Journal of Agripreneurship and Sustainable Development (JASD)
Volume 2, Number 1, June, 2019
ISSN (Print): 2651-6144; ISSN (Online): 2651-6365

EFFECTS OF VARIETY, FERTILIZER AND FUNGICIDE ON PEARL MILLET DOWNY MILDEW SEVERITY AND YIELD IN TWO DIFFERENT AGRO-ECOLOGICAL ZONES IN NIGERIA

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ABSTRACT
Downy mildew caused by *Sclerospora graminicola* (Sacc.) Schroet is a serious constraint to the cultivation and improvement of pearl millet in Nigeria. Therefore, a field trial was carried out during the 2014 rainy season at Bauchi (latitude $10^0$17' N, 9^0 49' E) and Maiduguri (latitude 11^0 51' N, 13^0 05' E) located in the in Northern Guinea Savanna and Northern Sudan Savanna of Nigeria, respectively. The aim was to evaluate the effects of fungicide and fertilizer on downy mildew and the performance of pearl millet varieties. Randomized Complete Block Design was used with factorial arrangement of treatments, which comprised five nitrogen fertilizer rates (0, 15, 30, 45 and 60 kg N/ha), metalaxyl fungicide (treated and untreated) and two millet varieties (PEO 5984 and Super SOSAT). Results indicated significant ($p<0.05$) difference between locations, varieties, fungicides and among nitrogen rates. With respect to the locations, severity of downy mildew was lower, with better crop performance in terms grain yield at Bauchi than in Maiduguri. In respect of the varieties, severity of downy mildew was lower in the millet variety, PEO 5984 which also gave more yields, than Super SOSAT. There was significant stepwise decrease in downy mildew severity by 11.3% and 8.3%, and yield increase 293.2 kg/ha from each successive additional N-rates. Metalaxyl seed treatment significantly decreased downy mildew severity by 10.2 and 11.6% at Bauchi and Maiduguri, respectively. Overall, treatment combination of PEO 5984seed dressed with metalaxyl at 2 g a.i/kg, and application of fertilizer $N_{60}P_{30}K_{30}$ gave significantly ($p<0.05$) good control of downy mildew and yield increase.

Keywords: Downy Mildew, Fertilizer, Metalaxyl, Pearl Millet, Severity.

INTRODUCTION
Pearl millet (*Pennisetum glaucum* (L.) R. Br. is a major cereal food crop in northern Nigeria. The crop is cultivated on about 5.0 million hectares of land, with annual production of 3.4 million metric tonnes in Nigeria (FAOSTAT, 2011). Thus, Nigeria is the leading producer of pearl millet, with about 28% of the global production; however, downy mildew caused by *Sclerospora graminicola* (Sacc.) Schroet is a major threat to both the cultivation and improvement of pearl millet, as it causes over 65% loss in grain yield annually. Presently, metalaxyl is the most effective and widely used fungicide for the control of downy mildew in pearl millet, mainly as seed dressing chemical. However, there are indications that varietal difference and nitrogen fertilization could affect the efficacy and fungicidal activity of metalaxyl (Zarafi, 2005).

Pearl millet plays a significant role in the food security of the entire drier regions of northern Nigeria. Regrettably, its production is highly constrained by three major panicle diseases namely, downy mildew, smut and ergot. Downy mildew caused by the fungus,

Journal of Agripreneurship and Sustainable Development (JASD)
Volume 2, Number 1, June, 2019
ISSN (Print): 2651-6144; ISSN (Online): 2651-6365

Sclerospora graminicola (Sacc.) *Schroet* is the most serious of these diseases. Furthermore, downy mildew disease has impeded progress in hybrid millet development, while several other improved cultivars have succumbed to the disease (Williams, 1984). Several degrees of losses arising from seedling mortality, tiller and panicle infections are responsible for the wide range of losses 15 - 65% reported from farmers' field. Such wide variations in losses mainly arise due to differences in cultivated varieties, fungicidal use and crop nutrition (fertilizer use) factors that are often overlooked in field research. However, disaggregating the effects of these factors would provide insights into the observed variation in losses.

The need by farmers to grow more food, in order to feed themselves and other people requires that problems associated with downy mildew are curtailed. Despite the fact that the traditional millet cultivars are highly susceptible to downy mildew, farmers have continued to cultivate them, thus necessitating the need to grow improved varieties with some level of resistance. Pearl millet is mainly cultivated by resource-poor farmers who make little attempts in the management of this disease through cultural measures. Metalaxyl is so far the only fungicide recommended for the control of the disease, hence the need to maximize its usage. Apart from the direct losses by downy mildew, farmers equally suffer losses from the benefits on investments from other inputs, especially seed and fertilizers.

Critical analysis of the biology of *S. graminicola* and pearl millet suggests the need for a well-articulated integrated approach for the control of the downy mildew disease (Haward and David, 2005). Downy mildew is a polycyclic (compound interest) disease in which several generations of the pathogen re-infects the crop within the same growing season. Primary infection starts from oospores existing in the soil from straw humus or seed borne mycelia, in which planted seedlings get infected as it emerges from the soil. Subsequently, sporangia released within the season results in secondary infection; thus, both oospores and sporangia contribute to disease epidemics. From the foregoing therefore, appropriate and well-matched options need to be adopted for control of the disease.

The nature of downy mildew infection suggests the need for integrated management options, aimed at providing continuous control throughout the entire crop growth period. Such measures comprise the exploitation of newly developed varieties with durable genetic resistance, and of short growth duration that can easily escape secondary infections. Fungicidal seed dressing with metalaxyl aimed at the reduction of primary infection by oospores in the first early three weeks of seedling growth. Fungicides equally control other diseases in the crop and thereby permit vigorous growth of the crop, while different genotypes react differently to infection by the diseases (Aliyu *et al*., 2011). Metalaxyl is very effective in the control of downy mildew of pearl millet. It is a systemic fungicide with both protective and curative action. When applied as seed dressing chemical, it protects the seeds against soil and seed borne inoculum, as well as seedlings (Aliyu *et al*., 2011). Further impetus to the present study stemmed from previous reports that fertilizer reduces the incidence of downy mildew disease (Ajayi *et al*., 1998; Zarafi *et al*., 2004). Fertilizers have also been reported to enhance crop vigour against diseases **(**Deshmukh *et al*., 1978). Hence, enhanced crop nutrition by fertilizer application aimed at minimizing the effects of the disease by boosting plant vigour has been recommended.

In spite of the importance of downy mildew in yield reduction of pearl millet, there is insufficient information in respect of interaction of fertilizer and fungicides on pearl millet genotypes, which the present study seeks to address. Bringing this information to bear, in a holistic approach, in order to harness the benefits of synergistic effects of fungicide, fertilizer and genotype resistance form the focus of the study. Therefore, integration of fungicide (metalaxyl), fertilizer and variety appropriately would result in a better control of the disease

Journal of Agripreneurship and Sustainable Development (JASD)
Volume 2, Number 1, June, 2019
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under integrated pest management programme. The study was, therefore, designed with the following objectives:

i. Assess the combined effects of metalaxyl and fertilizer on downy mildew disease severity and yield of two pearl millet varieties.
ii. Assess the interactive effect of metalaxyl and fertilizer on downy mildew disease severity and yield of two pearl millet varieties of different resistance.

MATERIALS AND METHODS

Description of Experimental Site

The trial was carried out during the 2014 rainy season in two sites: at Abubakar Tafawa Balewa University Teaching and Research Farm Bauchi (latitude 10^0 17' N, 9^0 49' E and 690.2m above sea level) in Northern Guinea Savannah and Research Farm of Lake Chad Research Institute (LCRI) in Maiduguri (latitude 11^0 51' N, 13^0 05' E and 315.5 m above sea level) in Sudan Savannah of Nigeria.

Sources of Experimental Materials and Description

Both compound (NPK 15:15:15) and Urea (46% N) fertilizers (Natore Plc brand) were procured from a reputable Agro-dealer in Bauchi. The two pearl millet varieties namely, LCIC-MV4 (PEO 5984) and LCIC-MV3 (Super SOSAT) were obtained from the germplasm bank of LCRI Maiduguri. Characteristics of the varieties are as indicated below:

Field Preparation and Experimental Layout

The land was ploughed using a disc plough and harrowed twice to give a fine tilth. The harrowed land was then levelled and divided into three blocks (replicates). Pegs were used to demarcate boundaries between blocks. Each plot was 5.0 m x 4.5 m, and distance between blocks was 1.0 m, while plots were 50 cm apart. The total area for the experiment was 1697.25 m^2.

Infector rows were established with a highly susceptible variety (7042S) obtained from the germplasm bank of LCRI Maiduguri between blocks, three weeks before the test varieties, to serve as a source of inoculum. Seeds of the susceptible cultivar were mixed with ground infected leaf containing oospores collected from the previous season at Bauchi and Maiduguri to ensure that maximum infection takes place during the trial. Five millet seeds were sown per hole at the beginning of the rainy season on 24th June 2014 and 26th July 2014 at Bauchi and Maiduguri respectively, at the depth of 3 – 4 cm, and at a spacing of 75 cm x 30 cm between and within rows, respectively. Seedlings were thinned to two plants per hole at two weeks after sowing. Weeding was done by hoe at three and six weeks after sowing.

Experimental Design and Treatments

The trial was laid out in a randomized completely block design (RCBD). There were 20 treatments, obtained by combinations of two varieties (PEO 5984 and Super SOSAT), five nitrogen levels (0, 15, 30, 45 and 60 kg N/ha), and two fungicide seed treatments (Untreated and Metalaxyl-treated) as follows:

Data collection

1. Downy mildew severity (%):

   Downy mildew severity was assessed at 75 DAS, using the scale for disease reaction category (Singh *et al*., 1997) as follows:

$$\text{Disease severity (\%)} = \frac{y(1-1)+y(2-1)+y(3-1)+y(4-1)+y(5-1)}{n(4)} \times 100 \quad \ldots (1)$$

where;
y = Number of plants in each reaction category (severity rating)

Journal of Agripreneurship and Sustainable Development (JASD)
Volume 2, Number 1, June, 2019
ISSN (Print): 2651-6144; ISSN (Online): 2651-6365

1 = No disease
2 = Disease only on nodal tillers
3 = Less than 50% of the basal tillers of the plants infected
4 = More than 50% basal tillers of the plants infected
5 = No productive panicle produced
n = Total number of plants in each net plot

Disease severity class was then determined based on the severity score (Khairwal *et al.,* 2007) for each treatment as follows:
0 - 5% = Resistant (M)
6 - 20% = moderately resistant (MR)
21 - 50% = moderately susceptible (MS)
≥ 50% and above = susceptible

2. Grain yield:

Threshed grains for each of the treatments in the four central rows were weighed using top-loader weighing balance (Salter®, England).

Statistical Analysis

Data collected was subjected to analysis of variance (ANOVA) to determine the significance of treatments effects and their interactions. Means were separated using least significant difference (LSD) at 5% level of significance.

RESULTS AND DISCUSSION

Results on the effects of variety, fertilizer and fungicide treatments on downy mildew severity for the two locations are presented in Table 1. Disease severity in the two varieties differed significantly ($p<0.05$) in Maiduguri at 75 DAS (Table 1). Severity was higher in Super SOSAT than PEO 5984. Disease severity significantly decreased with increase in fertilizer rate. The effect of fungicide application was significant both at 60 and 75 DAS at the two locations, with disease severity on the millet plants in the treated plots being lower than on those in the untreated check. Fungicides and fertilizers play significant role in the performance of crop varieties, thus quantification of their effects is of paramount importance in crop protection and nutrition. The present study evaluated the effects of N-fertilizer rates and metalaxyl fungicide on the severity and yield performance of two millet varieties in two diverse ecologies.

The results showed differences between the Sudan (Maiduguri) and Guinea (Bauchi) savannah locations, in terms of disease severity of downy mildew which was found to be higher at Maiduguri than Bauchi. The higher downy mildew prevalence at Maiduguri in the Sudan savannah could be attributed to higher inoculum build-up due to continuous cultivation of the crop, where the millet is more popular; inspite of more favourable weather conditions (rainfall and humidity) for the disease at Bauchi in the Guinea savannah area. Reports has shown that millet crop is more popular in the Sudan savannah being a traditional millet belt, with vast production area solely devoted to the crop, than the Guinea savannah agro-ecological zones of Nigeria (Mohammed and Salisu, 2014; Okeke-Agulu and Onogwu, 2014). Downy mildew strains were also reported to exhibit diverse levels of virulence (Ball and Pike, 1984) and strains had been observed within and between different ecological zones in Nigeria (Gwary *et al.* 2007). The higher severity of the disease at Maiduguri than Bauchi, in the present study therefore, could be as the result of pathotype diversity between, or even within the same ecology.

Journal of Agripreneurship and Sustainable Development (JASD)
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Table 1: Effect of Variety, Metalaxyl and Fertilizer rate on Pearl Millet on Downy Mildew Severity (%) at Bauchi and Maiduguri

	Bauchi		Maiduguri	
Treatment	**60 DAS**	**75 DAS**	**60 DAS**	**75 DAS**
Variety (A)				
PEO 5984	26.00	26.60	28.11	28.90
Super SOSAT	26.70	27.90	28.34	39.30
$LSD_{0.05}$	Ns	0.98	Ns	Ns
Fertilizer (B)				
0 kg N/ha	48.71	50.80	51.83	52.40
15 kg N/ha	26.70	27.80	29.70	30.13
30 kg N/ha	24.42	25.30	25.50	27.53
45 kg N/ha	18.10	18.20	18.50	19.10
60 kg N/ha	13.90	14.20	15.60	16.32
$LSD_{0.05}$	1.76	1.56	2.12	1.70
Fungicide (C)				
Untreated	31.70	32.33	33.94	34.92
Treated	21.01	22.15	22.51	23.30
$LSD_{0.05}$	1.12	0.98	1.34	1.08
Interaction				
A x B	Ns	Ns	Ns	Ns
A x C	Ns	Ns	Ns	Ns
B x C	**	**	**	**
A x B x C	Ns	Ns	Ns	*

*Ns = Not significant at 5% probability of the F-test; **, * = Significant at 1 and 5% probability of the F-test, respectively.*
DAS = Days after sowing

The interactions of fertilizer x fungicide on downy mildew severity was significant ($p<0.05$) at 60 and 75 DAS in both locations, in which downy mildew severity was significantly higher when both fertilizer and fungicides were not used; except at 60 DAS at 60 kg N (Table 2). Results from the present study further revealed that there were differences between the two evaluated millet varieties in terms of both disease reaction and millet grain yield, wherein disease severity were both lower on PEO 5984 than Super SOSAT. Thakur *et al*. (2004) interpreted such variations in the reaction of millet varieties as being due to the existence of races in the pathogen. Selection history of the two evaluated varieties indicates that both genotypes were bred with downy mildew resistant lines as parents in addition to yield (NACGRAB, 2014). However, inspite of the resistance in the two varieties to the downy mildew fungus in the present study, both varieties were infected to downy mildew pathogen with highest values recorded for severity being 73%. This is a clear indication of breaking down of resistance afore seen in these varieties. Former reports are in support of this observed phenomenon (Werder and Ball, 1992). Beside, researches have also shown that disease severity arise from both primary and secondary infections. However, favourability of the environment also comes into play in the disease infection triangle (Khairwal *et al*., 2007).

Journal of Agripreneurship and Sustainable Development (JASD)
Volume 2, Number 1, June, 2019
ISSN (Print): 2651-6144; ISSN (Online): 2651-6365

Table 2: Interaction Effect of Fertilizer x Fungicide on Downy Mildew Severity (%) 60 and 75 DAS, at Bauchi, Maiduguri and Combined

Fertilizer rates	Fungicide untreated	Fungicide treated
	DS at 60 DAS	
	Bauchi	
0	65.83	31.60
15	29.60	23.78
30	27.95	20.88
45	20.30	15.80
60	14.77	12.97
$LSD_{0.05}$	2.4929	
	Maiduguri	
0	71.07	32.58
15	32.38	27.02
30	29.07	22.02
45	20.55	16.38
60	16.63	14.57
$LSD_{0.05}$	3.0050	
	Combined	
0	68.44	32.09
15	30.99	25.40
30	28.51	21.45
45	20.43	16.09
60	15.70	13.77
$LSD_{0.05}$	1.9090	
	DS at 75 DAS	
	Bauchi	
Fertilizer rates		
0	66.92	34.65
15	29.95	25.62
30	29.22	21.37
45	20.35	15.97
60	15.23	13.13
$LSD_{0.05}$	2.2005	
	Maiduguri	
0	73.25	31.55
15	32.42	27.85
30	30.28	24.78
45	20.98	17.15
60	17.67	14.97
$LSD_{0.05}$	2.4073	
	Combined	
0	70.08	33.10
15	31.18	26.73
30	29.75	23.08
45	20.67	16.56
60	16.45	14.05
$LSD_{0.05}$	1.5907	

DAS = Days after sowing

Journal of Agripreneurship and Sustainable Development (JASD)
Volume 2, Number 1, June, 2019
ISSN (Print): 2651-6144; ISSN (Online): 2651-6365

Effect of variety x fertilizer x fungicide interaction on downy mildew severity was also significant at 75 DAS in Maiduguri (Table 3). Results did not show significant difference in severity between varieties when seeds were not dressed, irrespective of fertilizer level. Conversely, seed dressing significantly reduced downy mildew severity in all varieties over the untreated, at the same N-level, except at 60 kg N. In the absence of fertilizer, Super SOSAT had higher disease severity when seeds were dressed; while PEO 5984 had higher severity at 30 kg N-rates. Results of the present study further indicated downy mildew severity of 26.60 and 27.90% in PEO 5984 and Super SOSAT, respectively. Therefore, these two varieties both fell into the moderately susceptible (MS) disease category, based on disease classification according to Ball in 1983. This being moderate in disease severity could be attributed to the high virulence of the pathogen at the two locations, as earlier reported that the Nigerian downy mildew strains are more virulent compared to strains seen outside the country (Werder and Ball, 1992; Jones *et al*., 1995).

Gwary *et al*. (2006) found 36% severity of downy mildew disease on Ex-Borno, in Maiduguri. Therefore, different pearl millet genotypes exhibit different reaction to downy mildew in different environments, and level of downy mildew severity is dependent on the degree of virulence of the pathogen, vulnerability of the variety, especially when millet crop is confronted by a new or foreign pathotype or strain (Jones *et al*., 1995).

The present result showed significant stepwise decrease in downy mildew severity, with each successive additional N-rates of 15, 30, 45 and 60 kg/ha. This result agrees with the findings of Deshmukh *et al*. (1978) who reported that application of nitrogen reduced downy mildew severity at Aurangabad, India by26.1% as the quantity of N fertilizer was increased from 25 - 100 kg N/ha over the control (0 kg N/ha). However, the highest level of N (100 kg/ha) significantly reduced the disease at both locations. .

There was significant stepwise decrease in downy mildew severity, while the grain yield increased with each successive additional N-fertilizer. This is in conformity with both findings of Deshmukh *et al*. (1978) and Zarafi *et al*. (2005) who had earlier on independently reported that grain yield increase was in response to the higher levels of N fertilizer applied.

Results from the present study revealed significant decrease in the severity by 10.2 and 11.6%; while yield increased by 30.6 and 52.5% as the result of metalaxyl application in Bauchi and Maiduguri, respectively.

Table 3: Interaction Effect of Variety x Fertilizer x Fungicide on Downy Mildew Severity (%) 75 DAS, at Maiduguri

	Fungicide untreated		**Fungicide treated**	
Fertilizer rates	**PEO 5984**	**Super SOSAT**	**PEO 5984**	**Super SOSAT**
0	73.800	72.700	29.100	34.000
15	32.633	32.200	27.300	28.400
30	29.767	30.800	26.800	22.767
45	21.300	20.667	17.169	17.133
60	16.600	18.733	14.133	15.800
$LSD_{0.05}$		3.4044		

DAS = Days after sowing

Table 4 shows the effects of variety, fertilizer rate and fungicide application on grain yield of millet infected by downy mildew pathogen, at Maiduguri and Bauchi. The results

Journal of Agripreneurship and Sustainable Development (JASD)
Volume 2, Number 1, June, 2019
ISSN (Print): 2651-6144; ISSN (Online): 2651-6365

indicated significant ($p<0.05$) difference in grain yield between the two varieties at Bauchi, within the yield of PEO 5984 being significantly higher than that of Super SOSAT. Equally, fertilizer application showed significant ($p<0.05$) effect on grain yields which increased with fertilizer level at both locations. Similarly, there was significant increase in the yield of pearl millet at both locations due to metalaxyl application, only fertilizer and fungicide interaction was significant at Maiduguri. All other interaction was not significant at both Bauchi and Maiduguri. Previous studies indicate that metalaxyl, (C15H21NO4, methyl N-(2,6-dimethylphenyl)-N-(methoxyacetyl) DL alanine,) a fungicide with unique combination of residual and systemic properties, is highly effective against phylogenetically related pathogens, Bremia, Peronospora, Plasmopara and Phythopthora (Deepak *et al*., 2006**)**, and other species causing downy mildews, late blight, damping-off and root, stem and fruit rots **(**Keun *et al*., 2002). Results also indicate that metalaxyl was equally effective on both Super SOSAT and PEO 5984. However, earlier findings had revealed higher effects of metalaxyl on relatively more resistant than susceptible millet varieties **(**Keun *et al*., 2002; Aliyu *et al*., 2011).

Table 4: Effect of Variety, Metalaxyl and Fertilizer Rate on Grain Yield (kg/ha) of Pearl Millet infected with Downy Mildew at Bauchi and Maiduguri

Treatment	**Grain yield (kg/ha)**	
	Bauchi	**Maiduguri**
Variety (A)		
PEO 5984	1152.6	1029.1
Super SOSAT	980.7	1060.7
SE±	20.39	28.70
Fertilizer (B)		
0 kg N/ha	522.2	433.30
15 kg N/ha	781.5	842.50
30 kg N/ha	988.9	1006.10
45 kg N/ha	1351.9	1216.70
60 kg N/ha	1688.9	1725.90
SE±	32.24	45.38
Fungicide (C)		
Untreated	897.8	827.60
Treated	1235.5	1262.20
$LSD_{0.05}$	58.37	82.18
Interaction		
A x B	Ns	Ns
A x C	Ns	Ns
B x C	Ns	*
A x B x C	Ns	Ns

Ns = Not significant at 5% probability of the F-test; * = Significant at 5% probability of the F-test.

Seed treatment was as effective as increasing the rate of N in the untreated plots at Maiduguri (Table 5). However, fungicide consistently increased grain yield over the untreated check at each same level of N. An experiment was conducted to evaluate the effects of N-fertilizer rates (0, 15, 30, 45, 60 kg N/ha) and Metalaxyl fungicide (treated and untreated) on downy mildew disease severity and yield performance of two millet varieties (Super SOSAT,

Journal of Agripreneurship and Sustainable Development (JASD)
Volume 2, Number 1, June, 2019
ISSN (Print): 2651-6144; ISSN (Online): 2651-6365

PEO 5984), at Bauchi in Northern Guinea Savannah [latitude 10^0 17' N, 9^0 49' E) and Maiduguri in Northern Sudan Savannah [latitude 11^0 51'N, 13^0 05'E] of Nigeria. The results showed lower severity of downy mildew, and better grain yield at Bauchi than Maiduguri.

In respect of the evaluated millet varieties, disease severity (26.60%) was relatively lower in the millet variety, PEO 5984 than Super SOSAT, with severity values of 27.90%. Both varieties were moderately susceptible (MS). With respect grain yield, PEO 5984 gave more yield than Super SOSAT.

There was significant stepwise decrease in downy mildew with each successive additional N-rate, in which each kg N reduced the severity of the disease by 8.280 - 8.319%. Results further indicated that a yield improvement of 7.6 - 63.6% was obtained as N-rate was increased from 15 - 60 kg N/ha, over the control, equivalent to 290.38 - 295.94 kg/ha yield increase from each kg N application.

Metalaxyl seed treatment significantly decreased downy mildew severity by 10.2 vs 11.6%, while yield increased by 30.6 vs 52.5%, over the untreated at Bauchi and Maiduguri, respectively. Results also indicate that metalaxyl was equally effective on both Super SOSAT and PEO 5984.

Table 5: Interaction Effect of Fertilizer x Fungicide on Grain Yield (kg/ha) at Maiduguri

	Grain yield (kg/ha)	
Fertilizer rates	**Fungicide untreated**	**Fungicide treated**
	Maiduguri	
0	340.8	525.9
15	648.1	1037.0
30	786.3	1225.9
45	977.8	1455.6
60	1385.2	2066.7
$LSD_{0.05}$	183.75	

CONCLUSION AND RECOMMENDATIONS

It can be concluded that downy mildew was lowered by application of nitrogen, with attendant significant improvement in grain yield of millet. Furthermore, the study clearly indicated that dusting pearl millet seed with 2 g a.i/kg seed provided an acceptable level of downy mildew control, and increase in the yield of millet. Therefore, for both varieties, combination of seed dressing with Metalaxyl at 2 g a.i/kg and $N_{60}P_{30}K_{30}$ were effective against downy mildew and increased the yield of millet. From the foregoing results, both evaluated millet varieties, PEO 5984 and Super SOSAT could be recommended for cultivation in the Sudan and northern Guinea agro-ecologies of Nigeria. In addition, both combination of seed dressing of PEO 5984 with Metalaxyl at 2 g a.i/kg and $N_{60}P_{30}K_{30}$ is recommended for control of downy mildew and increase in the yield of millet.

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