SMART Farm Trials
Results from Malawi: Pyxus 2020

In partnership with the Soybean Innovation Lab (SIL), Pyxus International conducted two SMART (Soybean Management with Appropriate Research and Technology) Farm input omission trials at Chilanga and Mpale, Malawi (**Figure 1**, **Table 1**).

Figure1: Pyxus trial locations for the 2020 season

Summary

Bundle recommendation for the Chilanga field site: Yellow Bundle- Best Management Practices, Certified Seed, and Rhizobia Inoculant. Gross margins were $142 /ha higher than what the standard famer brings home in southern Africa.

Bundle recommendation for the Mpale field site: Green Bundle- Best Management Practices, Certified Seed, Phosphorus Fertilizer, Potassium Fertilizer, and Rhizobia Inoculant. Gross margins for the I +P+K bundle were $1618 /ha higher than what the standard famer brings home in Southern Africa.

The input omission trials at both locations were composed of 16 treatment combinations (**Table 2**) of phosphorus, potassium, lime, and inoculant (**Table 3**). Each set of 16 treatments were randomized and replicated 4 times. The soybean variety "Serenade" was planted in 5 meter by 3 meter plots with a seed spacing of 5cm. Each plot contained 4 rows with a spacing of 75 cm. Seeds were treated with Hi-Stick rhizobium inoculum 1 hour prior to planting. Calciprill lime was applied in-furrow coinciding with planting. Approximately 21 days after germination at the V2 or V3 developmental stage, single super phosphate and potash were applied to treated plots as a side-dress 5 centimeters from the furrow, and 5 centimeters deep. Both trials were irrigated using horse pipes.

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
Malawi	Chilanga	7/6/2020	12/15/2020	12°56'06.66"S	33°28'05.16"E	1036m
Malawi	Mpale	7/4/2020	12/19/2020	13°24'30.73"S	33°37'04.36"E	1114m

Table 1: Site information for the Pyxus omission trials, including planting and harvest date. Dates are written as: month/day/year.

	Phosphorus	Potassium	Inoculum	Lime	Seed
Product	Single Super Phosphate	Muriate of Potash	Hi Stick	Calciprill	Serenade
Source	-	-	BASF	OMYA	Seed Co.
Concentration	P2O5-18%	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.

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Figure 2: Field plots at the Pyxus SMART Farm Ommissions Trials

Month	Min Temperature (°C)		Max Temperature (°C)		Rainfall (mm)	
	Chilanga	Mpale	Chilanga	Mpale	Chilanga	Mpale
June	14.0	13.1	24.4	23.8	0.0	0.2
July	12.7	11.9	23.4	22.9	2.7	0.0
August	14.5	13.8	26.9	26.4	0.0	0.0
September	16.8	16.2	28.7	28.3	0.0	0.1
October	19.9	19.2	31.0	30.5	10.8	5.7
November	21.4	20.8	32.8	32.4	26.8	34.6
December	20.2	19.6	29.4	28.8	183.7	140.9

Table 4: Monthly averages for maximum and minimum temperatures and the total monthly rainfall for 2020 season at the both Pyxus sites.

Seasonal temperature and precipitation information for the field sites are displayed in **Table 4**. Temperatures peaked in November for Chilanga and Mpale at 32.8°C and 32.4°C, respectively. Minimum temperatures of 12.7°C and 11.9°C were observed in July for Chilanga and Mpale, respectively. Between the months of June and December the total observed rainfall was 224.0 and 181.5 mm for Chilanga and Mpale, respectively. It should be noted these plots were irrigated using horse pipes with approximately 5 mm of water applied daily. During this trial soybean maturity was delayed from the expected 90-120 days after planting to 162 days for Chilanga and 168 days for Mpale. Two potential reasons for this delay are the shift in photoperiod and reduced temperatures due to planting during the winter season. Further delays occurred during harvest as drying soybean plants encountered the December rains. For future winter trials in Malawi early planting during late May or early June will help avoid a wet harvest.

Test	Method	Units	Chilanga	Mpale
Soil pH	1:1 - Water pH	-	5.8	5.3
Phosphorus (P)	Mehlich 3	ppm	10	18
Potassium (K)	Mehlich 3	ppm	129	66
Calcium (Ca)	Mehlich 3	ppm	830	843
Magnesium (Mg)	Mehlich 3	ppm	297	189
Sulfur (S)	Mehlich 3	ppm	8	12
Boron (B)	Mehlich 3	ppm	0.22	0.25
Copper (Cu)	Mehlich 3	ppm	2.36	1.94
Iron (Fe)	Mehlich 3	ppm	92	69
Manganese (Mn)	Mehlich 3	ppm	96	74
Zinc (Zn)	Mehlich 3	ppm	1.16	0.99
Sodium (Na)	Mehlich 3	ppm	14	15
Organic Matter	Loss On Ignition	%	2.63	2.57

Table 5: Soil fertility results for Pyxus SMART Farm sites generated from Brookside Laboratories. Soil nutrient amounts are displayed in parts-per-million (mg/kg). high.

Soil properties analyses were completed by Brookside Labs (New Bremen, Ohio, USA) and displayed in **Table 5**. Soils at the Chilanga location were acidic, insufficient in P, and sufficient in K. At Mpale, soils were acidic and insufficient in both P and K. Both site were also low in organic matter.

Data collection metrics for the input omission trials are described in **Table 6**. Stand counts were measured at the V2 and R8 growth stages. Plant heights were measured at R1 and R8 growth stages. Nodule count and weight were measured as R3. Measurements for yield, seed count, and 100 seed weight were measure post-harvest.

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 SMART Farm omission trials

Treatment	Rank Yield	Yield	V2 Stand Count	R1 Flowering	R1 Height	Nodule Count	Nodule Weight	R8 Height	100 seed Weight
		MT/ha	count	days	cm	nodules	g	cm	g
I+P+K	1	5.50	199	68	27	12	0.03	61	25.5
L+I+P	2	5.29	195	68	28	8	0.02	60	26.5
I+P	3	5.08	195	68	25	13	0.03	62	24.5
L+I	4	5.00	194	70	23	8	0.01	52	25.5
L+I+P+K	5	4.84	195	69	25	11	0.05	60	25
I (***)	6	4.68	199	69	25	10	0.02	56	26.5
I+K	7	4.67	196	70	24	8	0.03	55	25
L+I+K	8	4.36	197	71	21	4	0	49	25
L+P+K	9	4.04	196	69	26	0	0	52	27.5
L+P	10	4.03	196	69	26	0	0	60	26
P+K	11	3.81	198	69	26	0	0	58	26.5
L+K	12	3.72	197	68	24	1	0	56	25.5
P (***)	13	3.62	199	69	25	0	0	57	26.5
No Input	14	3.51	196	69	23	0	0	51	27
K	15	3.39	197	69	22	0	0	51	27
L	16	3.36	193	69	20	0	0	48	26.5
AVG		4.31	196.2	68.8	24.5	4.8	0.0	55.5	26.0
LSD		0.71	4.9	1.9	3.8	4.4	0.0	8.1	2.2
CV%		19.24	1.8	2.0	12.7	117.6	173.2	13.2	6.3

Table 7: Averages, Least Significant Differences (LSD) at an alpha of 0.05, and Coefficient of Variations (CV%) for Yield, Stand Count, R1 Flowering and Height, R3 nodule count and weight, R8 Stand Count, R8 Height, 100 Seed Weight, and Seed Moisture for the 2020 omission trial at Mpale, Malawi. In the treatment column: I-Inoculum, P-Phosphorus, K-Potassium, L-Lime. P-values for each treatment main-effect or interaction are represented as follows: (.)<0.10, (*)<0.05, (**)<0.01, (***)<0.001.

Mpale

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 Shapiro's Wikle and Brown-Forsythe test were employed to confirm residual normality and homogeneity of variance, respectively. Based on the ANOVA, there were significant I and P main effects. Treatments including the input had 34% and 10% higher yields than without the input for I and P, respectively.

There were significant main effects and/or interactions for R1 and R8 plant heights and nodule count and weight. For R1 and R8 plant heights, there was a significant P main effect where treatments that included the input produced taller plants than those without. For nodule count and weight, there were significant I and P main effects as well as a significant I*P interaction where the I+P treatment had higher counts and weights than without these inputs or with only one input. **It should be noted** that grain moisture could not be captured post-harvest due to the tool's unavailability. Given the wet conditions during soybean harvest, it is possible that yield values across treatments are overestimated as soybean grains may not have sufficiently dried down prior to weighing.

Mean yields ranged from 3.36 (L) to 5.5 (I+P+K) MT/ha. Stand counts ranged from 193 (L) to 199 (I+P+K, I, P). Plant heights ranged from 20 (L) to 28 (L+I+P) and 48 (L) to 62 (I+P) cm at R1 and R8, respectively. Flowering ranged from 68 to 71 days after planting. For reference, R1 flowering occurred at 40 days after planting during the 2019-2020 Summer season at Mpale. Nodule count ranged from 0 for most treatments that did not include I to 13 (I+P) nodules/plant and nodule weight ranged from 0 to 0.05 (L+I+P+K) grams/plant. Seed weight ranges from 24.5 (I+P) to 27.5 (L+P+K) grams.

For further information on the 2020 trial at Mpale, Malawi, contact the trial operator
Yaona Mtonga, at ymtonga@pyxus.com

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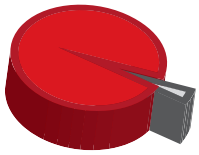
Red Bundle

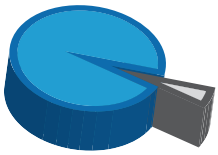


Best Management Practices
Certified Seed
22x return on input costs compared to farmer practice
Marginal Ratio: 6.52*

Yellow Bundle

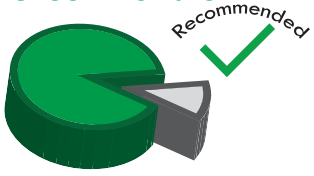
Best Management Practices
Certified Seed
Rhizobium Inoculant
32x return on additional input costs compared to Red Bundle
Marginal Ratio: 1.38**

Blue Bundle



Best Management Practices
Certified Seed
Rhizobium Inoculum
Lime
11x return on additional input costs compared to Red Bundle
Marginal Ratio: 1.46**

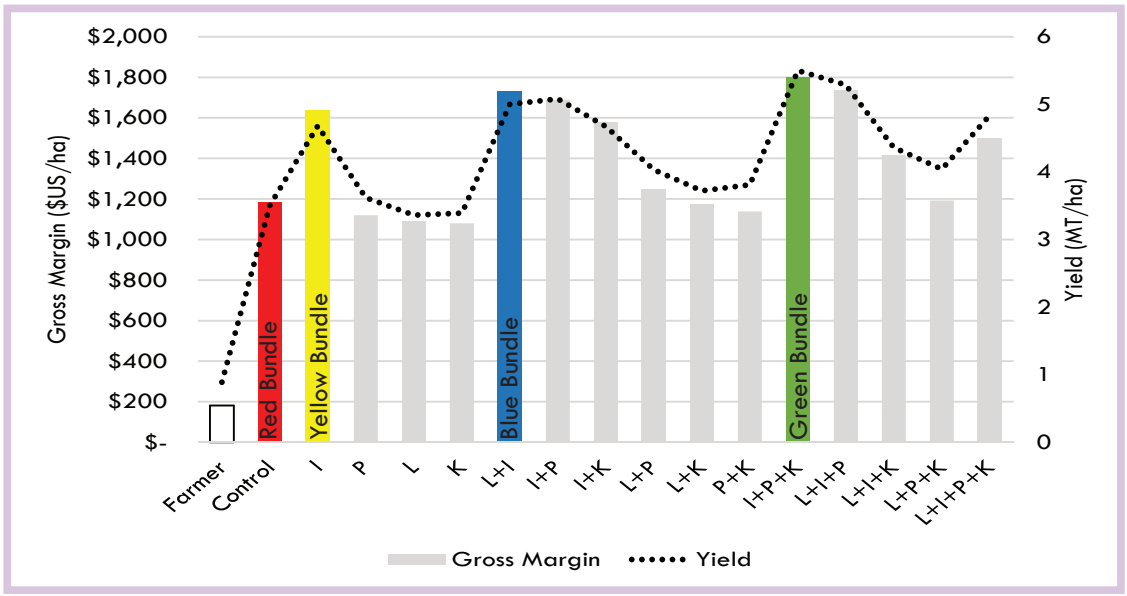
Green Bundle



Best Management Practices
Certified Seed
Rhizobium Inoculum
Phosphorus Fertilizer
Potassium Fertilizer
3x return on additional input costs compared to Red Bundle
Marginal Ratio: 1.52**

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

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



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[1] and yield averages are displayed in **Figure 3.** 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[2]. Under these conditions it is estimated that a typical farmer will generate a gross margin of $182 USD and a yield of 0.89 MT 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 Mpale generated an average gross margin of $1186 USD, a marginal ratio increase of 6.52 compared to typical farming practices and yielded 3.51 MT per hectare. This produces a 22x return on seed costs and provides an implicit wage of $6.86 USD for every $1.00 USD of labor spent (a 786% 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 $1640 USD, a marginal ratio increase of 1.38 compared to the Red Bundle, and yielded 4.68 MT per hectare. This produces a 32x return on inoculant costs and provides an implicit wage of $9.48 USD for every $1.00 USD of labor spent (a 1048% increase in wages compared to the typical farmer).

The **Blue Bundle** includes the use of lime along with rhizobium inoculum, certified soybean seed and the adop-tion of best management practices. The blue bundle generated an average gross margin of $1731 USD, a marginal ratio increase of 1.46 compared to the Red Bundle and yielded 5.00 MT per hectare. This produces an 11x return on rhizobium inoculum and lime costs and provides an implicit wage of $10.00 USD for every $1.00 USD of labor spent (a 1100% increase in wages compared to the typical farmer).

The **Green Bundle** includes the use of phosphorus and potassium fertilizer along with rhizobium inoculum, certified soybean seed and the adoption of best management practices. The green bundle generated an average gross margin of $1800 USD, a marginal ratio increase of 1.52 compared to the Red Bundle and yielded 5.50 MT per hectare. This produces an 3x return on rhizobium inoculum and phosphorus and potassium fertilizer costs and provides an implicit wage of $10.40 USD for every $1.00 USD of labor spent (a 1140% increase in wages compared to the typical farmer). **Based on these observations, the Green Bundle is recom-mended for the Mpale location.**

Treatment	Rank Yield	Yield	V2 Stand Count	R1 Flowering	R1 Height	Nodule Count	Nodule Weight	R8 Height	100 seed Weight
		MT/ha	count	days	cm	nodules	g	cm	g
I (***)	1	1.39	238	82	43	14	0.01	60	19.3
I+P	2	1.34	239	82	49	16	0.01	67	17.8
L+I+P+K	3	1.34	240	83	50	13	0.01	69	18
L+I	4	1.18	240	82	39	18	0.01	59	21
I+K	5	1.10	239	82	42	13	0.02	61	19.3
L+I+P	6	1.09	240	83	45	19	0.01	67	20.3
I+P+K	7	1.04	240	82	49	14	0.01	69	19
L+I+K	8	1.00	240	82	41	14	0.01	62	17.8
K	9	0.97	238	83	38	1	0	51	16
P+K	10	0.86	240	83	40	0	0	56	18
No Input	11	0.83	237	82	36	1	0	52	17.8
P	12	0.79	239	82	42	0	0	55	16.3
L+P	13	0.75	240	82	43	0	0	54	16
L+P+K	14	0.75	238	82	39	0	0	53	23
L	15	0.60	239	83	36	0	0	51	15.8
L+K	16	0.56	239	83	37	0	0	50	14.5
AVG		0.98	239.0	82.2	41.8	7.7	0.0	58.4	18.1
LSD		0.45	2.4	1.3	4.5	6.9	0.0	7.0	4.3
CV%		39.04	0.7	1.1	13.4	112.4	119.6	13.5	20.3

Table 8: Averages, Least Significant Differences (LSD) at an alpha of 0.05, and Coefficient of Variations (CV%) for Yield, Stand Count, R1 Flowering and Height, R3 nodule count and weight, R8 Stand Count, R8 Height, 100 Seed Weight, and Seed Moisture for the 2020 omission trial at Chilanga, Malawi. In the treatment column: I-Inoculum, P-Phosphorus, K-Potassium, L-Lime. P-values for each treatment main-effect or interaction are represented as follows: (.)<0.10, (*)<0.05, (**)<0.01, (***)<0.001.

Chilanga

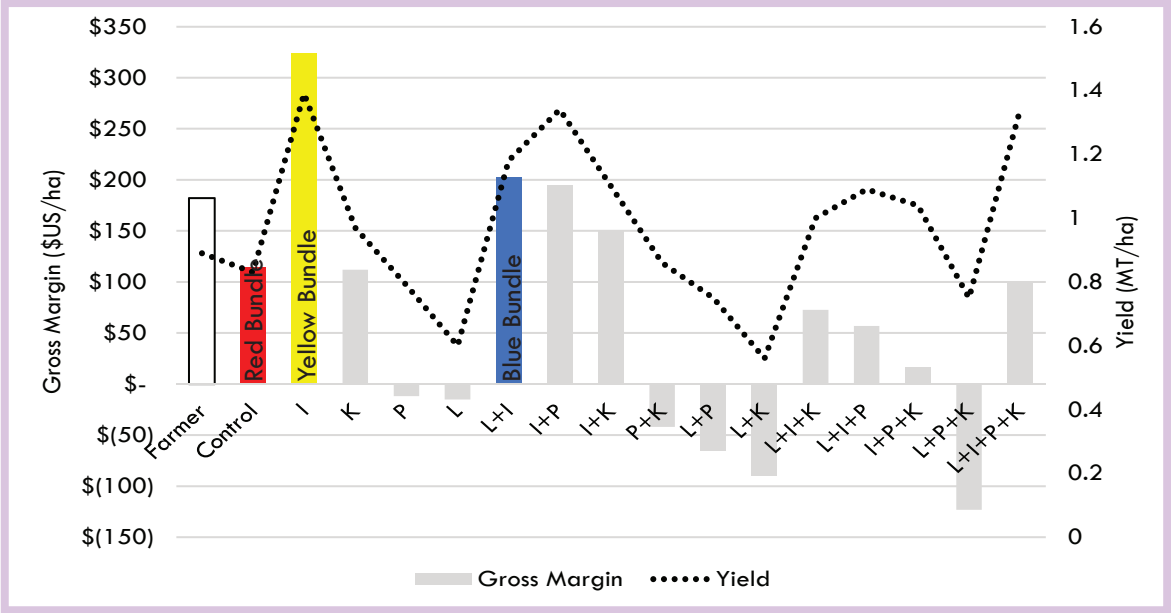
An Analysis of Variance (ANOVA) was conducted in JMP 15.0 using the Fit Model platform to test the main treatment effects, 2-way, 3-way, and 4-way treatment interactions in the omission trial. The Shapiro's Wikle and Brown-Forsythe test were employed to confirm residual normality and homogeneity of variance, respectively. Based on the ANOVA, there was a highly significant ($P < 0.001$) I main effect where applying I increased yields by 55%. **Yields at Chilanga were negatively impacted across treatments by wet conditions during grain/pod maturation and harvest.** While Maple also experienced wet conditions during harvest, Chilanga received an additional 43mm of rainfall during pod maturity. Using days to R1 flowering as a measure, the Chilanga location was about 14 days behind Mpale in terms of soybean reproductive development. This combination of slower development and heavier rains likely contributed heavily to Chilanga's poor harvest.

There were significant main effects and/or interactions for R1 and R8 plant heights, nodule count and weight, and 100 seed weight. For R1 plant heights, there were significant I and P main effects as well as a I*P*K interaction where I+P and I+P+K treatments had significantly taller plant heights than any other treatment. For R8 plant heights, there were significant I and P main effects where treatments with either I or P were significantly taller than treatments without either input. For nodule count and weight there was a highly significant I main effect where treatments with inoculum had higher nodule counts and nodule weights than treatments without the input. For 100 seed weight, there was a significant I main effect as well as significant P*K and L*I*K interactions where P+K had significantly higher seed weights than K alone and L+I had significantly higher seed weights than other treatments.

Mean yields ranged from 0.56 (L+K) to 1.39 (I) MT/ha. V2 stand counts ranged from 237 (No Input) to 240 for several treatments. R1 flowering ranged from 82 to 83 days after planting. Plant heights ranged from 36 cm (No Input, L) to 50 cm (L+I+P+K) and 50 cm (L+K) to 69 cm (L+I+P+K, I+P+K) at R1 and R8, respectively. Nodule count ranged from 0 to 1 for all treatments that did not include I to 19 (L+I+P) nodules/plant and nodule weight ranged from less than 0.1 to 0.2 grams/plant. 100 seed weight ranged from 14.5 g (L+K) to 23 g (L+P).

For further information on the 2020 trial at Chilanga, Malawi, contact the trial operator Yaona Mtonga, at ymtonga@pyxus.com

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 2020 SMART Farm omission trial has assessed the usage of these inputs and has assembled a single input bundle for the Chilanga 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[1] and yield averages are displayed in **Figure 4**. The "Farmer" treatment represents typical soybean farming practices in Malawi. 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 0.82 MT 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 Chilanga generated an average gross margin of $114 USD and yielded 0.83MT per hectare. Due to the wet growing conditions and the resulting yield losses experienced at the Chilanga site, economic returns cannot be accurately represented across input treatments.

The **Yellow Bundle** represents a step up from the Red Bundle with the inclusion of rhizobium inoculum. Despite the yield losses across treatments, the inclusion of inoculum still results in a significant increase in soybean yields within the trial. Even with a wet harvest, the Yellow Bundle generated an average gross margin of $324 USD, a marginal ratio increase of 2.84 compared to the Red Bundle and yielded 1.39 MT per hectare. This produces a 15x return on inoculum costs and provides an implicit wage of $1.87 USD for every $1.00 USD of labor spent (a 287% increase in wages compared to the typical farmer).

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	$44.40	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
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)