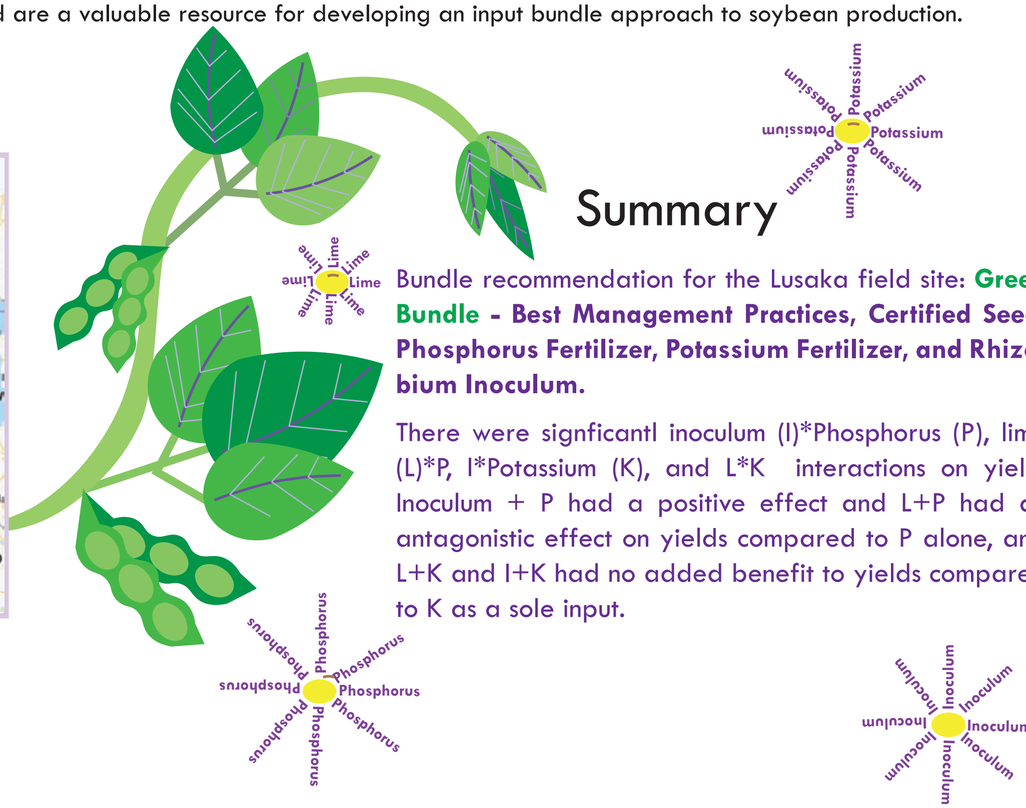
SMART Farm Trials

Results from Zambia: SIL-IITA 2019-2020

In partnership with the Soybean Innovation Lab (SIL), the International Institue of Tropical Agriculture conducted a SMART (Soybean Management with Appropriate Research and Technology) Farm input omission trial at Lusaka, Zambia (**Table 1**). 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.

Figure1: SIL-IITA trial location for the 2019-2020 season



Summary

Bundle recommendation for the Lusaka field site: **Green Bundle - Best Management Practices, Certified Seed, Phosphorus Fertilizer, Potassium Fertilizer, and Rhizobium Inoculum.**

There were signficantl inoculum (I)*Phosphorus (P), lime (L)*P, I*Potassium (K), and L*K interactions on yield. Inoculum + P had a positive effect and L+P had an antagonistic effect on yields compared to P alone, and L+K and I+K had no added benefit to yields compared to K as a sole input.

The input omission trial is composed of 16 treatment combinations (**Table 2**) of P, K, L, and I (Table 3). Each set of 16 treatments were randomized and replicated 4 times. The soybean variety "TGX 2014-16FM" from IITA was planted in 3 meter by 5 meter plots with a seed spacing of 5cm. Each plot contained 4 rows with a spacing of 75cm. Seeds were treated with Hi-Stick Inoculum 1 hour prior to planting. Calciprill Lime was applied in furrow at planting. Approximately 21 days after germination at the V2 or V3 developmental stage, Triple 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	P	K	S
1					+
2		+			+
3			+		+
4				+	+
5		+	+		+
6		+		+	+
7			+	+	+
8		+	+	+	+
9	+				+
10	+	+			+
11	+		+		+
12	+			+	+
13	+	+	+		+
14	+	+		+	+
15	+		+	+	+
16	+	+	+	+	+

Table 2: Treatment combinations for the Omission trial. L=Lime, I=Inoculum, P=Phosphorus, K=Potassium, S=Seeds.

Country	Location	Planting Date	Harvest Date	Latitude	Longitude	Elevation
Zambia	Lusaka	20/12/2019	28/05/2020	-15.393714	28.582434	1097m

Table 1: Site information for the SIL-IITA omission trial, including planting and harvest date.

	Phosphorus	Potassium	Inoculum	Lime	Seed
Product	Triple Super Phosphate	Muriate of Potash	Hi-Stick	Calciprill	TGX 2014-16FM
Source	-	-	BASF	OMYA	IITA
Concentration	P2O5-46%	K2O-60%	-	CaO-36%	-
Appication Rate	75kg ai/ha	75kg ai/ha	400g/100kg	300kg/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.

Trait	Unit	Measurement Metrics
Yield	tons/hectare	Plants harvested and threshed, seed winnowed and weighed at 13% moisture
Stand Count	count	Sum of plants in row 2 and 3
R1 Flowering	days	Days until mid-flowering
Plant Height	centimeters	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	grams	Mass of rhizobium nodules on roots collected at R3-pod filling stage
100 Seed Weight	grams	Random sets of 100 seeds selected and weighed
Seed Moisture	%	Percent moisture at harvest

Table 4: Data metrics for the 2019-2020 SMART Farm omission trial

Data collection metrics for the input omission trial are described in **Table 4**. Stand count was measured at V2 and R8 developmental stages. Nodules were counted and weighed at R3. Plant height was measured at R1 and R8 developmental stages.

Treatment	Rank	Yield	V2 Stand Count	R1 Flowering	R1 Height	Nodule Count	Nodule Weight	R8 Stand Count	R8 Height	100 seed Weight	Seed Mositure
		ton/ha	count	days	cm	nodules	g	count	cm	g	%
I+P+K	1	1.90	142	41	62	64	1.8	129	68	15.1	8.1
L+I+P+K	2	1.80	155	41	68	54	2	139	71	15.4	7.6
P+K	3	1.73	152	40	62	43	1.5	147	65	14.1	8.2
L+P+K	4	1.72	163	41	63	41	1.2	147	66	14.4	7.8
I+P (*)	5	1.65	152	42	61	52	1.2	129	65	14.6	8.2
L+K (**)	6	1.48	169	40	64	35	1.5	148	69	15.3	7.6
P (***)	7	1.44	152	41	60	40	1.3	144	65	14.7	7.5
L+I+P	8	1.42	123	41	65	35	1.3	110	68	15.3	7.5
L+I+K	9	1.34	167	40	61	30	1.2	137	64	14.5	8.0
I	10	1.31	172	41	68	33	1.1	122	72	16.6	8.2
K (***)	11	1.20	129	40	59	25	0.9	96	63	14.5	7.9
L	12	1.12	160	40	57	33	1.1	143	63	14.5	7.6
L+P (*)	13	1.12	126	40	60	36	1.3	115	66	14.9	8.0
I+K	14	1.02	106	41	61	33	1.3	91	65	14.7	8.1
L+I	15	0.93	194	42	55	32	1.1	134	59	14.5	7.7
No Input	16	0.92	107	41	54	25	0.9	92	62	14.5	7.7
AVG		1.38	148.0	40.5	61.3	38.1	1.3	126.3	65.7	14.8	7.9
LSD		0.31	66.6	2.3	6.1	12.8	0.4	53.1	6.4	2.0	0.8
CV%		26.51	34.5	4.3	9.0	35.2	29.8	32.6	7.8	11.4	6.9

Table 5: Averages, Least Significant Differences (LSD) at an alpha of 0.05, and Coefficient of Variations (CV%) for Yield, Stand Count, R1 Flowering, R1 Height, Nodule Count, Nodule Weight, R8 Stand Count, R8 Height, 100 Seed Weight, and Seed Moisture for the 2019-2020 omission trial at Lusaka, Zambia. In the treatment column: I-Inoculum, P-Phosphorus, K-Potassium, L-Lime. P-values for yield 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 JMP 15.0 using the Fit Model Platform to test the main treatment effects, 2-way, 3-way, and 4-way treatment interactions in the omission trial. The Anderson-Darling and Brown-Forsythe tests were employed to confirm residual normality and homogeneity of variance respectively. **Based on the ANOVA, there were significant (P < 0.05) main effects for P and K fertilizer and signficant interactions for I*P, L*P, I*K, and L*K on yields (Table 5).** As sole inputs, P and K fertilization both significantly increased yields, however they did interact with other inputs. Adding inoculum to P fertilizaton signficantly increased yields, while adding lime signficantly decreased yields, compared to using P alone. The addition of lime or inoculum to K fertilization had no significant impact on yields compard to K alone. **The recommended bundle of I+P+K signficantly increased yields by 106% compared to Certified Seed Only.**

The signficant increase in yields by 44% (P) and 20% (K) by just adding a single nutrient input could be explained by either low soil fertility or low pH tying up nutrients in the soils. Although we do not have data on soil fertility from this season, historically this area has highly acidic soils (4.8-5.5) which may tie up most nutrients in the soil making them unavailable to the plant. This low pH may also explain why inoculum alone did not signficantly impact yield. A soil pH under 5.8 reduces nodule viability and nitrogen fixation. However, we did see a significant increase when inoculum and P were applied. Rhizobium symbiosis requires high amounts of P which may explain why the two together increased yields. Although we did see higher yields when lime was applied compard to the control, overall it was not signficant. This may be due to the concentration of lime applied was not enough to make an impact on soil pH. **It should be noted the Lusaka field site experienced a period of drought at the onset of flowering. This negatively impacted pod set and maturation thus resulting in reduced yields for the 2019-2020 season.**

There were signficant main effects and interactions for several other variables collected. Inoculum, P fertilizer, and K fertilizer all had signficant main effects for R1 plant heights as well as signficant interactions bewteen L*K and L*I*P. For both interactions there were no antagonistic effects between inputs and all treatment combinations either increased or did not significantly change height. There was a signficant interaction for L*I*P for R8 plant heights. Nodule count and weight were both signficantly increased by main effects of inoculum and P and K fertilization. For nodule count, there were signficant interactions between I*P, P*K, L*I, and L*P. Lime was antagonistic when combined with P fertilizer and inoculum. Both K fertilizer and rhizobium inoculum signficantly increased nodule count when paired with P fertilizer. For nodule weight, there was a signficant interaction between I*K, I*P*K, and L*I*P. Addition of K fertilizer, P fertilizer, and lime to inoculum all increased nodule weight compard to single input treatments.

Mean yields ranged from 0.92 tons/ha (No Input) to 1.90 tons/ha (I+P+K). Stand count ranged from 106 (I+K) to 194 (L+I) plants and 91 (I+K) to 148 (L+K) plants at V2 and R8 developmental stages respectively. R1 flowering ranged from 40 to 42 days after planting. For plant height, all treatments lay between 54cm (No Input) and 68cm (L+I+P+K) at R1 and 59cm (L+I) and 122 (I) for R8 developmental stages. Nodule counts ranged from 25 (No Input) to 64 (I+P+K) and nodule weights ranged from 0.9g (No Input and K treatments) to 2.0g (L+I+P+K). Mean values for seed weight ranged from 14.1g (P+K) to 16.6g (I). Seed moisture at harvest ranged from 7.5% (P) to 8.2% (I).

Month	Max Temperature (°C)	Min Temperature (°C)	Rainfall (mm)
November	31.5	20.6	106.3
December	29.7	19.8	93.0
January	27.7	19.2	370.7
February	27.2	18.8	221.1
March	27.7	18.0	58.3
April	28.5	16.3	3.2
May	26.4	12.4	6.3

Table 6: Monthly averages for maximum and minimum temperatures and the total monthly rainfall for 2019-2020 season at the Lusaka site.

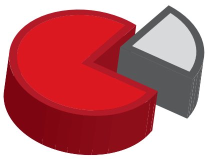
Seasonal temperature and precipitation information for the field sites are displayed in **Table 6**. In season, temperatures peaked in December 2019 reaching 29.7°C. A minimum temperature of 12.4°C was observed in May 2020. Between the months of November and May, the total observed rainfall was 858.9mm.

For further information on the 2019-2020 trials at Lusaka with IITA, contact the trial operator Dr. Godfree Chigeza, at g.chigeza@cgiar.org

SMART Farm Trials

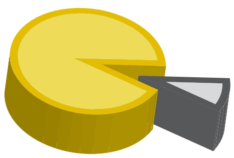
Results from Zambia: SIL-IITA 2019-2020

Red Bundle



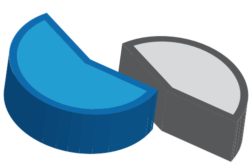
Best Management Practices
Certified Seed
3x return on input costs compared to farmer practice
Marginal Ratio: 1.3*

Yellow Bundle



Best Management Practices
Certified Seed
Rhizobium Inoculum
3x return on additional input costs compared to Red Bundle
Marginal Ratio: 1.9**

Blue Bundle



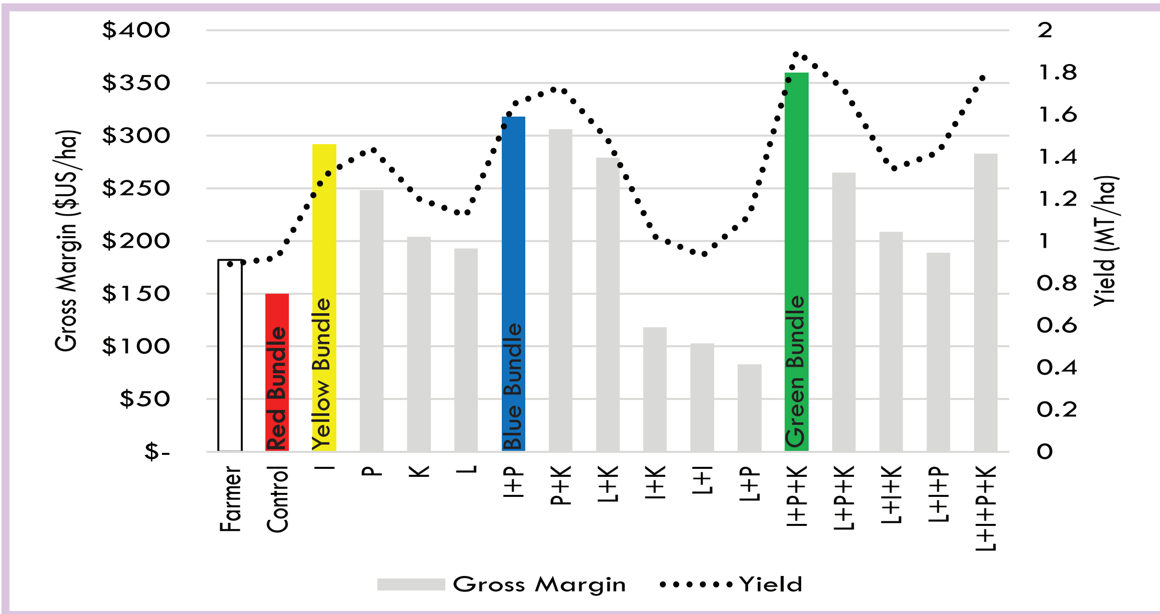
Best Management Practices
Certified Seed
Rhizobium Inoculum
Phosphorus Fertilizer
4x return on additional input costs compared to Red Bundle
Marginal Ratio: 2.1**

Green Bundle

Best Management Practices
Certified Seed
Rhizobium Inoculum
Phosphorus Fertilizer
Potassium Fertilizer
5x return on additional input costs compared to Red Bundle
Marginal Ratio: 2.4**

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

Figure 4: Treatment yields (line graph) and gross margins (bar graph)



Agricultural inputs such as Lime, Inoculum, Phosphorus and Potassium contribute to increases in soybean yield. However, the combination of specific field conditions and a farmer's limited cash funds may make using all four inputs either unnecessary or financially impractical. The 2019 SMART Farm omission trial has assessed the usage of these inputs and has assembled three input bundles for the Lusaka 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.

The gross margins and yield averages are displayed in **Figure 4**. The "Farmer" treatment represents typical soybean farming practices in southern Africa. It is assumed that saved seed is used with no additional inputs, and that labor costs are absorbed by the household. Under these conditions it is estimated that a typical farmer will generate a gross margin of $182 USD and a yield of 0.89MT per hectare laboring between 60 and 70 work days in a season. This generates an implicit wage of $1.05 USD for every $1.00 USD of labor spent.

The Red Bundle is the standard growing package. Based on our results this is not a recommended option for this trial, and more inputs are required to make a positive impact on profit. The Yellow Bundle is the next step up and includes the use of rhizobium inoculum along with certified soybean seed and the adoption of best management practices in the Red Bundle. The Yellow Bundle generated an average gross margin of $292 USD, a marginal ratio increase of 1.9 compared to the Red Bundle, and yielded 1.31MT per hectare. This produces an 3x return on inoculum costs and provides an implicit wage of $1.69 USD for every $1.00 USD of labor spent (a 69% increase in wages compared to the typical farmer).

The Blue Bundle includes the use of rhizobium inoculum and P fertilizer along with certified soybean seed and the adoption of best management practices in the Red Bundle. The blue bundle generated an average gross margin of $318 USD, a marginal ratio increase of 2.1 compared to the Red Bundle, and yielded 1.65MT per hectare. This produces an 4x return on rhizobium inoculum and P fertilizer costs and provides an implicit wage of $1.84 USD for every $1.00 USD of labor spent (a 84% increase in wages compared to the typical farmer).

The Green Bundle includes the use of rhizobium inoculum, P fertilizer, and K fertilizer along with certified soybean seed and the adoption of best management practices in the Red Bundle. The blue bundle generated an average gross margin of $360 USD, a marginal ratio increase of 2.4 compared to the Red Bundle, and yielded 1.90MT per hectare. This produces an 5x return on rhizobium inoculum and P and K fertilizer costs and provides an implicit wage of $2.08 USD for every $1.00 USD of labor spent (a 108% increase in wages compared to the typical farmer). **Based on the above observations, the Green Bundle is recommended for the Lusaka location.**

SMART Farm Trials

Appendix for Economic Costs, Definitions, and Assumptions

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 as 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 minus the revenue generated from seed sales.

Marginal Ratio: 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	$44.80	1
Rhizobium Inoculum	$14.13	2
Phosphorus Fertilizer	$109.00	3
Potassium Fertilizer	$58.14	4
Lime	$37.25	5
Labor Costs		
Labor (Land preparation, planting, weeding, harvest, bagging)	$173.01	6
Soybean Selling Price		
Item	$USD/ Kg of Seed	Source
Seed Price	$0.40 ($400.00/MT)	7

*Costs and prices are average values aggregated from multiple sources

Source

1) Internal SIL communications, Analysis of the Soya Bean Value Chain in Zambia's Eastern Province (2012), Soybean Value Chain-AECOM International Development (2011), IAPRI-soybean value chain and market analysis -Zambia (2014), Profitability and technical efficiency of soybean production in northern Nigeria (2017), Income and Cost Budgets for summer crops in South Africa- (2018-2019), Soybean Production Guide In Uganda (2015)

2) Internal SIL communications, IAPRI-soybean value chain and market analysis -Zambia (2014), N2F-Production and use of Rhizobial inoculants in Africa (2011)

3) Internal SIL communications, Income and Cost Budgets for summer crops in South Africa- (2018-2019), South African Fertilizer Market Analysis Report (2018), Agricultural Prices, USDA, National Agricultural Statistics Service (2020), Spatial variation in fertilizer prices in Sub-Saharan Africa (2020)

4) Internal SIL communications, Income and Cost Budgets for summer crops in South Africa- (2018-2019), South African Fertilizer Market Analysis Report (2018), Agricultural Prices, USDA, National Agricultural Statistics Service (2020), Spatial variation in fertilizer prices in Sub-Saharan Africa (2020)

5) Internal SIL communications, Income and Cost Budgets for summer crops in South Africa- (2018-2019)

6) Internal SIL communications, Soybean Costs of Production-(2019), Soybean Value Chain-AECOM International Development (2011), IAPRI-soybean value chain and market analysis -Zambia (2014), Profitability and technical efficiency of soybean production in northern Nigeria (2017), Soybean Production Guide In Uganda (2015)

7) Internal SIL communications, www.selinawamucii.com (2020), Soybean Prices (2019), Zambia National Farmers Union (2020), USDA Market News (2020)