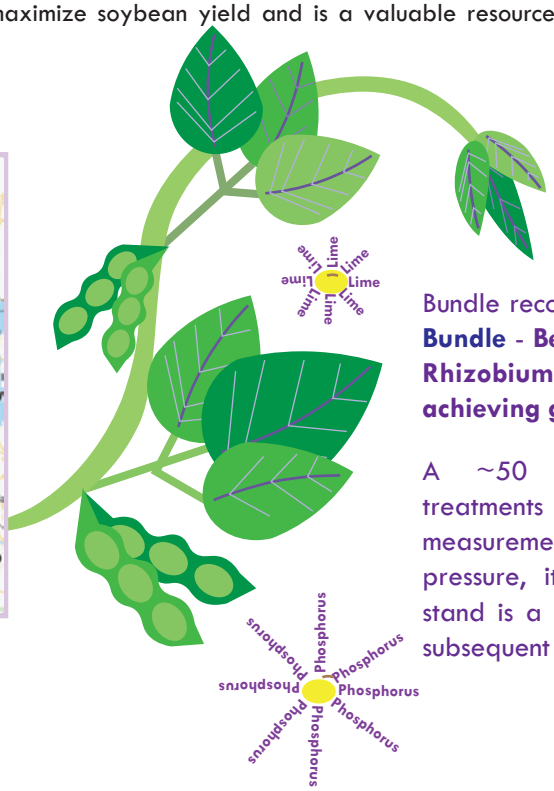
SMART Farm Trials

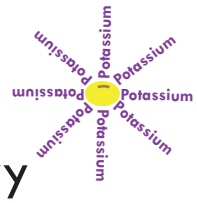
Results from Zambia: IITA 2020-2021

In partnership with the Soybean Innovation Lab (SIL), the International Institute of Tropical Agriculture (IITA) conducted a SMART (Soybean Management with Appropriate Research and Technology) Farm input omission trial in Lusaka, Zambia (**Figure 1**, **Table 1**). This trial provides information on which inputs are best suited to maximize soybean yield and is a valuable resource for developing an input bundle approach to soybean production.

Figure 1: IITA trial location for the 2020-2021 season.

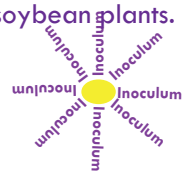


Summary



Bundle recommendation for the Lusaka field site: **Blue Bundle - Best Management Practices, Certified Seed, Rhizobium Inoculum and Potassium Fertilizer, achieving gross margins of $824 USD/ha.**

A ~50 plant reduction was noted across treatments between V2 and R8 stand count measurements. In the absence of disease or pest pressure, it is possible that the reduction in plant stand is a result of over-planting within rows and subsequent competition among soybean plants.



The input omission trial is composed of 16 treatment combinations (**Table 2**) of phosphorus, potassium, lime, and inoculum (**Table 3**). Each set of 16 treatments were randomized and replicated 4 times. The soybean variety "TGX 2014-16FM" from IITA was planted in 3m by 5m 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 as a 10cm top dress at planting. 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 5cm from the furrow, and 5cm 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	12/26/2020	5/3/2021	-15.39371	28.582434	1097m

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

	Phosphorus	Potassium	Inoculum	Lime	Seed
Product	Single Super Phosphate	Muriate of Potash	Hi-Stick	Calciprill	TGx2014-16FM
Source	-	-	BASF	OMYA	IITA
Concentration	P2O5-13%	K2O-60%	-	CaO-52%	-
Application Rate	75kg ai/ha	75kg ai/ha	400g/100kg	150kg/ha	320,000 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.

Figure 2: Field plots at the IITA SMART Farm Omissions Trials. The left image shows soybean growth in Lusaka at 26 days after planting (photo taken January 21, 2021). The right image shows soybean growth at 55 days after planting (photo taken February 19, 2021).

Month	Min Temperature (°C)	Max Temperature (°C)	Rainfall (mm)
November	20.0	31.8	106.3
December	19.0	27.3	326.0
January	18.9	27.0	218.5
February	18.9	27.3	152.9
March	17.2	27.6	29.4
April	14.5	27.0	8.3

Table 4: Monthly averages for minimum and maximum temperatures and the total monthly rainfall for the 2020-2021 season at the Lusaka site.

Test	Method	Units	Lusaka
Soil pH	1:1 - Water pH	-	6
Phosphorus (P)	Mehlich 3	ppm	26
Potassium (K)	Mehlich 3	ppm	72
Calcium (Ca)	Mehlich 3	ppm	713
Magnesium (Mg)	Mehlich 3	ppm	165
Sulfur (S)	Mehlich 3	ppm	19
Boron (B)	Mehlich 3	ppm	0.1
Copper (Cu)	Mehlich 3	ppm	1.6
Iron (Fe)	Mehlich 3	ppm	65
Manganese (Mn)	Mehlich 3	ppm	62
Zinc (Zn)	Mehlich 3	ppm	1.4
Sodium (Na)	Mehlich 3	ppm	26
Organic Matter	Loss On Ignition	%	2.1

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

Seasonal temperature and precipitation information for the Lusaka field site is displayed in **Table 4**. Minimum temperatures of 14.5°C were observed in April. Temperatures peaked in November reaching 31.8°C. Between the months of November and April the total observed rainfall was 841.4mm in Lusaka.

Soil properties for Lusaka are shown in **Table 5**. The field site had a sandy clay loam texture with low fertility levels. The soil has a pH of 6.0, which is close to the optimal pH threshold of 6.5 for soybean production. Both potassium (threshold 110mg/kg) and phosphorus (threshold 30mg/kg) levels are shown to be low and would be benefit from in-field fertilizer application.

Data collection metrics for the input omission trial are described in **Table 6**. Stand count was measured at the V2 and R8 developmental stage. Plant height was measured at R1 and R8 developmental stages. Measurements for nodule count, weight, and viability were measured at the R3 developmental stage.

Trait	Unit	Measurement Metrics
Yield	tonnes/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

Table 6: Data metrics for the 2020-2021 SMART Farm omission trial.

Treatment	Rank Yield	Yield	V2 Stand Count	R1 Flowering	R1 Height	Nodule Count	Nodule Weight	Nodule Viability	R8 Stand Count	R8 Height	100 seed Weight	Seed Moisture
		ton/ha	count	days	cm	count	g	%	count	cm	g	%
L+I+P+K	1	2.89	228	39	48	91	2.42	78	195	92	18	16
I+K	2	2.79	223	41	46	82	2.12	80	198	85	16	12
L+I+P	3	2.76	214	40	47	86	2.01	71	181	90	16	16
P+K	4	2.73	201	40	47	86	2.22	84	160	88	17	15
L+P+K	5	2.70	222	41	45	82	1.40	85	167	87	18	15
L+I	6	2.68	225	41	46	85	2.01	77	153	89	17	16
I+P+K	7	2.68	251	40	47	86	2.09	84	169	92	16	13
P	8	2.66	217	40	50	88	2.08	78	158	94	17	15
L+P	9	2.64	229	41	49	84	2.06	77	169	90	17	15
L	10	2.61	253	40	48	73	1.55	80	200	92	17	13
I	11	2.59	223	41	47	71	1.55	80	157	90	18	15
L+I+K	12	2.57	237	40	47	80	2.01	70	186	88	17	14
No Input	13	2.55	231	40	48	73	1.75	80	163	91	16	14
L+K	14	2.51	221	40	48	83	2.31	82	196	92	15	17
K	15	2.44	242	41	45	73	1.70	67	173	89	17	14
I+P	16	2.44	223	40	46	79	1.72	86	141	90	17	15
AVG		2.6	227.3	40.1	47.2	81.3	1.9	78.7	173.8	89.9	16.8	14.8
LSD (0.05)		0.5	45.9	1.9	4.4	25.5	1.1	18.5	64.6	9.1	2.2	4.2
CV%		12.9	13.6	3.2	6.2	20.6	36.6	16.0	25.4	6.6	9.2	19.4

Table 7: 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 weight, nodule viability, 100 seed weight, and seed moisture for the 2020-2021omission trials at Lusaka, Zambia. In the treatment column: I-inoculum, P-phosphorus, K-potassium, L-lime.

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. **Based on the ANOVA, there were no significant treatment effects on yield.**

Mean yields ranged from 2.44 tons/ha (I+P) to 2.89 tons/ha (L+I+P+K). Stand count ranged from 201 to 253 and 141 to 214 at V2 and R8 developmental stages, respectively. **It is notable that on average 53 plants were lost across treatments between the V2 and R8 stand count measurements. No major disease issues were reported during the growing season, so it is possible that the reduction in stand count is caused by over-planting. While soybeans have some ability to compensate for too few or too many plants within a row through increasing or decreasing branching and pod set, too high of a planting population will result in soybeans competing with neighboring plants for resources.** As a result healthy soybeans can overshadow smaller soybeans and lead to a decrease in plant stand. Being mindful of planting population at the beginning of the season can help lead to consistent plant stands and yields at harvest.

R1 flowering ranged from 39 to 41 days. For plant height, all treatments lay between 45cm (K, L+P+K) to 50cm (P), and 85cm (I+K) to 94cm (P) at R1 flowering and R8 developmental stages, respectively. Nodule counts ranged from 71 (I) to 91 (L+I+P+K) and nodule weights ranged from 1.40g (L+P+K) to 2.42g (L+I+P+K). An average nodule viability of 78% was observed across all treatments. Mean values for 100-seed weight ranged from 15g (L+K) to 18g (L+I+P+K, L+P+K, I). Seed moisture ranged from 12% to 17%. 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, 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 2020-2021 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.

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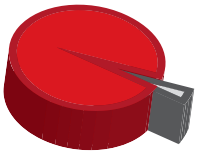
Red Bundle



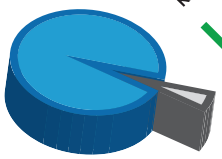
Best Management Practices
Certified Seed
14x return on input costs compared to farmer practice
Marginal Ratio: 4.40*

Yellow Bundle

Best Management Practices
Certified Seed
Rhizobium Inoculant
0x return on additional input costs compared to Red Bundle
Marginal Ratio: 1.00**

Blue Bundle

Recommended



Best Management Practices
Certified Seed
Rhizobium Inoculum
Potassium
0x return on additional input costs compared to Red Bundle
Marginal Ratio: 1.02**

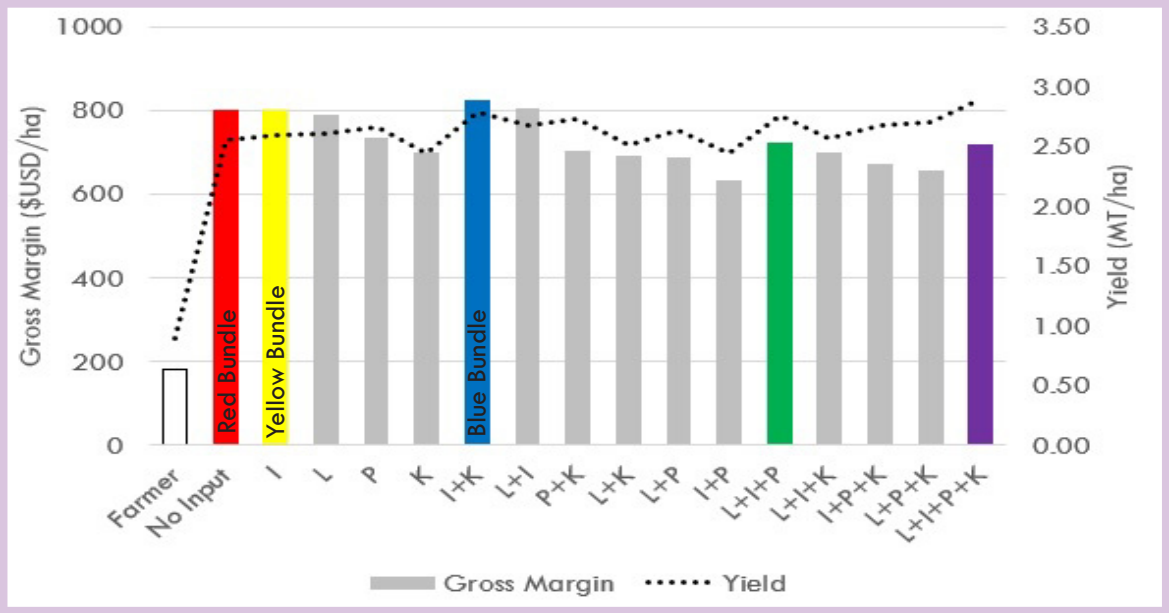


Figure 3: Treatment yields (line graph) and gross margins (bar graph).

The gross margins[1] and yield averages are displayed in **Figure 3**. The white bar represents the typical soybean farmer. It is assumed that saved seed is used with no additional inputs, and that labor costs are absorbed by the household[2]. Under these conditions it is estimated that a typical farmer will generate a gross margin of $182 USD and a yield of 0.82MT per hectare laboring between 60 and 70 workdays 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. This includes the usage of certified soybean seeds and the adoption of best management practices (early planting, planting in rows, increased seed population, and timely weeding). The Red bundle in Lusaka generated an average gross margin of $802 USD, a marginal ratio increases of 4.40 compared to typical farming practices and yielded 2.55 MT per hectare. This produces a 14x return on seed costs and provides an implicit wage of $4.64 USD for every $1.00 USD of labor spent (a 364% increase in wages compared to the typical farmer).

The **Yellow Bundle** represents a step up from the Red Bundle with the inclusion of rhizobium inoculum. The Yellow Bundle generated an average gross margin of $803 USD, a marginal ratio increases of 1.00 compared to the Red Bundle and yielded 2.59 MT per hectare. This produces a 0x return on inoculant costs and provides an implicit wage of $5.58 USD for every $1.00 USD of labor spent (a 364% increase in wages compared to the typical farmer).

The **Blue Bundle** includes the use of rhizobium inoculum along with potassium, certified soybean seeds and the adoption of best management practices. The blue bundle generated an average gross margin of $824 USD, a marginal ratio increases of 1.02 compared to the Red Bundle and yielded 2.79 MT per hectare. This produces an 0x return on rhizobium inoculum and potassium costs and provides an implicit wage of $4.76 USD for every $1.00 USD of labor spent (a 376% increase in wages compared to the typical farmer).

While the Blue Bundle, including rhizobium inoculum and potassium, generated the highest gross margins observed at the Lusaka site, it did not greatly outperform the Red Bundle. Based on soil tests, potassium amendments are recommended for this field location, and the Blue Bundle delivers on this. However, the additional efforts of sourcing and applying potassium fertilizer may make the Red Bundle a more appropriate option for growers.

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

For further information on the 2020-2021 trial at Lusaka, Zambia, contact the trial operator Dr. Godfree Chigeza, at g.chigeza@cgiar.org

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
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
Grain Price	$0.40 ($400.00/MT)	7

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, USDA Market News.