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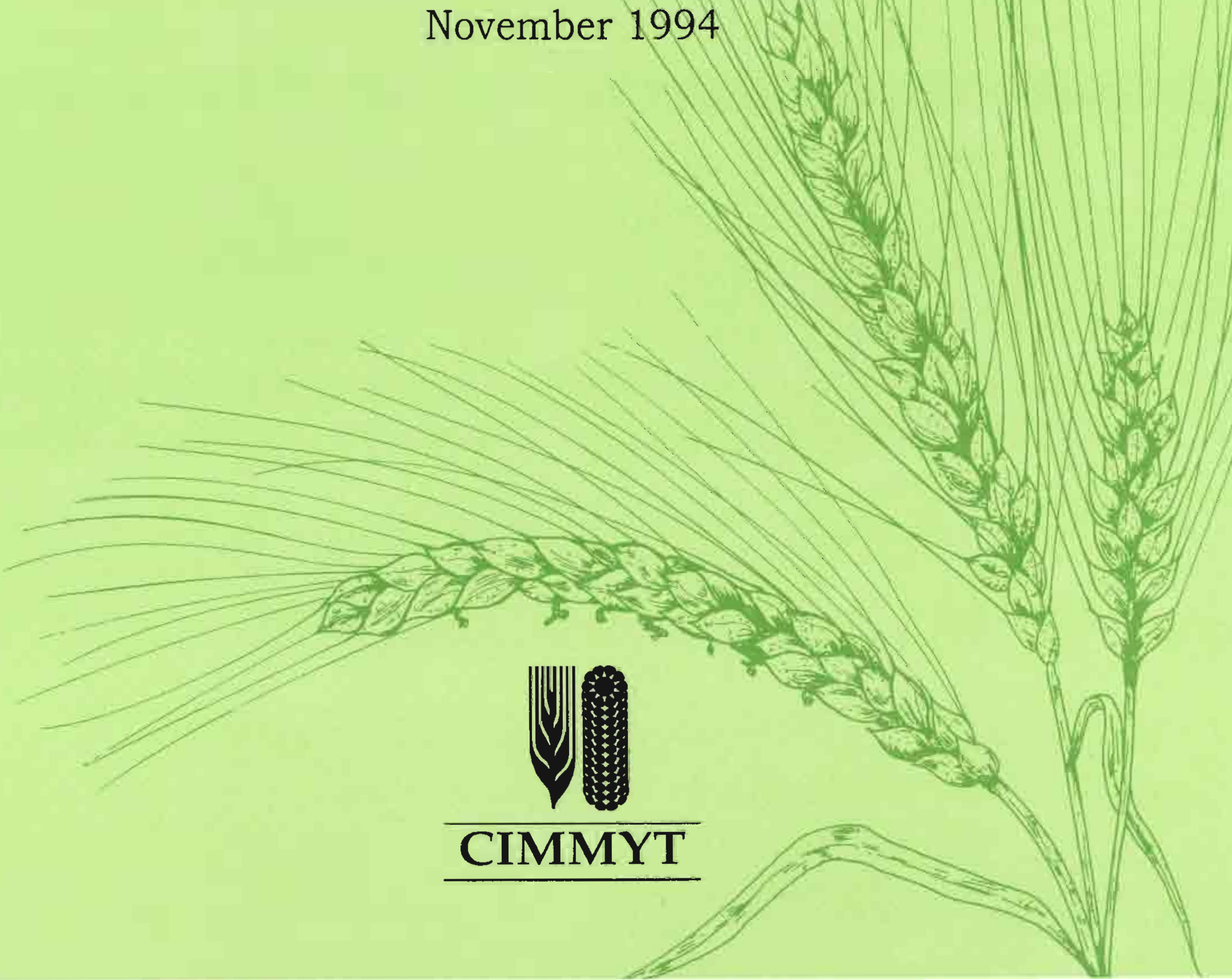

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## Preface

The rice-wheat rotation is a recent phenomenon in South Asia and little is known concerning biotic and abiotic constraints to yield and the sustainability of the system. This Special Report represents an attempt to identify and prioritize some important diseases of wheat in the rice-wheat cropping system of lowland Nepal. The research was a collaborative effort between the National Wheat Research Program (NWRP), the National Agricultural Research Council of Nepal, and CIMMYT's South Asia Regional Wheat Program.

**H.J. Dubin**
Crop Protection Unit
Wheat Program

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## Introduction

Wheat yields in the Tarai (plains) of Nepal are low, about 1.5 t/ha (Anonymous 1990). Average yields on experiment stations are also depressed and declining. Morris et al. (1992) estimated that yield of the major Tarai cultivar, UP262, in variety trials, had declined at a rate of 4.3% per year between 1976 and 1990. These data were based on yields from five experimental stations. Furthermore, **Figure 1** illustrates that yields of advanced wheat lines in uniform yield experiments on the National Wheat Research Program (NWRP) experiment station, Bhairahawa, had declined over the 1980-90 period (H.J. Dubin and R.N. Devkota, unpubl.). The causes for these rather poor yields are not clearly understood although it is thought that management, soil factors, diseases, and the effects of the predominant crop rotation, rice-wheat, may be playing significant roles.

The traditional disease of note in the Tarai area is leaf rust (*Puccinia recondita* Rob. ex Desm.) (Joshi 1986), but in recent years it has been held in check by durable resistance in the predominant cultivar grown by farmers, UP262. Other diseases reported in this area that are associated with important yield losses are Helminthosporium foliar blights (HLB) caused by a combination of *Bipolaris sorokiniana* (Sacc. in Sorok.) Shoem. and *Drechslera tritici-repentis* (Died.) Shoem. (Nema 1986). Based on various surveys, Karki (1981) indicated that *D. tritici-repentis* was the predominant HLB foliar pathogen in the Tarai of Nepal. Although little is known and adequate survey data do not exist concerning soilborne diseases of wheat, observations of roots at the NWRP station showed poor root development due to soil structural problems and associated root and subcrown internode (SCI) necrosis (H.J. Dubin and H.P. Bimb, unpubl.).

There was a need to understand the bases of the apparent wheat yield decline and to prioritize disease research at the NWRP. Thus, studies were carried out principally to determine the following: 1) if soilborne and/or foliar diseases were causing significant yield losses at the NWRP and, if so, how much; 2) to identify and/or confirm the identity of the primary pathogens; 3) to get a preliminary assessment of the importance of these diseases in farmers' fields. Consequently, this special report deals mainly with the biotic factors that appear to be reducing yields. Preliminary reports on the results have been presented (Dubin and Bimb 1991, 1992, 1994).

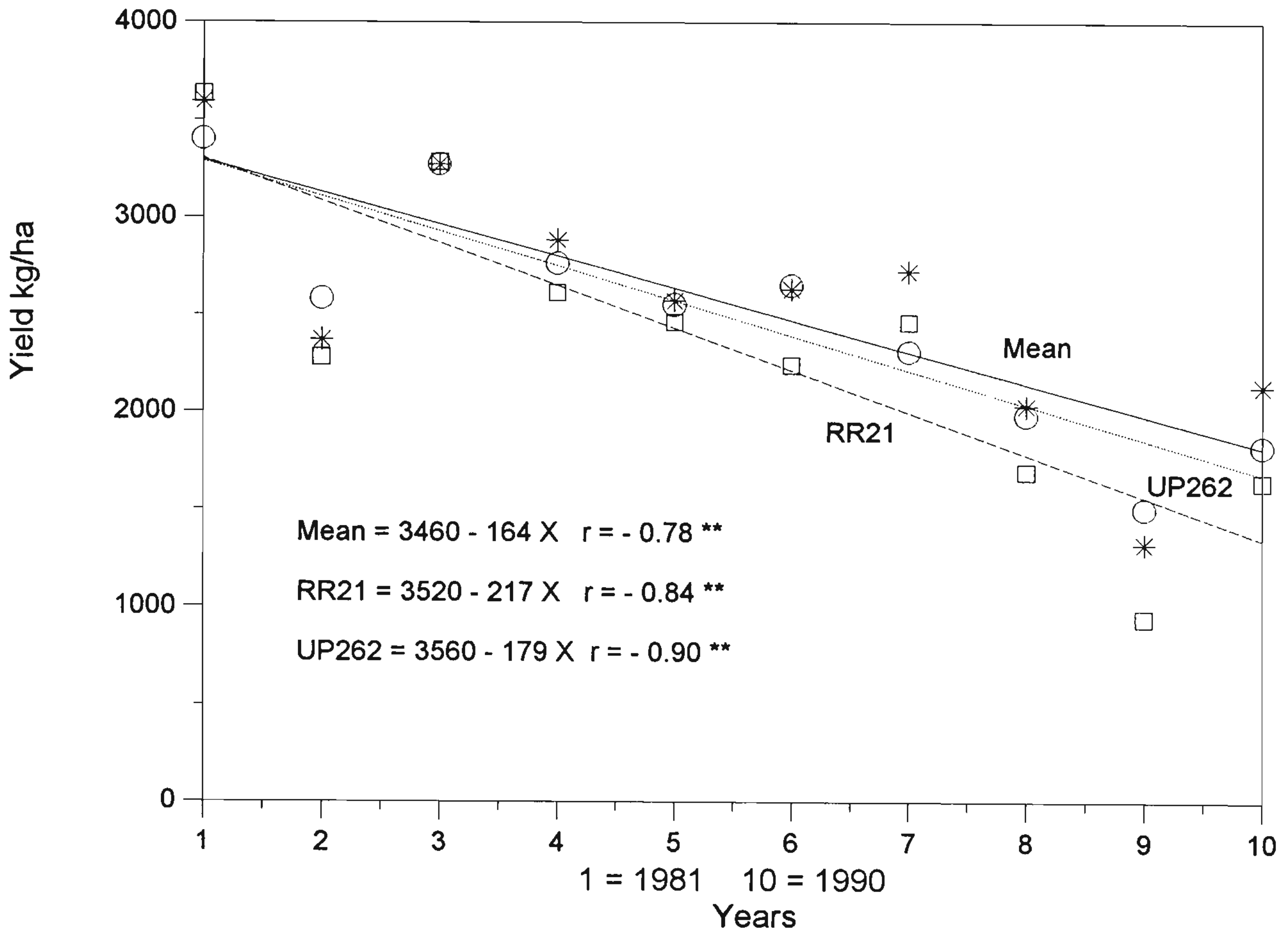


**Figure 1. Wheat yields of Advanced Varietal Trials regressed on the year of the trial over a 10-year period (1981-90). Data from the National Wheat Research Program experiment station. Bhairahawa. RR21 and UP262 are long-term checks and commercial cultivars. Mean = mean yield of 23 advanced wheat lines being tested for good adaptation and yield potential in that particular year.**

## Materials and Methods

### Effects of combined solarization and HLB control on yield and other parameters

All studies reported were done at the NWRP, Bhairahawa, experiment station (105 masl, $27^{o}$ 6' N, $83^{o}$ 4' E) in the Tarai of Nepal or in nearby farmers' fields. **Figure 2** shows the location in Nepal. Soil solarization, rather than fumigation, was used as a tool to control possible soilborne pathogens since it is environmentally friendly and it is not as severe a

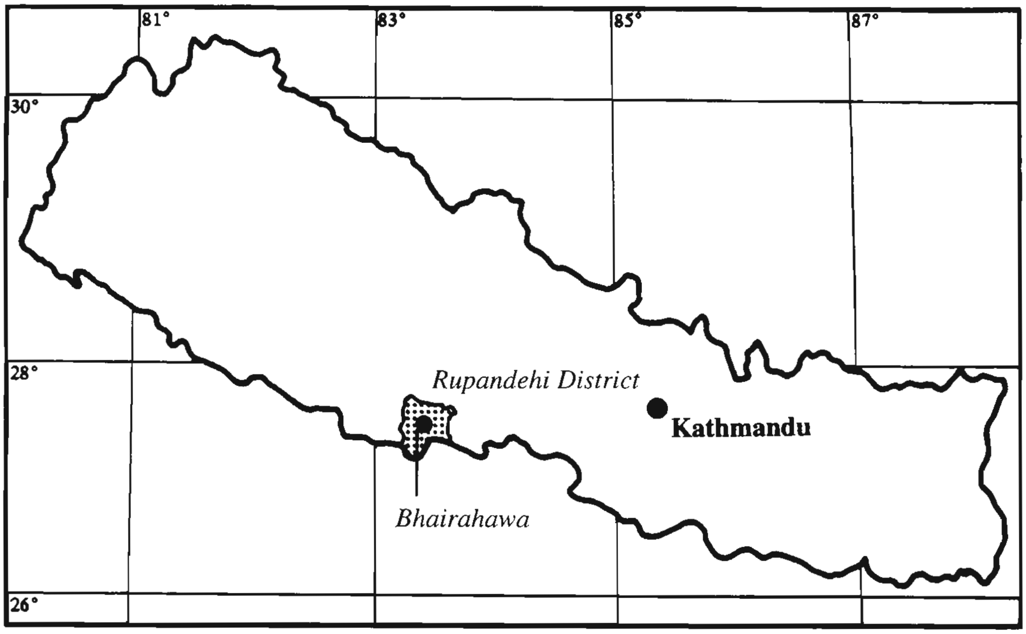


**Figure 2. Map of Nepal showing the town of Bhairahawa in Rupandehi District where the National Wheat Research Program experiment station is located and the reported research was carried out.**

treatment. Propiconazole was used as a foliar spray to control foliar blights since it did not contain any metals that might influence growth and is systemic. Propiconazole also controls leaf rust but cv. UP262 used in all studies was resistant to leaf rust, as noted.

The experiments, in crop years 1987-88 and 1989-90, were laid out in a split plot design with solarization as main plots and propiconazole as subplots. This was done to facilitate irrigation and minimize movement of irrigation water from the plots. In 1990-91, the main plots were sprayed and subplots were solarized. This was done to obtain a more precise estimate of the effects of solarization. In the first two experiments, there were four replications and in the third there were five.

The solarization was done during November for about 30 days using clear polyethylene (PE) sheets about 2 mil thickness. The soil type is a silty clay loam. High residual moisture was present and the rice crop was recently cut. The maximum temperatures recorded under the PE, at the soil surface, varied from $39^{o}$ in 1987-88, $41^{o}$ in 1989-90, and $43^{o}C$ in 1990-91. The solarized plots were aerated for 2, 6, and 7 days in the first, second, and third years, respectively. After aeration all plots were watered to thoroughly wet the soil so that both treatments had about the same moisture levels.

Land preparation was normal for the experiment station. UP262 was hand-planted in the three experiments at 120 kg/ha. Viability was >90%. Fertilizer rate was 120-60-40 (N-$P_2O_5$-$K_2O$). Plot size varied between 8-10 rows by 5 m length (25-cm row spacing) depending on the year. The N rate was considered high for the experiment station, but this was desirable so as to minimize any possible effects of increased N caused by the solarization. Weeding was done by hand. Irrigations were given as needed. Total wheat yield (12% moisture content) was taken from 6-8 $m^2$ of net plot, depending on the year. Components of yield and other parameters were taken from the net area harvested

Propiconazole (Tilt 100EC or 250EC) was sprayed with a backpack sprayer at the rate of 125 cc a.i./ha in 800 L of water. Two sprays were given in 1987-88 at stem elongation (about fourth node) and post flowering. In 1989-90 and 1990-91, four sprays were given. The first at about the fourth node and thereafter every 12 days. Unsprayed plots were protected by PE screens during spraying.

HLB severity was measured with the aid of a standard area diagram, as actual percent necrosis and chlorosis from the flag, flag-1, and flag-2 leaves in 1987-88 and from the flag leaf in the other years. They were read at differing growth stages (GS) between 77-83 each year (Tottman and Makepeace 1979). Four plants from each plot were marked and read. Necrosis severity was taken on roots and subcrown internodes (SCI), if present. The plants were extracted by removing an approximate 400 $cm^2$ and 15-cm deep core of wet soil with the plant. After placing the soil and roots in water, they were washed until the roots were clean. Ten plants from the second row and near the ends of the plot were harvested, rated, and averaged for analysis at GS69-75. The rating scales are as follows: Root rot: 1=10%, 2=20%, 3=30%, 4=40%, and 5=50% necrosis. The SCI scale was 1=clean, 2=slight, 3=moderate, and 4=severe. Root volume was taken as follows: 1=good, 2=moderate, and 3=poor.

Levels of nitrate in the plant tissue were taken at GS65 and in soil using Merck nitrate test kits in 1989-90.

### May soil solarization

These were executed similarly to the November solarization except they were done in May for about four weeks before transplanting rice in late June 1990. The solarization done in 1990 reached a maximum of 52$^{o}$C and the one in 1991 a maximum of 56$^{o}$C under the PE at the soil surface. Rice yields were taken and expressed as paddy at 14% moisture content. Net plot size was 5.7 $m^2$. Nematodes were extracted from the rice roots, at around hard dough stage, in 1990 by shaker technique (Barker 1985), and their genus identified. Species identifications were done by D.J. Hunt (International Institute of Parasitology, UK).

**Residual effects of soil solarization on the following crop**

When possible, residual effects of the soil solarization in November and May were tested by planting the following crop in the sequence. Bunds were maintained and the soil prepared by hand. Planting, harvest, and disease data were taken as previously noted. Results are presented for four November solarizations and two May solarizations.

**Effects of soil solarization on wheat yields and soilborne diseases in farmers' fields**

In November 1989, soil solarizations, ahead of wheat planting, were carried out in three farmers' fields in the Rupandehi District of which Bhairahawa is a part. Methodology for these experiments was as described for the experiment station soil solarization except there were two replications at each site. There were no effects of site and the ANOVA was done as an RCB design with six replications.

**Identification and incidence of root or SCI inhabiting fungi**

Fungi were isolated from roots or SCIs by washing the plant part for several minutes in tap water, then in 0.5% NaOCl for one minute, rinsing in sterile water, and plating on water agar amended with penicillin (100 g/ml), streptomycin (200 g/ml), or Rifampicin (10 g/ml) to reduce bacterial contamination. Hyphal tips or multiple conidia were subcultured to standard one half strength potato dextrose agar (PDA) (Anonymous 1983) and kept at room temperature with natural daylight for identification. Several samples of Fungi Imperfecti were sent to the International Mycological Institute (IMI), UK for identification or confirmation.

$P_{10}VP$ medium was used as the selective medium for *Pythium* spp. identification (Martin 1992). Instead of commercial cornmeal agar, an infusion was made with local corn (30 g) (Anonymous 1983). All *Pythium* spp. were sent for species identification or confirmation to IMI or to F.N. Martin (University of Florida). Where the culture was deposited at IMI, an IMI number is noted in Table 9. *Fusarium* spp. noted in Table 9 were identified or confirmed by L. Burgess, University of Sydney, NSW, Australia. Foliar fungi, specifically *B. sorokiniana* and *D. tritici-repentis,* were identified by standard keys.

Incidence of putative pathogens were determined on roots and SCIs from control plots in the 1990-91 solarization experiments. A total of 250 isolations were made from 50 roots and 167 isolations from 70 SCIs.

**Pathogenicity tests with *B. sorokiniana*.**

The pathogenicity of *B. sorokiniana* as a root pathogen was tested in 1992 in pot trials. Inoculum was prepared by infecting sterilized wheat seed with a typical culture of the fungus isolated from roots. About 200 infected seeds per 30-cm diameter pot were placed in soil at a 4-cm depth. The soil was treated in various ways. Soil was autoclaved, solarized, or natural (field soil without treatment).

Twenty surface-treated (1% NaOCl) wheat seeds were placed in the soil near the infected seed. Controls did not have *B. sorokiniana* added, but were otherwise identical. There were four pots per treatment. The treatments were completely randomized. Data were taken on the necrosis scale noted earlier and seedling emergence determined. The experiment was analyzed as a completely randomized design. Koch's postulates were carried out.

**Conidial counts of *D. tritici-repentis* and *B. sorokiniana* on wheat leaves**

Counts of conidia were taken from leaf surfaces in conjunction with the combined solarization-fungicide experiments over four years. In 1987-88, 1988-89, and 1989-90, counts were taken from four flag leaves per treatment (n = 16) during grain-filling period by using cellophane tape mounts of the entire leaf surface and counting all conidia of *D. tritici-repentis* and *B. sorokiniana* at 100X with a compound microscope. In 1990-91, 3-$cm^2$ random counts from each leaf surface were made (n = 20).

### Conidia dispersal study

An aerobiology study was made of the conidial dispersal of both HLB pathogens between mid-December 1987 and mid-May 1988. Four petroleum jelly-covered microscope slides were placed vertically on 1-m high poles around the control plots of the combined solarization-propiconazole experiment. They faced into the prevailing westerly winds. The slides were changed every two or three days and conidia were counted on the entire surface (19 $cm^2$) at 100X under a compound microscope. Lactophenol cotton blue was used as a mountant. The means of conidia on the four slides are presented for the Julian Day that the slides were removed. Rainfall, mean air temperature, and relative humidity (RH) were taken and are presented on the same basis as the conidial dispersal.

### Statistical analysis

Where appropriate, all treatments were analyzed for significance by ANOVA. In the split plot analyses, where interactions were not significant, only the average effects data are presented. Significant differences were measured by F-test, LSD, *t* test, or Chi-square test as noted. Angular transformations were done on percentage data and square root transformation on nematode counts. In some cases where main effects were not additive, a log transformation was done. Original data are presented.

## Results

### Combined solarization and HLB control experiment

*Effects of solarization and HLB control on yield*--In the three years of experiments, both November solarization and fungicidal control of HLB gave significant increases in yield. There was no interaction between the treatments and average effects are presented (**Table 1**). Preliminary observations indicate that solarization affects soilborne pathogens and may also be influencing the soil nutritional status as well as structure. Nitrogen is reported in the literature to be increased by solarization (Chen et al. 1991). However, we feel that major nutrients are not of importance since we are applying ample levels of N-P-K (see section on nitrate). The data show that the effect of spray on yield is greater than solarization, except in 1987-88. Other studies done at the NWRP support this. The largest increase in yield with a November solarization was 18% in 1987-88 and with foliar treatment it was 37% in 1989-90. Based on the above, it is concluded that HLB is causing greater yield losses (average of 22%) than soil-mediated problems (average of 9%) on the NWRP experiment station. It should be noted that the literature regarding solarization deals with increases in yields rather than using it as a tool for estimating yield losses (Katan and DeVay 1991a).

**Table 1. Effects of November soil solarization and foliar fungicide application on wheat yields during 1987-88, 1989-90, and 1990-91.[1]**

| | Yield (kg/ha) | | |
|---|---|---|---|
| Treatments | 1987-88 | 1989-90 | 1990-91 |
| Solarized | 3038a | 3607a | 3267a |
| Nonsolarized | 2582b | 3391b | 3034b |
| Yield loss, % | 15 | 6 | 7 |
| Propiconazole | 3004a | 4044a | 3600a |
| Unsprayed | 2616b | 2954b | 2701b |
| Yield loss, % | 13 | 27 | 25 |

[1] Principal foliar pathogen in 1987-88 = *Drechlera tritici-repentis* and *Bipolaris sorokiniana* in 1989-91. Treatment interactions nonsignificant. Average means presented. Means in columns followed by different letters significantly different at P≤0.05.

We refer to our results in both ways at times in this special report since both are of interest.

*Effects of solarization and HLB control on yield components and plant height*--**Table 2** summarizes the effects of solarization and propiconazole on yield components and height in the three yield experiments. In all experiments, there was no interaction between solarization and propiconazole. Yields based on components were significantly correlated with total yield data. In 1987-88, solarization had a significant effect on spikes/$m^2$, grains/spike, and plant height. Fungicide increased grains/spike, and thousand grain weight (TGW). Significant effects of fungicide were seen on grains/spike, TGW, and plant height in 1989-90. Solarization increased spikes/$m^2$, grains/spike, and height in 1990-91 whereas fungicide increased spikes/$m^2$, grains/spike, and TGW.

**Table 2. Effects of soil solarization and foliar fungicide application on wheat yield components and height, 1987-88, 1989-90, 1990-91[1].**

| | 1987-88 | | | | 1989-90 | | | | 1990-91 | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Treatments | Spikes /$m^2$ | Grains/ spike | TGW (g) | Plant Ht.(cm) | Spikes /$m^2$ | Grains/ spike | TGW (g) | Plant Ht. (cm) | Spikes /$m^2$ | Grains/ spike | TGW (g) | Plant Ht. (cm) |
| Solarized | 322a | 35a | 34a | 94a | 312a | 36a | 43a | 84a | 282a | 28a[3] | 45a | 81a |
| Nonsolarized | 294b | 33b | 34a | 89b | 303a | 35a | 42a | 83a | 248b | 30b | 44a | 77b |
| Propicon-azole | 307a | 35a | 35a | 91a | 317a | 34a[2] | 48a | 84a | 272a | 30a | 49a | 80a |
| Unsprayed | 309a | 33b | 32b | 92a | 298a | 36b | 37b | 82b | 258b | 29b | 40b | 78a |

[1] Principal foliar pathogen in 1987-88 = *Drechslera tritici-repentis* and *Bipolaris sorokiniana* in 1989-91. Treatment interactions nonsignificant. Average means presented. Means in columns followed by different letters significantly different at P≤0.05 except where noted.
[2] P=0.09.
[3] P=0.06.

*Effects of solarization and propiconazole on HLB control*--Several points are of interest. First, propiconazole gives excellent control of HLB. Second, in two of three experiments, solarization significantly reduced the level of HLB (**Table 3**). Data from May solarizations presented later support this observation.

*Effects of solarization and propiconazole on root and SCI necrosis and root volume*--These data were only taken in 1990-91 in the November combination solarization and fungicide experiment (**Table 4**). Propiconazole and solarization both reduced root necrosis significantly. SCI necrosis was significantly reduced by solarization but not fungicide. Root volume was increased by fungicide and solarization.

*Levels of nitrate in soil and stems of plants in the solarization-propiconazole studies*--Levels of nitrate were measured in the stems of all treatments and there were no significant differences in the 1990-91 experiment. Nitrate in plant stems ranged from 1400-1525 mg/kg of plant tissue. Solarized soil had less nitrate than nonsolarized (62 vs 66 kg/ha, P=0.07). Samples were taken at about GS65.

**Soilborne disease studies**

*Emergence of seedlings from plots with and without solarization and stand establishment problems*--In 1987-88, total emergence was 287 seedlings/m$^2$ in the November nonsolarized plots and 253 in the solarized ones. This same relationship existed in other years. This may be due to insufficient aeration of the soil after solarization even though it was aerated generally 2-7 days after removing the PE tarp. Where emergence of wheat seedlings was determined in experiments with May solarization, there was no significant effect of solarization on emergence. Thus, the negative effect appeared transient. However, a series of May 1991-92 solarization studies carried out in farmers' fields and the experiment station indicated significant increases in emergence of wheat seedlings (M. Ruckstuhl, pers. comm.). Further studies are needed to clarify these conflicting results, but in general, the density responses were small and unlikely to affect yield by themselves.

Plant emergence has been a common problem in experiments at the NWRP. Initial stand counts should be about 300 plants/m$^2$, but are very often less than 200. Between 1987 and 1989, seed and soil treatments were carried out to see if fungi, insects, or nematodes were involved in stand or emergence problems. Treatments with triadimenol, carbendazim, metalaxyl, thiram, carboxin, phenamiphos, and carbofuran did not increase stand count.

**Table 3. Effect of November soil solarization and foliar fungicide application on HLB (%), 1987-88, 1989-90, 1990-91.[1]**

| Treatments | 1987-88 | 1989-90 | 1990-91 |
|---|---|---|---|
| Solarized | 25a | 46a | 19a |
| Nonsolarized | 39b (P=0.07) | 51a | 25b |
| Propiconazole | 17a | 9a | 1a |
| Unsprayed | 47b | 88b | 42b |

[1] Principal foliar pathogen in 1987-88 = *Drechslera tritici-repentis* and *Bipolaris sorokiniana* in 1989-91. Treatment interactions nonsignificant. Average means presented. Means in columns followed by different letters significantly different at $P \leq 0.05$ except where noted.

[2] In 1987-88 data taken from flag, F-1, and F-2 leaves at various growth stages. In other years data from flag leaf only. Percentages transformed to arcsine for ANOVA. Data presented are original percentages.

**Table 4. Effect of November solarization and foliar fungicide application on root and subcrown internode necrosis (SCI) and root volume, 1990-91.[1]**

| Treatments | Root necrosis | SCI necrosis | Root volume |
|---|---|---|---|
| Solarized | 1.7a | 2.4a | 1.9a |
| Nonsolarized | 2.3b | 2.9b | 2.4b |
| Propiconazole | 1.9a | 2.5a | 2.0a |
| Unsprayed | 2.2b | 2.8a | 2.3b |

[1] Treatment interactions nonsignificant. Average means presented. Root necrosis rated on a scale of 1-5, SCI necrosis rated on a scale of 1-4, and root volume rated on a scale of 1-3. In all cases 1 is best. See text for detailed description of scales.Means in columns followed by different letters significantly different at $P \leq 0.05$.

Further studies in farmers' fields in 1990 with diverse seed and soil treatments also resulted in no stand increase (M. Ruckstuhl, pers. comm.).

*Solarization done in May and effects on rice crop and rice root nematodes*--Solarization in May, before late June transplanting of paddy rice, provides a significant yield increase as well as reduces common root pathogens of rice, *Hirschmanniella oryzae* (van Breda de Haan) Luc & Goodey and *H. mucronata* (Das) Luc & Goodey (**Table 5**). The correlation

**Table 5. Effect of May soil solarization on rice yield and rice root nematodes, 1990.**[1]

| Treatments | Yield (kg/ha) | Rice root nematodes Number/10 g root |
|---|---|---|
| Solarized | 7062a | 38a |
| Nonsolarized | 5896b | 409b |

[1] Rice root nematodes = *Hirschmanniella oryzae* and *H. mucronata*. Solarization done one month before transplanting rice into plots. Means in columns followed by a different letter are significant at the P≤0.01.

between nematode number and yield is significant (r = - 0.80, P<0.02, n = 8). Soil temperatures during solarization were considerably higher at this time compared to November solarization. A yield loss attributable to the root nematodes and possibly other causes would have been 17% without solarization.

*Residual effects of solarization on succeeding crops*--In all experiments, a positive residual effect was observed in the succeeding crop. **Table 6** presents the positive residual effects from November solarization, before wheat seeding, on the yield of the following rice crops planted in June of the next year. However, the increase is not always significant. In May solarization, done before rice planting, the succeeding wheat crops had significant yield increases. **Tables 7** and **8** are from experiments in 1990-91 and 1991-92 showing the effects on yield and yield components as well as height and disease in the following wheat crop. Several points are noteworthy. In the May solarization, spikes/m$^2$ and height are consistently increased as in November ones. HLB, root, and SCI necrosis are reduced by solarization. Table 7 also shows a significant increase in root volume due to solarization.

**Table 6. Residual effects of November wheat soil solarizations, before wheat planting, on the 1988-91 rice crops.**[1]

| | Yield (kg/ha) | | | |
|---|---|---|---|---|
| Treatments | 1988 | 1989 | 1990 | 1991 |
| Solarized | 4033a | 4151a | 4313a | 4680a |
| Nonsolarized | 3589b | 3470b | 4085a | 4350a |

[1] Rice planted after wheat harvest into plots of the solarization experiments about seven months after solarization. Means followed by different letters in the same columns significantly different at P=0.05.

**Table 7. Residual effects of May 1990 soil solarization, before rice planting, on the following wheat crop, 1990-91.[1]**

| | Solarized | Nonsolarized |
|---|---|---|
| Yield (kg/ha) | 3116a | 2355b |
| Spikes/$m^2$ | 344a | 280b |
| TGW (g) | 35a | 33a |
| Grains/spike (P=0.10) | 28a | 25b |
| Height (cm) | 87a | 80b |
| Root necrosis | 1.3a | 2.1b |
| SCI necrosis | 1.8a | 2.6b |
| Root volume | 1.4a | 2.2b |
| HLB | 28a | 44b |

[1] Values across columns followed by a different letter significantly different at P<0.05 unless noted. Root necrosis scale 0-5 where 0=clean and 5=severely infected; SCI scale 1-4 where 1=clean and 4=severely infected; Root volume scale 1-3 where 1=good and 3=poor. Complete scales in text. HLB=percent necrosis of flag leaf at GS77.

**Table 8. Residual effects of May 1991soil solarization, before rice planting, on the following wheat crop, 1991-92.[1]**

| | Solarized | Nonsolarized |
|---|---|---|
| Yield (kg/ha) | 4531a | 4029b |
| Spikes/$m^2$ (P=0.06) | 408a | 350b |
| TGW (g) | 43a | 40b |
| Grains/spike | 32a | 32a |
| Height (cm) | 105a | 98b |
| Root necrosis | 0.88a | 2.64b |
| SCI necrosis | 2.08a | 2.80b |
| HLB | 11a | 16b |

[1] Values across columns followed by a different letter significantly different at P≤0.05 unless noted. Root necrosis scale 0-5 where 0=clean and 5=severely infected; SCI scale 1-4 where 1=clean and 4=severely infected; Root volume scale 1-3 where 1=good and 3=poor. Complete scales in text. HLB=percent necrosis of flag leaf at GS75.

*Effects of solarization on wheat yields and root rots in farmers' fields*--In 1989-90, November solarization were carried out in three farmers' fields in Rupandehi District. The results supported those in the experiment station, but the yield responses were not as great, 3225 vs 3100 kg/ha (P = 0.11), for solarized and nonsolarized, respectively. However, root necrosis and SCI necrosis were clearly reduced by solarization, 1.5 vs 2.7 ($P = 0.01$), and 2.1 vs 2.9 ($P = 0.05$), respectively.

*Yield loss due to root necrosis*--A combined regression analysis of three years of data from three solarization experiments (November 1989, May 1990, and November 1990) on the effects of root necrosis on yield are presented in **Figure 3**. Three years of data were combined to obtain a good range of root necrosis. A significant negative linear relationship and correlation are observed ($r = -0.77$, $P<0.01$, $n = 26$). If yield in the solarized and nonsolarized plots are partitioned and regressed separately on necrosis, the linear regressions are also significant and the slopes are homogeneous, however, the intercepts are significantly different. This indicates that, although necrosis is the principal factor affecting yield, there are other soil factors involved also.

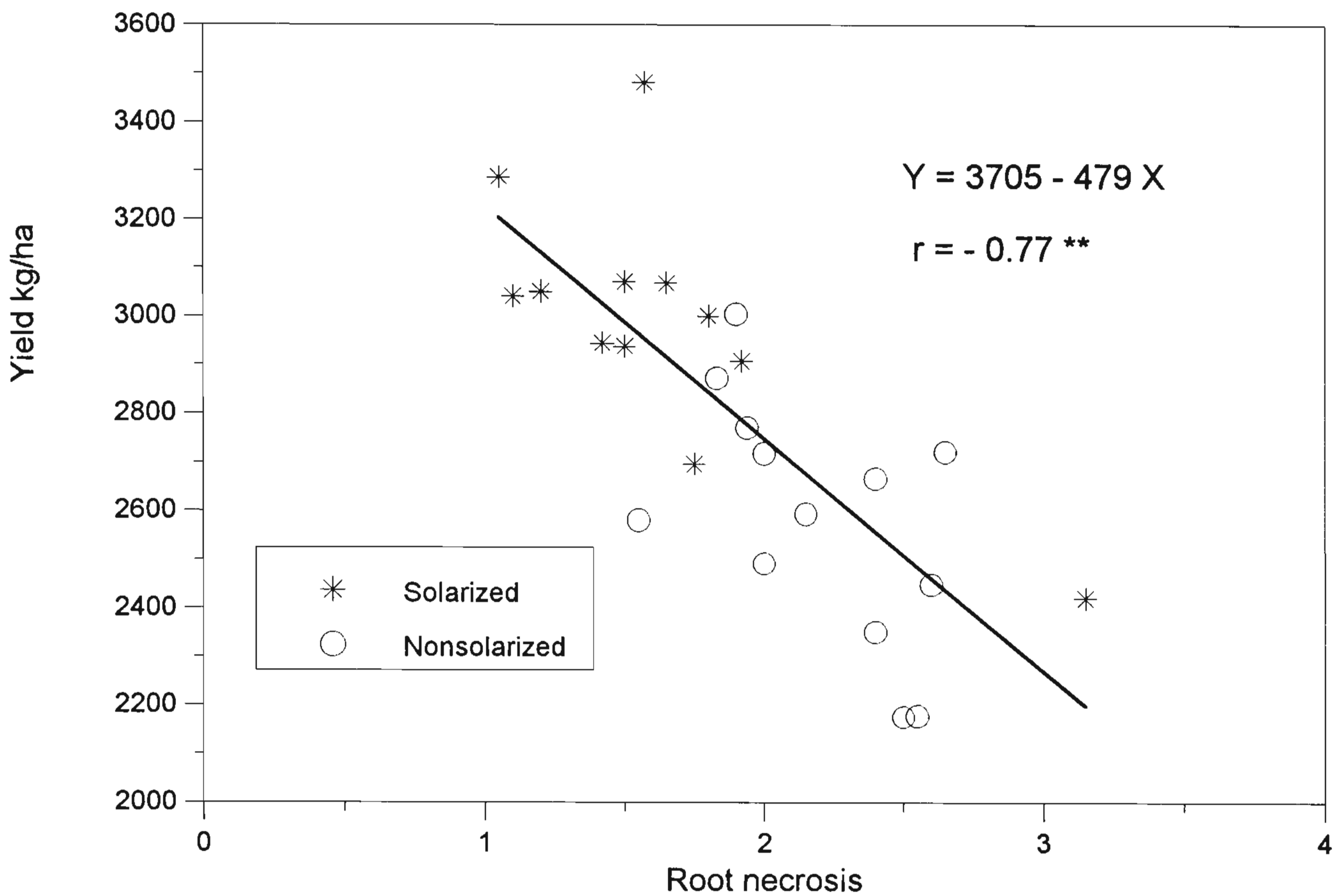


**Figure 3. Simple linear regression of yield on root necrosis at the National Wheat Research Program experiment station. The data are combined from three separate solarization experiments done in November 1989 and 1990.**

*Fungi isolated from necrotic lesions of wheat roots and SCIs, 1989-92*--Isolations of fungi from control plots of the solarization experiments were done in an attempt to determine putative pathogens. **Table 9** presents data on the species of fungi found over the years. *B. sorokiniana* was the most common known pathogen of wheat found in roots and especially in SCIs. Several *Pythium* spp. were found and are of interest since typical watery root rot symptoms containing oospores were associated with these isolations. Both *P. graminicola* and *P. aristosporum* are known pathogens of wheat. *P. spinosum* is a pathogen of rice but is not reported to be a pathogen on wheat, as far as we know. *Sclerotium rolfsii* was isolated infrequently, but is a common root rot pathogen in the region in the warmer areas. A common *Fusarium* observed in roots was *F. nygamai*. This species had not been identified in South Asia previously and was not known to be associated with wheat (L. Burgess, pers. comm.). *Curvularia* spp. were observed at a low level. Other putative pathogens were seen infrequently.

*Percent incidence of fungi isolated from necrotic roots and SCIs in control plots of solarization experiments--Fusarium* spp. predominated on roots and *B. sorokiniana* did on SCIs (**Table 10**). The individual *Fusarium* species was not identified in this case. *B. sorokiniana* was second in number on roots and *Fusarium* second on SCIs. Ten percent of the isolations on roots were *Pythium* spp. Since selective media were not used in this case,

**Table 9. Fungi isolated from necrotic lesions of wheat roots and subcrown internodes at NWRP, 1989-92.[1]**

+ *Bipolaris sorokiniana* (Sacc. in Sorok.) Shoem.
+ *Pythium aristosporum* Vanterp. (IMI 357264)
+ *P. graminicola* Subr.
+ *Curvularia* sp.
+ *Periconia macrospinosa* Lefebvre & A.G. Johnson
+ *Rhizoctonia* sp.
+ *Sclerotium rolfsii* Sacc.
? *Alternaria* sp.
+ ? *Fusarium nygamai* Burgess & Trimboli
? *F. moniliforme* Sheldon
? *F. solani* (Mart.) Appel & Wollenw. emend Snyder & Hanson
? *Phoma levellei* Boer. & G.J. Bollen (IMI 348205)
? *P. spinosum* Sawada (IMI 357266)
- *F. oxysporum* Schlect. emend Snyder & Hanson
- *Myrothecium verrucaria* (Alb. & Schw.) Ditm. ex Fr.

[1] + = Known pathogen of wheat; - = Not known pathogen of wheat; ? = Not sure.

**Table 10. Percent incidence of fungi isolated from roots and subcrown internodes in control plots of solarization-fungicide experiments, 1990-91.[1]**

| Fungus | Roots | Subcrown internodes |
|---|---|---|
| *Bipolaris sorokiniana* | 21 | 59 |
| *Fusarium* spp. | 50 | 31 |
| *Pythium* spp. | 10 | - |
| *Curvularia* spp. | 12 | 6 |
| *Alternaria* spp. | 4 | - |
| *Bipolaris* spp. | 3 | 3 |

[1] Total number of roots observed = 50: Total number of isolations = 248. Total number of subcrown internodes observed = 70: Total number of isolations = 167.

this may be an underestimate. These data should be considered as a preliminary estimate of the presence of the fungi.

*Pathogenicity of some key soil fungi on wheat roots*--Pathogenicity tests showed that *B. sorokiniana* was highly pathogenic to wheat roots. In various soil treatments, there was significant necrosis and reduction of seedling number (**Table 11**). The highest level of

**Table 11. Pathogenicity of *Bipolaris sorkiniana* (BS) on wheat roots with various soil treatments.**

| Soil treatment | Root necrosis[1] | Plants/pot[2] |
|---|---|---|
| Solarized + BS | 1.05* | 8** |
| Solarized - BS | 0.83 | 15 |
| Autoclaved + BS | 1.75* | 8** |
| Autoclaved - BS | 0.50 | 14 |
| Natural soil + BS | 1.40* | 13** |
| Natural soil - BS | 0.83 | 17 |

[1] * = root necrosis significantly different from check (-BS) at P=0.05. Analysis done on log transformed root necrosis scale to correct for non-additivity. Original data shown. Roots rated at boot stage as follows: 0 = clean; 1 = 10%; 2 = 20%; 3 = 30%.

[2] ** = plants survived significantly different from check (-BS) at P<0.005. Determined by Chi square analysis. Twenty seeds were placed in each pot.

root necrosis was in autoclaved soil. Solarized soil had the least necrosis although it was still significantly higher than the control. Preliminary pathogenicity tests of the three fusaria, (*F. nygamai, F. solani, F. oxysporum*) commonly isolated, showed that only *F. nygamai* produced clear cut necrosis on wheat roots, but not as severe as *B. sorokiniana*. *Pythium spinosum* and *P. aristosporum* did not cause damping off or root necrosis of wheat seedlings in preliminary tests. *P. graminicola* was not tested due to bacterial contamination. Further tests are required to confirm the results presented.

**Foliar blight studies**

*Potential yield losses caused by HLB*--Data from the fungicide trials in 1989-90 provided a sufficient range of disease to be able to regress yield on HLB. **Figure 4** shows that, for each percentage point of HLB, 62 kg/ha of yield is lost (r = - 0.85, P = 0.01, n = 16). In other years, the range in disease levels in sprayed and unsprayed plots did not allow a clear linear relationship to be drawn although negative correlations were significant.

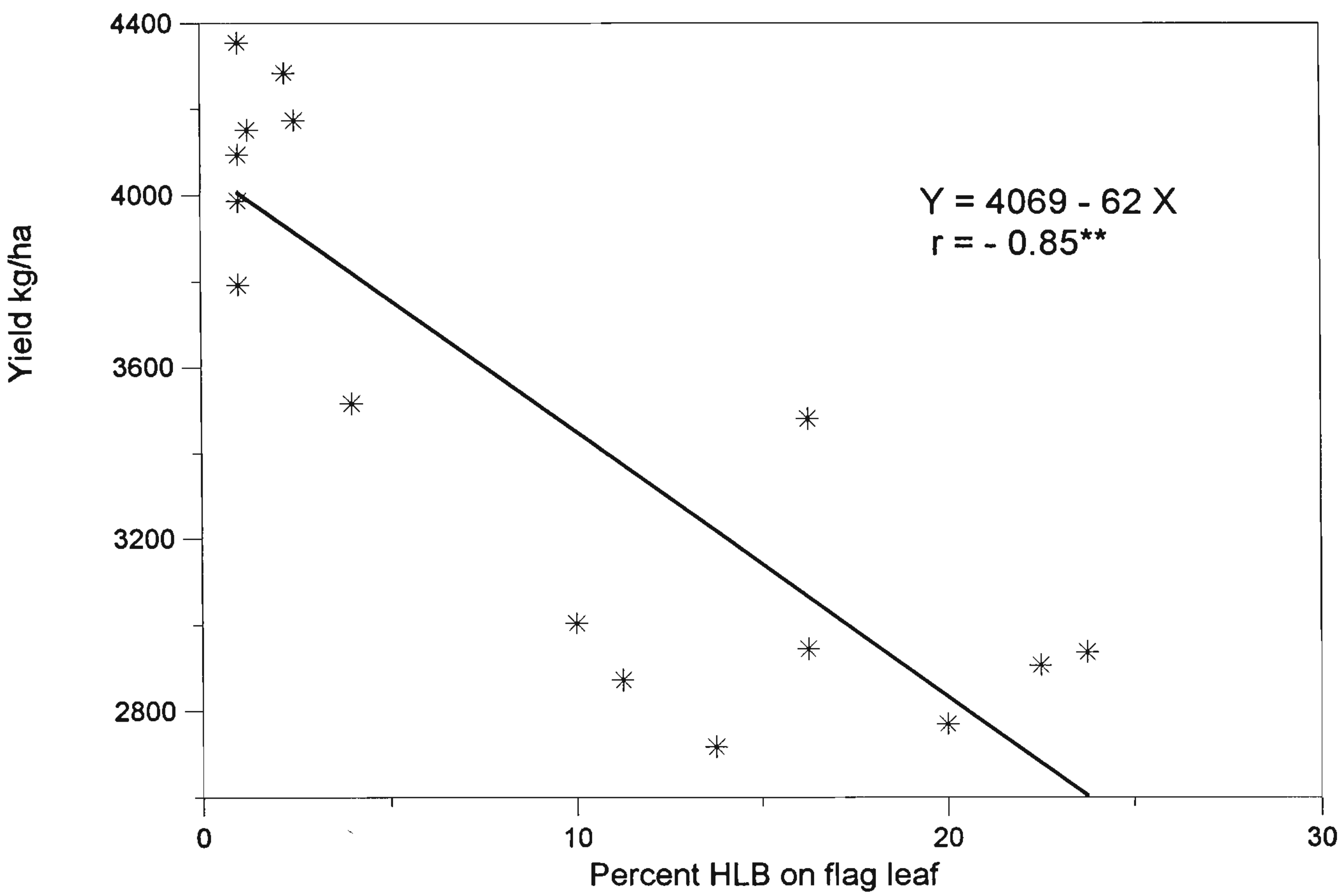


**Figure 4. Simple linear regression of yield on percent of Helminthosporium leaf blight at the NWRP experiment station, 1989-90.**

*Conidial counts on leaf surfaces*--Early surveys indicated that the principal HLB pathogen observed in the Nepal Tarai was *D. tritici-repentis* (Karki 1981). Our observations supported this. However, in the 1989-90 growing season, it appeared that *B. sorokinina* increased relative to *D. tritici-repentis*. Counts of conidia on leaf surfaces in conjunction with the combined solarization and foliar spray experiments supported these observations (**Table 12**). Indeed, since 1990 *B. sorokiniana* has predominated in the experiment station and in Rupandehi District. Circumstantial evidence indicates that this change is associated with a higher than normal average night-time temperatures in January 1990 (9.5 vs 8.0°C).

*Conidia dispersal study*--Conidia sampling started in the mid-December 1987 and was terminated on 15 May 1988. Very low quantities of spores of both fungi were trapped in mid-December through about Julian Day 45 (14 February) when there was an increase in both fungi. Although low, *B. sorokiniana* predominated earlier in the season. We hypothesize that, in December-January, conidia came from soil or residues since the wheat experiments had only recently been planted and there were no plants with sporulating lesions observed. *D. tritici-repentis* inoculum most probably came from residues or weed hosts and also had its first peak on day 45. **Figure 5** is plotted from Julian Day 1 (January 1) since so few conidia were obtained in December. It clearly shows the rapid production and dispersal of conidia of both fungi from day 55, just after heading of the wheat in the experiments. Several key observations may be made from Figure 5. It is clear that rainfall

**Table 12. Conidial counts on wheat leaves of *D. tritici-repentis* and *B. sorokiniana* between 1987-88 and 1990-91.[1]**

| | 1987-88 | 1988-89 | 1989-90 | 1990-91 |
|---|---|---|---|---|
| *D. tritici-repentis* | 5577a (89%)[2] | 528a (84%) | 1140a (25%) | 69a (5%) |
| *B. sorokiniana* | 684b (11%) | 101b (16%) | 3385b (75%) | 1496b (95%) |

[1] Data taken on four flag leaves per plot (n = 16 ) at various growth stages. In 1987-88 to 1989-90 figures represent conidia on the entire leaf surfaces. In 1990-91, numbers represent average random counts of 3 $cm^2$ of leaf surface. Percentages of total conidia are in parentheses. Counts should only be compared within each year.

[2] Counts in columns followed by a different letter are significantly different at P<0.05. Data were transformed from percentages to arcsine. Original data presented.

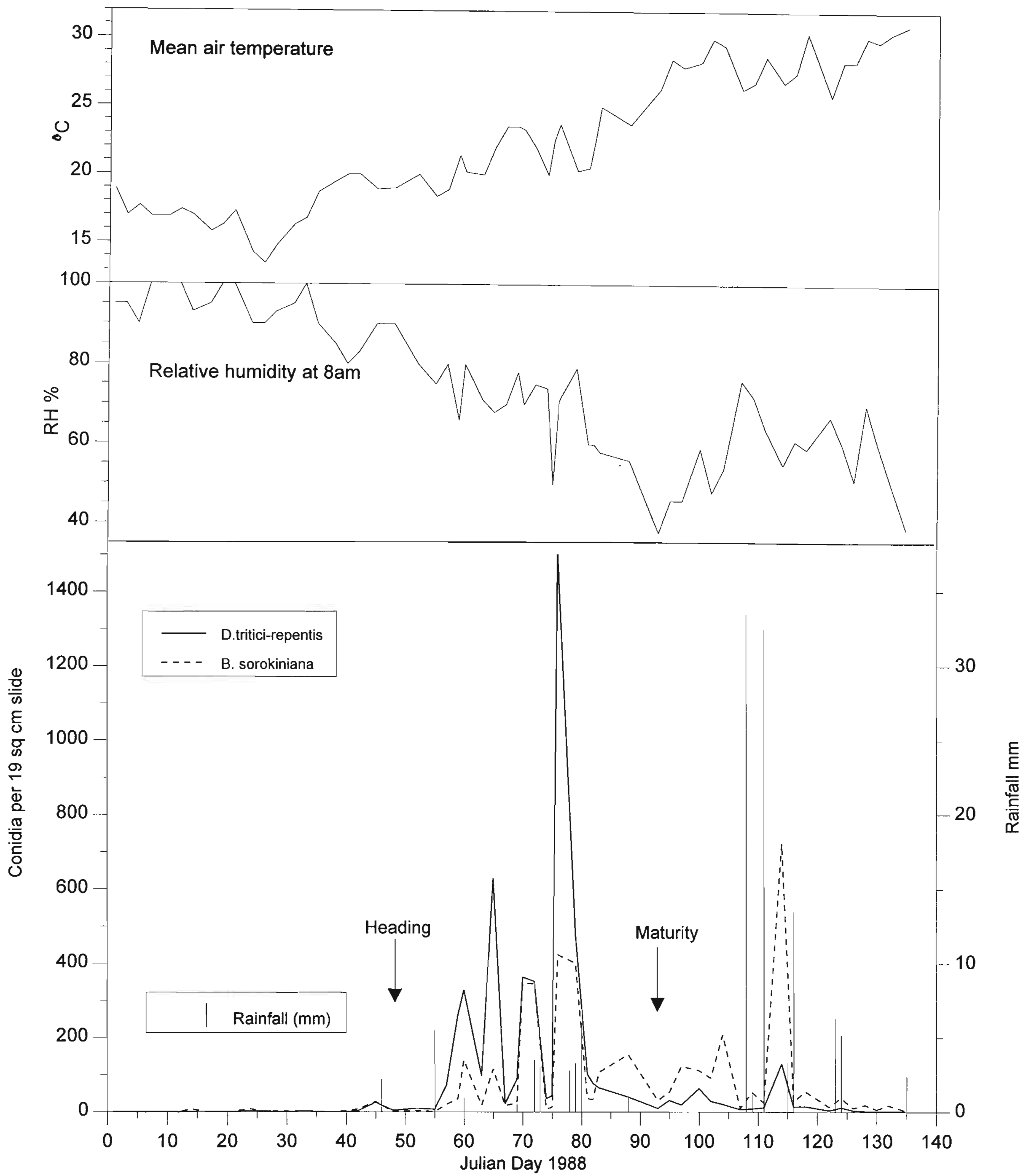


**Figure 5. Conidia dispersal of *D. tritici-repentis* and *B. sorokiniana*, mean air temperatures, and relative humidity (around 8 a.m.), from mid-December 1987 to mid-May 1988 at the NWRP experiment station.**

is important for spore production. Even 1 mm of rain appeared to induce production. Peak dispersal periods were associated with drops in RHs and concomitant winds, which are common at this time of year. Higher temperatures favored the high levels of *B. sorokiniana* in April, almost one month after maturity. Starting in February, *D. tritici-repentis* had higher levels of dispersal and this coincided with high levels of blight on the foliage. Both fungi had peaks at the same time before maturity. Higher levels of *B. sorokiniana* were only observed close to harvest and after.

The RH data in Figure 5 indicate several periods of free moisture due to dews/fog in January and, although the temperatures were low, infection most probably was occurring at this time when dews are most frequent. In February, lower leaves of the plants began to show HLB lesions.

## Discussion

Solarization was used as a tool to estimate actual losses due to soilborne pathogens. As with fumigation or other chemical controls, solarization has limitations in determining losses. It not only affects microorganisms but may modify soil nutrient levels and composition as well as soil structure (Chen et al. 1991). The length of solarization and temperatures reached will influence the effectiveness of control and collateral factors. However, its advantages are that it is not as severe a treatment as fumigation and is environmentally friendly. Thus, it is a reasonable method to estimate losses, acquire attainable yield information, and at the same time provides data on its possible use as an economic way to increase yields.

Propiconazole is a curative-preventative triazole that inhibits ergosterol synthesis in fungal cell walls. Preliminary studies had shown that it did not interact with cultivars and, further, does not contain any microelement type metal compounds (Microelement deficiencies appear as possible factors in low yields besides biotic ones in this region).

Our results of 6-15% losses (Table 1) due to soilborne factors may be considered conservative since the level of solarization given was mild based on the maximum temperatures observed in the literature (around $50^{o}C$) (DeVay and Katan 1991). Furthermore, completely clean roots are never obtained with solarization as noted in Figure 3. If the relationship in Figure 3 is extrapolated to O% necrosis, the loss estimate would be 20%. Since it is known that solarization will affect the chemical composition in the soil

(Chen et al. 1991), it is of value to note that Tables 4, 7, and 8 and Figure 3 show a significant decrease of necrosis of roots and SCI with solarization. There are significant negative correlations of necrosis with yield ($r = -0.82$, $P<0.01$, $n = 10$), and SCI necrosis vs yield ($r = -0.77$, $P<0.05$, $n = 10$) for the data in Table 4. Thus, it is reasonable to conclude that the major effect we observe on yield, from solarization, is a reduction of soilborne pathogens affecting the root system. Although solarization experiments with wheat are uncommon, Smith et al. (1984) and Katan and DeVay (1991b) report significant increases in wheat yields due to control of soil pathogens and nematodes, respectively.

Propiconazole control of HLB provides a clear picture of the losses due to this disease complex at the NWRP with an average loss of 22%. Taken together, average yield losses are greater than 30%. Average yield of wheat experiments at NWRP are presently around 3 t/ha. Control of these diseases would indicate an attainable yield level of at least 4.3 t/ha. We hypothesize that with improved soil and crop management and disease control, the attainable yield levels would be above 5 t/ha.

Differences in treatment effects over the years may be partially due to modifications in methodology as well as environment. In the second and third years, additional propiconcazole sprays were given for better control of HLB. In the third year, there were five replications and the main plots and subplots were switched to more precisely measure the effects of solarization. Solarization may have a bigger effect in a poor yield year. Furthermore, 1989-90 was an optimal year for wheat yields with an overall cool season and rain in February.

Solarization more consistently increased fertile tiller number than other yield components (Tables 2, 7, and 8). Cook et al. (1987) noted that fumigation and solarization mainly increased wheat yield by adding more tillers to the plants. As well, plant height was increased in their studies as was observed in ours. Smith et al. (1984) only measured grain yield and TGW and both were significantly increased by solarization.

The effects of propiconazole were most consistent on increasing TGW, however, there was a general increase in grains/spike, possibly due to early HLB control before flag leaf emergence. It should be noted that the first spray was at fourth node (ca GS 34) and fertility of florets may have been affected by HLB. In one case (1989-90), grains/spike were actually reduced by spray. It is interesting that propiconazole increased plant height in

1989-90 and spikes/$m^2$ in 1990-91. Both of these may due to excess spray dripping to the soil and controlling soilborne pathogens. This remains to be investigated.

Two to four propiconazole sprays provide excellent control of HLB and increase yields significantly (Tables 1 and 3 and Figure 4). Although chemical control of HLB is a useful research tool to determine effects of HLB on yield, it would appear to be uneconomical for commercial use alone. Nevertheless, as part of an integrated disease control program, in conjunction with resistance and cultural practices it might be useful (Dubin and van Ginkel 1991).

Solarization significantly reduced HLB in most experiments presented (Tables 3, 7, and 8). However, the decrease was not large. This beneficial result may be due to a decrease in inoculum in soil or residue and/or general improvement in plant health caused by improved nutrition. Katan and DeVay (1991b) indicate that solarization has been observed to reduce foliar diseases in crops such as peanuts and cucumbers.

Root and SCI necroses were significantly reduced by solarization (Tables 4, 7, and 8) and there were concomitant yield increases. In general, the literature reports on reductions of incidence of soilborne inoculum by solarization but reports little on reduced symptom expression (Katan and DeVay 1991a). We were not able to study solarization effects on inoculum, but conclude that inoculum of the principal pathogen, *B. sorokiniana*, would be greatly reduced. Smith et al. (1984) note a reduction in incidence of wheat plants infected with *B. sorokiniana* from solarized soil in South Africa. Solarization increases root volume in our studies and is correlated with increased yield. This is reported in the literature (Tjamos 1991). Again, where propiconazole appears to decrease root necrosis and increase root volume (Table 4), this may be due to drip from the leaves to the ground.

As noted, increased growth response with solarization may be linked to mineral nutrition as well as disease reduction. This is a complex phenomenon. In our studies, we could only determine that nitrate levels in plant tissues were not different, but there was apparently more nitrate left in the nonsolarized soil. Since ample nitrogen was applied and yield and root growth were reduced in these plots, it is reasonable to conclude that any excess nitrogen would be left in the soil. Concurrent solarization studies done in farmers' fields in 1991-92 showed that Mn was consistently increased by solarization (R. Graham, M. Ruckstuhl, and H.J. Dubin, unpubl.). This could have significance in relation to root rot control as noted by Huber and McCay-Buis (1993).

Poor seedling emergence is an issue that still must be clarified. Preliminary evidence indicated that biotic factors do not appear to be associated with poor emergence and our observations support the idea that soil physical condition associated with excessive moisture at planting play a major role in reduced emergence.

In the process of determining wheat yield losses in the rice-wheat system, it was possible to obtain some idea about rice yield losses as well (Table 5). Solarization has not previously been shown to be effective against *H. oryzae* and *H. mucronata* with a concomitant yield increase, as far as we know. The results highlight the need to take a systems perspective in determining yield losses and the effects of control measures.

Residual effects of solarization are quite common and may be due to induced suppressiveness (DeVay and Katan 1991) or, in some cases, simply a delay of pathogens to recolonize the soil. It was surprising that, even with a mild November solarization, residual effects were clearly shown in three of four years (Table 6). This may be due to an increase of microbial antagonists relative to the pathogens.

Residual effects from May solarization were also obvious (Tables 7 and 8). Since paddy rice was the rotation crop in our studies, it was difficult to keep water from nonsolarized plots getting into the solarized ones. Thus, it is highly probable that we had recontamination by pathogens. Nevertheless, a residual effect was observed and it is likely that reduced disease is due to enhancement of microbial antagonists such as *Trichoderma* spp., *Bacillus* spp., or others (DeVay and Katan 1991, Stapleton 1991). This would be a fertile area of research in Nepal. Lastly, we have observed significant residual yield increases for two succeeding crops after the solarization.

Only preliminary results are presented on the possible effects of soilborne diseases in farmers' fields. Moreover, further work done in farmers' fields in 1992-93 indicated that May solarization was very effective in increasing rice (32%) and subsequent wheat (17%) yields and reducing root and SCI necrosis in wheat (M. Ruckstuhl, pers. comm.). Surveys are presently in progress in the Rupandehi District to determine the level of root rots in selected wheat fields.

A range of root inhabiting fungi were isolated from necrotic areas of roots and SCIs (Tables 10 and 11). However, only *B. sorokiniana* was common and highly pathogenic, causing root and SCI necrosis as well as damping off (Table 11). Complete pathogenicity studies could not be done with the other key fungi but preliminary studies showed most fusaria and pythia to be nonpathogenic. Further research needs to be done to elucidate the role of *F. nygamai* as well as *P. graminicola* in the root rot complex. The fact that fusaria predominated on roots does not mean that they are the most important since we could not separate the more pathogenic ones from the saprophytes at this point. The evidence at present would indicate that they are secondary. However, an association of *B. sorokiniana* and fusaria is common in the drier root rot areas (Cook and Veseth 1991).

HLB studies concentrated on the two known foliar pathogens, *B. sorokiniana* and *D. tritici-repentis.* Significant effects on attainable yield are seen in Figure 4. Studies in 14 farmers' fields in Rupandehi District in 1990-91 showed average yield losses of 7% due to HLB but few losses in succeeding years. (M. Ruckstuhl, pers. comm.). Surveys in the Nepal Tarai are needed to measure the effects of the disease in other areas. In neighboring areas of Bangladesh and India, farmers' fields control studies indicate losses greater than 20% (H.J. Dubin, unpubl.).

Conidial dispersal data in 1987-88 showed that *D. tritici-repentis* dominated *B. sorokiniana* (Figure 5). We know little about the main source of inoculum for either fungus. *B. sorokiniana* conidia are found in the soil and it is the predominant root rot pathogen. It is found on rotted wheat stubble after the monsoon season but there is not much residue around after monsoon. (M. Ruckstuhl, unpubl.). As well, it occurs on rice and is a saprophyte. However, it does not seem to occur commonly on weeds, although it is reported on many grass hosts. Since paddy requires four months of standing water, it is doubtful that soilborne conidia are as important as in Brazil where they survive for 37 months and produce infection (Reis 1991). However, this needs to be studied. Experiments showed that infection coming from seed can provide initial leaf infection by splash dispersal (M. Ruckstuhl, unpubl.). *D. tritici-repentis* also occurs on wheat residue. We have not seen it on rice or weeds, as yet in Nepal, nor have we observed the teleomorphic stage of either fungus.

Once the lower leaves are infected, both fungi appear to behave as reported in the literature, in that *D. tritici-repentis* appears better adapted to slightly lower temperatures than *B. sorokiniana* (Shaner 1981). *D. tritici-repentis* produces conidiophores and conidia optimally at 21$^{o}$C (Shaner 1981) and our mean air temperatures at peak sporulation are around 18-22$^{o}$C. Maraite et al. (1992) indicate similar relationships with *D. tritici-repentis* with regard to temperature and rainfall. Conidial dispersal paralleled the foliar infection in our plots indicating a local inoculum source. Although conditions for *B. sorokiniana* may not be optimum during the wheat season, they certainly are conducive to sporulation and infection. Shaner (1981) notes that seasons where temperatures reach 28-30$^{\circ}$C during the day, but do not remain there for long periods of time may be favorable for the disease and this is common later in the wheat season.

It seems that *D. tritici-repentis* is better adapted as a pathogen to this area since its major dispersal period was during the crop season rather than after. However, note that as of January 1990, *B. sorokiniana* became the predominant pathogen in this area due possibly to a slight change in minimum temperatures.

The change of predominance from *D. tritici-repentis* to *B. sorokiniana* in 1990-91 (Table 12) highlights the need to monitor the causes of HLB on station and in farmers' fields. Since resistance is the most appropriate control measure at present it is imperative to identify the causal organisms and assure we are screening and breeding for resistance to the complex of relevant pathogens. As the environment or cultural practices change so may the pathogens.

The data presented show that significant losses occur on the NWRP and warrant control measures. Breeding for HLB resistance is ongoing in the NWRP program. Soilborne disease control efforts require more research on the causal organisms, disease epidemiology, and the interactions with crop management and nutrition. Integrated disease control including modification of crop management and plant nutrition will likely reduce soilborne diseases and HLB on the NWRP.

More research is required to determine the impact of both groups of diseases in farmers' fields throughout the Tarai. Some survey work is in progress to determine this. The evidence indicates that HLB is the most important disease problem at this time in the Tarai and adjacent areas of Bangladesh and eastern India.

Solarization, with the limitations noted, appears to be a good method for estimating losses and conversely attainable yields possible. Further studies should be done to see if it has commercial value for specific uses in seedling production of rice or small farmer wheat seed production. Quality seed production is a problem and small areas of the farm can be set aside for solarization to produce good seed. In certain cases it may be economical for small farmers to use it for overall crop productivity especially where long term residual effects are observed.

Further research should be done on microelements in relation to solarization, disease control, and increased productivity on the NWRP and in farmers' fields.

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**International Maize and Wheat Improvement Center**
Centro Internacional de Mejoramiento de Maíz y Trigo
Lisboa 27, Apartado Postal 6-641, 06600 México, D.F., México