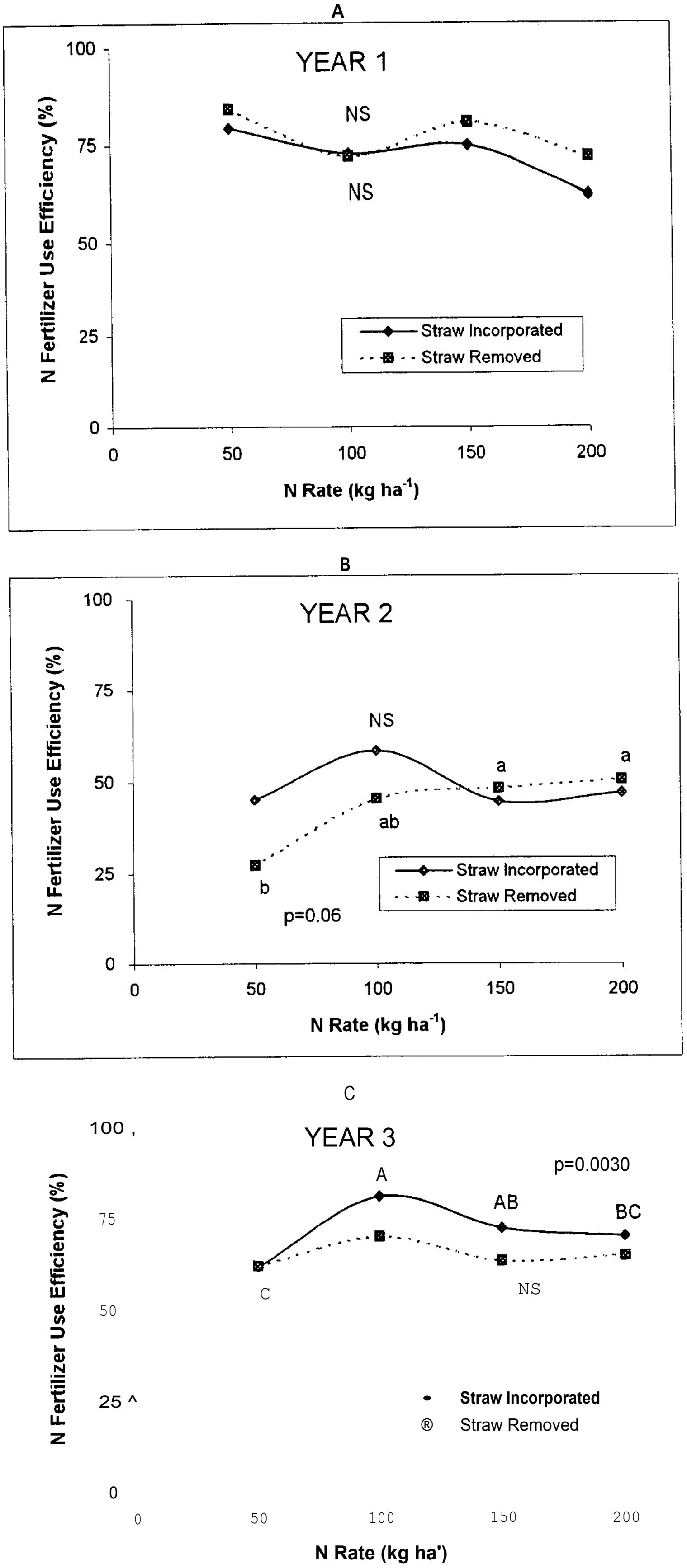

Figure 17. N fertilizer use efficiency as affected by N rate and straw management. Upper and lower case letters represent statistical t grouping of the data where straw was incorporated and removed, respectively. NS - Not Significant

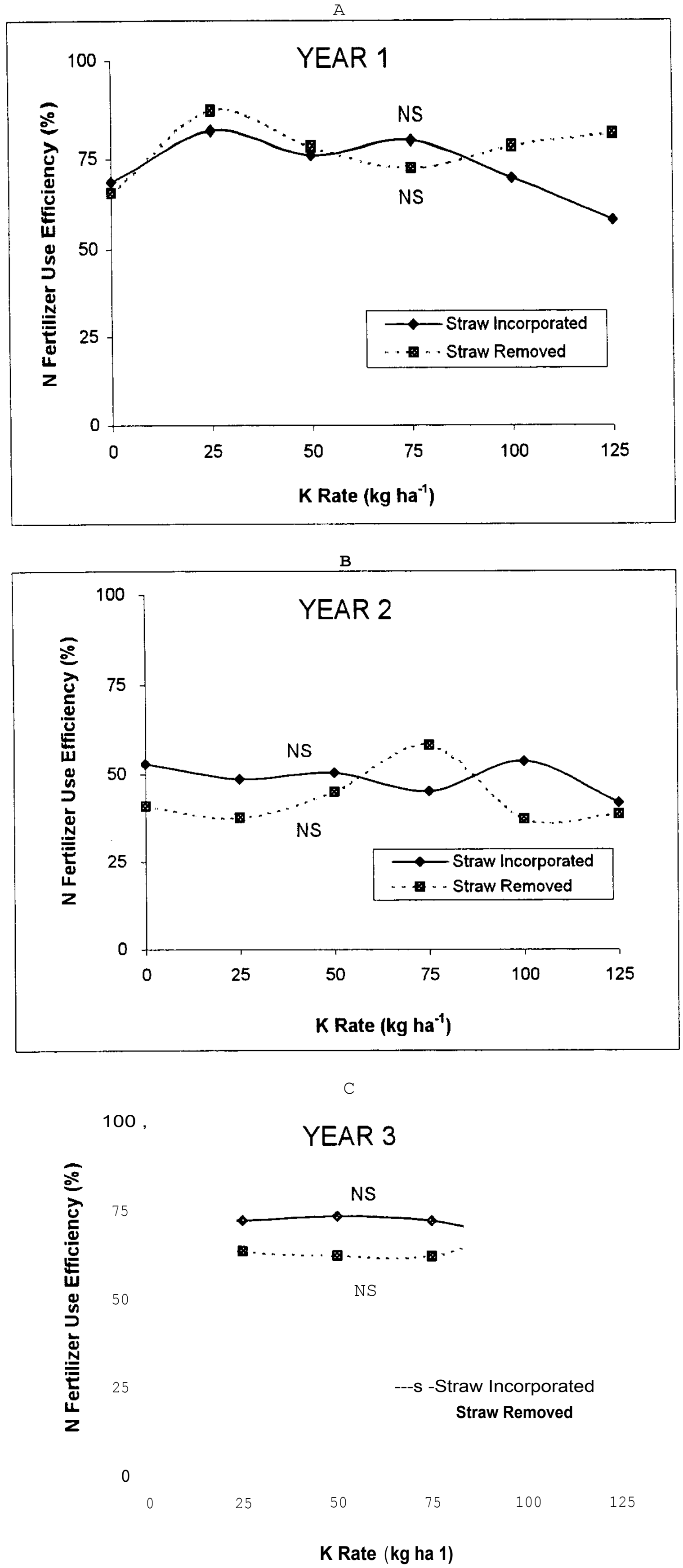

Figure 18. N fertilizer use efficiency as affected by K rate and straw management. Upper and lower case letters represent statistical t grouping of the data where straw was incorporated and removed, respectively. NS - Not Significant

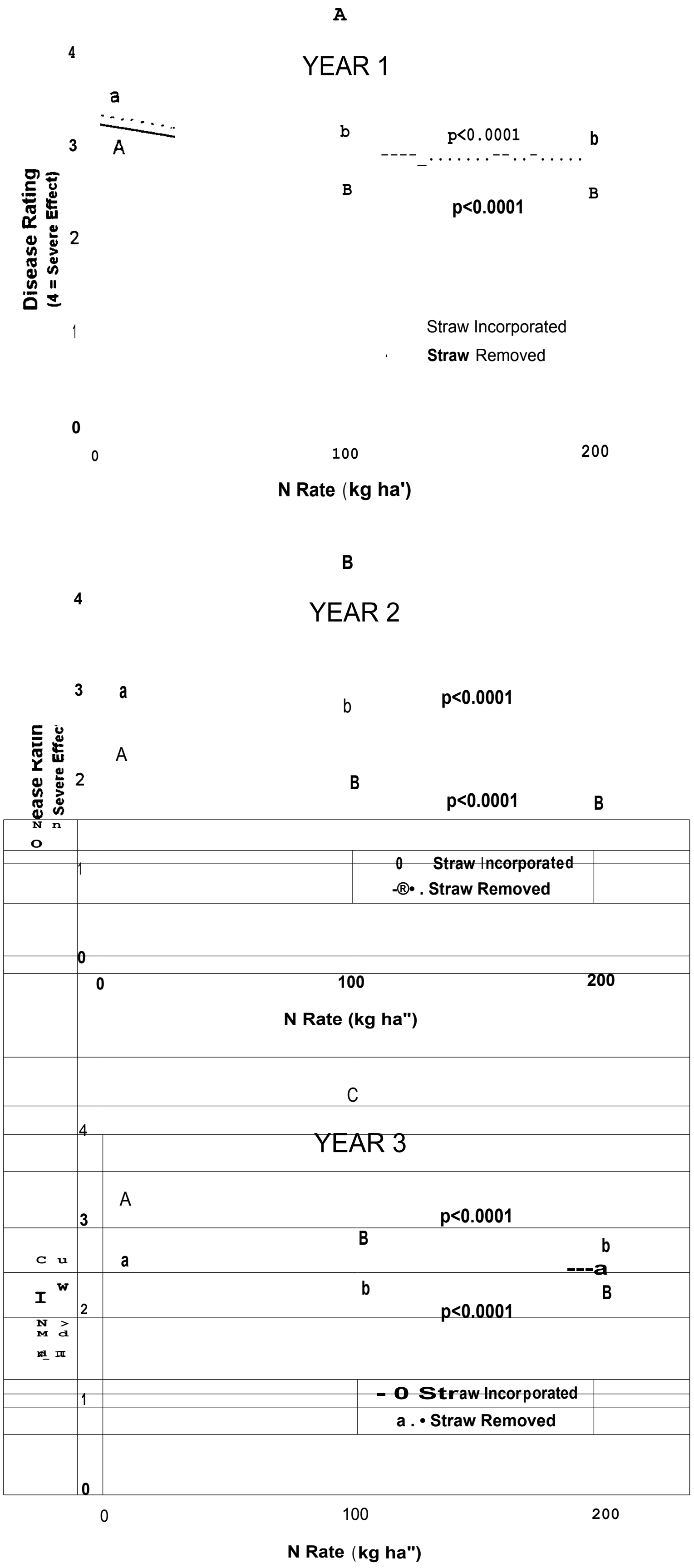

Figure 19. The severity of AgSS as affected by straw management and N application. Upper and lower case letters represent statistical t grouping of the data where straw was incorporated and removed, respectively.

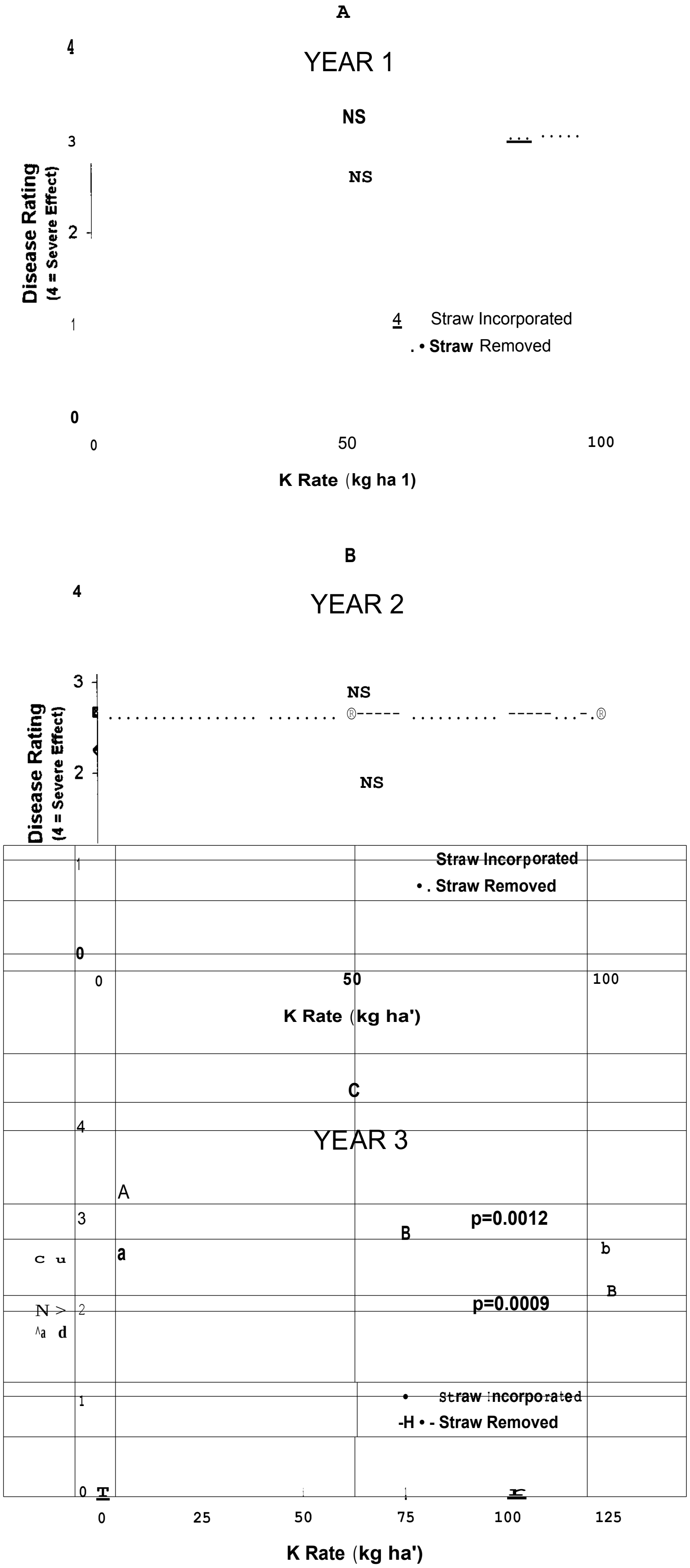

Figure 20. The severity of AgSS as affected by straw management and K application. Upper and lower case letters represent statistical t grouping of the data where straw was incorporated and removed, respectively.

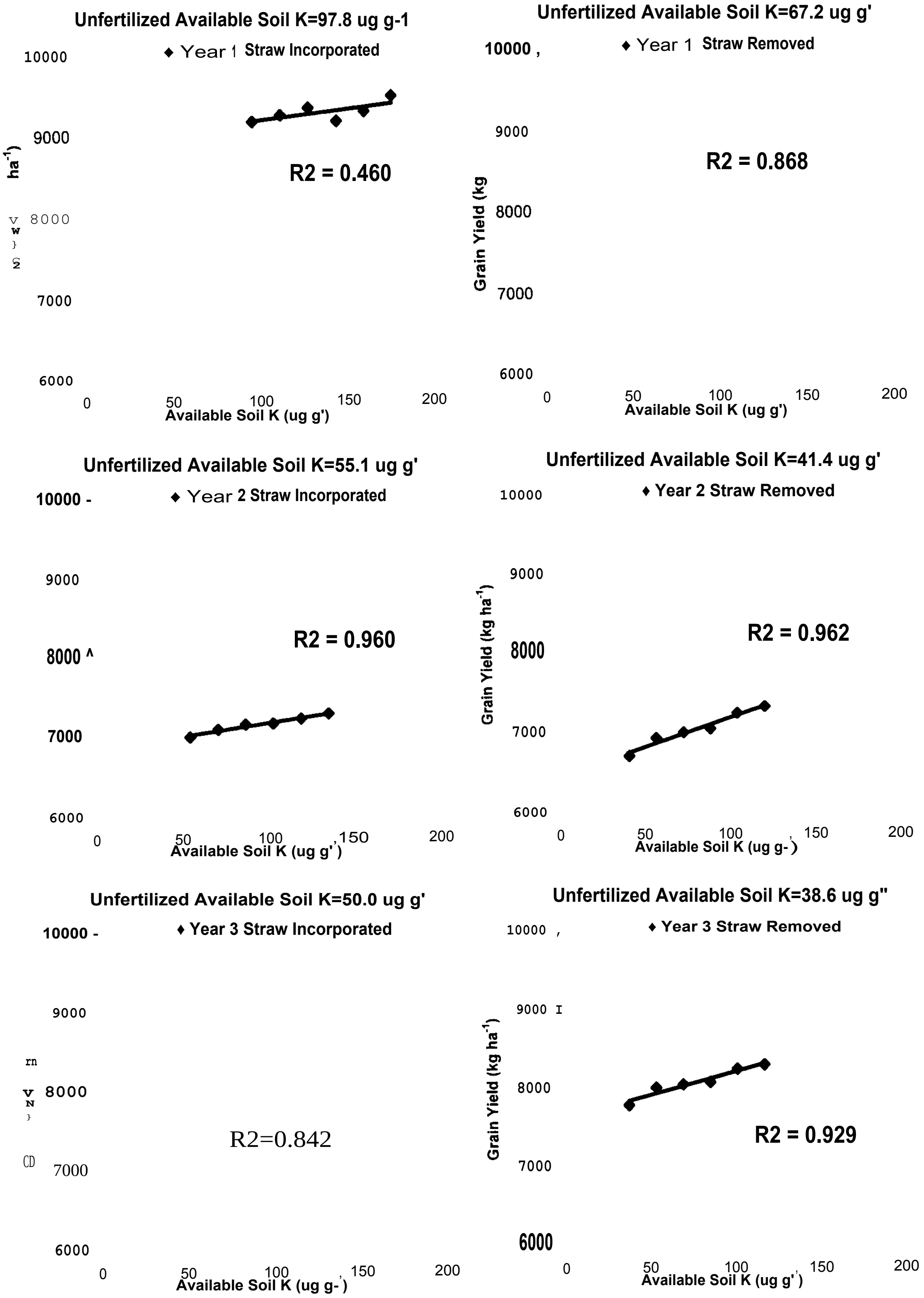

Figure 21. The interrelationship between straw management, available soil K, and grain yield at Mathews Farms.

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