SMART Farm Trials

Results from Malawi: CAT-Land o' Lakes 2021-2022

In partnership with the Soybean Innovation Lab (SIL), the Center for Agricultural Transformation (CAT) Land o' Lakes conducted two SMART (Soybean Management with Appropriate Research and Technology) Farm input omission trials at Bunda and the National Research Center (NRC) campus in Malawi (**Table 1**).

Figure 1: CAT trial locations for 2021 - 2022 season.

Summary

The **Red Bundle**, which includes Best Management Practices and Certified Seed, is recommended for both Bunda and NRC field locations generating gross margins of $1,104 USD/ha and $1,114USD/ha, respectively.

Seed germination before planting was 94%, creating the foundation for good plant stands and high planting populations.

Fertilizer application at both Bunda and NRC did not significantly increase soybean yields.

The input omission trial is composed of 8 treatment combinations (Table 2) of lime, compound D, and inoculum (Table 3). Each set of 8 treatments were randomized and replicated 4 times. The soybean variety "Serenade" from SeedCo was planted in 3-meters by 5-meter plots with a seed spacing of 5-centimeter. Each plot contained 4 rows with a spacing of 75 centimeters. Seeds were treated with Hi-Stick inoculum 1 hour prior to planting. Lime was applied at planting as a 10 centimeter top-dress, above the seed-furrow. Approximately 21 days after germination at the V2 or V3 developmental stage, single super phosphate and muriate of potash were applied to treated plots as a side-dress 5 centimeters from the furrow, and 5 centimeters deep.

Treatment	L	I	C	S
1				+
2		+		+
3			+	+
4		+	+	+
5	+			+
6	+	+		+
7	+		+	+
8	+	+	+	+

Table 2: Treatment combinations for the Omission Trial. L=lime, I=inoculum, C=compound D

Country	Location	Planting Date	Harvest Date	Latitude	Longitude	Elevation
Malawi	Bunda Farm	1/5/2022	5/5/2022	-14.1765	33.800139	1123
Malawi	NRC	1/6/2022	5/6/2022	-14.026667	33.668306	1099

Table 1: Site information for the CAT omission trial, including planting and harvest date. Dates are represented as "month/day/year"

	Lime	Inoculum	Compound D	Seeds
Product	Dolomitic Lime	Hi-stick	Compound D	Serenade
Source	-	BASF	-	SeedCo
Concentration	CaO-36%	-	8N 18P 15K 6S 0.1B	-
Application rate	300kg/ha	400g/100kg	416kg/ha	320000 seed/ha

Table 3: The product names, sources, concentrations and application rates of inputs used for the omission trial. kg ai/ha – Kilograms of active ingredient per hectare.

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Figure 2: Images from Bunda field location. The left image depicts plant growth 93 days after planting (April 8th , 2022), and the right images shows lime application (January 18th, 2022)

Test	Method	Units	Bunda	NRC
Soil pH	1:1 - Water pH	-	6.3	5.1
Phosphorus (P)	Mehlich 3	ppm	46.2	5.3
Potassium (K)	Mehlich 3	ppm	71.0	78.0
Calcium (Ca)	Mehlich 3	ppm	981.4	252.8
Magnesium (Mg)	Mehlich 3	ppm	90.2	101.4
Sulfur (S)	Mehlich 3	ppm	6.1	28.0
Boron (B)	Mehlich 3	ppm	0.3	0.2
Copper (Cu)	Mehlich 3	ppm	1.9	3.6
Iron (Fe)	Mehlich 3	ppm	33.8	43.7
Manganese (Mn)	Mehlich 3	ppm	5.1	15.1
Zinc (Zn)	Mehlich 3	ppm	1.1	1.2
Sodium (Na)	Mehlich 3	ppm	11.9	13.2
Organic Matter	Loss On Ignition	%	0.3	1.0

Table 5: Soil fertility results for the Bunda and NRC sites generated from Brookside Laboratories. Soil nutrient amounts are displayed in parts-per-million (mg/kg).

Seasonal temperature and precipitation information for the field sites are displayed in **Table 4**. Temperatures peaked in December reaching 31.0°C Bunda. Minimum temperatures of 13.3°C in NRC were observed in May. Between the months of December and May the total observed rainfall was 393mm for Bunda and 291mm for NRC.

Month	Min Temperature (°C)		Max Temperature (°C)		Rainfall (mm)	
	Bunda	NRC	Bunda	NRC	Bunda	NRC
December	20.3	20.4	31.1	30.8	7.4	4.9
January	18.0	18.0	24.5	24.8	214.4	173.9
February	18.1	18.0	23.7	24.1	101.1	65.4
March	17.8	17.6	25.0	25.3	42.6	22.6
April	16.6	16.5	24.6	24.9	27.5	15.2
May	13.9	13.3	25.2	25.2	0.2	0.0
Sum					393.2	282.0

Table 4: Monthly averages for minimum and maximum temperatures and the total monthly rain fall for the 2021-2022 season at the Bunda and NRC sites.

Soil properties for Bunda and NRC are shown in **Table 5**. The trial sites had a soil pH of 6.3 in Bunda and 5.1 for NRC which would benefit from additional liming to raise the pH closer to the optimal level of 6.5. Phosphorus levels (threshold 30mg/kg) and potassium levels (threshold 110mg/kg) for NRC are shown to be low and would benefit from in-field fertilizer application. The Bunda location is sufficient in phosphorus and deficient in potassium.

	Test 1	Test 2	Test 3	Test 4	Test 5	Test 6	Test 7	Test 8	
Seeds Tested	50	50	50	50	50	50	50	50	
Healthy Seedlings	46	47	48	47	48	47	47	48	
Abnormal Seedlings	3	1	2	0	2	1	0	1	
Dead Seeds	1	2	0	3	0	2	3	1	
Germination Rate (%)	92	94	96	94	96	94	94	96	**94.5**

Table 6: Germination test results.

The seed lot used at the Bunda and NRC locations was tested prior to planting. 400 seeds were divided in to 8 50-seed tests. Germinated seedlings were counted at 5 and 8 days after planting. Abnormal seedlings exhibiting any damaged or absent organs were not counted as successfully germinated. **Soybeans germinated at an average rate of 94.5%.** Tests were either conducted using the soil or paper towel method.

Data collection metrics for the input omission trial are described in **Table 7**. Stand count was measured at V2 and R8 developmental stages. Plant Height was measured at R1and R8 developmental stages. Measurements for Nodule Count, Weight, and Viability were measured at the R3 developmental stage.

Trait	Unit	Measurement Metrics
Stand Count	count	Sum of plants in Row 2 and 3
Days to Flowering	day	Days after planting when the first flower is observed
Plant Height	centimeter	Distance from soil to the Shoot Apical Meristem on main stem
Nodule Count	count	Number of Rhizobium nodules on roots collected at R3-pod filling stage
Nodule Weight	gram	Mass of Rhizobium nodules on roots collected at R3-pod filling stage
Nodule Viability	%	Percentage of counted nodules that are active and viable
Yield	ton/hectare	Plants harvested and threshed, seed winnowed and weighed at 13% moisture
100 Seed Weight	gram	Random sets of 100 seeds selected and weighed

Table 7: Data metrics for the 2021-2022 SMART Farm omission trial.

Bunda Trial Results

Treatment	Rank Yield	Yield	V2 Stand Count	R1 Flowering	R1 Height	Nodule Count	Nodule Viability	R8 Stand Count	R8 Height	100 seed Weight	Seed Moisture
		ton/ha	count	days	cm	nodules	%	count	cm	g	%
C	1	2.80	221	45	32	14	75	191	53	22.9	9.9
L+C	2	2.53	279	45	34	22	86	204	56	22.7	10.8
No Input	3	2.40	221	45	32	11	75	200	55	22.7	10.3
I+C	4	2.39	277	45	31	22	71	201	55	22.7	10.7
L+I+C	5	2.30	208	45	30	17	79	186	56	23.1	10.4
L+I	6	2.27	251	45	34	15	78	202	56	22.8	10.4
I	7	2.25	201	45	31	14	77	182	55	23.1	9.7
L	8	2.19	218	45	33	15	74	201	81	22.7	10.6
AVG		2.39	234	45	32.1	16	77	195	58.2	22.8	10.4
CV		19.89	19	0	9.4	34.4	11.4	8.7	28.8	1.44	7.6
LSD		0.73	58	0	4.5	6.9	13	25.0	23.8	0.48	1.2

Table 8: Averages, Least Significant Differences (LSD) at an alpha of 0.05, and Coefficient of Variations (CV%) for yield, stand count, R1 flowering, height, nodule count, nodule viability, 100 seed weight, and seed moisture for the 2021-2022 omission trials at Bunda, Malawi. In the treatment column: I-inoculum, C-Compound-D, L-lime. P-values for each treatment main-effect or interaction are represented as follows: (.)>0.10, (*)>0.05, (**)>0.01, (***)>0.001.

An Analysis of Variance (ANOVA) was conducted in R using the package "car" to test the main treatment effects, 2-way, 3-way, and 4-way treatment interactions in the omission trial. The Shapiro's Wilk and Brown-Forsythe test were employed to confirm residual normality and homogeneity of variance, respectively. **None of the treatment combinations significantly impacted soybean yields.**

Mean yields ranged from 2.8 tons/ha (C) to 2.19 tons/ha (L). Stand count ranged from 201 to 279 and 186 to 204 at V2 and R8 developmental stages, respectively. R1 flowering occurred at 45 days after planting for all treatments. For plant height, all treatments lay between 30 and 34cm, and 53 and 81cm at R1 flowering and R8 developmental stages, respectively. Mean values for 100-seed weight ranged from 23.2g (I) to 22.7g (L). Seed moisture ranged from 9.8% to 10.8%.

Nodule count and nodule viability showed a similar result for treatments containing inoculum and for treatments without inoculum. Treatments with and without inoculum produced 11-22 nodules and 14-22 nodules, respectively. An average nodule viability of 77% was observed across all treatments. This trial provides information on which inputs are best suited to maximize soybean yield and are a valuable resource for developing an input bundle approach to soybean production.

Agricultural inputs such as lime, inoculum, and compound D contribute to increases in soybean yield. However, the combination of specific field condi-tions and a farmer's limited cash funds may make using all three inputs either unnecessary or financially impractical. The 2021-2022 SMART Farm omission trial has assessed the usage of these inputs and has assembled two input bundles for the Bunda field site. To balance the financial risk of applying new inputs, SIL recommends a stepwise investment in new technology. This prioritizes the maximum financial returns on the minimum input costs and allows initial successes to feed into additional future inputs.

For further information on the 2021-2022 trials at Bunda with CAT-Land o' Lakes, contact the trial operator, Robert Chana at RChana@landolakes.org

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Bunda Trial Results

Recommended

Red Bundle

Best Management Practices
Certified Seed
18x return on input costs compared to farmer practice
Marginal Ratio: 3.5*

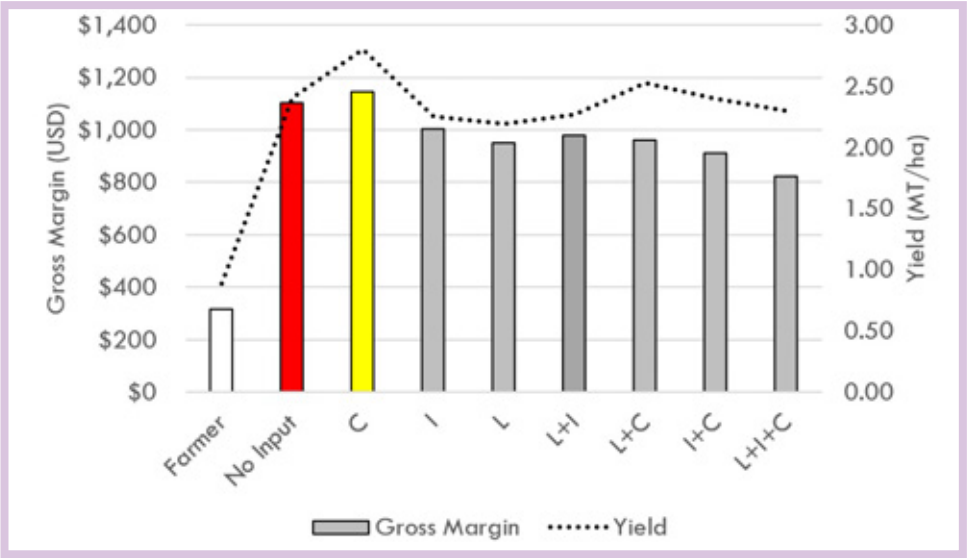


Figure 3: Treatment yields (line graph) and gross margins (bar graph) for the Bunda field site.

Yellow Bundle

Best Management Practices
Certified Seed
Potassium
-7x return on additional input costs compared to Red Bundle
Marginal Ratio: 0.9**

The gross margins[1] and yield averages are displayed in **Figure 3.** The white bar represents typical farming practices in Malawi. It is assumed that saved seed is used with no additional inputs, and that labor costs are absorbed by the household2. Under these conditions it is estimated that a typical farmer will generate a gross margin of $315 USD and a yield of 0.89MT per hectare laboring between 60 and 70 workdays in a season. This generates an implicit wage of $1.82 USD for every $1.00 USD of labor spent.

The Red Bundle is the standard growing package. This includes the usage of certified soybean seeds and the adoption of best management practices (testing seed germination, planting in ridges, early planting, planting in rows, increased seed population, timely weeding, and regular disease scouting). The Red Bundle in Bunda generated a gross margin of $1,104 USD, a marginal ratio increases of 3.5 compared to typical farming practices and yielded 2.4 MT per hectare. This produces a 18x return on seed costs and provides an implicit wage of $6.34 USD for every $1.00 USD of labor spent (a 538% increase in wages compared to the typical farmer). **The Red Bundle is recommended for the Bunda location.**

The Yellow Bundle represents a step up from the Red Bundle with the inclusion of compound D, certified soybean seeds and the adoption of best management practices. The Yellow Bundle generated an average gross margin of $ $1,147 USD, a marginal ratio increases of 1.93% compared to the Red Bundle, and a yielded 2.8MT per hectare. There is an implicit wage of $6.63 USD for every $1.00 USD of labor spent (a 563% increase in wages compared to the typical farmer). **While the Yellow Bundle generated slightly higher gross margins than the Red Bundle, treatments using compound D did not significantly increase soybean yields. The moderately fertile soils at the Bunda location may account for the lack significant fertilizer effect.**

*Marginal Ratio compared to farmer practices
**Marginal Ratio compared to Red Bundle

[1]gross margin=revenue – variable costs

[2]Van Vugt, D., Franke, A. C., & Giller, K. E. (2017). Participatory research to close the soybean yield gap on smallholder farms in Malawi. Experimental Agriculture, 53(3), 396-415.

NRC Trial Results

Treatment	Rank Yield	Yield	V2 Stand Count	R1 Flowering	R1 Height	Nodule Count	Nodule Viability	R8 Stand Count	R8 Height	100 seed Weight	Seed Moisture
		ton/ha	count	days	cm	nodules	%	count	cm	g	%
I+C	1	2.77	195	46	70.0	3	25	189	70.1	19.0	9.7
C	2	2.53	172	46	67.7	6	25	172	67.7	19.0	9.8
L+I+C	3	2.51	220	46	63.2	8	75	210	63.3	18.5	9.6
No Input	4	2.42	150	46	65.3	2	72	150	65.6	20.8	9.7
L+C	5	2.31	194	46	65.3	4	44	194	65.4	18.8	10.0
I	6	2.21	143	46	61.8	1	49	148	62.4	20.0	9.9
L+I	7	2.14	202	46	58.1	5	75	197	58.4	19.5	10.0
L	8	2.03	210	46	63.0	5	50	205	63.3	18.8	9.2
AVG		2.40	183	46	64.3	4	51.8	183	64.5	19.3	9.7
CV		19.6	39	0	5.6	6	95.9	35	5.6	1.2	0.6
LSD		0.67	19	0	8.7	143	76.0	19	8.6	6.2	5.8

Table 9: Averages, Least Significant Differences (LSD) at an alpha of 0.05, and Coefficient of Variations (CV%) for yield, stand count, R1 flowering, height, nodule count, nodule viability, 100 seed weight, and seed moisture for the 2021-2022 omission trials at NRC Malawi. In the treatment column: I-inoculum, C-compound-D, L-lime. P-values for each treatment main-effect or interaction are represented as follows: (.)>0.10, (*)>0.05, (**)>0.01, (***)>0.001.

An Analysis of Variance (ANOVA) was conducted in R using the package "car" to test the main treatment effects, 2-way, 3-way, and 4-way treatment interactions in the omission trial. The Shapiro's Wilk and Brown-Forsythe test were employed to confirm residual normality and homogeneity of variance, respectively. **None of the treatment combinations significantly impacted soybean yields.**

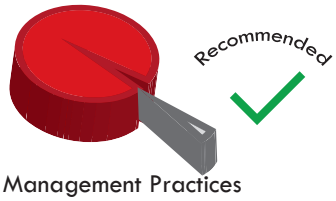
Mean yields ranged from 2.77 tons/ha (C) to 2.03 tons/ha (L). Stand count ranged from 210 to 143 and 209 to 148 at V2 and R8 developmental stages, respectively. R1 flowering occurred at 46 days after planting for all treatments. For plant height, all treatments lay between 70 and 58cm, and 70 and 58cm at R1 flowering and R8 developmental stages, respectively. Mean values for 100-seed weight ranged from 20.8g (I) to 28.5g (L). Seed moisture ranged from 10.0% to 9.2%.

Nodule count and nodule viability showed a similar result for treatments containing inoculum and for treatments without inoculum. Treatments with and without inoculum produced 1-8 nodules and 2-6 nodules, respectively. An average nodule viability of 52% was observed across all treatments. This trial provides information on which inputs are best suited to maximize soybean yield and are a valuable resource for developing an input bundle approach to soybean production.

For further information on the 2021-2022 trials at NRC, contact the trial operator, Robert Chana at RChana@landolakes.org

NRC Trial Results

Red Bundle



Best Management Practices

Certified Seed

18x return on input costs compared to farmer practice

Marginal Ratio: 3.5*

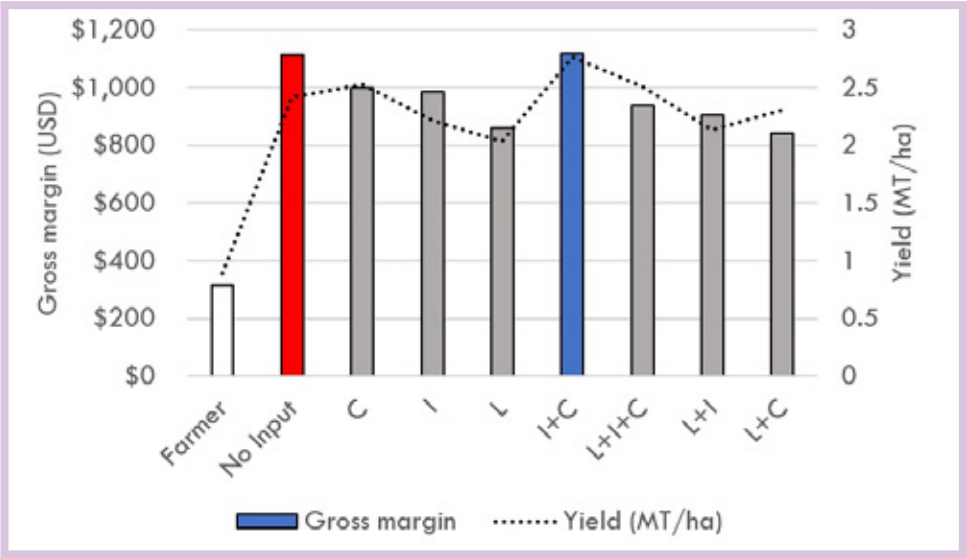


Figure 4: Treatment yields (line graph) and gross margins (bar graph) for the NRC field site.

The Red Bundle is the standard growing package. This includes the usage of certified soybean seeds and the adoption of best management practices (testing seed germination, planting in ridges, early planting, planting in rows, increased seed population, timely weeding, and regular disease scouting). The Red Bundle in Bunda generated a gross margin of $1,114 USD, a marginal ratio increases of 3.5 compared to typical farming practices and yielded 2.42 MT per hectare. This produces a 18x return on seed costs and provides an implicit wage of $6.44 USD for every $1.00 USD of labor spent (a 543% increase in wages compared to the typical farmer). **The Red Bundle is Recommended for the NRC location.**

The Blue Bundle represents a step up from the Red Bundle with the inclusion of compound D and inoculum, certified soybean seeds and the adoption of best management practices. The Yellow Bundle generated an average gross margin of $1,117 USD, a marginal ratio increases of 1.003 compared to the Red Bundle (i.e the gross margins are essentially equal), and a yielded 2.77MT per hectare. There is an implicit wage of $6.46 USD for every $1.00 USD of labor spent (a 545% increase in wages compared to the typical farmer). **The Blue Bundle gross margins at NRC are about equal to the Red Bundle. However, the interaction between inoculum and compound-D does not significantly increase soybean yields. Therefore, the more simplistic Red Bundle is recommended for NRC.**

For both the Bunda and NRC field locations fertilizer treatments did not significantly increase yields. In the case of inoculum, it is possible that carry-over rhizobia were present at both field locations from previous SMART Farm plantings, reducing the impact of additional inoculum application. Conversely, it is also possible that the low organic matter levels and acidic soils at the field locations prevented the rhizobium bacteria from surviving and nodulating soybeans.

Based on the soil fertility results, both locations should benefit from lime application to bring field pHs closer to neutral. It is possible that the minimal, targeted application of lime at planting is not sufficient to significantly improve soils to benefit soybean growth. Applying lime before the planting season or in greater quantities will allow for improved pH remediation but may be less appropriate or affordable for small-holder farmers.

Somewhat surprisingly, compound-D fertilizer did not result in significant yield improvements at either location. It is possible soil acidity at both locations prevented the fertilizer from realizing its full potential. Compound-D appeared to have an increased (but not significant) impact on yield at Bunda compared to NRC. Bunda's soil pH of 6.3 compared to NRC's 5.1 would support this soil acidity hypothesis.

*Marginal Ratio compared to farmer practices

Economic Assumptions

- For the typical Southern African farmer it is assumed that soybean seeds are saved from one year to the next, and that no additional inputs are purchased.
- A season of labor is estimated to be 60-70 workdays (472-560 hours) from land preparation to harvest. It is assumed that for a given household any necessary field labor will be conducted by members of that household.
- Fixed costs such leasing costs for land, property tax, insurance, managerial overhead, or transportation costs are not included in the variable cost estimates. It is assumed that these costs are consistent across treatments.
- It is assumed that the labor involved in applying different input treatments is equal.
- It is assumed that local African soybean prices are linked to and stabilized by world-wide soybean prices.

Definitions

Gross Margin: For the SMART Farm reports SIL defines the Gross Margin as the Variable Costs of soybean production, including labor, minus the Revenue generated from grain sales.

Marginal Ratio: is the quotient between two gross margin values.

Return on Input Costs: The return on input costs compares how much was spent on inputs to how much additional monetary value that input provides.

Values for Economic Analysis

Item	$USD/Hectare	Source
Input Costs		
Certified Soybean Seed	$44.40	1
Inoculum	$14.13	2
Compound-D	$172.64	3
Lime	$37.25	4
Labor Costs		
Labor (land preparation, planting, weeding, harvest, bagging)	$173.01	5
Soybean Selling Price		
Item	$USD/Kg of Seed	
Grain Price	$0.55 ($550.00/MT)	6

Source

1) Internal SIL communications,
2) Internal SIL communications,
3) Internal SIL communications,
4) Internal SIL communications,
5) Internal SIL communications
6) Internal SIL communications, www.selinawamucii.com (2022), indexmundi (2022)