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Effect of Phosphorus-Based Fertilizer on Groundnut Yield and Incidence of Groundnut Rosette Disease in West Nile Region of Uganda

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Abstract. The objective of this study was to establish the effects of Di-ammonium phosphate (DAP) fertilizer micro-dosing on yields and the incidence of groundnut rosette disease (GRD) on five groundnut varieties in West Nile region of Uganda. The field experimental design used in this study was 5x2 factorial laid in a randomized complete block design (RCBD) with three replicates per location across 6 locations. The results indicated that there were significant ($p = 0.05$) differences in groundnuts yields across locations and varieties (0.554 – 1.742 tons per hectare) with or without micro-dosing with DAP fertilizer. The effects of DAP fertilizer micro-dosing in groundnut production were twofold: increase in yields across locations from 427.27kg/acre with no micro-dosing to 525.73kg/acre with micro-dosing (23.04% increment) and varieties from 420.46kg/acre with no micro-dosing to 529.71kg/acre with micro-dosing (13.77% increment); and a reduction of groundnut rosette virus disease incidence across locations from 15.13% with no micro-dosing to 11.20 with micro-dosing (27.76% reduction) and on varieties from 15.08% with no micro-dosing to 11.82% with micro-dosing (34.62% reduction). This is the first report of a prospective DAP fertilizer micro-dosing alongside other improved agronomic practices which can be integrated fully into groundnut production in West Nile region of Uganda. To manage yields and GRD incidences, micro-dosing of crops should be taken as a climate smart technology as identified by Food and Agricultural Organization.

Keywords: DAP fertilizer, Groundnut yield; Rosette Disease; Micro-dosing.

Introduction

Groundnut (*Arachis hypogaea*, L.) is the second most highly produced food legume in Uganda after common bean (*Phaseolus vulgaris)* (UBOS, 2013), with total area harvested of 330,000 hectares and a production of 336,047 tones (FAOSTAT, 2020). The crop has gained popularity especially in the eastern and northern regions of the country (Mahmoud *et al*., 1991) and fast becoming a cash crop (Okello *et al.,* 2010). Groundnut seeds are rich in oils (40-50%), proteins (20-50%) and carbohydrates (10-20%), making it an important food, feed, oil, and income generating crop in Uganda (Okello *et al.,* 2013). Groundnut kernels are rich in proteins and vitamins A, B, E, amongst other micro and macro elements (Savage and Keenan, 1994); can be eaten raw, roasted, fried, sweetened or boiled; and its industrial application in confectionery products may include cookies, snacks, and butter (Odi) (Semalulu *et al*., 2013).

Despite its importance in the food, feed and industrial applications, groundnut production in Uganda is constrained by numerous factors including pests and diseases, unreliable rains with recurrent droughts, poor agronomic practices, shortage of good planting seed among small scale farmers and low levels of input use (Mahmoud *et al*., 1991; Adipala *et al*., 1998). Of these factors, groundnut rosette disease (GRD) that is spread by groundnut aphids (*Aphis craccivora*) has been singled out as the most challenging constraint to groundnut production (Busolo-Bulafu, 2004; Mugisa *et al*., 2015; Deom and Okello, 2018; Okello *et al.,* 2021). Varietal resistance to GRD has been reported as the most practical and effective way to manage the disease and reduce yield loss (Busolo-Bulafu, 2004). In a bid to develop these resistance varieties, a collaboration between plant breeders from the National Semi Arid Resources Research Institute (NaSARRI) under NARO, of Uganda and International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) of Malawi was created and led to the development of the earlier GRD resistance line such as Serenut 1R, 2, 3R and 4T between 1999 and 2002 (Busolo-Bulafu, 2004).

Other GRD resistant Serenut groundnut varieties that were later developed between 2010 and 2011 include Serenut 5R, 6T, 7T, 8R, 9T, 10R, 11T, 12R, 13T, and 14R (Okello *et al*., 2013 and 2015). Alongside resistance to GRD, several traits of importance were identified in these new groundnut varieties such as high yield potential, short duration, drought resistance, and other seed characteristics like color and taste that would help to meet the consumer demand (Busolo-Bulafu, 2004). Several rates of adoption of high yielding and GRD resistant varieties have been reported in Eastern Uganda (Jelliffe *et al*., 2018), with Shiferaw *et al.* (2020) observing that the income per ha from improved varieties is about 80% higher than local cultivars on average. Okello *et al.* (2010) reported that while groundnut yields of over 2.5 t/ha have been achieved in experimental plots, farm level data show averages of 0.75 t/ha. The low farm yields could be attributed to several factors as presented by Mahmoud *et al*., (1991) and Adipala *et al*., (1998).

Additionally, lack of integrated soil and water management practices in the farms that degrade most of the land for crop production (Kaizzi *et al*., 2012) has been advanced for this low yield. Attempt to improve groundnut productivity through fertilizer application has been reported in some parts of Uganda (Kaizzi *et al.,* 2012; Semalulu *et al.,* 2013). This increase in yield could be associated with the fact that application of DAP fertilizer releases PO3- and NH4+ that increases their availability in the soil to plants and also the NH4+ dissociates to provide a starter Nitrogen required for the BNF to occur when the soil N is at critical level. Kaizzi *et al.* (2012) used the fertilizer rates of 0, 15, 30, and 45 Kg P ha^{-1} whereas Semalulu *et al.* (2013) the rates were 0, 17.48, 34.96 and 52.44 Kg P ha^{-1} in 2009 and 0, 4.37, 8.73, 13.10 and 17.46 KgP ha^{-1} in 2010. For both studies, the groundnut yields were linear to the rates of applied fertilizer, suggesting that soil fertility management and improvement could boost groundnut production in Uganda. Bonabana-Wabbi *et al.* (2015) therefore suggested that increasing land productivity and being able to contribute to profitable agriculture requires among other things, addressing the major biophysical factors on land through technologies on soil enhancement, prevention of nutrient loss, and conserving available nutrients either individually or in technology combinations. Micro-dosing which is the application of small quantities of fertilizer with the seed at planting time or as top dressing three to four weeks after emergence is one such option. Micro-dosing has been identified as a climate smart technology (CST) and is being considered a pathway for the intensification of agricultural systems in Sub-Saharan Africa (Murendo and Wollni, 2015).

It has also been observed that different regions in the country have varying levels of GRD pressure, however, the disparity in occurrence is not known. Mugisa *et al.* (2015) reported that GRD incidence; severity and groundnut yields were significantly affected by season, location and genotype. Naidu *et al.* (1998) highlighted the importance of detailed studies on the pattern of GRD spread at a representative range of sites in different agro-ecologies and cropping systems. A better understanding of the agro-ecological factors affecting GRD incidence and severity is critical for the successful development of sustainable disease management strategies. For West Nile Agro-ecology, there is no available information on GRD pressure, adoption rates for GRD resistant varieties, fertilizer application rates, effects of fertilizer application on groundnut rosette disease incidence, and or the contribution of groundnuts to the livelihood improvement of the people of West Nile region of Uganda. Therefore, the goal of this study was to generate literature that can be used to position groundnut production in this region as an emerging enterprise commodity. The specific objectives of this study were to: i) assess the yield performance of the Serenut groundnuts varieties to different parts of Adjumani district, with or without DAP fertilizer, ii) test the effect of DAP fertilizer applications on groundnut rosette disease (GRD) incidence and iii) evaluate farmers' preferences to these Serenut groundnut varieties in forms of participatory evaluation.

Methods

Study Area and Duration

The study was conducted between the 2019B (September to December) and 2020A (April to July) seasons in the 6 parishes (locations) that fall within the three sub-counties of Ukusijoni, Itirikwa and Dzaipi. The six parishes were Ayiri and Payaru parishes for Ukusijoni sub-county, Mungula and Kolididi parishes for Itirikwa sub-county, and Miniki and Loguangwa parishes for Dzaipi sub-county. Three parishes were used in each of the growing season: Ayiri, Mungula and Miniki parishes for 2019B whereas Payaru, Kolididi and Loguangwa parishes for 2020A season.

The Plant Material

Breeder's seed of four GRD tolerant varieties of Serenuts 5R, 8R, 11T and 14R were sourced from National Groundnut Improvement Program based at NaSARRI, Serere, Uganda. In addition to these new improved varieties, a local groundnut cultivar (Red Beauty) was procured from the groundnut farmers within Adjumani to be used as a local check. The Red Beauty was procured from within Adjumani and not NaSSARI to represent the commonly informal seed acquisition by farmers. Red Beauty was chosen to be included in this study as a local check for two reasons: wider distribution and most preferred amongst groundnuts farmers in the study locations.

Experimental Design and DAP Fertilizer Micro-Dosing

The field experimental design was a 5x2 factorial (of five varieties and two levels micro-dosing) laid down in RCBD with three replicates per site. The five varieties are presented in 2.2 above; whereas the micro-dosing levels were: 40kg/ha and 0kg/ha as a control. The plot sizes varied by locations depending on the available land: Ayiri parish ($92m^2$), Mungula parish ($180m^2$), Miniki parish ($168m^2$), Payaru parish ($56m^2$), Kolididi parish ($70m^2$), and Loguangwa parish ($86m^2$) that were at least 30Km apart from each other. These plots were equally divided into two, and a half was broadcasted with DAP fertilizer at planting time at the rate of 40Kg ha^{-1} to represent the micro-dosed plots while the other a half was left without micro-dosing to act as a control. DAP fertilizer broadcast was done between lines of groundnuts spaced at 45cm by 15cm. The choice to use DAP as a fertilizer for this study didn't result from soil testing, but from the results of Cowpeas study using DAP in the same region which indicated that phosphorus is a major limiting nutrient in soils within West Nile region as a result of P fixation (Nyamaizi *et al*., 2016 and Nyamaizi *et al*., 2020).

Data Collection and Analyses

Several physiological data sets were collected including groundnuts rosette disease (GRD) incidence at 4, 8 and 12 weeks after planting. GRD incidence was expressed as the percentage of plants showing GRD symptoms over the total number of plants in the plot. GRD infected plants were identified using the disease symptoms described by Okello *et al.* (2014) but the GRD infected plants were not tested in the laboratory. GRD severity was scored at 12 weeks after planting using a scale of 1-9 based on the intensity of disease attack as described by Okello *et al.,* (2014), where; 1-3 = Low GRD severity, 4-6 = Moderate severity, 7-9 = High GRD severity. GRD incidence was recorded as the proportion of the infected plants to the total number of plants in the plot. Specifically, for this study, it relied on the natural disease pressure of GRD in these locations and no additional source of inoculation was provided. Other parameters collected at 15 weeks after planting were: number of pods per plant, fresh pod weight per plant, fresh pod yield per plot, and haulm weight as described in Mubai *et al.* (2020). Following successful drying in the sunshine, dry pod weight per plant and dry pod weight per plot, were recorded and used to estimate yields per acre. The cleaned and summarized data was subjected to PAST3 (Hammer, Harper, and Ryan, 2001) and R Program statistical packages (R Core Team, 2017) for both descriptive and ANOVA analyses.

Results

Groundnut Yield variation and the effect of DAP Fertilizer Application on Yield

Groundnut yields and yield related parameters for varieties varied significantly at 5% level of significance for yield per plant (df = 5; $p \leq 0.01809$) and estimated yield per acre (df = 5; $p \leq 0.0003144$) but not the number of pods per plant (df = 5; $p \leq 0.2046$) without DAP fertilizer micro-dosing (Table 1 and 2). Equally, yield per plant (df = 5; $p \leq 0.0001399$) and estimated yield per acre (df = 5; $p \leq 0.000001997$) varied significantly at 5% level of significance after DAP fertilizer application but not the number of pods per plants (df = 5; $p \leq 0.0748$). Groundnut yields ranged from 221.55 kg to 696.77 kg per acre by varieties with averages of 420.46 kg and 529.71 kg for without and with micro-dosing, respectively. The highest yield was recorded in Serenut 5R while the lowest yield was recorded in the local groundnut (Red Beauty) with or without DAP application (Table 1). There was an increase in the yields and yield related parameters for groundnut varieties after DAP fertilizer application (Table 1). Particularly for yields, the highest increase following DAP application was recorded in the local groundnut (28.87%) and the lowest was in Serenut 14R (7.88%), with an average of 13.77% (Table 1). A paired t-test confirmed that there were significant differences between the non-micro-dosed and the micro dosed for yields and yield related parameters: number of branches per plant ($\alpha = 0.05$; $p \leq 0.000000098998$), fresh pod weight in grams ($\alpha = 0.05$; $p \leq 0.0020463$), dry pod weight in grams ($\alpha = 0.05$; $p \leq 0.00042358$), Haulmn weight in grams ($\alpha = 0.05$; $p \leq 0.0000010257$), yield per plant ($\alpha = 0.05$; $p \leq 0.00042358$), and the estimated yield per acres in kilograms ($\alpha = 0.05$; $p \leq 0.0010723$) while the number of pods per plants ($\alpha = 0.05$; $p \leq 0.12482$) did not vary significantly between the non-micro-dosed and the micro-dosed.

Table 1. Variations in yields across groundnut varieties with or without DAP fertilizer

	Yield Related Parameters								
Variety	NBPP		NPPP		YPP (g)		EYPA (Kg)		% change in EYPA
	Fert-	Fert+	Fert-	Fert+	Fert-	Fert+	Fert-	Fert+	
Local	5	6	10	10	6.02	6.43	221.55	274.33	28.87
Serenut 11 T	6	8	11	13	12.62	14.60	444.92	548.00	12.00
Serenut 14R	8	8	13	13	11.32	11.67	479.58	503.31	7.88
Serenut 5R	6	7	16	18	13.26	17.61	510.76	696.77	10.90
Serenut 8R	8	9	12	15	10.78	14.12	445.47	626.12	9.18
Mean	6	7	12	14	11	13	420.46	529.71	13.77
% change	16.15		9.12		19.32		25.98		

NBPP = number of branches per plant, NPPP = number pf pods per plant, YPP = yields per plant, EYPA = estimated yield per acre based on plot yields, F- = Non micro-dosed, and F+ = micro-dosed.

Groundnut yields and yield related parameters varied greatly across locations with or without micro dosing (Table 2). Yields and yield related parameters for varieties varied significantly at 5% level of significance for no of pods per plant (df = 5; $p \leq 0.0000001059$), yield per plant (df = 5; $p \leq 0.0000004428$), and estimated yield per acre (df = 5; $p \leq 0.0000001579$) without DAP fertilizer application (no micro-dosing). Equally, yield per plant (df = 5; $p \leq 0.00003052$) and estimated yield per acre (df = 5; $p \leq 0.000004787$) varied significantly at 5% level of significance after DAP fertilizer application but not the number of pods per plants (df = 5; $p \leq 0.8957$). Groundnut yields ranged from 156.68 kg per acre in Loguangwa parish to 948.62 kg per acre in Payaru parish with averages of 427.27 kg and 525.73 kg per acre for without and with micro-dosing respectively; the highest yield was recorded in Payaru parish while the lowest yield was recorded in the Loguangwa parish with or without DAP application (Table 2). There was an increase in the yields and yield related parameters for groundnut across all locations after DAP fertilizer application (Table 2). Particularly for yields, the highest increase following DAP application was recorded Kolididi parish (63.43%) and the lowest was in Mungula parish (6.41%), with an average of 23.04% (Table 2).

Table 2. Variations in yields across groundnut varieties with or without DAP fertilizer

Parameters	Treatment	Location						Mean
		Ayiri	*Mhungula*	*Miniki*	*Payaru*	*Kolididi*	*Loguangwa*	
Number of branches per plant	Fert-	5	5	4	8	8	9	6
	Fert+	6	6	5	8	10	10	8
Number of pods per plant	Fert-	16	16	17	13	8	5	13
	Fert+	18	17	19	13	10	6	14
Fresh pod weight per plot (g)	Fert-	137.47	156.73	174.4	143.19	93.28	41.45	124.42
	Fert+	168.14	153.73	182.47	152.61	136.97	62.17	142.68
Dry pod weight per plot (g)	Fert-	60.43	69.07	77.27	65.13	32.93	20.2	54.17
	Fert+	78.77	69.41	82.53	71.87	55.47	28.13	64.36
Haulmn weight per plot (g)	Fert-	857.07	632.73	770.27	2365.43	1929.28	1016.26	1261.84
	Fert+	904.36	667.27	863.87	3012.68	3200.07	2539.14	1864.57
Yield per plant (g)	Fert-	12.09	13.81	15.47	13.03	6.59	4.04	10.84
	Fert+	15.75	13.88	16.51	14.37	11.09	5.63	12.87
Yield per plot (Kg)	Fert-	5.03	10.24	11.07	5.61	1.83	1.69	5.91
	Fert+	6.83	10.89	12.4	6.83	2.99	2.12	7.01
Estimated yield per acre (Kg)	Fert-	437.47	454.89	527.05	779	208.51	156.68	427.27
	Fert+	594.13	484.06	590.69	948.62	340.77	196.08	525.73
Estimated yield per hectare (Kg)	Fert-	1093.68	1137.23	1317.64	1947.49	521.28	391.69	1068.17
	Fert+	1485.32	1210.15	1476.72	2371.54	851.91	490.21	1314.31
Percentage yield increase after micro-dosing per acre (%)		35.81	6.41	12.07	21.77	63.43	25.15	23.04

F- = Non micro-dosed, and F+ = micro-dosed.

Effect of DAP Fertilizer Micro-Dosing on Groundnut Rosette Disease Incidence

Application of DAP fertilizer through micro-dosing in groundnut reduces the GRD incidence when a paired t-test was performed to compare the GRD incidences between the micro-dosed and non-micro-dosed plots over the two seasons produced a significant difference (df = 89; p≤0.0000030323) at 5% level of significance, although the difference was greater for 2019B season (df = 44; p ≤ 0.00000000037627) than 2020A season (df=44; p≤0.0096444). GRD incidence was reduced at all sites (Table 3) and on all varieties (Table 4) following DAP fertilizer application although the magnitude varies. There was more GRD incidence reduction in 2019B than in 2020A (Table 4) although there was more GRD incidence in 2020A season with an average of 22.10% compared to the 2019B season with an average of 5.43%. The highest percentage GRD incidence reduction was recorded in Mungula (57.86%), Ayiri (49.85%), Miniki (34.69%), Luguangwa (12.77%), Kolididi (6.71%), and Payaru (4.63%), while in terms of varieties, the highest reduction was in Serenut 14R (40.64%), Serenut 8 (40.04%), Serenut 5R (40.01%), Serenut 11T (30.01%) and a local (22.05%). Overall, GRD incidence ranged from 0.92% in Payaru parish to 90.4% in Loguangwa parish, with an overall average of 13.77% over the two seasons (Table 4). Across locations, GRD incidence was highest in Loguangwa parish (38.80%), followed by Kolididi parish (20.93%), Ayiri parish (7.38%), Payaru parish (7.30%), Mungula parish (5.25%), and Miniki parish (3.67%) over the two seasons. In terms varieties, GRD incidence was highest on the local groundnut (28.87%), followed by Serenut 11T (12.00%), Serenut 5 (10.90%), Serenut 8 (9.18%), and Serenut 14 (7.88%) across the two seasons.

Table 3. Variations in GRD incidence and percentage reduction by locations

Season	Location	Fertilizer micro-dosing	GRD incidence (%)	Percentage GRD incidence reduction
2019B season	Ayiri	F-	9.83	49.85
		F+	4.93	
	Mungula	F-	7.38	57.86
		F+	3.11	
	Miniki	F-	4.44	34.69
		F+	2.90	
	Mean		5.43	47.47
2020A season	Payaru	F-	7.56	04.63
		F+	7.21	
	Kilididi	F-	22.05	06.71
		F+	20.57	
	Loguangwa	F-	39.55	12.77
		F+	34.50	
	Mean		21.91	08.04

F- = Non micro-dosed, and F+ = micro-dosed

Table 4. Incidence of Groundnut rosette virus disease by season, location, groundnut varieties and DAP fertilizer

Season	Location	Varieties										Mean
		Local		*Serenut 5R*		*Serenut 8R*		*Serenut 11T*		*Serenut 14R*		
		Fert-	Fert+	Fert-	Fert+	Fert-	Fert+	Fert-	Fert+	Fert-	Fert+	
2019B	Ayiri	7.54	5.19	11.17	3.62	7.58	4.84	13.69	5.45	9.19	5.54	7.38
	Mungula	5.65	3.77	4.76	1.99	6.69	2.93	12.53	4.43	7.25	2.45	5.25
	Miniki	3.79	2.37	4.93	2.35	3.47	2.79	4.25	3.69	5.73	3.28	3.67
	Mean	5.66	3.78	6.95	2.65	5.91	3.52	10.16	4.52	7.39	3.76	5.43
GRD Reduction (%)		33.27		61.84		40.47		55.46		49.17		48.04
2020A	Payaru	25.62	24.67	3.33	0.92	4.43	2.77	3.68	3.67	2.17	1.74	7.30
	Kolodidi	52.11	51.91	19.49	11.89	19.21	6.78	17.03	13.84	10.23	6.78	20.93
	Loguangwa	90.4	73.36	33.28	33.09	27.64	21.05	30.45	31.32	23.98	16.18	38.08
	Mean	56.04	49.98	18.70	15.30	17.09	10.20	17.05	16.28	12.13	8.23	22.10
GRD Reduction (%)		10.82		18.18		40.33		4.55		32.11		21.2

Fert- = No micro-dosing with DAP fertilizer, and Fert+ = micro-dosed with DAP fertilizer.

Farmers preferences of the new groundnut varieties in West Nile region

Participatory evaluation was conducted on a total of 245 (Male 114; Female 131) farmers across the 6 study sites and their preferences to these groundnut varieties were segregated by gender as presented in Table 5 below. Across locations, groundnut farmers in Adjumani preferred the varieties of Serenut 5R, followed by Serenut 8R, Serenut 14R, Serenut 11T, and the local was least preferred as seen in the ranking. This result shows that farmers' preferences to new varieties differ significantly at 5% significance level although the preference between males and females doesn't differ significantly.

Table 5. Farmers' preferences for groundnut varieties by study locations

Location	Sex	Groundnut varieties					Total
		Local	*Serenut 11T*	*Serenut 14R*	*Serenut 5R*	*Serenut 8R*	
Ayiri	M	2	3	4	7	3	19
	F	1	4	4	7	5	21
Mungula	M	0	4	6	7	7	24
	F	1	4	3	9	5	22
Miniki	M	0	4	3	7	4	18
	F	2	4	4	9	7	26
Payaru	M	1	4	5	6	4	20
	F	0	4	4	5	3	16
Kolididi	M	0	3	3	7	4	17
	F	1	4	6	9	5	25
Loguangwa	M	1	3	3	5	4	16
	F	1	3	8	5	4	21
Grand Total		10	44	53	83	55	245
Rank in preferences		5	4	3	1	2	

M = males, and F = females

Discussion

Groundnut yield and yield associated parameters varied significantly (p = 0.05) across varieties and locations. Groundnut yield varied by varieties from 221.55 kg/acre (0.554 t/ha) in the local variety to 696.77 Kg/acre (1.742 t/ha) in Serenut 5R while the yield variation by location varied from 156.68 kg/acre (0.391 t/ha) in Lugwangua parish, Dzaipi sub county to 948.62 kg/acre (2.372 t/ha) in Payaru parish, Ukusijoni sub county. The fact that yield variations reported in this study were irrespective of whether there was micro-dosing or not suggests that both plant response to GRD and the level of soil nutrients contributed greatly to these yield variations. Equally, the variation in the genetic yield potential of these lines is another factor for the observed variations in yields and yields related parameters. The variation in yields and yield related parameters have been reported in groundnut in several studies (Nutiyal *et al.*, 2011; Oteng-Frimpong *et al.*, 2017; Berhe *et al.*, 2020). The yield variation reported in this study is lower than the yield variation (1.60 to 5.73 t/ha) reported by Oteng-Frimpong *et al.* (2017) when they evaluated thirty genotypes of groundnut in Ghana. Yield associated parameters that also varied significantly were number of pods per plant, plant height, haulm yield and number of branches per plants. Also, the correlations between yields and associated yield parameters have been reported in groundnuts (Zongo *et al*., 2017). However, it's important to note here that, much as yields related parameters contribute greatly to the overall yields of groundnuts, farmers pay less attention to them, except number of pods per plant and number of seeds per pod. Besides yield and yield associated parameters, photosynthetic rate and stomatal conductance have been reported to vary greatly among groundnut genotypes in Spain (Nutiyal *et al*., 2011).

Application of DAP fertilizer in groundnuts at planting time at a rate of 40 kg/ha increased groundnut yield for both varieties (13.77%) and locations levels (23.04%). The highest yield increment in the local genotype (Red Beauty) at 28% compared to SERENUT 14R an improved variety at 7.88% suggests that the local genotype is well adapted to these locations however, its yields was being limited by the soil nutrients including Phosphorous. Additionally, Red beauty was already low yielding so any incremental volume registers a larger response than the already higher yielding. Nyamaizi *et al.* (2016 and 2020) observed a similar finding in cowpeas when they compared a local genotype (Agondire) to an improved variety (SECOW 2W). Phosphorus based fertilizer has been reported to increase yield in groundnut (Kaizzi *et al*., 2012; Semalulu *et al*., 2013). Kaizzi *et al.* (2012) used the fertilizer rates of 0, 15, 30, and 45 Kg P ha^{-1} whereas for Semalulu *et al.* (2013) the rates were 0, 17.48, 34.96 and 52.44 Kg P ha^{-1} in 2009 and 0, 4.37, 8.73, 13.10 and 17.46 KgP ha^{-1} in 2010 and both studies showed that groundnut yields were linear to the rates of applied fertilizer, suggesting that soil fertility management and improvement could boost groundnut production in Uganda. Berhe *et al.* (2020) studied the response of three groundnut genotypes in Ethiopia using a combination of phosphorus based and foliar zinc spray fertilizers at four different levels (P_0Zn_0, $P_{10}Zn_{0.5}$, $P_{20}Zn_{1.0}$, and $P_{30}Zn_{1.5}$) and confirmed that groundnut yield to fertilizer application is linear to the amount of fertilizer applied. The increase in yields following the application of DAP fertilizer through micro-dosing could be attributed to the release of PO^{3-} and NH^{4+} that increase their availability in the soil and also the NH^{4+} dissociates to provide a starter Nitrogen that is required for the BNF to occur when the soil N is at critical level. These combined effects of DAP micro-dosing help to enrich soil fertility and strengthening plant immunity thus increasing yields and reducing GRD incidence. The increase in output and yield in crops following fertilizer micro-dosing is not unique to groundnuts only as (Murendo and Wollni, 2015) had reported that fertilizer micro-dosing positively increases maize output, sorghum output and yield in Zimbabwe. Bonabana-Wabbi *et al.* (2015) suggested that increasing land productivity and being able to contribute to profitable agriculture requires among other things, addressing the major biophysical factors on land through technologies on soil enhancement, prevention of nutrient loss, and conserving available nutrients either individually or in technology combinations. Therefore, increased groundnut yield after DAP fertilizer application can be attributed to increased host-plant resistance to GRD following a modification of soil biophysical environment.

Groundnut rosette disease (GRD) incidence varied by groundnut varieties and study locations in this study. This result suggest that different groundnut varieties respond to DAP fertilizer micro-dosing differently and to the soil characteristics as well. This confirms the study of Mugisa *et al.* (2015) which reported that GRD incidence and severity were significantly affected by season, location and genotype. Naidu *et al.* (2007) had also reported that GRD has negative effects on the performance of groundnut genotypes: reduced plant height, reduced pod/seed weight and reduced dry haulm weight; and that the level of reduction is directly proportional to disease severity of the disease on different genotypes. Specifically, Mugisa *et al.* (2015) reported that the level of disease infection was found to be majorly influenced by rainfall and wind speed; that is, disease incidence and severity were generally higher in conditions with less rainfall and low wind speeds. Therefore, the reduction of GRD incidence in this study across study locations and by genotypes could be explained by the modification in soil micro-environment and plant vigor following DAP fertilizer application. Studies conducted in Egypt showed that application of P-fertilizer and foliar spray of Zn in a poor soil significantly improved seed yield (Mirvat *et al*., 2006) and Dordas (2008) also demonstrated the role of P in improving host-resistances and toxicity of Zn to several pathogens, respectively. This further suggests that soil fertility management through inorganic and organic fertilizer application is an option that can be taken forward for the management of GRD and improving groundnut production. Improving groundnut production is directly linked to the observation of Mubai *et al*. (2020) that grain yield showed a strong negative correlation with GRD infection due to the disease's devastating effects on groundnuts.

Farmers in these study locations showed preferences to different genotypes and they gave several reasons for their preferences to these varieties including early maturity, number of pods per plants and seed coat color were key amongst other parameters. These reasons are not surprising because the study of Mubai *et al*. (2020) on phenotypic correlations and multiple regressions for yield and yield associated traits demonstrated that yield is directly correlated to: plant height, number of pods per plant, 100 seed weight, GRD incidence and number of secondary branches. Additionally, Ntare *et al*. (2008) and Banla *et al*. (2018) had also reported on high pod and fodder yield, pod size, resistance to diseases, taste, oil content, drought tolerance and marketability as being other set of criteria used for selecting and adopting groundnuts in West Africa. Although yield was taken as the overall measure for the farmers' preferences to these varieties, this study confirms that farmers are aware of the yield associated trait as part of their indigenous knowledge. Elsewhere, similar reasons associated with agronomic traits were reported by farmers in other commodities as aiding their selection: common beans (Assefa *et al*., 2005; Asfaw *et al*., 2012; Isaacs *et al*., 2016; Bruno *et al*., 2018), cassava (Njukwe *et al*., 2013; Nduwumuremyi *et al*., 2016) and sorghum (Nkongolo *et al*., 2008) amongst others.

Conclusions

This study has demonstrated for the first time in Northwestern Agro-ecology of Uganda that, phosphorus-based fertilizer (Di-ammonium phosphate - DAP) micro-dosing in groundnuts production has two effects: increased groundnut yield, and reduced GRD incidence. This study illustrates the need for integrated approaches in enhancing groundnut productivity and groundnut rosette diseases. Application of fertilizers including DAP through micro-dosing is currently being considered as a climate smart technology (CST) that can be integrated in crop production systems by FAO. Therefore, soil fertility management including micro-dosing, good agronomic practices and use of high yielding and disease tolerant varieties can be integrated to improve groundnut production and marketing in Northern Uganda. However, this study makes two recommendations in order to validate the finding presented here: i) there is need for a site specific soil test to ascertain the soil health prior to the experimentation; and ii) DAP is not the only phosphorus-based fertilizer in the Ugandan market, therefore this study should be replicated using other phosphorus-based fertilizers like single superphosphate (SSP) and triple superphosphate (TSP) among others and their results compared to give groundnut farmers wide choices for fertilizers based on the market price.

Conflict of Interest

The authors declare that they have no conflicts of interest in relation to this article.

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