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Full Length Research Paper

Microdose and N and P fertilizer application rates for pearl millet in West Africa

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The objective of this study was to determine the grain and stover yield response of pearl millet to microdose fertilizer application alone, and microdose combined with N and P fertilizer application rates across years and locations in West Africa. Microdose fertilizer application increased pearl millet grain yields by 240 to 300 kg ha^{-1} on sandy soils across a broad range of climatic and soil conditions in West Africa, while increasing pearl millet grain yields by 400 kg ha^{-1} on silty clay soils in Mali. Stover yield increases of pearl millet were 250 to 400 kg ha^{-1} on sandy soils and 500 to 2500 kg ha^{-1} on silty clay soils in Mali. Application of 20 kg ha^{-1} P_2O_5 and 30 kg ha^{-1} N in addition to microdose commonly increased grain yields by 140 to 180 kg ha^{-1} and stover yields by 600 to 1500 kg ha^{-1} over that of microdose application only. These results indicate that micodose in combination with 20 kg ha^{-1} P_2O_5 and 30 kg ha^{-1} N fertilizer application is required to optimize both grain and stover yield of pearl millet in West Africa to meet food, fuel and soil improvement needs of farmers.

Key words: *Pennisetum glaucum* (L.) R. Br., grain yield, stover yield.

INTRODUCTION

Pearl millet (*Pennisetum glaucum* (L.) R. Br.) is one of the most important food crops produced in semi-arid West Africa (FAOSTAT, 2011). It is grown under environmental conditions with limited and erratic rainfall, high temperatures, and poor soil conditions and low nutrient levels to harsh for other cereal crops (National Academy of Science, 1996). Research has indicated that pearl millet grain and stover yields increase with fertilizer application, but little adoption has occurred due to availability and cost of fertilizer, and low grain prices (Abdoulaye and Sanders, 2005; Vitale and Sanders, 2005). Fertilizer use rates in Africa are only 8 kg ha^{-1} with most of fertilizer applied to cash crops for export (Buerkert et al., 2000; Morris et al., 2007).

Bush fallow has traditionally been the key component of West African cropping systems to increase soil organic matter and nutrient status, but with increased population growth and reduced fallow periods, this cannot meet crop nutrient needs (Schlecht and Buerkert, 2004).

Studies indicate that the quantity of nutrients removed by crops is far greater than additions in West Africa, thus degrading the soil natural resource critical to crop management (Bagayoko et al., 1996; Bekunda et al, 1997; Sanchez et al., 1997). It is generally considered that P is the most limiting nutrient for pearl millet production in West Africa, with N being the second most limiting (Bationo and Mokwunye, 1991). Animal feces and urine contribute to nutrient needs, but the supply is inadequate to meet plant nutrient needs (Giller et al., 1997; Bationo et al., 1998), thus increased chemical fertilizer application is essential to increase yields and maintain/improve the soil nutrient status. Leaving crop residues in the field also increase infiltration of water into soils (Nicou and Charreau, 1985), increases soil organic matter content (Klaij and Hoogmoed, 1993) increases nutrient recycling (Geiger et al., 1992), increases soil pH and nutrient levels (Coulibaly et al., 2000; Michels et al., 1995) and increases yield (Bationo et al., 1993; Coulibaly

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Table 1. Field and experimental procedures for on-station research for pearl millet on sandy soils in Burkina Faso, Mali and Niger in 2001 to 2006.

Country	Microdose treatment	Planting distance	Hills/ha	Tillage	Plot size (m^2)	Harvest area (m^2)	P source and application method	N source and application method	Variety	Seed treatment
Burkina Faso	4 g of 15-15-15	0.8 m x 0.8 m	15,625 (2 plants/hill)	Tractor (disc plow w/o ridges)	32	17.9	0-46-0 broadcast and incorporated before planting	Urea (46-0-0) side dressed 2 - 3 weeks after planting	IKMP5 (IKMP8201 in 2002 due to late planting)	Apron Plus (2001 to 2) or Apron Star (2003 to 5)
Mali	2 g of 18-46-0	0.75 m x 0.8 m	16,600 (2 plants/hill)	Tractor (disc plow followed by ridging)	36	18	0-46-0 side dress after emergence	Urea (46-0-0) side dressed with P	Toroniou (millet)	Apron Plus (2001 to 2) or Apron Star (2003 to 5)
Niger	4 g of 15-15-15	0.8 m x 0.8 m	15,625 (2 plants/hill)	Hand hoeing (Scarification)	32	15	0-18-0 broadcast and incorporated before planting	Urea (46-0-0) split side dressed at 3 and 6 weeks	Zatib	Apron Plus (2001 to 2) or Apron Star (2003 to 5

et al., 2000), but is seldom are crop residues left in fields due to high economic value and use as livestock feed and fuel (Schlecht and Buerkert, 2004).

Increased stover production would increase the likelihood of meeting livestock and fuel needs while having more stover available to be left in fields. Chemical fertilizer application rates are low except for cash crops that can consistently be marketed for a profit (Buerkert et al., 2000).

Point application (microdose) has been widely promoted due to the low fertilizer application rate, high probability of yield response (Muehlig-Versen et al., 2003; Palé et al., 2009) and due to a favorable fertilizer/grain price ratio (Abdoulaye and Sanders, 2005; Vitale and Sanders, 2005). Microdose application can reduce P fixation, promote early season shoot and root growth, enhance infection with vesicular arbuscular mycorrhizae leading to increased nutrient uptake of grain and stover yields (Bagayoko et al., 2000). Research on the combination of microdose fertilizer application combined with N and P fertilizer application has not been reported.

The objective of this study was to determine the grain and stover yield response of pearl millet to microdose fertilizer application along and in combination with N and P fertilizer across years and locations in West Africa.

MATERIALS AND METHODS

Station and on-farm studies were conducted on sandy soils (all > 85% sand) at Saria, Burkina Faso (Oxic Paleustalf - Ferric Lixisol); Cinzana, Mali (Typic Plinthustalf - leached ferriginous;) and Kalapaté, Niger (Psammentic Paleustalf – sol ferrigineux peu lessivé en argile et èvolué) in 2001 until 2005. In addition, an experiment was conducted on a silty clay textured Vertic Ustifluvent (sol hydromorphe à Gley reduit et tendance vertic) soil in 2003 through 2005 in Cinzana, Mali. All sandy soils had pH ≤ 5.5, < 1.0% organic matter, 9 to 15 ppm available P levels, and low levels of other nutrients. The station experiments were conducted in randomized complete block design with 4 replications. The fertilizer treatments consisted of zero (farmer practice, thus consider to be check treatment), microdose, microdose + 20 kg P_2O_5 ha^{-1}, microdose + 40 kg P_2O_5 ha^{-1}, microdose + 30 kg N ha^{-1}, microdose + 60 kg N ha^{-1}, microdose + 20 kg P_2O_5 ha^{-1} + 30 kg N ha^{-1} N, and microdose + 40 kg P_2O_5 ha^{-1} + 60 kg N ha^{-1} and fertilizer treatments were applied to the same plots each year.

A blank study (Smith, 1938; Bagayoko et al., 1992) was planted in 2005 without application of fertilizer. In Niger, the 2005 crop was lost due to poor emergence caused by a heavy rainstorm, thus the blank trial was conducted in 2006. Grain and stover were hand harvested at maturity, dried, grain threshed and weights recorded. Information on plot size, production practices and fertilizer application are presented in Tables 1 and 2. Planting date varied across locations and years, with planting occurring following early season rainfall in each year. Data were analyzed separately by country since experimental practices were slightly different. Analysis consisted of standard ANOVA with single degree of freedom orthogonal contrasts for mean separation. On-farm experiments were conducted in areas surrounding the station experiments in Burkina Faso and Niger, and the number of treatments was reduced to a no fertilizer check, microdose only, and microdose plus 20 kg ha^{-1} P (Niger) or zero and microdose plus 20 kg P_2O_5 ha^{-1} + 30 kg N ha^{-1} (Burkina Faso).

In Mali, on-farm plots were planted on farms in zones with historic annual rainfall of 400, 550 and 700 mm. Plot size varied among countries, but grain and stover yields were determined from bordered area on each farm. Data were analyzed separately by country due to the slightly different experimental treatments used. Standard ANOVA was conducted with farms considered to be replications within each country and single degree of freedom orthogonal contrasts were used for mean separation.

RESULTS AND DISCUSSION

Seasonal rainfall ranged from 488 to 767 mm with the lowest average season rainfall in Niger, intermediate in Mali and greatest in Burkina Faso (Table 3). Seasonal rainfall (< 60 mm) and monthly distribution was relatively constant in Burkina Faso, except for higher rainfall in the months of July 2004, August 2005 and September 2002 than in other years. The variability of

Table 2. Field and experimental procedures for on-station research for pearl millet and sorghum on silty clay soil in Mali in 2002, 2003 and 2006.

Crop	Micro-dose treatment	Planting distance	Hills/ha	Tillage	Plot size (m^2)	Harvest area (m^2)	P source and application method	N source and application method	Variety	Seed treatment
Sorghum	2 g of DAP (18-46-0)	0.75 m x 0.50 m	(3 plants/hill)	Tractor (disc plow by ridging before planting)	36	18	0-46-0 side dress after emergence	Urea (46-0-0) side dressed 2 to 3 weeks after planting	CSM 279E	Apron Plus (2001 to 2) or Apron Star (2003 to 5)
Millet	2 g of DAP (18-46-0)	0.75 m x 0.8 m	16,600 (2 plants/hill)	Tractor (disc plow followed by ridging)	36	18	0-46-0 side dress after emergence	Urea (46-0-0) side dressed 2 to 3 weeks after planting	Toroniou (millet)	Apron Plus (2001 to 2) or Apron Star (2003 to 5)

Table 3. Precipitation distribution at experimental locations in Burkina Faso, Mali and Niger, 2001 to 2006.

Precipitation	Burkina Faso					Mali					Niger					
	2001	2002	2003	2004	2005	2001	2002	2003	2004	2005	2001	2002	2003	2004	2005	2006
	mm															
June	52	53	162	78	105	131	112	60	139	93	120	95	79	70	209	89
July	164	198	164	290	116	250	175	205	105	177	305	142	100	153	160	168
August	204	221	217	192	320	128	116	253	157	162	106	216	266	121	145	157
September	131	183	130	133	130	38	86	59	103	166	47	94	108	82	74	179
October	41	25	58	30	21	22	35	31	1	0	0	18	0	0	25	0
Total	722	708	767	742	736	615	538	622	514	612	477	609	552	488	695	592

seasonal rainfall and the monthly rainfall distribution was greatest in Niger, especially during the months of June, July (> 200 mm variation) and August (>150 mm). Mali had intermediate seasonal variability (≈ 100 mm) with > 140 mm variation in rainfall in July and August. The experimental results presented grain and stover yields produced over a wide range of seasonal rainfall amounts with variable distribution during the growing season.

Grain yields

Averaged across years, microdose fertilizer application increased pearl millet grain yields by 240 to 300 kg ha^{-1} in Burkina Faso, Mali and Niger (Tables 4, 5 and 6). Year analysis indicated that microdose application increased pearl millet grain yield two out of 4 years in the low and more variable rainfall locations in Mali and Niger, while microdose application increased yield each year in the higher rainfall location in Burkina Faso. Yields produced in response to microdose application on a heavier, higher water holding capacity, more fertile soil in Mali was approximately 400 kg ha^{-1} (Table 7). On average on-farm studies indicated large grain yield increases in Burkina Faso and Niger, and across a large rainfall gradient in Mali (Table 8). However, in Niger, microdose application did not increase yield in 2001 when most of the seasonal rainfall occurred in the month of July (Table 3) while increasing grain yields by 400 to 500 kg ha^{-1} in other years (data not presented). These results combined with other research (Muehlig-Versen et al., 2003; Palé et al., 2009) indicated that microdose fertilizer application results in a high probability of pearl millet grain yield increases over a wide range of production conditions in West Africa, and with a favorable fertilizer/grain price ratio (Abdoulaye and Sanders, 2005; Vitale and Sanders, 2005), provides oppor-tunity to improve food security, farmer economic status and reinvest increased revenue to further improve agricultural productivity. Fertilizer appli-cation in addition to microdose increased grain yields in all location year combinations except 2002 and 2004 on sandy soil in Mali, 2003 and 2004 on silty clay soil in Mali (Tables 4, 5, 6 and 7). Averaged across years, the addition of 20 kg P_2O_5 ha^{-1} and 30 kg N ha^{-1} increased grain yield by 250 to 400 kg ha^{-1} over that with microdose application in Burkina Faso, Niger and on both the sandy and silty clay soil in Mali. No further yield increase to application of the higher rate of 40 kg P_2O_5 ha^{-1} and 60 kg N ha^{-1} N was found. On-farm studies indicated that application of 20 kg P_2O_5 ha^{-1} in

Table 4. Pearl millet grain yield as influenced by fertilizer treatment in Kalapaté, Niger in 2001 to 2006.

Fertilizer treatment	2001	2002	2003	2004	Mean	2006 blank Trial[†]
	kg ha^{-1}					
Zero	521	167	163	48	225	250
Microdose	643	570	391	313	479	365
Microdose + 20 kg ha^{-1} P_2O_5	765	960	521	357	651	427
Microdose + 40 kg ha^{-1} P_2O_5	456	1025	399	317	549	479
Microdose + 30 kg ha^{-1} N	944	570	317	316	547	385
Microdose + 60 kg ha^{-1} N	977	439	415	339	543	604
Microdose + 20 kg ha^{-1} P_2O_5 + 30 kg ha^{-1} N	903	1335	651	682	893	468
Microdose + 40 kg ha^{-1} P_2O_5 + 60 kg ha^{-1} N	977	1172	627	662	859	438
Contrast comparisons:						
Zero vs Microdose	NS	*	NS	+	**	NS
Microdose vs Microdose + 20 kg ha^{-1} P_2O_5	NS	**	NS	NS	0.06	NS
Microdose + 20 kg ha^{-1} P_2O_5 vs Microdose + 40 kg ha^{-1} P_2O_5	*	NS	NS	NS	NS	NS
Microdose vs Microdose + 30 kg ha^{-1} N	*	NS	NS	NS	NS	NS
Microdose + 30 kg ha^{-1} N vs Microdose + 60 kg ha^{-1} N	NS	NS	NS	NS	NS	NS
Microdose vs Microdose + 20 kg ha^{-1} P_2O_5 + 30 kg ha^{-1} N	*	**	*	**	**	NS
Microdose + 20 kg ha^{-1} P_2O_5 + 30 kg ha^{-1} N vs Microdose + 40 kg ha^{-1} P_2O_5 + 60 kg ha^{-1} N	NS	NS	NS	NS	NS	NS

[†] 2005 blank trial lost due to poor emergence due to a large rainfall event shortly after planting.
[+], * and ** indicate significance at $P \leq 0.10$, 0.05 and 0.01, respectively.

Table 5. Pearl millet grain yield as influenced by fertilizer treatment in Saria, Burkina Faso in 2001 to 2005.

Fertilizer treatment	2001	2002	2003	2004	Mean	2005 blank trial
	kg ha^{-1}					
Zero	581	321	293	209	351	279
Microdose	527	713	698	614	637	502
Microdose + 20 kg ha^{-1} P_2O_5	815	766	907	635	781	614
Microdose + 40 kg ha^{-1} P_2O_5	831	832	1011	712	847	614
Microdose + 30 kg ha^{-1} N	605	745	621	530	625	419
Microdose + 60 kg ha^{-1} N	733	750	698	630	695	474
Microdose + 20 kg ha^{-1} P_2O_5 + 30 kg ha^{-1} N	829	976	1019	698	880	670
Microdose + 40 kg ha^{-1} P_2O_5 + 60 kg ha^{-1} N	1067	1071	1186	816	1035	642
Contrast comparisons:						

Table 5. Contd.

Zero vs Microdose	**	**	**	**	**	*
Microdose vs Microdose + 20 kg ha^{-1} P_20_5	NS	NS	**	NS	*	NS
Microdose + 20 kg ha^{-1} P_20_5 vs Microdose + 40 kg ha^{-1} P_20_5	NS	NS	NS	NS	NS	NS
Microdose vs Microdose + 30 kg ha^{-1} N	NS	NS	NS	NS	NS	NS
Microdose + 30 kg ha^{-1} N vs Microdose + 60 kg ha^{-1} N	NS	NS	NS	NS	NS	NS
Microdose vs Microdose + 20 kg ha^{-1} P_20_5 + 30 kg ha^{-1} N	**	**	**	**	**	NS
Microdose + 20 kg ha^{-1} P_20_5+ 30 kg ha^{-1} N vs Microdose + 40 kg ha^{-1} P_20_5 + 60 kg ha^{-1} N	NS	NS	NS	NS	NS	NS

$^{+}$, * and ** indicate significance at P ≤ 0.10, 0.05 and 0.01, respectively.

Table 6. Pearl millet grain yield as influenced by fertilizer treatment in Cinzana (Segou), Mali in 2001 to 2005.

Fertilizer treatment	2001	2002	2003	2004	Mean	2005 blank trial
	---------- kg ha^{-1} ----------					
Zero	517	882	917	743	764	785
Microdose	808	1104	1361	910	1046	819
Microdose + 20 kg ha^{-1} P_20_5	892	1229	1299	1035	1114	854
Microdose + 40 kg ha^{-1} P_20_5	1013	1403	1632	1236	1321	1042
Microdose + 30 kg ha^{-1} N	850	951	1347	1028	1044	861
Microdose + 60 kg ha^{-1} N	906	1118	1215	1139	1094	979
Microdose + 20 kg ha^{-1} P_20_5 + 30 kg ha^{-1} N	1281	1056	1313	38	1147	951
Microdose + 40 kg ha^{-1} P_20_5 + 60 kg ha^{-1} N	1183	1292	1347	1118	1235	1007
Contrast comparisons:						
Zero vs Microdose	+	NS	**	NS	*	NS
Microdose vs Microdose + 20 kg ha^{-1} P_20_5	NS	NS	NS	NS	+	NS
Microdose + 20 kg ha^{-1} P_20_5 vs Microdose + 40 kg ha^{-1} P_20_5	NS	NS	*	NS	+	NS
Microdose vs Microdose + 30 kg ha^{-1} N	NS	NS	NS	NS	NS	S
Microdose + 30 kg ha^{-1} N vs Microdose + 60 kg ha^{-1} N	NS	NS	S	NS	NS	NS
Microdose + vs Microdose + 20 kg ha^{-1} P_20_5 + 30 kg ha^{-1} N	**	NS	NS	NS	NS	NS
Microdose + 20 kg ha^{-1} P_20_5 + 30 kg ha^{-1} N vs Microdose + 40 kg ha^{-1} P_20_5 + 60 kg ha^{-1} N	NS	NS	NS	NS	NS	NS

$^{+}$, * and ** indicate significance at P ≤ 0.10, 0.05 and 0.01, respectively.

Table 7. Pearl millet grain and stover yields as influenced by fertilizer treatment on silty clay soil at Cinzana (Segou), Mali in 2003 to 2004.

Fertilizer treatment	Grain yield			Stover yield		
	2003	2004	Mean	2003	2004	Mean
	---------------------------- kg ha^{-1} ----------------------------					
Zero	1250	889	1069	2278	2222	2500
Microdose	1619	1215	1417	4792	2708	3750
Microdose + 20 kg ha^{-1} P_20_5	1722	1174	1448	3858	2928	3428
Microdose + 40 kg ha^{-1} P_20_5	1737	1201	1469	4722	2778	3750
Microdose + 30 kg ha^{-1} N	2153	1021	1587	5417	2917	4167
Microdose + 60 kg ha^{-1} N	1903	1243	1573	4931	3194	4063
Microdose + 20 kg ha^{-1} P_20_5 + 30 kg ha^{-1} N	2153	1271	1712	5069	3542	4306
Microdose + 40 kg ha^{-1} P_20_5 + 60 kg ha^{-1} N	2263	1153	1708	5278	3194	4236
Contrast comparisons:	NS	NS	*	**	NS	**
Zero vs Microdose	NS	NS	NS	NS	NS	NS
Microdose vs Microdose + 20 kg ha^{-1} P_20_5	NS	NS	NS	NS	NS	NS
Microdose + 20 kg ha^{-1} P_20_5 vs Microdose + 40 kg ha^{-1} P_20_5	NS	NS	NS	NS	NS	NS
Microdose vs Microdose + 30 kg ha^{-1} N	NS	NS	NS	NS	NS	NS
Microdose + 30 kg ha^{-1} N vs Microdose + 60 kg ha^{-1} N	NS	NS	*	NS	NS	NS
Microdose vs Microdose + 20 kg ha^{-1} P_20_5 + 30 kg ha^{-1} N	NS	NS	NS	NS	NS	NS
Microdose + 20 kg ha^{-1} P_20_5 + 30 kg ha^{-1} N vs Microdose + 20 kg ha^{-1} P_20_5 + 60 kg ha^{-1} N	1250	889	1069	2278	2222	2500

$^{+}$, * and ** indicate significance at P ≤ 0.10, 0.05 and 0.01, respectively.

Niger and 20 kg P_2O_5 ha^{-1} + 30 kg N ha^{-1} N in addition to in Burkina Faso increased grain yields by approximately140 to 180 kg ha^{-1} (Table 7).

Although microdose application may be the most economical fertilizer rate (Abdoulaye and Sanders, 2005; Vitale and Sanders, 2005), the results of this study suggest that higher fertilizer rates are needed to produce maximum grain yield in all production environments tested. Given the increasing human population growth and economic development in West Africa resulting in food consumption pattern change (Delgado, 2003), attention to “sustainable high yield production systems” with increased fertilizer use will become of increasing importance.

Stover yields

Averaged across years, microdose application increased pearl millet stover yields by >1000 kg ha^{-1} in Mali and Niger but not in Burkina Faso (Tables 7, 9, 10 and 11). Pearl millet Sorghum stover yield on silty clay soil in Mali was increased 500 to 2500 kg ha^{-1} (Table 7). Although not declared significant, plots with microdose fertilizer produced 600 kg ha^{-1} greater pearl millet stover in Burkina Faso (Table 10). Individual year analysis indicated that microdose application increased pearl millet stover yield but was seldom declared significant (Tables 7, 9, 10, and 11), due to great variability in stover yields. On average on-farm studies indicated that pearl millet stover yields more than doubled in Burkina Faso and Niger, and were increased by approximately 2000 kg ha^{-1} across a large rainfall gradient in Mali (Table 8). However, in Burkina Faso, stover yields were approximately 50% higher in 2001 than other years, and stover yield increases were also much larger in 2001 (data not presented). In Mali, pearl millet stover yield without microdose fertilizer application was 7125, 6067, and 4731 kg ha^{-1} for the 700, 550 and 400 mm rainfall locations, respectively, while application of microdose fertilizer increased stover yields to 8071, 8896 and 7377 kg ha^{-1}. This indicates that in Mali, microdose fertilizer application in lower rainfall locations

Table 8. On-farm response of pearl millet to fertilizer treatments in Niger and Burkina Faso in 2001 to 2005, and in Mali across a rainfall gradient of 400 to 700 mm in 2002, 2003 and 2006.

Location	Zero	Microdose	Increase	Probability	Microdose + 20 kg/ha P_2O_5 + 30 kg/ha N	Microdose + 20 kg/ha P_2O_5	Increase (over microdose)	Probability
	---------- $kg\ ha^{-1}$ ----------		%		------------ $kg\ ha^{-1}$ -----------		%	
Burkina Faso:								
Grain (n = 36)	237	545	130	**	686		26	**
Stover (n = 36)	652	1461	124	**	1904		30	**
Niger:								
Grain (n = 15)	328	577	76	**		801	39	**
Stover (n = 10)	2309	4877	111	**		4437	-9	NS
Mali:								
Grain (n = 72)	1052	1444	37	**				
Stover (n = 72)	5974	8115	36	**				

$^{+}$, * and ** indicate significance at $P \le 0.10$, 0.05 and 0.01, respectively.

Table 9. Pearl millet stover yield as influenced by fertilizer treatment in Kalapaté, Niger in 2001 to 2006.

Fertilizer treatment	2001	2002	2003	2004	Mean	2006 blank trial[†]
	---------- $kg\ ha^{-1}$ ----------					
Zero	4134	1366	448	316	1566	1354
Microdose	6315	2132	651	1006	2526	1063
Microdose + 20 $kg\ ha^{-1}$ P_2O_5	6755	4484	1123	1107	3367	1542
Microdose + 40 $kg\ ha^{-1}$ P_2O_5	5322	3507	960	850	2660	1500
Microdose + 30 $kg\ ha^{-1}$ N	8643	2075	927	1149	3199	1333
Microdose + 60 $kg\ ha^{-1}$ N	8789	2441	1107	918	3314	1438
Microdose + 20 $kg\ ha^{-1}$ P_2O_5 + 30 $kg\ ha^{-1}$ N	8382	4769	1367	1761	4070	1438
Microdose + 40 $kg\ ha^{-1}$ P_2O_5 + 60 $kg\ ha^{-1}$ N	8447	3402	1316	1686	3713	1354
Contrast comparisons:						
Zero vs Microdose	**	NS	NS	NS	**	NS
Microdose vs Microdose +20 $kg\ ha^{-1}$ P_2O_5	NS	**	NS	NS	+	NS
Microdose + 20 $kg\ ha^{-1}$ P_2O_5 vs Microdose +40 $kgha^{-1}$ P_2O_5	*	NS	NS	NS	*	NS
Microdose vs Microdose + 30 $kg\ ha^{-1}$ N	**	NS	NS	NS	**	NS
Microdose + 30 $kg\ ha^{-1}$ N vs Microdose + 60 $kg\ ha^{-1}$ N	NS	NS	NS	NS	NS	NS

Table 9. continued

Microdose vs Microdose + 20 kg ha^{-1} P_20_5 + 30 kg ha^{-1} N	**	**	NS	NS	**	NS
Microdose + 20 kg ha^{-1} P_20_5 + 30 kg ha^{-1} N vs Microdose +40 kg ha^{-1} P_20_5 + 60 kg ha^{-1} N	NS	*	NS	NS	NS	NS

†Blank trial lost due to poor emergence due a large rainfall event shortly after planting.
+, * and ** indicate significance at P ≤ 0.10, 0.05 and 0.01, respectively.

Table 10. Pearl millet stover yield as influenced by fertilizer treatment in Saria, Burkina Faso in 2001 to 2005.

Fertilizer treatment	2001	2002	2003	2004	Mean	2005 blank trial
	kg ha^{-1}					
Zero	1486	544	1186	502	929	530
Microdose	2197	1144	1863	1186	1597	977
Microdose + 20 kg ha^{-1} P_20_5	2336	1381	2357	1270	1836	1200
Microdose + 40 kg ha^{-1} P_20_5	2434	1228	2288	1437	1847	1061
Microdose + 30 kg ha^{-1} N	1919	1200	1681	1172	1493	782
Microdose + 60 kg ha^{-1} N	2120	1200	1828	1339	1622	1116
Microdose + 20 kg ha^{-1} P_20_5 + 30 kg ha^{-1} N	2783	1451	2483	1674	2098	1451
Microdose + 40 kg ha^{-1} P_20_5 + 60 kg ha^{-1} N	2644	1800	2762	1786	2248	1312
Contrast comparisons:						
Zero vs Microdose	NS	NS	NS	NS	NS	NS
Microdose vs Microdose + 20 kg ha^{-1} P_20_5	NS	NS	NS	NS	NS	NS
Microdose + 20 kg ha^{-1} P_20_5 vs Microdose + 20 kg ha^{-1} P_20_5	NS	NS	NS	NS	NS	NS
Microdose vs Microdose + 30 kg ha^{-1} N	NS	NS	NS	NS	NS	NS
Microdose + 30 kg ha^{-1} N vs Microdose + 60 kg ha^{-1} N	NS	NS	NS	NS	NS	NS
Microdose vs Microdose + 20 kg ha^{-1} P_20_5 + 30 kg ha^{-1} N	NS	NS	NS	NS	NS	NS
Microdose + 20 kg ha^{-1} P_20_5 + 30 kg ha^{-1} N vs Microdose + 40 kg ha^{-1} P_20_5 + 60 kg ha^{-1} N	NS	NS	NS	NS	NS	NS

+, * and ** indicate significance at P ≤ 0.10, 0.05 and 0.01, respectively.

produced a larger increase in pearl millet stover yield than in higher rainfall locations.

Fertilizer application in addition to microdose increased pearl millet stover yields in about half of the location-year combinations in Mali and Niger, but not in Burkina Faso (Tables 7, 9, 10 and 11). Averaged across years, the addition of 20 kg P_2O_5 ha^{-1} and 30 kg N ha^{-1} increased stover yields by 400 to 1500 kg ha^{-1} in Niger and Mali with no further stover yield increase to application of the higher rate of 40 kg P_2O_5 ha^{-1} and 60 kg N ha^{-1} (Tables 7, 9 and 11). Although not declared significant in the on-station plots, microdose fertilizer produced > 500 kg ha^{-1} greater pearl millet stover in Burkina Faso (Table 10). Similar stover yield increases occurred in on-farm plots in Burkina Faso, while larger stover yield increases occurred across rainfall zones in Mali, but no stover yield increase occurred in Niger (Table 8).

In spite of the economic value to farmers of pearl millet stover production for animal feed, fuel

Table 11. Pearl millet stover yield as influenced by fertilizer treatment in Cinzana (Segou), Mali in 2001 to 2005.

Fertilizer treatment	2001	2002	2003	2004	Mean	2005 blank trial
	----------	----------	----------	kg ha^{-1}	----------	----------
Zero	1944	1250	1736	1250	1545	2431
Microdose	3993	1736	2639	1875	2561	2014
Microdose + 20 kg ha^{-1} P_20_5	4201	2083	2639	2153	2769	2292
Microdose + 40 kg ha^{-1} P_20_5	5764	2431	3368	2639	3541	3125
Microdose + 30 kg ha^{-1} N	4375	1736	2500	2014	2656	2222
Microdose + 60 kg ha^{-1} N	4549	1944	2778	2014	2821	2569
Microdose + 20 kg ha^{-1} P_20_5 + 30 kg ha^{-1} N	5889	1944	3056	2222	2328	2778
Microdose + 40 kg ha^{-1} P_20_5 + 60 kg ha^{-1} N	7139	2292	3263	2569	3816	2778
Contrast comparisons:						
Zero vs Microdose	**	NS	*	NS	**	NS
Microdose vs Microdose + 20 kg ha^{-1} P_20_5	*	NS	NS	NS	*	NS
Microdose + 20 kg ha^{-1} P_20_5 vs Microdose + 40 kg ha^{-1} P_20_5	**	NS	NS	NS	*	NS
Microdose vs Microdose + 30 kg ha^{-1} N	NS	NS	NS	NS	NS	NS
Microdose + 30 kg ha^{-1} N vs Microdose + 60 kg ha^{-1} N	NS	NS	NS	NS	NS	NS
Microdose vs Microdose + 20 kg ha^{-1} P_20_5 + 30 kg ha^{-1} N	**	NS	NS	NS	**	NS
Microdose + 20 kg ha^{-1} P_20_5 + 30 kg ha^{-1} N vs Microdose + 40 kg ha^{-1} P_20_5 + 60 kg ha^{-1} N	**	NS	NS	NS	+	NS

$^{+}$, * and ** indicate significance at $P \leq 0.10$, 0.05 and 0.01, respectively.

and other uses (Schlecht and Buerkert, 2004), they are seldom factored into decisions about recommended fertilizer application rates.

Increased crop residue production also has value as soil maintenance and improvement through potential increases in soil organic matter, increased nutrient supply, soil water conservation (increased infiltration, reduced evapotranspiration) and increased grain yield to succeeding crops (Nicou and Charreau, 1985; Klaij and Hoogmoed, 1993; Geiger et al., 1992; Coulibaly et al., 2000; Michels et al., 1995; Bationo et al., 1993). With increasing human population growth in West Africa, demand for animal feed and fuel is increasing (Ejigu, 2008) and as soils are degrading and being depleted of nutrients (Bagayoko et al., 1996; Sanchez et al., 1997), increased stover production is essential to meet both human and soil maintenance/improvement needs.

Conclusion

Microdose fertilizer application increases grain and stover yields of pearl millet across a broad range of climatic and soil conditions in West Africa. Current efforts to extend this fertilizer application method should increase poor farmers' pearl millet grain and stover yields, affording an opportunity to increase food, animal feed and fuel supply. In addition, this should increase stover availability for compost production and leaving mulch in fields to increase soil organic matter, nutrient and water supply for reversing soil degradation and improving grain and stover yields of succeeding crops. Increasing fertilizer application to include microdose combined with at least 20 kg P_2O_5 ha^{-1} and 30 kg N ha^{-1} would further increase pearl millet grain and stover yields. Application of fertilizer is essential to create "high" yield production systems that have potentials to reverse soil degradation and meets human food and animal feed needs in West Africa.

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