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EFFECT OF SEED PRIMING AND MICRO-DOSING OF FERTILIZER ON GROUNDNUT, SESAME AND COWPEA IN WESTERN SUDAN

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SUMMARY

The effect of seed priming and micro-dosing in groundnut, cowpea and sesame was studied for three years in on-farm and on station experiments under rainfed agriculture in North Kordofan, Sudan. The on-station trials showed that seed priming increased groundnut pod and hay yields by 18% and 20% respectively. Micro-dosing of 0.3, 0.6 and 0.9 g fertilizer per pocket increased groundnut pod yield across the three years by 36.7, 67.6 and 50.8% respectively compared to the control. The highest yield increases were consistently obtained when micro-dosing was combined with seed priming. A combination of seed priming and micro-dosing of 0.6 g increased groundnut yield by 106%. Priming alone did not significantly affect sesame seed or hay yield, but micro-dosing of 0.6 g per pocket increased the grain yield by 38% over the control. Cowpea grain yield in the on-station experiments was not significantly affected by seed priming or micro-dosing. However, both seed priming and micro-dosing increased cowpea hay yield. In the on-farm trials, seed priming increased groundnut and cowpea yields by 18.2 and 25.5% respectively, and seed priming combined with 0.3 g fertilizer increased their yields by 42.2 and 54.5% respectively compared to the control. For sesame the yield increase after 0.3 g fertilizer per pocket was 46.3%. The economic analyses of the on-station experiments showed that the highest gross margin was obtained when combining seed priming with 0.6 g micro-dosing for all the crops. These results show that the combination of micro-dosing and seed priming has the potential to increase productivity and improve net return in the crops tested.

INTRODUCTION

Traditional rainfed agriculture is one of the three major production systems in Sudan. It covers about 9.0 million ha, representing more than 50% of the total national cultivated land. Crop production in this system is dominated by traditional farming methods and is entirely dependent on rainfall. Most of the areas in the traditional rainfed sector are in the semi-arid zone of western Sudan, which has experienced several drought cycles in recent decades. The average annual rainfall varies from less than 150 mm on the northern border of western Sudan to more than 600 mm on the southern border. The rainy season varies from less than three months in the north to more than four months in the south and rains occur between May and October. Seasonal variations in rainfall amount and distribution are common. The natural resource base is fragile and severely degraded, especially in the north (DLRC, 2005).

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Groundnut (*Arachis hypogaea*) and sesame (*Sesamum indicum*) are the main cash crops occupying between 20 and 30% of the farmers' cultivated land in the traditional rainfed sector, especially in the Kordofan and Darfur states. The average total groundnut area in the traditional rainfed sector for the period 1979/80 to 2008/09 is about 0.97 million ha and the average total area of sesame for the same period is about 0.71 million ha (Osman and Ali, 2009). During the past 30 years (1979/80–2007/08), groundnut and sesame area and total production in the traditional rainfed sector have increased while productivity has decreased (Osman and Ali, 2009). The average productivity of groundnut and sesame are 497 and 186 kg ha^{-1} respectively (Osman and Ali, 2009). The low yields are due to natural and socio-economic constraints such as erratic rainfall, poor and low soil fertility, and limited access to inputs.

Cowpea (*Vigna unguiculata*) is a food crop generally grown as a minor subsistence intercrop in many parts of western Sudan. It is cultivated in small plots as a sole crop or in intercropping systems with pearl millet, sorghum, sesame, groundnut or hibiscus. Cowpea is also grown extensively in home garden (*jubraka*) systems, especially the extra-early maturing varieties, to provide food during the hunger period in August. The total annual area allocated to cowpea is about 154 000 ha with an annual total production of 19 000 t and a mean grain yield of 181 kg ha^{-1} (Hassan and Elasha, 2009).

The objective of this study was to use on-station and on-farm trials to evaluate the effect of seed priming and micro-fertilizing on groundnut, sesame and cowpea in the marginal and dry areas of the North Kordofan State in western Sudan. Seed priming has been found to increase crop yields in the dryland areas of India, Pakistan and southern Africa (Harris, 2006) and is particularly effective in improving crop establishment, which is a serious problem in the drylands of Africa. Micro-dosing is the application of a small amount of mineral fertilizer in the planting pocket (Aune and Bationo, 2008; Aune *et al.*, 2007; Hayashi *et al.*, 2008).

MATERIALS AND METHODS

On-station and on-farm trials were conducted for three seasons (2007, 2008 and 2009) under rainfed conditions.

On-station trials

Three on-station trials (researcher managed) on groundnut, sesame and cowpea were carried out at the research farm at the El-Obeid Agricultural Research Station (lat: 13°10′N, long: 30°14′E, alt. 570 m, 650 km west of Khartoum), North Kordofan State, Sudan. The soil of the experimental site has more than 90% sand and is classified as a Quartzipsamments. It has very low organic matter (0.112%), organic carbon (0.560%), nitrogen (0.030%), available phosphorus (4 ppm-HCO_3), C/N (18) and a pH of about 7. The total annual rainfall and its distribution during the study seasons are presented in Aune and Ousman (2011). No irrigation was applied.

Each of the three seed priming / micro-fertilizing trials was a 2×4 factorial design, consisting of eight treatments. Micro-dosing treatments were 0.0, 0.3, 0.6 and 0.9 g

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Table 1. Calculated fertilizer dose per hectare for groundnut, sesame and cowpea.

Crop	Spacing (cm)	Micro-dose (g per hole) 0	0.3	0.6	0.9	Planting date 2007–2009	Harvesting date 2007–2009
		Equivalent dose (kg per ha)					
Groundnut	60 × 20	0	25.0	50.0	75.0	6/7–24/7	9/10–3/11
Sesame	60 × 40	0	12.5	25.0	37.5	5/7–16/7	5/10–15/10
Cowpea	60 × 30	0	16.7	33.4	50.1	15/7–20/7	20/9–25/9

fertilizer per pocket and priming treatments were without and with priming. There were four replications.

Primed seeds were soaked in water for eight hours, surface dried and sown. The fertilizer (NPK) applied was 17-17-17 in the 2007 and 2008 seasons and 15-15-15 in the 2009 season. This choice was based on the availability of fertilizer within Sudan. Fertilizer was applied with the seeds at planting as a micro-dose, i.e. a small amount added to the planting pocket. This corresponds to a fertilizer rate per hectare as presented in Table 1.

The experimental plot was 5 m × 3 m and the between-rows distance was 60 cm. Varieties used were Gubeish groundnut (85–90 days maturity), El-Obeid-1 sesame (75 days maturity) and Ein-Elgazal cowpea (55–60 days maturity). Before sowing and after priming, the seeds were treated with Furnisan-D at the rate of 3 g kg^{-1} seed. Two seeds per pocket were planted. Weeding was done twice using a hand hoe. The first weeding was undertaken two–three weeks after sowing and the second a month after the first weeding.

Data collected were grain and hay yields, number of fruits per plant, plant population/unit area and vigour score. The plant vigour score was measured using a 1–4 rating scale (score) where: 1 = low, 2 = moderate, 3 = vigorous and 4 = highly vigorous.

The effects of the treatment were tested using the interaction treatment × years as an error in the analysis of variance.

On-farm trials

On-farm trials (farmer managed) were conducted to compare seed priming and micro-fertilizing in farmers' fields in order to evaluate the technologies under real farming conditions and to enhance farmers' appreciation of the technologies. Participating villages and the number of participating famers for the three seasons of the study are presented in Table 2.

The treatments in each farmer's field consisted of control (1), seed priming (2) and seed priming + 0.3 g fertilizer/planting pocket (3). All the cultural practices were carried out by the farmers and the recommended planting density was used. Yield measurements were taken from all farmers' plots. Plot size for each treatment was 360 m^2 (15 m × 24 m) and one farmer represented a replicate in the statistical analysis. The treatments were tested using the interaction treatment × replication (farmer) as an error.

Table 2. On-farm trials – participating villages and number of farmers.

Village	Distance (km) and direction from El-Obeid	Season of participation	Number of trials/farmers			Total trials
			Groundnut	Cowpea	Sesame	
Fragalla	12-N	1st	5	5	–	10
Kazgail	45-W	1st and 2nd	9	9	5	23
Himera	25-NW	2nd	5	5	3	13
Shigia	37-W	2nd and 3rd	10	10	9	29
Faris	60-SW	1st, 2nd and 3rd	25	25	20	70
Total			54	54	37	145

Agronomic efficiency of fertilizer

The agronomic efficiency of fertilizer of the different priming and micro-dosing treatments was calculated by dividing the increase in grain yield (kg ha^{-1}) in each treatment over the amount of fertilizer applied (kg ha^{-1}).

Economic analysis

All the seed priming and micro-dosing treatments were economically evaluated using gross margin and the value-cost ratio (VCR).

The gross margin was calculated by subtracting the production cost from the total income (value of grains). All monetary values were converted from Sudanese pounds to US$ at an exchange rate of 1 US$ equivalent to 2.50 Sudanese pounds, and the average yields over seasons and replications in each treatment were calculated. The average field prices of the crops during the past three years were taken from the markets where the farmers sell their produce. Average prices per kg of groundnut, sesame and cowpeas were respectively 0.42, 0.69 and 0.33 US$ kg^{-1}. Production cost is the sum of labour and input costs (without fertilizer). These data were taken from surveys conducted by the Ministry of Agriculture, North Kordofan State, Sudan (MOA North Kordofan, 2008). Costs of production (without fertilizer) for groundnut, sesame and cowpea were 119, 53 and 42 US$ ha^{-1}, respectively. A fertilizer cost of 0.80 US$ kg^{-1} was added in the micro-fertilizer treatment based on the amount of fertilizer used. Fertilizer application does not increase the labour cost as seeds and fertilizer are applied simultaneously in the same operation.

The VCR for each treatment was calculated as in Aune and Ousman (2011).

RESULTS

On-station trials

Groundnut. Seed priming affected groundnut crop establishment positively. Seed priming increased groundnut stand number and vigour score by 18% and 34% respectively (Table 3). The number of pods per plant was not significantly changed by seed priming, but this characteristic was increased by micro-dosing. There was no significant interaction between priming and micro-dosing for any of these traits.

Table 3. Effect of seed priming and micro-dosing on crop establishment of groundnut, sesame and cowpea (average results across three seasons).

	Groundnut			Sesame			Cowpea		
Treatment	Plant number (per m^2)	Vigour score	Pods per plant (no)	Plant number (per m^2)	Vigour score	Capsules per plant	Plant number (per m^2)	Vigour score	Pods per plant (no)
				Seed priming					
Non-primed	8.72	2.38	26.2	5.48	2.88	44.5	31.1	2.31	17.4
Primed	10.3	3.19	29.1	5.53	3.63	45.1	59.6	3.31	18.6
±*s.e.*	0.36**	0.163**	1.21*n.s.*	0.17*n.s.*	0.14**	3.53*n.s.*	2.55**	0.18**	0.99*n.s.*
				Micro-dosing					
Control	9.60	2.13	23.1	5.25	3.13	37.2	42.3	2.50	17.1
0.3g per hole	9.53	2.50	26.8	5.46	3.25	44.2	41.8	2.75	18.2
0.6g per hole	9.42	2.75	28.9	5.40	3.00	48.0	49.1	2.75	17.0
0.9g per hole	9.54	2.75	31.6	5.90	3.63	50.0	48.3	5.25	19.6
±*s.e.*	0.51*n.s.*	0.230*n.s.*	1.72**	0.24*n.s.*	0.20*n.s.*	5.0*n.s.*	3.60*n.s.*	0.25*	1.40*n.s.*
Mean	9.52	2.78	27.6	5.50	3.25	44.8	45.4	2.81	18.0

Note: *n.s.*,*, ** indicate respectively, not significant, significant at $p \leq 0.05$ and 0.01

Seed priming and micro-dosing increased grain and hay yields significantly (Table 4). Pod yield and hay yield were increased by 18% and 20% respectively as a result of seed priming. Grain yield increased significantly by seed priming and micro-dosing in two of the three years. Seed priming and micro-dosing had a significant effect in the years when the rainfall was low (2008 and 2009). Micro-dosing of 0.3, 0.6 and 0.9 g fertilizer per pocket increased groundnut pod yield across the three years, by 36.7, 67.6 and 50.8% respectively compared to the control. The corresponding yield increase for groundnut hay was 26.9, 38.2 and 39.2%. The combination of seed priming and 0.6 g fertilizer per pocket more than doubled the average yield across the three seasons. There was no significant interaction between priming and micro-fertilizing for yields.

Sesame. Analysis of variance results showed a highly significant effect of seed priming on vigour score. Priming increased vigour score by 26% compared with the control. The number of capsules per plant and stand count were not significantly changed by either priming or micro-dosing. There was no significant interaction between priming and micro-dosing for any of these traits (Table 3).

Seed priming did not increase sesame yield in any of the years or across the years (Table 5). The application of 0.3 g fertilizer per pocket increased sesame seed yield across the years by 11.7%, and 0.6 and 0.9 g per pocket increased grain yield by 37.8% compared to the control. Hay yield increase for 0.3, 0.6 and 0.9 g fertilizer per pocket was 35.4, 38.7 and 51.7% respectively (Table 5). Contrary to the results for groundnut, sesame yields were greatest in the third season and least in the first season. Generally, sesame is not tolerant to excessive water and frequent cloudy weather. There was no significant interaction between priming and micro-fertilizing.

Cowpea. Seed priming improved stand number and vigour score in cowpea by 92% and 43% respectively. The number of pods per plant was not influenced by priming.

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Table 4. Effect of seed priming and micro-dosing on groundnut pod and hay yields (kg ha^{-1}) for 2007, 2008, 2009 and across three seasons.

		Pod yield (kg ha^{-1})						Hay yield (kg ha^{-1})					
		Micro-dosing (g per planting hole)						Micro-dosing (g per planting hole)					
Season	Seed priming	Control	0.3	0.6	0.9	Mean	*s.e.*±	Control	0.3	0.6	0.9	Mean	*s.e.*±
2007	Non-primed	1422	1826	2014	1615	1719	123 *n.s.*	2093	2568	2551	2443	2414	121 *n.s.*
	Primed	1345	1536	1856	1719	1615		2218	2576	2651	2710	2539	
	Average	1384	1681	1935	1667	1667		2155	2572	2601	2576	2477	
	s.e. ±		174 *n.s.*						172 *n.s.*				
2008	Non-primed	277	615	838	804	633	75**	636	1081	1116	1670	1126	162**
	Primed	651	1048	1760	1433	1226		1030	1826	2400	1798	1764	
	Average	464	831	1299	1124	929		833	1453	1758	1734	1445	
	s.e. ±		107**						229**				
2009	Non-primed	618	939	1042	1008	902	29*	1084	1168	1279	1334	1216	15*
	Primed	807	1031	1071	1132	1010		1216	1279	1446	1585	1381	
	Average	713	985	1056	1070	956		1150	1223	1362	1450	1299	
	s.e. ±		42**						72*				
Average	Non-primed	772	1127	1298	1142	1085	53**	1271	1605	1649	1816	1585	62**
three	Primed	934	1205	1562	1431	1283		1488	1894	2166	2031	1895	
Years	Average	853	1166	1430	1287	1184		1379	1750	1907	1923	1740	
	s.e. ±		75***						87***				

Note: *n.s.*,*, **,*** indicate respectively, not significant, significant at $p \leq 0.05$, 0.01 and 0.001.

Table 5. Effect of seed priming and micro-dosing on sesame seed and hay yields (kg ha^{-1}) for 2007, 2008, 2009 and across three seasons.

		Pod yield (kg ha^{-1})						Hay yield (kg ha^{-1})					
		Micro-dosing (g per planting hole)						Micro-dosing (g per planting hole)					
Season	Seed priming	Control	0.3	0.6	0.9	Mean	*s.e.*±	Control	0.3	0.6	0.9	Mean	*s.e.*±
2007	Non-primed	121	134	195	293	186	20 *n.s*	629	512	440	480	515	44 *n.s.*
	Primed	242	177	274	199	223		359	474	492	582	477	
	Average	182	156	234	246	205		494	493	466	531	496	
	s.e. ±		28***						62 *n.s.*				
2008	Non-primed	291	226	276	252	261	36 *n.s*						
	Primed	248	249	244	308	262							
	Average	269	237	260	280	262							
	s.e. ±		51 *n.s.*										
2009	Non-primed	245	369	344	363	330	33 *n.s.*	414	778	765	865	705	62 *n.s.*
	Primed	137	281	435	356	302		556	883	1015	1043	874	
	Average	191	325	390	359	316		485	831	890	954	790	
	s.e. ±		47*						88**				
Average	Non-primed	219	243	272	303	259	15 *n.s.*	521	645	602	672	610	158 *n.s.*
three	Primed	209	236	318	288	263		457	678	753	812	675	
Years	Average	214	239	295	295	261		489	662	678	742	643	
	s.e. ±		22**						223 *n.s.*				

Note: *n.s.*,*, ** indicate respectively, not significant, significant at $p \leq 0.05$ and 0.01.

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Table 6. Effect of seed priming and micro-dosing on cowpea seed and hay yields (kg ha^{-1}) for 2007, 2008, 2009 and across three seasons.

		Pod yield (kg ha^{-1})						Hay yield (kg ha^{-1})					
		Micro-dosing (g per planting hole)						Micro-dosing (g per planting hole)					
Season	Seed priming	Control	0.3	0.6	0.9	Mean	*s.e.*±	Control	0.3	0.6	0.9	Mean	*s.e.*±
2007	Non-primed	816	781	924	859	845	94 *n.s.*	1793	1851	1851	1884	1845	95 *n.s.*
	Primed	792	651	731	735	727		1892	1659	2151	2034	1934	
	Average	804	716	828	797			1843	1755	2001	1959	1890	
	s.e. ±		134 *n.s.*						133 *n.s.*				
2008	Non-primed	153	146	233	314	212	21**	254	426	552	648	470	68**
	Primed	273	311	482	431	374		636	870	1247	1253	1002	
	Average	213	228	358	373			445	648	900	951	736	
	s.e. ±		29**						96**				
2009	Non-primed	285	389	458	358	372	27 *n.s.*	396	293	482	654	456	52**
	Primed	303	411	409	442	391		620	656	763	931	743	
	Average	294	400	433	400	382		508	475	623	793	600	
	s.e. ±		38**									73*	
Average three Years	Non-primed	418	439	539	510	476	22 *n.s.*	814	857	961	1062	924	43**
	Primed	456	457	541	536	498		1049	1062	1387	1406	1226	
	Average	437	448	540	523	487		932	959	1175	1234	1075	
	s.e. ±		32 *n.s.*						61**				

Note: *n.s.*,*, **,*** indicate respectively, not significant, significant at $p \leq 0.05, 0.01, 0.001$.

With the exception of vigour score, these traits were not significantly affected by micro-dosing. There was a significant interaction between priming and micro-dosing for vigour score (Table 3).

Seed priming significantly increased cowpea pod yield in one out of three years, but there was no significant effect across the seasons (Table 6). The hay yield increased by 32.6% across the seasons. Grain yield increased by 3, 24 and 20% with micro-dose applications of 0.3, 0.6 and 0.9 g respectively. Hay yield was significantly increased by micro-dosing. There was no significant interaction between priming and micro-fertilizing for grain or hay yields.

On-farm trials

In general there was a highly significant effect of seed priming and micro-dosing in the crops tested (Table 7). For groundnut, the yield increase due to priming was consistent across the sites and ranged from 5 to 29% in the villages. The average groundnut pod yield increase compared to the control was 18% for seed priming. The yield increase due to priming combined with 0.3 g fertilizer per pocket ranged among villages from 11 to 99% with an average yield increase across locations of 42.2%.

Priming increased cowpea yields among the villages from 5 to 40%, with an overall average increase across locations of 26%. The yield increase due to priming together with micro-dose application ranged from 23 to 80%, with an overall average increase across locations of 55%.

Table 7. On-farm trials – effect of seed priming and micro-dosing on groundnut, cowpea and sesame yields (kg ha^{-1}).

Village	Season of participation	Total number of farmers	Control	Priming	Priming + 0.3 g per pocket	Mean	*l.s.d.* (5%)
			Groundnut				
Fragalla	1st	5	541	700	1076	772	130**
Kazgail	1st and 2nd	9	672	789	960	807	95**
Himera	2nd	5	918	968	1022	969	37**
Shigia	2nd and 3rd	10	757	845	963	855	40**
Faris	1st, 2nd and 3rd	25	781	953	1150	962	48**
Total		54	749	884	1065	899	36**
Fertilizer efficiency (kg yield per kg fertilizer)			–	–	12.6	–	–
Value cost ratio			–	–	6.63	–	–
Net benefit (US $ per ha)			196	253	309	–	–
			Cowpea				
Fragalla	1st	5	336	436	606	459	131**
Kazgail	1st and 2nd	9	402	474	563	480	59**
Himera	2nd	5	564	591	695	617	55**
Shigia	2nd and 3rd	10	292	343	415	350	58**
Faris	1st, 2nd and 3rd	25	286	400	496	394	66**
Total		54	337	423	521	427	35**
Fertilizer efficiency (kg yield per kg fertilizer)			–	–	11.0	–	–
Value cost ratio			–	–	4.54	–	–
Net benefit (US $ per ha)			69.3	97.7	117	–	–
			Sesame				
Kazgail	2nd	5	452	–	584	518	69*
Himera	2nd	3	230	–	339	285	137 *n.s.* (8%)
Shigia	2nd and 3rd	9	382	–	518	450	83**
Faris	1st, 2nd and 3rd	20	395	–	616	505	53**
Total		37	386	–	565	476	37**
Fertilizer efficiency (kg yield per kg fertilizer)			–	–	14.3	–	–
Value cost ratio			–	–	12.4	–	–
Net benefit (US $/ha)			215	–	329	–	–

Note: *n.s.*,*, ** indicate respectively, not significant, significant at $p \leq 0.05$ and 0.01. *l.s.d.*: least significant difference.

For sesame on-farm trials, seed priming was not practiced and only micro-dose application of 0.3 g per pocket was tested. Micro-dosing increased sesame yield on average by 46.3%.

Fertilizer use efficiency

The fertilizer use efficiency (FUE) for the three crops in the on-station and on-farm trials is presented in Tables 7 and 8. In the on-station trials, FUE was clearly improved by seed priming. It was consistently higher for groundnut with the combination of priming and 0.3 g fertilizer per pocket giving a fertilizer efficiency of 17 kg grain per kg fertilizer, and in sesame and cowpea the highest fertilizer efficiency was around 4 kg

Table 8. Agronomic efficiency of fertilizers, gross margin and value/cost ratio (VCR) of the different priming and micro-dosing treatments across seasons in on-station experiments.

	Groundnut			Sesame			Cowpea		
Treatments (priming/ micro-dose per pocket)	Fertilizer efficiency	Net benefit (US$ per ha)	VCR	Fertilizer efficiency	Net benefit (US$/ha)	VCR	Fertilizer efficiency	Net benefit (US$ per ha)	VCR
1. contol	–	184.62	–	–	99.80	–	–	96.01	–
2. No priming +0. 3 g	14.2	334.72	7.47	2.00	106.36	1.73	1.26	89.58	0.52
3. No priming +0. 6 g	10.52	386.54	5.52	2.16	116.37	1.86	3.62	109.22	1.80
4. No priming +0. 9 g	4.93	301.02	2.60	2.27	127.76	1.96	1.84	86.29	0.94
5. Priming no dose	–	273.66	–	–	92.90	–	–	108.55	–
6. Priming +0. 3 g	17.32	367.48	9.06	1.44	101.53	1.24	2.33	95.52	0.96
7. Priming +0. 6 g	15.8	497.42	8.29	4.00	148.11	3.45	3.68	109.88	1.52
8. Priming +0. 9 g	8.79	422.40	4.61	1.87	117.41	1.61	2.36	94.87	0.97

Note: groundnut, sesame, cowpea and fertilizer prices are: 0.42, 0.69, 0.33 and 0.80 US $ per kg, respectively.

grain per kg fertilizer. In the on-farm trials, FUE for groundnut, sesame and cowpea was 12.6, 14.3 and 11.0 kg grain per kg fertilizer respectively.

Economic analysis

Calculations of the gross margin and VCR for the different crops and treatments in the on-station and on-farm trials are summarized in Tables 7 and 8. For all the crops, the highest gross margins were obtained when both seed priming and micro-dosing were used. The treatment in the on-station trials that gave the highest gross margin for all the crops tested was the combination of seed priming and 0.6 g fertilizer per pocket. The increase in gross margin for this treatment compared to the control was 313, 48 and 14 US $ ha^{-1} for groundnut, sesame and cowpea respectively.

The VCR was also clearly higher in groundnut compared to cowpea and sesame in the on-station experiments. The highest VCR recorded was 9.06 when combining seed priming and micro-dosing. The VCR in sesame in the on-station experiments was above 2 for all the micro-fertilizer treatments in combination with seed priming. The VCR for cowpea was below 2 for all the treatments. In the on-farm trials, the groundnut gross margin increased from 196 US $ ha^{-1} in the control to 253 US $ ha^{-1} in the priming treatment and 309 US $ ha^{-1} in the combination of seed priming and 0.3 g fertilizer per pocket. In cowpea, priming increased the net return from 69 US $ ha^{-1} to 98 US $ ha^{-1}, and the gross margin in the treatment where seed priming was combined with micro-dosing was 117 US $ ha^{-1}. The sesame gross margin increased from 215 US $ ha-1 in the control to 329 US $ ha^{-1} in micro-dosing using 0.3 g fertilizer per pocket.

DISCUSSION

Seed priming and micro-dosing were able to improve crop establishment, increase yields and improve economic return in groundnut, sesame and cowpea production.

However, the effects differed among the crops and between the on-station and the on-farm experiments. These results are the first to our knowledge to document the effect of seed priming and micro-dosing in groundnut, sesame and cowpea. Yields in the drylands of West Africa have been stagnating (Aune and Bationo, 2008), and these results indicate that it is possible to increase yields in these areas at a meagre cost.

The most consistent effect of seed priming among the crops tested was found in groundnut. Seed priming increased crop vigour for all the crops while the effect on plant number was only observed in groundnut and cowpea. Seed priming increased the yield in groundnut grain in both the on-station and on-farm experiments by 18%. The groundnut hay yield also increased as a result of seed priming in the same order. Seed priming on its own increased cowpea yield in the on-farm experiments. For sesame, no effect of seed priming was found. Seed priming can be recommended for groundnut and cowpea independently of the economic resources of the farmers. Seed priming has previously been found to work both for species with large (maize and chickpea) and small seeds (pearl millet and mungbean) (Harris, 2006).

Micro-dosing did not improve plant stand or vigour for any of the crops tested, except for vigour in cowpea. However, there was a clear effect of micro-dosing on grain and hay yield for all the crops. The on-station experiments showed an effect on yield up to 0.6 g fertilizer per pocket while the straw yield can be increased by using up to 0.9 g fertilizer per pocket. The interaction of seed priming and micro-dosing was not significant, but the highest yields were consistently found when seed priming and micro-dosing were combined. If micro-dosing is used, it should preferably be used in combination with seed priming to reduce the risk of fertilizer application and to increase the fertilizer efficiency. The combination of seed priming and 0.6 g fertilizer per pocket gave a yield increase of 102.6, 45.2 and 29.4% compared to the control for groundnut, sesame and cowpea respectively. However, the on-farm experiment showed that the application of 0.3 g fertilizer per pocket in combination with seed priming can also significantly increase yield. This treatment gave a yield increase of 42.3, 54.6 and 46.4% compared to the control for groundnut, sesame and cowpea respectively in the on-farm experiments. The application of phosphorous fertilizer has previously been found to increase yields of groundnut and cowpea in the Sahel (Buerkert and Hiernaux, 1998; Buerkert *et al.*, 2001).

It appeared from the results that best effect of seed priming and micro-dosing in groundnut and cowpea was found in 2008 and 2009 which were the two driest years. No such a tendency was observed in sesame. This support the conclusion by Harris *et al.* (2005) that seed priming is a low cost and low risk technology of value to resource-poor farmers in marginal conditions as a form of insurance to mitigate the effects of poor management or adverse physical conditions.

Micro-dosing has been tested in sorghum and millet in the Sahel, but there are no published scientific papers on micro-dosing in groundnut or sesame. However, several studies have shown that micro-dosing is an efficient way to increase millet and sorghum yields in drylands (Aune *et al.*, 2007; Hayashi *et al.*, 2008; Tabo *et al.*, 2007). These results indicate that micro-dosing is an approach that effectively addresses the problem of low fertility in the sandy soils in the North Kordofan State. These soils have been found to have severe deficiencies of P and N (Madibo, 1987). The broadcasting of fertilizer, the traditional method of adding fertilizer, cannot be recommended because it is too costly and risky for the farmers.

The highest FUE in the on-station experiments for groundnut, sesame and cowpea was 17.3, 4.0 and 3.68 kg grains per kg fertilizer respectively, and in the on-station experiments it was 12.6, 11.0 and 14.3 kg grains per kg fertilizer. It appears therefore that the most consistent effect of fertilizer can be found in groundnut. The generally higher FUE in the on-farm experiments compared to the on-station experiments might be explained by a general lower fertility in the on-farm fields compared to the on-station field. The practice of fallowing is systematically used to maintain soil fertility in the fields on the station, while this is less frequently practised in farmers' fields.

The economic analysis of the on-station experiments showed that the best economic return was found in groundnut. For groundnut, the gross margin increased from 184 in the control to 497 US \$ ha^{-1} in the treatment where seed priming and 0.6 g fertilizer were combined. Micro-dosing in sesame of 0.6 g fertilizer per pocket in combination with seed priming increased the gross margin by 48%. In cowpea there was only a marginal increase in the gross margin as a result of priming and micro-dosing. The on-farm experiments showed that seed priming in combination with 0.3 g fertilizer per pocket increased the gross margin for the three crops tested. The absolute increase in US \$ ha^{-1} was highest in groundnut, whereas the percentage increase was highest for cowpea. These gross margin calculations underestimate the effect of the treatments because the value of hay is not taken into consideration. The VCR for groundnut up to 9.06 in the on-station experiments and 6.6 in the on-farm experiments show that micro-dosing is a very good investment. The VCR should be above 4 in order to cater for the risk under dryland conditions (Koning *et al.*, 1998).

Micro-dosing and seed priming can also contribute to strengthening livestock production in the area by increasing the supply of high quality groundnut and cowpea hay. El-Hag (1992) points out that one of the primary constraints to livestock productivity in the region is the unavailability of adequate nutritional resources on a year-round basis.

It has been shown that nitrogen fixation increases with increasing biomass production in groundnut (Pimratch *et al.*, 2007) and increased nitrogen fixation as a result of seed priming and micro-dosing is therefore likely. The value of these crops in rotation will therefore increase with increasing yield.

Access to mineral fertilizer is a problem in North Kordofan, but it is used in areas of Sudan where irrigated agriculture is practiced. It should therefore not be difficult to introduce fertilizer to North Kordofan if there is a demand.

CONCLUSIONS

The on-farm as well as the on-station experiments showed that seed priming combined micro-dosing of fertilizer is a promising approach for increasing crop productivity particularly for groundnut but also for sesame and cowpea. Application of 0.6 g fertilizer per pocket combined seed priming gave the best economic return for all crops. The technology developed through this research project was approved by the Crop Husbandry Committee in Sudan in 2010 and can therefore be promoted through the national extension system in Sudan. This technology not only increases grain yields but will also increase fodder production thereby strengthening crop-livestock interactions. Extension departments and development projects can play a major role in the transfer and dissemination of knowledge about these technologies, while the agricultural banks need to ensure the availability and accessibility to fertilizers on affordable terms.

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