USAID-SIL MRA 3 – SMART FARM REPORT

2019 Soil Fertility and Input Omission Evaluation Report - Ghana

Feed the Future Innovation Lab for Soybean Value Chain Research (Soybean Innovation Lab, SIL)

Report Submitted

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Summary

Seed quality has been a major concern due to higher temperatures during seed development, diseases, mechanical injury during threshing and storage conditions. In this year's trials, 3 soybean varieties ('Favor', 'Afayak', and 'Jenguma') were used. Seeds were sorted and tested for germination percentage for better crop establishment as the first step to achieving greater grain yield. Germination percentage obtained were 'Favor' (85%), 'Afayak' (83%) and 'Jenguma' (79%). Seeding density was adjusted appropriately to ensure adequate field germination. Soil fertility test and input omission trials were conducted at Manga (Bawku), Dokpong (Wa) and Nyankpala (Tolon) all in northern Ghana. Soil texture were loamy sand at Dokpong and sandy loam at Manga and Nyankpala. Soil pH was strongly acidic of 5.2 for Manga and Nyankpala and 5.5 at Dokpong. Lime requirement were 1.3 tons acre^{-1} for Dokpong and 2.0 tons acre^{-1} each for Nyankpala and Manga. Available phosphorus at Dokpong and Manga was medium but optimal at Nyankpala. Organic matter, Potassium, Sulphur, Copper, and Sodium varied from low to very low in locations. Nyanakpala had medium levels of Boron and Zinc but were low and very low at Dokpong and Manga. In the omission trials, phosphorus was identified as the key nutrient element triggering yield increase, but significant results were obtained when combined with inoculum and/or lime. Hence, nutrient application could increase soybean yield in the savannahs but with proper stewardship to avoid negative environmental effects. Lime should be applied with soil test recommendation. The main effects of herbicide and hand weeded did not differ significantly in yield and crop development. However, herbicide use was more effective in weed control, easier, and saved human effort and time compared to hand weeding. Application of Priaxor did not provide significant yield difference probably due to low disease pressure during the growing season. Higher seeding density at 333,333 plants ha^{-1} provided the greatest grain yield and provided early canopy cover reducing weeding regime. Weeds were effectively managed with herbicides at higher seeding density than at lower seeding density. The sedges were effectively managed with herbicides use was than hand weeded. In the P and K rate trials, application of $P_{100}K_{100}$ and $P_{100}K_{50}$ had the highest grain yield, 100 seed weight, and plant height. In the lime placement trial, grain yield and crop development were greater at 1000 kg ha^{-1} but was not significantly different from 400 and 1500 kg ha^{-1} lime placement. Residual lime increased grain yield and soil pH. In general, soil test results indicated the need for soil fertility amendments through nutrient stewardship to improve and sustain soil nutrient budget that can increase yield.

1.0. Introduction

The inherent ability of soils in northern Ghana to provide adequate nutrients for crop growth has declined amidst increased population and demand for food. To improve and/or sustain soil fertility, nutrient management technologies and innovations must be developed and implemented in a manner that increase crop production while maintaining environmental quality. The objective of nutrient management is to use nutrient stewardship to improve and sustain soil fertility capable of providing plant nutritive needs without detrimental effects to the environment. Placement of nutrients from the right source, rate, time and place are key to nutrient management. Hence, knowledge of soil fertility status and pattern over time are important challenges and opportunities in nutrient management (Fixen and Roberts (2002).

Over the past 6 years, SIL collaborates with the Savannah Agricultural Research Institute (SARI) in soybean agronomic research across 3 locations Guinea and Sudan Savannahs of northern Ghana. This report summarizes soybean nutrient management trials under SIL Soybean Management with Appropriate Research and Technology (SMART) during 2019 cropping season at Manga, Bawku East District (Upper East Region), Dokpong, Wa West District (Upper West Region) and Nyankpala, Tolon District (Northern Region).

2.0. Objectives

2.1. Determine seed quality for planting through a germination test. Co-operation, SIL/SARI/Heritage Seed.

2.2. Identify field sites, determine coordinates and conduct soil samples for fertility analysis, Co-operation, SIL/SARI/Waypoint Analytical Lab. Ltd/DHL- Ghana

2.3. Conduct nutrient amendment trials in field experiments to:

- 2.4. Evaluate various herbicide/fungicide spray program with the highest benefit for soybean farmers in Ghana, Co-operation SIL/BASF/RMG/UDS-Agric. Faculty.
- 2.5. Evaluate the effects of input bundle of lime, inoculum, phosphorus and potassium on soybean yield with the greatest benefit for soybean farmers in Ghana as determined by omission. Co-operation, SIL/BASF/Omyia Calciprill/ Green-Ef Eco Village Business.
- 2.6. Evaluate the effects of input bundle of lime, inoculum and phosphorus on soybean yield with the highest benefit for soybean farmers in Ghana as determined by omission. Co-operation, SIL/BASF/Omyia Calciprill/ Green-Ef Eco Village Business.
- 2.7. Evaluate the effects of phosphorus and potassium rates on soybean yield that provides the maximum benefit to soybean farmers in Ghana. Co-operation, SIL/Garnoma Agro-Chemical Ltd/ Green-Ef Eco Village Business Ltd.
- 2.8. Evaluate seeding density with and without herbicide spray on weed control and yield with the highest benefit to Ghanaian soybean farmers. Co-operation, SIL/BASF
- 2.9. Evaluate lime placement method for pH adjustment that provides the highest benefit to soybean farmers in Ghana. Co-operation, SIL/Omyia Calciprill.
- 2.10. Assess residual effects of Calciprill lime for pH adjustment and yield on various rates of Calciprill lime applied in 2018 and 2017.
- 2.11. Provide backstop for SIL and participate in the 5th Annual Soybean Kick-off Event scheduled Oct. 22, 2019 in Nyankpala.

2.12. Carry out any collaborative activities relevant to SIL's mission in Ghana.

2.1. Seed Germination Test

2.1.1. Materials and Methods

Three soybean varieties were tested for gemination and used in experiments. Three were considered top yield yielding varieties in Ghana. The 3 varieties tested were: 1. Afayak; 2. Jenguma; and 9. Favor (TGx 1844-22E). Germination test followed methodology described by Seefeldt, 2014.

2.1.2. Results and Discussion

Percent seed germination was not significantly differed among varieties. Percent seed germination were TGx 1844-2E (85%), Afayak (83%) and Jenguma (79%). In each variety, seeding density was adjusted appropriately to ensure adequate field germination.

2.1.3. Conclusion

Seed quality and storage conditions impact on germination percentage and crop field establishment. One of the most important steps to higher grain yield is to ensure adequate percentage field germination. Farmers are encouraged to use certified soybean seeds from certified seed companies and institutions to plant. Also, plant on ridges to ensure proper crop management.

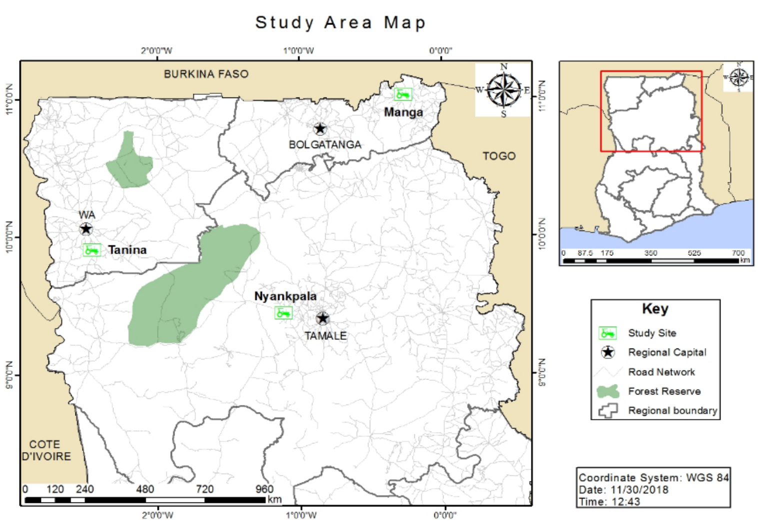

Fig. 1. Map showing study sites Nyankpala, Manga (Bawku) and Dokpong (Wa)

2.2. Soil Sampling before planting

2.2.1. Materials and Methods

Field were identified at Dokpong (Wa), Manga (Bawku), and Nyankpala (Tolon) (Fig. 1). Sites co-ordinates, elevation and area were determined by Garmin GPS (Oregon 400t) at each site (Table 1). The fields had a cropping rotation history of soybean-maize (Nyankpala), soybean - millet (Manga) and soybean – sorghum (Dokpong). Soil samples were extracted before planting in all locations, processed and submitted following international soil shipment protocol for physio-chemical analysis at Waypoint Analytical Laboratories Inc., Memphis, TN, USA. Core samples consisted of 15 cores

Soil samples for shipment and analysis

taken to 15 cm (8") depth with a soil probe (2.86 cm × 35.56 cm; AMS Inc., American Falls, ID) to form composite samples. These were processed and weighed to 300 g per sample for analysis.

2.2.2. Results and Discussion

Coordinates of research field, elevation, area and dates sampled (Table 1).

Table 1. Field coordinates, elevation, area of research fields at Dokpong (Wa), Nyankpala (Tolon) and Manga (Bawku)

Field location	Point 1	Point 2	Point 3	Point 4	m a.s.l	Area (acres)	Dates sampled
Dokpong	N10°04'38.445" W02°30'21.305"	N10°04'37.874" W02°30'20.889"	N10°04'38.800" W02°30'20.649"	N10°04'38.211" W02°30'20.234"	310.8	0.4	07/05/2019
Nyankpala	N09°23.382' W01°00.218'	N09°23.432' W01°00.329'	N09°23.407' W01°00.340'	N09°23.356' W01°00.230'	184.0	3.0	07/05/2019
Manga	N11°00.841' W00°15.988'	N11°00.836' W00°15.975'	N11°00.853' W00°15.969'	N11°00.857' W00°15.981'	218	0.4	06/232019

Table 2. Soil physio-chemical and fertility ratings for 0 - 15 cm soil depth before planting at Dokpong, Manga and Nyankpala analyzed by Waypoint Analytical Inc. (Memphis – TN, USA).

Element Tested	Extraction Method	Field location and District		
		Dokpong (Wa West)	Manga (Bawku East)	Nyankpala (Tolon)
		0 - 15 (cm)	0 - 15 (cm)	0 - 15 (cm)
Soil texture (%)				
• Sand	Cal	84.0	54.0	58.0
• Silt	Cal	12.0	38.0	38.0
• Clay	Cal	4.0	8.0	4.0
Classification		Loamy sand	Sandy loam	Sandy loam
Fertility status				
Soil pH	1:1	5.5	5.2	5.2
Buffer pH	SMP	6.81	6.63	6.61
Phosphorus (P) (ppm)	M3	22 (M)	24 (M)	41(O)
Potassium (K) (ppm)	AA	66 (L)	49 (VL)	58 (L)
Calcium (Ca) (ppm)	AA	569 (M)	922 (M)	1035 (M)
Magnesium (Mg) (ppm)	AA	46 (L)	87 (M)	74 (M)
Sulfur (S) (ppm)	M3	6 (L)	6 (L)	7 (L)
Boron (B) (ppm)	M3	0.1 (VL)	0.1 (VL)	0.5 (M)
Copper (Cu) (ppm)	M3	0.5 (L)	0.5 (L)	0.6 (L)
Iron (Fe) (ppm)	M3	51 (M)	73 (M)	47(L)
Manganese (Mn) (ppm)	M3	57 (M)	73 (M)	25 (L)
Zinc (Zn) (ppm)	M3	1.0 (L)	1.1 (L)	2.2 (M)
Sodium (Na) (ppm)	AA	33 (VL)	38 (VL)	39 (VL)
Soluble Salts (dS/m)	SS1:2	0.15	0.1	0.15
Organic Matter (O. M) %	LOI	0.6 % ENR (VL)	0.5% ENR (VL)	0.1 % ENR 43 (VL)
Nitrate Nitrogen (ppm)	NO_3_N	4	4	1.0

Cal = Calculated; M = medium; L = low; VL = very low; O = optimum; LOI = Loss-on-ignition; ENR = Estimate Nitrogen Release; NO_3N = Nitrate Nitrogen; M3 = Mehlich 3; AA = Ammonium Acetate Method; SS1:2 = Soluble Salts; SMP = Shoemaker, MacLean, and Pratt.

The soils of Manga and Nyankpala were sandy loam while Dokpong was loamy sand (Table 2). Soil pH for all 3 locations were strongly acidic with buffer pH of 6.81, 6.63 and 6.61 for Dokpong, Manga, and Nyankpala, respectively (Table 2).

Dokpong (22 ppm) and Manga (24 ppm) had medium levels of available P but was optimal (41 ppm) at Nyankpala. Potassium was low at Dokpong (66 ppm) and Nyankpala (58 ppm), but very low in Manga (49 ppm) (Table 2). All 3 sites had medium values of Ca but varied in Mg that was low at Dokpong (46 ppm), but medium at Manga (87 ppm) and Nyankpala (74 ppm). All 3 locations had low S and Cu, and very low (38 ppm) Na. Boron was very low (0.1 ppm) at Dokpong and Manga but low at Nyankpala (0.5 ppm). Nyankpala had low (47ppm) levels of iron but was medium at Manga (73 ppm) and Dokpong (51 ppm) (Table 2). Manganese was medium for Dokpong (57 ppm) and Manga (73 ppm) but low at Nyankpala (25 ppm). Zinc was low at Dokpong (1.0 ppm) and Manga (1.1 ppm), but medium (2.5 ppm) at Nyankpala. Soluble salts were 0.15 dS/m for both Dokpong and Nyankpala locations and 0.1 dS/m in Manga. Percentage O. M was very low in all field sites, while Dokpong and Manga each contained 4 ppm NO_3N and only 1.0 for Nyankpala location (Table 2).

Table 3. Calculated cation saturation, Cation Exchange Capacity (CEC) for Dokpong, Manga and Nyankpala before planting analyzed by Waypoint Analytical Inc. (Memphis – TN, USA)

Cation	Field location and District		
	Dokpong (Wa West)	Manga (Bawku East)	Nyankpala (Tolon)
	0 - 15 (cm)	0 - 15 (cm)	0 - 15 (cm)
Potassium (K %)	3.6	1.5	1.6
Calcium (Ca %)	60.5	53.6	55.6
Magnesium (Mg %)	8.2	8.4	6.6
Hydrogen (H %)	25.5	34.9	34.4
Sodium (Na %)	3.1	1.9	1.8
K/Mg Ratio	0.44	0.17	0.24
Ca/Mg Ratio	7.38	6.38	8.42
CEC (meq/100g)	4.7	8.6	9.3

Table 4. Soil fertility recommendation for soybean cropping for Dokpong, Manga and Nyankpala before planting reported by Waypoint Analytical Inc. (Memphis – TN, USA)

Nutrient element	Field location		
	Dokpong	Manga	Nyankpala
	0 - 15 cm	0 - 15 cm	0 - 15 cm
Lime (tons/acre)	1.3	2.0	2.0
Nitrogen (N)	0	0	0
Phosphorus (P_2O_5) (kg/ha)	71.7	67.2	33.6
Potassium (K_2O) (kg/ha)	99.7	124.3	119.8
Magnesium (Mg) (kg/ha)	15.7	0	0
Sulfur (S) (kg/ha)	22.4	32.5	20.2
Boron (B) (kg/ha)	1.1	1.1	0.6
Copper (Cu)	1.1	1.1	1.1
Manganese (Mn) (kg/ha)	0	0	3.4
Zinc (Zn) (kg/ha)	2.2	2.2	0
Iron (Fe)	-	-	-
Yield goal: 3,362.55 kg/ha			

Calcium had the highest proportion of base saturation in all locations of 60.5%, 53.6%, and 55.6% for Dokpong, Manga and Nyankpala, respectively (Table 3). Hydrogen was the second highest contributor to base saturation followed by Mg. The ratio of Ca/Mg was 7.38, 6.38, and 8.42 for Dokpong, Manga, and Nyankpala, respectively (Table 3). Calculated cation exchange capacity (CEC) were 4.7 meq/100g, 8.6 meg/100g and 9.3 meq/100g for Dokpong, Manga and Nyankpala, respectively (Table 3).

Fertility recommendation was based on a yield target of 3,362.55 kg ha^{-1} (50 bu/acre) (Table 4) where lime was recommended for all 3 location at 1.3 t ha^{-1} for Dokpong location and 2.0 t ha^{-1} for Manga Nyankpala soils based on buffer pH values. The phosphorus (P_2O_5) was recommended at 71.7 kg ha^{-1}, 67.2 kg ha^{-1} and 33.6 kg ha^{-1} for Dokpong, Manga and Nyankpala, respectively. Potassium (K_2O) was 99.7 kg ha^{-1}, 124.3 kg ha^{-1} and 119.8 kg ha^{-1} for Dokpong, Manga and Nyankpala, respectively. Magnesium (Mg) was only recommended for Dokpong at 15.7 kg ha^{-1}, while S was suggested at 22.4, 32.5 and 20.2 kg ha^{-1} for Dokpong. Manga and Nyankpala, respectively. Boron (B) and others as Cu, and Zn were recommended in trace amounts (Table 4).

2.3. Agronomics of Field Experiments

Experimental location, dates planted, target plant population at planting and corresponding plant spacing (Table 5).

Table 5. Summary of agronomic management of field experiments

Location	Experiment	Date planted	Plant density (plants/ha)	Plant spacing (cm)	Date Lime applied	Date P applied	Date K applied	Date harvested
Nyankpala	BASF Herbicide/ fungicide trial	07/17/19	320,000	75 x 4	-	07/31/19	-	11/28/19
	Omission trial of Lime, inoculum, phosphorus, potassium	07/05/19	320,000	75 x 4	07/05/19	07/23/19	07/20/19	11/07/19
	Omission trial of Lime, inoculum, phosphorus	07/08/19	320,000	75 x 4	07/08/19	07/23/19	-	11/14/19
	Phosphorus, potassium rates trial	07/03/19	320,000	75 x 4	-	07/20/19	07/20/19	11/12/19
	Method of weed control and seeding density trial	07/30/19	133333; 177777; 266666; 333333	75 x 10; 75 x 7.5; 75 x 5; 75 x 4	-	08/15/19	-	11/26/19
	Lime placement trial (Drill vs. broadcast)	07/02/19	320,000	75 x 4	07/02/19	07/23/19	-	11/06/19
	2017 residual effect of lime on pH and yield	07/26/19	320,000	75 x 4	-	07/09/19	-	10/30/19
	2018 residual effect of lime on pH and yield	07/25/19	320,000	75 x 4	-	07/09/19	-	10/30/19
Dokpong	Omission trial of Lime, inoculum, phosphorus	07/06/19	320,000	75 x 4	07/06/19	07/06/19	-	11/25/19
Manga	Omission trial of Lime, inoculum, phosphorus	07/09/19	320,000	75 x 4	07/05/19	08/03/19	-	11/08/19
	2018 residual effect of lime on pH and yield	07/09/19	320,000	75 x 4	-	08/03/19	-	11/08/19

2.4. Objective: Evaluate various herbicide/fungicide spray program with the highest benefit for soybean farmers in Ghana, Co-operation SIL/BASF/RMG/UDS-Agric. Faculty.

2.4.1. Materials and Method

This trial evaluated 3 herbicides, Odyssey (WDG) (a.i. imazamox and imazethapyr), Raptor (SL) (a. i. imazamox) herbicides applied alone and in combination with Stomp (CS) (a. i. pendimenthalin) herbicide compared to hand weed for weed control on 'Favor' soybean variety at Nyankpala location.

Odyssey herbicide

There were 6 herbicide treatment levels of weed control methods compared to hand-weeded and weedy check. Odyssey was applied at 70 g ai ha^{-1} (0.1 kg ha^{-1}), Raptor at 40 g ai ha^{-1} (1.0 L ha^{-1}) , and Stomp at 1.36 kg ai ha^{-1} (3.0 L ha^{-1}). Herbicides were applied 2-3 leaf-stage of plant growth. An adjuvant (Outright 35-NIS) was included for Odyssey and Raptor herbicides at 0.75 L ha^{-1}.

Priaxor fungicide (a.i fluxapyroxad and pyraclostrobin) was incorporated as a second treatment factor. The fungicide application was targeted at Web blight (*Rhizoctonia solani*) and Cercospora leaf blight (*Cercospora kukuchii*), the most common soybean diseases within the research area. Priaxor fungicide was applied at 2 levels, beginning flowering (BBCH 60) and beginning pod development (BBCH 75) at 135.0 g ai ha^{-1} (0.6 L ha^{-1}) with a 16 L backpack sprayer fitted with a fan nozzle. All treatments were inoculated with HiStick inoculant at 400g per 100 kg^{-1} seed. Plot size was 3 x 5 m containing 4 ridges with plant spacing 75 cm between rows and 4 cm within rows. The below assessment criteria were used to evaluate disease score per plot area prior to application of Priaxor (Table 6). Data collected and results (Tables 7, 8 and 9).

Raptor herbicide

HiStick inoculant

Table 6. Disease score prior to flowering stage

Scale	Affected plot area
1	No visible disease symptoms
3	Approximately 5 – 10% of unit the area evaluated is infected
5	Approximately 20 – 30% of unit the area evaluated is infected
7	Approximately 40 – 60% of unit the area evaluated is infected
9	More than 80% of unit the area evaluated is infected
Source: CIAT 1987	

2.4.2. Results and Discussion

Table 7. Effects of weed control methods on plant injury and height (cm) weeks after treatment (WAT) on 'Favor' soybean variety in field experiment at Nyankpala, (2019).

Weed control methods	Crop Injury at 1, 2, 3 WAT				Plant height (cm) at 2, 4, 6, 8, 10 WAT				
	PP5R	PI1WAT	PI2WAT	PI3WAT	PH2WAT	PH4WAT	PH6WAT	PH8WAT	PH10WAT
Hand weeded	107	0	0	0	13.4	23.7	36.7	43.5	47.6
Odyssey	111	8.1	2.1	0	12.8	22.4	33.7	39.9	45.0
Raptor	110	21.9	6.3	0	11.2	20.4	32.3	37.3	44.6
Stomp	108	0	0	0	14.1	23.4	36.1	42.3	46.5
Stomp; hand weeded	109	0	0	0	14.6	23.9	35.3	41.5	46.6
Stomp; Odyssey	109	10.7	2.9	0	11.0	20.8	32.4	39.7	45.2
Stomp; Raptor	109	26.3	9.5	0	11.4	19.1	31.0	36.7	42.5
Weedy check	111	0	0	0	15.3	24.8	34.8	37.9	42.1
F	0.44	36.48	10.18		5.40	2.68	1.17	1.71	1.01
P	0.874	<.01	<.01		<.01	0.023	0.341	0.135	0.44

PP5R = Plants per 5 m row; PI1WAT = Percent Injury 1 week after treatment; PI2WAT = Percent Injury 2 Week After Treatment; PI3WAT = Percent Injury 3 Week After Treatment; PH2WAT = Plant Height 2 Week After Treatment; PH4WAT = Plant Height 4 Week After Treatment; PH6WAT = Plant Height 6 Week After Treatment; PH8WAT =Plant Height 8 Week After Treatment; PH10WAT = Plant Height 10 Week After Treatment.

Table 8. Effects of weed control methods on weed biomass at physiological maturity (Nyankpala, 2019)							
Weed control method	Fresh biomass weight (g m^{-2})			Dry biomass weight (g m^{-2})			Weed control at harvest (%)
	W wt. BLS	W wt. GRS	W wt. SES	D wt. BLS	D wt. GRS	D wt. SES	
Hand weeded	17.8	24.0	6.3	22.3	18.3	4.8	-
Odyssey	14.2	18.2	1.1	5.7	7.1	0.6	93.2
Raptor	15.6	13.8	1.9	6.3	6.2	1.0	91.1
Stomp	78.4	78.2	10.8	32.3	28.9	6.7	48.8
Stomp; hand weeded	12.9	9.3	3.6	4.9	5.4	2.0	80.0
Stomp; Odyssey	9.8	11.9	1.4	3.4	6.9	0.8	90.4
Stomp; Raptor	12.7	8.3	1.2	4.2	4.5	0.8	92.5
Weedy check	122.7	137.4	13.3	45.2	62.7	7.6	-
F	10.60	36.39	10.54	6.04	8.39	35.67	30.72
P	<.001	<.001	<.001	<.001	<.001	<.001	<.001

W wt. BLS = Wet weight of broadleaves; W wt. GRS = Wet wt. of grasses; W wt. SES = Wet weight of sedges; Dry wt. BLS = Dry weight of broadleaves; D wt. GRS = Dry wt. of grasses; D wt. SES = Dry weight of sedges.

Table 9. Effects of weed control methods and Priaxor fungicide on grain yield, plant height at maturity, days to 50% physiological maturity, and grain moisture at harvest (Nyankpala, 2019)							
Weed control method/ fungicide	PStCM	Yield ton ha^{-2}	100 seed wt (g)	PHM (cm)	D50M (days)	MC (%)	Disease score
Hand weed	82	2.04	13.1	59.5	115	12.1	1.0
Odyssey only	81	2.10	13.2	58.7	115	12.3	1.0
Odyssey; Priaxor	84	2.09	13.3	53.6	117	12.1	1.0
Odyssey; Priaxor; Priaxor	84	1.88	12.8	56.9	116	11.9	1.0
Raptor only	88	2.06	13.2	58.6	114	12.2	1.0
Raptor; Priaxor	81	2.08	13.6	60.5	117	11.9	1.0
Raptor; Priaxor; Priaxor	78	1.98	12.9	57.3	117	12.4	1.0
Stomp only	81	1.56	12.3	49.4	115	11.8	1.3
Stomp; hand weed	83	2.08	12.5	58.0	115	11.8	1.0
Stomp; Odyssey	84	1.93	13.5	54.4	115	12.2	1.0
Stomp; Odyssey; Priaxor	83	2.15	13.5	58.6	117	11.7	1.0
Stomp; Odyssey; Priaxor; Priaxor	84	1.81	13.3	55.7	117	12.0	1.0
Stomp; Raptor	80	1.91	13.1	56.5	114	12.1	1.0
Weedy check	80	1.23	11.6	47.3	115	11.7	1.3
Mean	82	1.9	13.0	56.1	116	12.0	1.0
F	ns	*	**	*	**	ns	ns
Means significantly different at * $p \leq 0.05$; ** $p \leq 0.01$; *** $p \leq 0.0001$; ns = non-significant ($p > 0.05$).							

PStCM = Plant count at maturity; PHM = Plant height at harvest; D%)M = Days to 50% maturity; MC = Moisture content at harvest; Disease rating 1 = Disease rated at R1 stage; Disease rating 2 = Disease rated R5 stage.

Crop injury was assessed based on number of plants per 5m row as a percentage of seeded population. Injury category included stunting, leaf scorching, leaf cupping, and red leaf veins. Weed control method caused significant differences in soybean injury (Table 7). Injury was significant for the first 2 weeks after treatment but recovered by the third week (Table 7). Plant showed significant difference within the first 4 weeks after treatment (Table 7). Plants treated with Raptor and Odyssey were shorter compared to hand weeded, Stomp only and weedy check. Other injury symptoms were leaf scorch and cupping. Plant height was not significant among treatments at 6 to 10 weeks after

Odyssey sprayed plot

treatment (Table 7). Weed biomass was assessed at physiological maturity and compared with weedy check. Weed biomass was significantly different amongst treatments (Table 8). Odyssey and Raptor treatments had lower weed biomass compared to hand weeded (Table 8). Grain yield, 100 seed weight, plant height at maturity, and days to maturity were significantly different between treatments. The weedy check had the lowest grain yield, 100 seed weight, plant height and shorter days to maturity (Table 9). Grain yield, 100seed weight, plant height and days to maturity in Odyssey, Raptor and Priaxor treatments were higher compared to hand weeded check. Grain yield, plant height, 100-seed weight and days to 50% maturity were lower in the weedy check. The average plant population at maturity was 82%, and grain moisture was not significantly different amongst treatments (Table 9). Plots sprayed with Priaxor had delayed leave drop and maturity. Results from grain yield and crop development indicated that Priaxor spray did not matter probably due to low disease incidence. The major weed species were broadleaves; *Ageratum conyzoides* (Linn), *Hyptis suaveolens* (G. Don), *Hyptis spicigera* (SW.), *Spermacoce verticillata* (Walt), *Commelina bengalensis* (L). Grasses were; *Rottboellia conchinchinensis* (Lour) W.D.Itch, *Eleusine indica* (Wild), *Paspalum scobiculatum* (Linn), and Sedges included *Cyperus rotundus* (L), *Fimbristylis miliacea* (L) and *Cyperus iria* (L)

2.5. Objective: Evaluate the effects of input bundle of lime, inoculum, phosphorus and potassium on soybean yield with the greatest benefit for soybean farmers in Ghana as determined by omission. Co-operation, SIL/BASF/Omyia Calciprill/ Green-Ef Eco Village Business.

2.5.1. Materials and Methods

This study was an omission trial in a 2 x 2 x 2 x 2 factorial arrangement of certified seed with or without lime (L), inoculum (I), phosphorus (P), potassium (K) and combinations in a randomized complete block design in 4 replications planted to soybean (cv. 'Jenguma'). The 2 factor treatment levels were lime (0, 1,500kg ha^{-1}) of Calciprill lime, inoculum (0, 1,000g per 100 kg seed of NoduMax inoculant, phosphorus [0, 75 kg ha^{-1} P_2O_5 (46% TSP)], and potassium [0, 75 kg ha^{-1} K_2O (60%)]. Certified seed only was the control treatment. Plot size was 3 x 5 m consisting 4 ridges planted in 75 cm spacing between rows and 4 cm within rows. This experiment was conducted at Nyankpala location only. Data collected and results (Table 10).

2.5.2. Results and Discussion

The average plant population across treatments at harvest was 82%. There was not a significant difference amongst treatments (Table 10). The average seed moisture at harvest was 11.3% with not significant difference among treatments. Mean grain yield across treatments was 2.16 kg ha^{-1} with significant differences among treatments. Grain yield was significant with the main effects of P, I, L and K applications. There was not a significant interaction on grain yield (Table 10). Seed weight (per 100 seeds) indicated significant difference with the main effect of P application. Plant height was significant with the main effects of P, I, L and K applications. There was L*P interaction on plant height. Yield and crop development were greater when P was combined with inoculation and /or liming (Table 10).

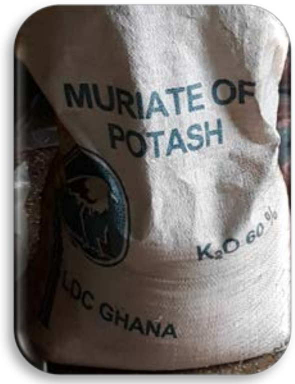

Table 10. Effects of input bundle of lime (L), inoculant (I), phosphorus (P), and potassium (K) on soybean (cv 'Jenguma') growth, development and yield (Nyankpala, 2019)

Treatments	Plant stand at maturity	Yield (tons ha^{-1})	100 Seed Wt., g	Seed moisture at harvest	Plant height at maturity (cm)	Days 50% flower	Days 50% maturity
+L +I +P +K	79	2.69	12.9	11.5	60.5	44	113
+L +I +P -K	83	2.55	13.1	10.9	60.8	44	114
+L +I -P +K	81	2.07	12.3	11.7	47.7	43	114
+L +I -P -K	82	2.09	12.0	10.8	53.6	44	114
+L -I +P +K	83	2.64	12.7	11.3	54.6	45	114
+L -I +P -K	77	2.47	13.2	10.8	49.6	44	114
+L -I -P +K	84	1.94	11.9	11.3	45.0	45	113
+L -I -P -K	83	1.76	12.1	11.3	46.8	45	115
-L +I +P +K	79	2.63	13.0	11.4	62.6	45	114
-L +I +P -K	81	2.62	12.8	11.5	58.0	44	114
-L +I -P +K	80	1.89	12.3	10.8	42.8	44	114
-L +I -P -K	84	1.89	12.2	10.4	43.9	44	113
-L -I +P +K	80	2.31	12.8	10.8	48.7	45	114
-L -I +P -K	85	2.20	12.6	11.0	56.2	44	114
-L -I -P +K	85	1.75	12.1	10.9	42.1	44	113
-L -I -P -K	84	1.11	12.0	11.3	38.1	45	114
Mean	82	2.16	12.5	11.1	50.7	44	114
F test							
L	ns	*	ns	ns	*	ns	ns
I	ns	**	ns	ns	***	ns	ns
L*I	ns	ns	ns	ns	ns	ns	ns
P	ns	***	***	ns	***	ns	ns
L*P	ns	ns	ns	ns	*	ns	ns
I*P	ns	ns	ns	ns	ns	ns	ns
L*I*P	ns	ns	ns	ns	ns	ns	ns
K	ns	*	ns	ns	ns	ns	ns
L*K	ns	ns	ns	ns	ns	ns	ns
I*K	ns	ns	ns	ns	ns	ns	ns
L*I*K	ns	ns	ns	ns	ns	ns	ns
P*K	ns	ns	ns	ns	ns	ns	ns
L*P*K	ns	ns	ns	ns	ns	ns	ns
I*P*K	ns	ns	ns	ns	ns	ns	ns
L*I*P*K	ns	ns	ns	ns	ns	ns	ns

Means significantly different at * $p \leq 0.05$; ** $p \leq 0.01$; *** $p \leq 0.0001$; ns = non-significant ($p > 0.05$).

This probably suggest that phosphorus might be the most important nutrient for increasing soybean yields. Days to flowering and physiological maturity was all not significant.

2.6. Objective: Evaluate the effects of input bundle of certified seed, lime, inoculum and phosphorus on soybean yield that provides with the highest benefit for soybean farmers in Ghana as determined by omission. Co-operation, SIL/BASF/Omyia Calciprill/ Green-Ef Eco Village Business.

2.6.1. Materials and Methods


Input bundle plot - Wa

This trial was an omission trial with a 2 x 2 x 2 factorial arrangement in a randomized complete block design conducted in all 3 research locations (Dokpong, Manga and Nyankpala) planted to soybean (cv. 'Jenguma'). The treatments were: lime (0, 1,500kg ha^{-1} of Calciprill lime); inoculum (0, 1,000g per 100 kg seed of NoduMax inoculum), and phosphorus [0, 75 kg ha^{-1} of P_2O_5 (46% TSP)]. Plot size was 3 x 5 m made up of 4 ridges at plant spacing of 75 cm between rows and 4 cm within rows. Certified seed was the control treatment. Data collected and results for Nyankpala, Dokpong, and Manga are indicated in Tables 11, 12 and13, respectively.

2.6.2. Results and Discussion

Plant population at harvest was 82, 77 and 76% for Nyankpala, Dokpong and Manga, respectively (Tables 10, 11, 12). Mean grain yields across treatments were 2.15, 2.59 and 1.01 tons ha^{-1} for Nyankpala, Dokpong and Manga, respectively (Tables 11, 12, 13).

At Nyankpala, the main treatments of L, I and P indicated significant differences on grain yield. There was a significant lime*phosphorus interaction on grain yield, an indication that the effect of lime on yield was depended on P application (Table 11). Seed weight and plant height were significantly influenced by the main effects of lime and phosphorus application, and P application increased the number of days to maturity by one day (Table 11).

At Dokpong, grain yield and crop development were good, but there was not a significant difference among treatments for yield, seed weight, seed moisture and plant height (Table 12). The lack of significance on these measured parameters was probably due to cropping on the experimental plot. The plot history indicated several years of millet - sorghum – soybean rotation which may have had residual effects from previously applied nitrogen and other fertilizers. However, days to flowering were significantly influenced by the main effects of phosphorus, while days to maturity was significantly influenced by the main effects of phosphorus and lime applications (Table 12).

At Manga, the main effect of lime application had significant influence on grain yield (Table 13). Plant height was significantly influenced by the main effects of lime and inoculation, and the main effect of P application increase days to flowering by one day (Table 13).

Table 11. Effects of input bundle of phosphorus (P), lime (L), and inoculum (I) on plant stand at maturity, grain yield, 100 seed weight, seed moisture at harvest, plant height at maturity, days to 50% flowering, and days to 50% maturity in soybean (cv.'Jenguma') plants (Nyankpala 2019).

Treatments	Plant stand at maturity (%)	Grain yield (tons ha⁻¹)	100 Seed Wt., g	Seed moisture %	Plant height maturity (cm)	Days 50% flowering	Days 50% maturity
-L -I -P	83	1.14	12.2	11.3	47.8	43	114
-L -I +P	81	2.32	13.3	11.5	58.6	43	115
-L +I -P	82	1.82	12.0	11.5	52.9	44	114
-L +I +P	81	2.50	13.1	11.1	61.2	44	114
+L -I -P	85	2.03	12.7	11.2	59.3	44	114
+L -I +P	81	2.51	13.4	11.2	63.0	44	114
+L +I -P	78	2.25	12.6	10.9	59.3	44	114
+L +I +P	83	2.65	13.4	11.3	66.1	43	115
Mean	82	2.15	12.8	11.3	58.5	44	114
F test							
L	ns	**	*	ns	**	ns	ns
I	ns	*	ns	ns	ns	ns	ns
L*I	ns	ns	ns	ns	ns	ns	ns
P	ns	***	***	ns	***	ns	*
L*P	ns	*	ns	ns	ns	ns	ns
I*P	ns	ns	ns	ns	ns	ns	ns
L*I*P	ns	ns	ns	ns	ns	ns	ns

Means significantly different at * $p \leq 0.05$; ** $p \leq 0.01$; *** $p \leq 0.0001$; ns = non-significant ($p > 0.05$).

Table 12. Effects of input bundle of phosphorus (P), lime (L), and inoculum (I) on plant stand at maturity, grain yield, 100 seed weight, seed moisture at harvest, plant height at maturity, days to 50% flowering, and days to 50% maturity in soybean (cv.'Jenguma') plants (Dokpong 2019).

Treatments	Plant stand at maturity (%)	Grain yield (tons ha⁻¹)	100 Seed Wt., g	Seed moisture%	Plant height maturity (cm)	Days 50% flower	Days 50% maturity
-L -I -P	82	2.52	13.4	11.3	62.1	45	114
-L -I +P	76	2.63	13.4	11.5	64.5	46	115
-L +I -P	76	2.52	13.7	11.5	60.2	45	114
-L +I +P	69	2.48	13.6	11.1	64.5	45	114
+L -I -P	81	2.72	13.6	11.2	65.5	45	113
+L -I +P	81	2.67	13.7	11.2	61.2	45	113
+L +I -P	70	2.62	13.3	10.9	58.5	45	113
+L +I +P	79	2.57	13.5	11.3	60.0	47	114
Mean	77	2.59	13.5	11.3	62.1	45	114
F test							
L	ns	ns	ns	ns	ns	ns	*
I	ns	ns	ns	ns	ns	ns	ns
L*I	ns	ns	ns	ns	ns	ns	ns
P	ns	ns	ns	ns	ns	*	*
L*P	ns	ns	ns	ns	ns	ns	ns
I*P	ns	ns	ns	ns	ns	ns	ns
L*I*P	ns	ns	ns	ns	ns	ns	ns

Means significantly different at * $p \leq 0.05$; ** $p \leq 0.01$; *** $p \leq 0.0001$; ns = non-significant ($p > 0.05$).

Table 13. Effects of input bundle of phosphorus (P), lime (L), and inoculum (I) on plant stand at maturity, grain yield, 100 seed weight, seed moisture at harvest, plant height at maturity (PHM), days to 50% flowering, and days to 50% maturity in soybean (cv.'Jenguma') plants (Manga 2019).

Treatments	Plant stand at maturity	Grain yield (tons ha^{-1})	100 Seed Wt., g	Seed moisture %	Plant height maturity (cm)	Days 50% flower	Days 50% maturity
-L -I -P	67	0.32	11.9	10.6	36.5	44	114
-L -I +P	75	0.81	12.5	10.8	37.2	45	114
-L +I -P	83	0.90	11.9	10.8	38.8	43	114
-L +I +P	73	1.00	12.4	11.0	44.5	45	113
+L -I -P	81	1.30	12.4	10.9	43.8	45	114
+L -I +P	74	1.33	12.4	11.0	40.8	45	114
+L +I -P	81	1.12	13.1	11.2	46.3	44	115
+L +I +P	70	1.29	12.5	11.3	47.5	45	114
Mean	76	1.00	12.4	10.9	41.9	44	114
F test	76	1.01	12.4	10.9	41.9	44	114
L	ns	*	ns	ns	*	ns	ns
I	ns	ns	ns	ns	*	ns	ns
L*I	ns	ns	ns	ns	ns	ns	ns
P	ns	ns	ns	ns	ns	*	ns
L*P	ns	ns	ns	ns	ns	ns	ns
I*P	ns	ns	ns	ns	ns	ns	ns
L*I*P	ns	ns	ns	ns	ns	ns	ns

Means significantly different at * $p \leq 0.05$; ** $p \leq 0.01$; *** $p \leq 0.0001$; ns = non-significant ($p > 0.05$).

2.7. Objective: Evaluate the effects of phosphorus and potassium rates on soybean yield thatprovides the maximum benefit to soybean farmers in Ghana. Networks: SIL/SARI/Garnoma Agro-Chemical Ltd/Green-Ef Eco Village Business Ltd.

2.7.1. Materials and Methods

This trial was designed as a 4 x 4 factorial experiment arranged in a randomized complete block design planted to soybean (cv. 'Jenguma') at Nyankpala location only. Treatments icluded 4 rates of phosphorus of $P_0 = 0$, $P_{25} = 25$, $P_{50} = 50$, and $P_{100} = 100$ kg ha^{-1} P_2O_5 (46% TSP), and 4 rates of potassium of $K_0 = 0$, $K_{25} = 25$, $K_{50} = 50$, and $K_{100} = 100$ kg ha^{-1} K_2O (60% MOP). Raptor herbicide (a.i. imazamox) was applied 2 weeks after planting for weed control. All treatments were inoculated with NoduMax inoculant prior to planting. Plot size was 3 x 5 m on 4 ridge plots planted 75 cm between rows and 4 cm within rows. Data collected and results are indicated in Table 14.

2.7.2. Results and Discussion

The average plant population recovered at harvest across treatments was 78% (Table 14). The main effects of phosphorus and potassium applications had significant effect on grain yield, 100 seed weight, and plant height (Table 14). Application of $P_{100}K_{100}$ and $P_{100}K_{50}$ had the highest grain yield, 100 seed weight, and plant height (Table 14). Grain yield and 100 seed weight ranged from 0.8 in P_0K_0 to 2.69 tons ha^{-1} and 11.1 to 13.5g per 100 seed weight, respectively (Table 14). There was a significant P*K interaction for grain yield and plant height at maturity, which probably explains the effect of phosphorus rates on yield and plant height depended on potassium K rate of application. Higher rates of phosphorus and produced greater plant height. Days to flowering and physiological maturity did not differ among treatments with averages of 45 and 114 days, respectively.

Table 14. Effects of Phosphorus (P) and potassium (K) rates on percentage plant stand at maturity, grain yield, 100 seed weight, seed moisture at harvest, plant height at maturity (PHM), days to 50% flowering, and days to 50% maturity in soybean (cv.'Jenguma') plants (Nyankpala, 2019).

Treatments	Plant stand at maturity	Grain yield (tons ha^{-1})	100 Seed Wt., g	Seed moisture %	Plant height maturity (cm)	Days 50% flower	Days 50% maturity
P_0K_0	77	0.80	11.1	10.6	42.6	44	114
P_0K_{100}	77	2.14	12.5	10.2	48.8	44	114
P_0K_{25}	82	1.60	12.7	11.2	44.7	45	114
P_0K_{50}	79	1.76	12.5	10.6	45.8	45	114
$P_{100}K_0$	79	2.18	13.0	9.9	55.6	45	114
$P_{100}K_{100}$	79	2.69	13.5	10.1	63.1	45	114
$P_{100}K_{25}$	74	2.27	13.3	11.9	61.4	45	114
$P_{100}K_{50}$	79	2.69	12.9	10.9	64.4	45	114
$P_{25}K_0$	76	1.65	12.0	11.2	45.0	44	114
$P_{25}K_{100}$	79	2.30	12.6	10.6	58.2	44	115
$P_{25}K_{25}$	78	1.77	12.6	10.4	47.0	45	114
$P_{25}K_{50}$	76	1.99	12.4	10.2	46.3	45	114
$P_{50}K_0$	79	1.95	12.2	10.5	43.0	45	114
$P_{50}K_{100}$	78	2.45	13.0	10.3	64.0	45	113
$P_{50}K_{25}$	80	1.98	12.3	10.5	43.9	45	115
$P_{50}K_{50}$	81	2.20	12.6	10.5	54.6	45	114
Mean	78	2.02	12.6	10.6	51.8	45	114
F test							
P	ns	***	***	ns	***	ns	ns
K	ns	***	**	ns	***	ns	ns
P*K	ns	*	ns	ns	**	ns	ns

Means significantly different at * $p \leq 0.05$; ** $p \leq 0.01$; *** $p \leq 0.0001$; ns = non-significant ($p > 0.05$).

2.8. Objective: Compare four seeding rates with hand weeded and herbicide spray for effective weed control and yield with maximum benefit to Ghanaian soybean farmers. Co-operation, SIL/BASF

2.8.1. Materials and Methods

This was a 2 x 4 factorial experiment in a randomized complete block design with 4 replications. The main factor was weed control methods at 2 treatment levels of Stomp (a.i. pendimethalin) followed by Raptor (a.i. imazamox) herbicides and hand weeding. Subplot factor was seeding rates at 4 treatment levels of 133,333 plants ha^{-1} (75 x10 cm), 177,777 plants ha^{-1} (75 x 7.5 cm), 266,666 plants ha^{-1} (75 x 5 cm), and 333,333 plants ha^{-1} (75 x 4 cm). Weeding regimes were 3 weeks after planting (WAP), 5 WAP and 7 WAP. Stomp was applied same day after planting at 2.5 L ha^{-1} and Raptor at 70 kg ha^{-1} at 2 – 3 leaf stage of soybean growth. An adjuvant (Outright 35-NIS) was included for Raptor herbicide at 750 ml ha^{-1}. Herbicide application was by 16 L backpack sprayer fitted with flat fan nozzle. Data collected and results (Table 15 and 16).

2.8.2. Results and Discussion

This trial on average achieved 86% plant population at harvest with a mean grain yield of 2.0 tons ha^{-1} across treatments (Table 15). The main effect of plant density was significant on grain yield and plant height at maturity. The highest grain yield was 2.78 tons ha^{-1} with a corresponding plant height of 65.2 cm on 333,333 plants ha^{-1}. Weed control method was not significantly different on all measured parameters (Table 15).

Fresh and dry biomass of broadleaves and grasses had significant M*D interaction (Table 16). This means effective weed control of herbicides on broadleaf and grass weeds was dependent on soybean plant density. The main effect of weed control method of fresh and dry biomass on weed sedges was significantly different. Herbicide use was a more effective weed control method on sedges than hand weeded. Visual weed control assessment at harvest had a significant M*D interaction. Weed control evaluated at harvest was depended on method of control and plant density (Table 16).

Table 15. Effect of Stomp (pendimenthalin) followed by Raptor (imazamox) herbicide compared with hand weeded on soybean (cv. Afayak) yield, development and weed control (Nyankpala, 2019)

Method (M)		PStCM	Grain yield (tons ha^{-1})	100 Seed Wt., g	Seed moisture %	Plant height maturity (cm)	Days 50% flower	Days 50% maturity
Weed control method	Application time/ weeding regime							
Hand weeded	3, 5, 7 WAP	85	1.99	12.0	11.4	56.8	43	114
Stomp; Raptor	PRE; 3 WAP	86	2.08	12.1	11.8	56.8	44	114
Density (ha^{-1})								
133,333	75 x 10	84	1.46	12.3	11.4	50.1	43	114
177,777	75 x 7.5	88	1.74	12.0	11.6	53.2	44	114
266,666	75 x 5	87	2.16	11.6	11.8	58.7	43	114
333,333	75 x 4	84	2.78	12.4	11.6	65.2	44	114
Method x density interactions								
Hand weeded	133,333	83	1.51	12.3	11.3	50.4	43	114
Hand weeded	177,777	88	1.74	12.3	11.4	52.3	44	115
Hand weeded	266,666	88	2.11	11.4	11.6	59.1	44	114
Hand weeded	333,333	83	2.61	12.0	11.5	65.4	44	115
Stomp; Raptor	133,333	85	1.41	12.3	11.5	49.8	44	114
Stomp; Raptor	177,777	89	1.75	11.7	11.9	54.1	43	114
Stomp; Raptor	266,666	86	2.20	11.7	12.0	58.3	43	114
Stomp; Raptor	333,333	85	2.96	12.8	11.8	64.9	44	114
Mean		86	2.0	12.1	11.6	56.8	43.6	114
F - Test								
M		ns	ns	ns	ns	ns	ns	ns
D		ns	***	ns	ns	***	ns	ns
M*D		ns	ns	ns	ns	ns	ns	ns

Means significantly different at * $p \leq 0.05$; ** $p \leq 0.01$; *** $p \leq 0.0001$; ns = non-significant ($p > 0.05$).

Major broadleaves weed species identified included *Ageratum conyzoides* (Linn*), Hyptis suaveolens* (G. Don), *Hyptis spicigera* (SW.*), Spermacoce verticillata* (Walt), *Commelina bengalensis* (L). Grasses included *Rottboellia conchinchinensis* (Lour) W.D.Itch, *Eleusine indica* (Wild), *Paspalum scobiculatum* (Linn), and Sedges were *Cyperus rotundus* (L), *Fimbristylis miliacea* (L) and *Cyperus iria* (L).

Table 16. Effect of weed control method on weed biomass at 6 weeks after treatment and weed control at harvest in soybean (cv. Afayak) (Nyankpala, 2019)

Method (M)		Fresh biomass Weight, g			Dry biomass Weight, g			Weed control at harvest (Visual assessment)
Weed control method	Application time/ weeding regime	Broadleaves (m^{-2})	Grasses (m^{-2})	Sedges (m^{-2})	Broadleaves (m^{-2})	Grasses (m^{-2})	Sedges (m^{-2})	
Stomp; Raptor	PRE; 3 WAP	12.2	0.14	4.8	5.6	0.1	2.1	74
Hand weeded	3, 5, 7 WAP	32.4	12.5	22.1	13.8	17.1	11.1	92
Density (D)								
Plant density (ha^{-1})	Plant spacing (cm)							
133,333	75 x 10	38.5	12.4	17.6	16.4	7.5	10.0	74
177,777	75 x 7.5	26.0	6.8	11.4	10.8	3.6	6.6	79
266,666	75 x 5	16.2	4.5	9.4	7.9	2.4	6.1	88
333,333	75 x 4	8.2	1.5	4.1	3.9	0.9	3.9	91
Method x density interaction								
Hand weeded	133,333	59.2	24.8	35.2	24.6	14.8	17.4	60
Hand weeded	177,777	36.8	13.4	18.5	14.3	7.1	10.4	65
Hand weeded	266,666	23.1	8.6	23.3	11.7	4.6	10.1	82
Hand weeded	333,333	17.8	3.0	11.3	4.7	1.7	6.8	88
Stomp; Raptor	133,333	12.2	0	5.5	8.2	0.2	2.5	88
Stomp; Raptor	177,777	10.4	0.2	6.0	7.3	0.1	7.8	93
Stomp; Raptor	266,666	9.4	0.3	5.2	4.0	0.1	2.2	94
Stomp; Raptor	333,333	6.5	0	2.5	3.0	0	1.0	95
Mean		22.1	6.3	12.1	9.7	4.3	7.0	83.1
F - Test								
M		***	***	*	***	***	*	***
D		***	***	ns	**	**	ns	***
M*D		**	***	ns	*	**	ns	***

Means significantly different at * $p \leq 0.05$; ** $p \leq 0.01$; *** $p \leq 0.0001$; ns = non-significant ($p > 0.05$).

2.9. Objective: Evaluate lime placement method for pH adjustment to provide the highest benefit to soybean farmers in Ghana. Co-operation, SIL/Omyia Calcipril.

2.9.1. Materials and Methods

This experiment evaluated drill application of four low lime rates verses broadcast application of two high lime rates in a randomized complete block design with 4 replications in Nyankpala. The low rates were 0, 50, 100, 200, and 400 kg lime ha^{-1} compared to 2 high rates at 1,000 and 1,500 kg lime ha^{-1}. Soybean seeds of all treatments were inoculated with NoduMax inoculant at 10g per kg seed and applied phosphorus at 60 kg ha^{-1} (P_2O_5). Seeding density was 320,000 kg ha^{-1} with plot size of 4.5 x 5 m on 6 ridges at plant spacing 75 cm between rows and 4 cm within row. Weed control was weeding.

2.9.2. Results and Discussion

The average plant establishment was 76% with average grain yield of 2.07 tons ha^{-1} across treatments (Table 17). Grain yield and plant height differed significantly with 1,000 kg ha^{-1} lime application been the highest but was not significantly different from 400 and 1,500 kg ha^{-1} (Table 17). Seed weight, seed moisture, days to flowering and maturity were non-significant among treatments. Grain yield ranged from 1.73 kg ha^{-1} in the no lime treatment to 2.77 kg ha^{-1} for 1,000 kg ha^{-1} lime application. Plant height ranged from 51.3 cm for no lime treatment to 65.0 cm in the 1,000 kg ha^{-1} lime treatment.

Table 17. Effects lime placement (drill vs broadcast) on percentage plant stand at maturity, grain yield, 100 seed weight, seed moisture at harvest, plant height at maturity (PHM), days to 50% flowering, and days to 50% maturity in soybean (cv.'Jenguma') (Nyankpala, 2019).

Lime rates (kg ha^{-1})	Plant stand at maturity	Grain yield (tons ha^{-1})	100 Seed Wt., g	Seed moisture %	Plant height maturity (cm)	Days 50% flower	Days 50% maturity
No lime	80	1.73	12.3	10.3	51.3	43	114
50	77	1.74	13.1	10.1	51.6	44	113
100	75	1.74	13.5	9.8	56.8	44	114
200	74	1.92	13.2	11.3	53.6	43	113
400	75	2.28	13.2	10.2	61.3	43	114
1000	76	2.77	12.9	10.8	65.0	43	114
1500	78	2.34	12.9	11.0	58.8	43	113
Mean	76	2.07	13.0	10.5	56.9	43	114
P	ns	***	ns	ns	***	ns	ns

Means significantly different at * $p \leq 0.05$; ** $p \leq 0.01$; *** $p \leq 0.0001$; ns = non-significant ($p > 0.05$).

2.10. Objective: Assess residual effects of Calciprill lime for pH adjustment and yield on various rates of Calciprill lime applied in 2018 and 2017.

2.10.1. Materials and Methods:

Calciprill lime rates applied during 2018 and 2017 crop seasons were replanted to soybean (cv. Jenguma) in 2019 for residual effects of soil pH and grain yield. Calcipril lime rates applied were 0, 500, 1000, 1500, 2000, 2500, and 3000 kg ha^{-1}. Plots were previously identified with perks and referenced coordinates to facilitate identification. Four core samples were extracted before planting to 15 cm depth on each treatment plot to form a composite sample for analysis. Classification of soil pH followed the USDA Natural Resources Conservation Service. A base application of 10g per I kg seed of NoduMax inoculum and phosphorus at 60 kg ha^{-1} (P_2O_5) was applied across treatments on each lime residual plots. Plot size was 4.5 x 5 m made up of 6 ridges at spacing 75 cm between rows and 4 cm within rows. These experiments were conducted at Nyankpala (2018 and 2017) and Bawku (2018).

2.10.2. Results and Discussion

In the 2018 residual plots at Nyankpala, the average plant establishment was 80% with average grain yield of 2.25 tons ha^{-1} across treatments (Table 18). Grain yield was significant among treatments ranging from 1.62 tons ha^{-1} in the no lime treatment to 2.84 tons ha^{-1} in the 2,500 kg ha^{-1} treatment, but did not differ from 1500, 2000, and 3000 kg ha^{-1} lime residual plots. The average plant height across treatments was 57.9 cm. Plant height differed significantly among treatments with a range of 51.8 cm in no lime to 63.8 cm in 2500 kg ha^{-1} lime treatments (Table 18). Soil pH averaged across treatment plots was 5.8 (Table 18). Soil pH increased from 5.3 in no lime treated plots to 6.7 in the 2500 kg ha^{-1} lime applied plot but dipped at 3000 kg ha^{-1} lime treated plots (Table 18). Available phosphorus fluctuated from medium in the no lime, 1500, and 3000 kg ha^{-1} lime plots to low in the 500, 1000, 2000, and 2500 kg ha^{-1} lime treated plots. Potassium was very low across treatments while Ca ranged from low in no lime treatment, medium and optimal as lime rates increased. Exchangeable Mg fluctuated from medium to optimal at 2000 kg ha^{-1} lime (Table 18).

Table 18. First year residual evaluation of 2018 lime rates trial on yield, plant height, soil pH, phosphorus, potassium and calcium (Nyankpala, 2019).

Lime rates (kg ha^{-1})	Plant stand at maturity	Grain yield (tons ha^{-1})	100 seed wt. g	Plant height (cm)	pH	P (ppm)	K (ppm)	Ca (ppm)	Mg (ppm)
No lime	83	1.62	12.2	51.8	5.3	20(M)	45(VL)	398(L)	69(M)
500	81	1.69	12.1	54.3	5.3	14(L)	39(VL)	526(M)	73(M)
1000	80	2.16	12.1	60.0	5.8	13(L)	46(VL)	634(M)	86(M)
1500	78	2.51	12.7	60.3	5.7	16(M)	48(VL)	572(M)	76(M)
2000	80	2.38	12.2	57.8	5.9	12(L)	49(VL)	626(M)	81(O)
2500	81	2.84	11.8	63.8	6.7	12(L)	40(VL)	773(O)	69(M)
3000	80	2.52	12.3	57.3	6.1	17(M)	40(VL)	707(O)	58(L)
Mean	80	2.25	12.2	57.9	5.8				
P	ns	**	ns	*					

Means significantly different at * $p \leq 0.05$; ** $p \leq 0.01$; *** $p \leq 0.0001$; ns = non-significant ($p > 0.05$).

In the 2017 residual trial in Nyankpala, plant population at harvest was 81% with a mean grain yield of 2.82 tons ha^{-1} across treatments. Grain yield was significant and ranged from 1.86 tons ha^{-1} in no lime treated plots to 3.38 tons ha^{-1} on 2000 and 3000 kg ha^{-1} lime plots (Table 19). Grain yield increased with increased amounts of residual lime. The same trend was observed in plant height. Soil pH averaged 5.5 across residual treatments with a ranged of 5.2 in no lime to 6.1 on 2500 kg ha^{-1} residual lime plots but reduced on 3000 kg ha^{-1} lime treated plots (Table 19).

The evaluation of 2018 residual lime trial at Manga had average plant establishment of 52% with an average grain yield of 0.68 tons ha^{-1} across treatments (Table 20). There was not a significant difference in grain yield among treatments. Plant height differed significantly among treatments with an average of 47 cm across treatments and ranged from 36 cm in the no lime treatment to 53 cm in 3,000 kg ha^{-1} lime treated plots (Table 20). The average soil pH across treatments was 6.3, with a pH of 4.9 in no lime treated plots to 7.5 on 2500 kg ha^{-1} lime applied plots. Available phosphorus was medium across treatments except for 1,000 kg ha^{-1} lime treated plots. Potassium was very low across treatments, and exchangeable Calcium increased with increased amounts of lime applied from low on no lime plots to very high 2500 and 3000 kg ha^{-1} lime rates. Exchangeable Mg was low for all treatments (Table 20).

Table 19. Second year residual evaluation of 2017 lime rates trial on yield, plant height, soil pH, phosphorus, potassium and calcium (Nyankpala, 2019).

Lime rates (kg ha-1)	Plant stand at maturity	Grain yield (tons ha⁻1)	100 seed wt. g	Plant height (cm)	pH	P (ppm)	K (ppm)	Ca (ppm)	Mg (ppm)
No lime	77	1.86	12.5	57.4	5.2	16(M)	45(VL)	600(M)	73(M)
500	81	2.14	12.7	54.6	5.2	28(M)	48(VL)	921(M)	101(M)
1000	83	2.91	12.6	59.5	5.3	15(M)	44(VL)	634(M)	84(M)
1500	81	2.98	12.5	62.5	5.2	13(L)	37(VL)	657(M)	76(M)
2000	80	3.38	12.1	65.3	5.7	16(M)	37(VL)	723(M)	84(M)
2500	83	3.10	12.4	64.7	6.1	22(M)	38(VL)	797(M)	83(M)
3000	82	3.38	12.3	66.6	5.9	18(M)	42(VL	785(M)	88(M)
Mean	81	2.82	12.4	61.5	5.5				
P	ns	***	ns	*					

Means significantly different at * *p* ≤ 0.05; ***p* ≤ 0.01; *** *p* ≤ 0.0001; ns = non-significant (*p* > 0.05).

Table 20. First year residual evaluation of 2018 lime rates trial on yield, plant height, soil pH, phosphorus, potassium and calcium (Manga, 2019).

Lime rates (kg ha^{-1})	Plant stand at maturity	Grain yield (tons ha^{-1})	100 seed wt. g	Plant height (cm)	pH	P (ppm)	K (ppm)	Ca (ppm)	Mg (ppm)
No lime	46	0.76	12.8	36	4.9	20(M)	20(VL)	412(L)	46(L)
500	46	0.60	12.5	41	6.4	18(M)	17(VL)	504(O)	48(L)
1000	51	0.76	11.9	49	5.4	14(L)	19(VL)	465(M)	44(L)
1500	52	0.64	12.1	48	6.7	18(M)	14(VL)	657(O)	47(L)
2000	55	0.54	12.7	50	6.2	18(M)	17(VL)	678(O)	48(L)
2500	60	0.68	12.5	49	7.5	18(M)	18(VL)	1193(VH)	47(L)
3000	55	0.80	12.9	53	7.3	16(M)	20(VL)	920(VH)	43(L)
Mean	52	0.68	12.5	47	6.3				
P	ns	ns	ns	***					

Means significantly different at * *p* ≤ 0.05; ***p* ≤ 0.001; *** *p* ≤ 0.0001; ns = non-significant (*p* > 0.05).

3.0. Pest Management

Pest pressure was low but with observed isolated cases. Leaf feeding insects mainly caterpillars and beetles were present at the vegetative stages but were not yield threatening. Much of the pressure was during the reproductive stages from flowering to maturity where and pod feeding insects posed threatening. Insects at this stage were mainly stink bugs, leaffooted bugs, and flower feeding beetles. Integrated control measures were applied to reduce pest populations.

4.0. Conclusion

Higher temperatures during seed development, diseases, mechanical injury during threshing and storage conditions affect seed quality. Seed sorting and germination test are good practices to improve seed quality to provide better crop establishment at planting. Ensuring adequate plant density at planting is the first step to higher grain yield. Farmers are encouraged to determine seed germination percentage through germination testing before planting.

Soil pH was determined strongly acidic for all locations at pH = 5.2 for Manga (Bawku) and Nyankpala and pH = 5.5 at Dokpong (Wa). These pH values are low within the range for soybean crop and require some lime application to raise pH values. Lime requirement were 1.3 tons acre^{-1} (Dokpong) and 2.0 tons acre^{-1} each for Nyankpala and Manga. Soil texture was loamy sand at Dokpong and sandy loam for Manga and Nyankpala. While available P was medium to optimal, organic matter, K, S, and B were low for all 3 locations. These results are a concern since crop production increases cannot be sustained with deficit nutrient budget that reduce soil fertility below optimum levels which illustrate the importance of regular soil testing.

Grain yield increased with input use but seem to suggest that P was the key driver for yield increase. However, addition of inoculant and or lime increased yield significantly compared to P applied alone. Therefore, application of phosphorus, inoculant, potassium, lime and combinations could increase soybean yield in the savannahs. Although potassium was the most limiting macronutrient reported in the soil test results for all 3 locations, it does not seem to indicate it is the driver of increased yields. Grain yield was not different with herbicide use in soybean for weed control compared to hand weeding. However, the use of herbicide was more effective in controlling weeds than hand weeding. Herbicide use was also easier and saved human effort and time compared to hand weeding. Grain yield was higher at a seeding density of 333,333 plants ha$^{-1,}$ and effective in weed control by providing early canopy cover reducing weeding regime. In the P and K rates trials, application of higher rates of P and K stimulated higher grain yield. Inputs such as inoculum, phosphorus, and lime increase soybean yields, but lime should be applied with soil test recommendation. Extension officers should be consulted when necessary.

5.0. Relevant activities of interest

- SARI Annual Researchers Field Day
  - SIL-SMART Farm participated in the 2019 SARI annual researcher field day visits. Schedules were made to visit each researcher field to familiarize with researcher activity and make inputs to the research. Oct. 16, 2019.
- Undergraduate student project
  - Worked with John Boscos, a final year undergraduate student of the University for Development Studies (UDS) on BASF herbicide and fungicide trial at the SMART Farm as part of a fulfillment for his BS Agronomy Degree.
- 5th Annual Soybean Kick-off Event
  - Participated in the 5th annual soybean kick-off event organized at SARI (Oct. 22, 2019).
- Conference Presentations
  - SMART Farm Omission Trial – Soybean innovation Laboratory. Presented at Gariba Lodge, Tamale. Oct. 22, 2019.
  - Best management Practices within the Context of Pan-African Soybean Variety Trials (PAT). Presented at Erata Hotel, Accra. Oct. 26, 2019.
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- Travel to Malawi and Zambia with Dr. Eric Sedivy to visit SMART farm sites.
  - Visited sites in Malawi were Japan Tobacco International, Pyxus, Horizon, Department of Agriculture and Research Services (DARS) in Chitedze and Zomba, and Good Nature Agro in Zambia. Nov. 29 – Dec. 4th, 2019
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- Mr. Adewole Fatokun, Technical and Regulatory Manager, Agricultural Solutions of BASF West Africa, and Mr. Suleimana Sualid BASF Technical and Regulatory manager of northern Ghana visit the SMART Farm.

6.0. References

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7.0. Sample pictures of BASF herbicide/fungicide trial


Odyssey, Priaxor, priaxor plot


Raptor plot


Odyssey plot


Weedy plot


Stomp, Odyssey, Priaxor, Priaxor plot


Stomp, Raptor plot


Raptor, Priaxor, Priaxor


Stomp only

8.0 Acknowledgement