PHOTOASSIMILATE SUPPLY DURING SEED FILLING LIMITS BEAN YIELD AND MINERAL COMPOSITION OF COMMON BEANS

Gerald Sebuwufu, and MarkWestgate *

Iowa State University, Department of Agronomy, 2104 Agronomy Hall, Ames, IA 50011-1050

Summary

Common bean (*Phaseolus vulgaris* L.) is a primary source of dietary protein and minerals in sub-Saharan Africa. Results of several studies suggest lack of photoassimilate supply might limit accumulation of these nutritional seed components. This study examined the relationship between assimilate supply per seed and seed yield, yield components, and seed composition of three common bean varieties adapted to sub-Saharan Africa. Incident radiation to the canopy was decreased by 48.5% from the beginning of seed filling to physiological maturity. Seed yield varied from 1.0 to 4.2 Mg/ha across environments and varieties. Shading decreased yield 0 to 44% with greatest variability at low yields. Yield loss was due predominately to decreased seed number/m^2. Harvest Index and Pod Harvest Index were fairly stable. Shading had a consistent positive impact on seed protein concentration, variable effects on seed oil, starch concentrations, and mineral concentrations. Seed Zn and Fe concentrations were not related to soil levels; but Variety and Shade effects were significant in two of three seasons.

Conclusions

- Common beans adjust pod load as well as seed composition in response to a decrease in assimilate supply per seed. As in other legumes, seed protein concentration is negatively related to seed oil and starch concentrations.
- Variety x Treatment interactions for seed Fe and Zn concentrations were not related to soil levels of these minerals. Shading tended to have a greater impact in the high yield environments.
- A positive correlation between seed protein (or N) and Fe and Zn concentrations suggests a common mechanism involving assimilate transport to the seeds.

Results

Bean yields of unshaded plants varied from 1017 to 4190 kg/ha across varieties and seasons (TABLE 1). Yields at the Horticulture farm in 2011 and 2012 were 2-3 times greater than 2010. This improvement reflected the better soil conditions (TABLE 2), lack of heavy rainfall events (FIGURE 2), and lack of residual herbicides in the soil (not shown). Shading decreased yields up to 40%, with the greatest variability at the low yielding site. At the high yield site, 50% shade during seed filling decreased yield ~30%, on average, compared to the unshaded controls. Treatment effects on yield were associated predominately with variation in seed number/m^2 Shading consistently increased seed protein concentration, but had variable effects on seed oil, starch, and mineral concentrations (TABLE 3 and TABLE 5). There was no correspondence between soil Fe and Zn levels and the final concentration of Fe and Zn in the seed. Variation in seed Fe and Zn concentrations, however, were closely correlated to seed protein concentration (TABLE 4).

TABLE 1: Grain yield and yield component data for three common bean varieties grown under full sun or under 50% shade cloth during seed filling. Data are the mean of three replicate plots. Pod Harvest Index is the ratio of seed wt to total pod weight. Values in red indicate significant differences between Control and Shade treatments at P ≤ 0.1.

Variety	Treat-ment	Yield (kg/ha)			Seeds number (#/m²)			Seed weight (g/100 seed)			Harvest Index (%plant DW)			Pod Harvest Index (%podDW)		
		2010	2011	2012	2010	2011	2012	2010	2011	2012	2010	2011	2012	2010	2011	2012
K131	Control	1017	3427	3551	724	2260	1680	14.1	15.2	21.2	31.1	48.0	41.0	79.8	73.6	78.0
K131	Shade	1180	2093	2351	878	1332	1049	13.4	15.8	22.3	35.7	35.9	35.2	81.6	73.7	80.0
NABE2	Control	2041	2225	4099	1274	1486	1900	16.1	15.0	21.6	36.9	39.5	44.7	76.0	80.2	78.6
NABE2	Shade	1140	1846	2569	736	1299	1210	15.5	14.2	21.2	36.7	47.0	43.2	79.2	78.9	78.9
NABE6	Control	1583	2439	4190	1085	1740	1975	14.6	14.0	21.2	38.3	44.2	45.3	75.0	75.6	74.9
NABE6	shade	1264	2089	2800	835	1607	1273	15.3	13.0	22.0	38.1	44.3	41.6	77.8	76.6	74.2

TABLE 2: Chemical analysis for the soils at the three experimental sites. The soil type at the Johnson Farm site was a Nicollet loam while the Horticulture Farm site was a Clarion loam.

Farm	Year	pH	P	K	Na	Mg	Ca	Mn	Cu	Fe	Zn
						(mg/kg)					
Johnson	2010	5.8	13	141	23	247	1813	57	1.5	258	0.8
Horticulture	2011	5.5	19	2068	20180	6306	40680	546	25	3202	65
Horticulture	2012	5.7	16	2222	20160	6970	44500	665	25	2782	66

TABLE 3: Chemical analysis of the seeds harvested from K131, NABE4, and NABE6 common bean varieties growth under full sun or 50% shade cloth during seed filling. Values in red indicate significant differences between Control and Shade treatments at P ≤ 0.1.

Variety	Treatment	P	K	Na	Mg	Ca	Mn	Cu	Fe	Zn
					(mg/kg)					
2010										
K131	Control	4989	18627	18.5	2179	1155	25.3	29.4	69.8	81.9
	Shade	4817	19687	14.3	1895	891	24.2	28.9	66.9	74.1
NABE2	Control	4761	13240	13.4	1861	1371	23.5	28.0	70.2	73.7
	Shade	4532	11404	11.3	1815	1878	24.9	28.0	68.6	75.0
NABE6	Control	5210	13400	12.9	2215	1856	26.1	29.2	85.7	89.7
	Shade	4735	12400	12.4	2207	1721	26.9	28.9	85.9	68.9
2011										
K131	Control	4485	12113	33.1	1985	1369	16.8	5.0	30.3	54.5
	Shade	4417	11880	38.1	1950	1067	15.7	3.8	22.8	58.7
NABE2	Control	5173	12073	34.7	1878	1003	16.5	2.3	20.8	61.1
	Shade	5276	10186	33.1	2115	1059	15.3	4.1	29.2	80.6
NABE6	Control	5251	13953	34.2	2104	2067	13.4	1.8	22.0	52.0
	Shade	5399	13693	31.3	2191	1486	12.7	2.6	34.6	57.1
2012										
K131	Control	5697	13740	34.1	1905	1309	13.2	5.2	42.1	64.3
	Shade	6245	13813	32.7	1967	1058	13.7	8.3	61.3	76.7
NABE2	Control	5370	13867	39.3	2093	1716	14.9	3.7	31.9	56.0
	Shade	5109	13493	35.2	1920	1319	14.6	5.9	40.8	59.6
NABE6	Control	6357	15060	31.7	2149	1418	13.5	7.1	45.2	67.7
	Shade	6275	14340	35.2	1959	1130	13.2	9.1	42.7	76.5

This project was supported by a grant from

PULSE CRSP Dry Grain Pulses Collaborative Research Support Program MICHIGAN STATE UNIVERSITY

FIGURE 1: Field plots showing 50% shade cloth over plants during seed filling.

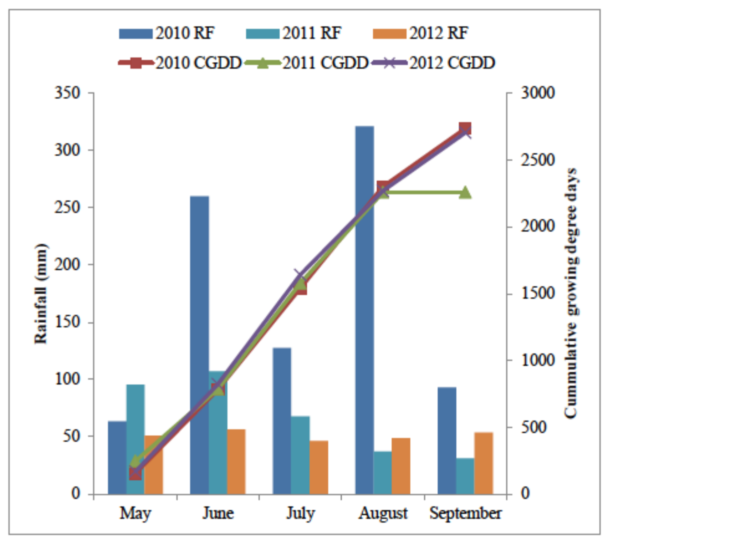

FIGURE 2: Rainfall and cumulative growing degree days (GDD) during the three growing seasons (1 May to 30 September)

TABLE 4: Pearson correlations between seed yield, protein, oil, starch and Fe and Zn concentrations. Above diagonal: correlations for control plants; below diagonal: correlations for shaded plants. *, **, ***: significant at p ≤ 0.05, p ≤ 0.01, and p ≤ 0.001, respectively.

	(kg/ha)	--------------- (%) DW -------------			------- (mg/kg) ------	
	Yield	Protein	Oil	Starch	Fe	Zn
Yield		-0.21	0.42	-0.16	-0.56	-0.63
Protein	-0.38		-0.76**	-0.68**	0.81**	0.80**
Oil	0.33	-0.70**		0.70	-0.56	-0.57
Starch	0.40	-0.91***	0.87**		-0.21	-0.21
Fe	-0.61	0.90	-0.66*	-0.88**		0.95***
Zn	-0.21	0.38	-0.51	-0.31	0.35	

TABLE 5: Response of seed protein, oil, and starch concentration in three Ugandan common bean varieties grown under full sun or under 50% shade cloth during seed filling. Data are the mean of samples collected from three replicate plots, and are presented at 13% (w/w) moisture. Values in red indicate significant differences between Control and Shade treatments at P ≤ 0.1.

		2010			2011			2012		
					%					
Variety	Shade	Protein	Oil	Starch	Protein	Oil	Starch	Protein	Oil	Starch
K131	Control	27.5	1.72	35.4	18.1	2.52	41.9	26.9	1.58	33.5
	Shade	30.6	1.64	31.6	20.0	2.49	40.8	27.5	1.59	33.0
NABE2	Control	26.9	1.63	34.1	20.0	1.99	37.3	23.1	1.95	35.5
	Shade	30.0	1.60	33.0	21.3	1.73	36.8	25.0	1.86	34.9
NABE6	Control	28.1	1.70	38.8	20.0	1.77	38.1	27.5	1.85	33.7
	Shade	32.5	1.53	28.9	24.4	1.56	33.8	30.0	1.68	33.5

Methods

The experiments were carried out at Iowa State University's Johnson Farm in 2010 and at the Horticulture farm in 2011 and 2012 located near Ames, Iowa (42°02'05"N 93°37'12"W).. Analyses indicated the Johnson Farm soils were much lower in macro and micronutrients compared to the soils at the Horticulture Farm (TABLE 2).

Three common bean varieties, K131, NABE2 and NABE6, improved varieties grown in Uganda, were used in the study. These varieties are small seeded and with a Type II growth habit characterized by indeterminate terminal growth, small to medium guide development, and low to moderate climbing. Seeds were coated with peat-based BioStacked® inoculant before planting planted at 20 plants m^{-2} in 76-cm rows. Plot size was 6 m x 3 m (FIGURE 1). The experiment was laid out in a randomized complete block design with three replicates. In 2010, 59 kg/ha of nitrogen were applied as dry urea before planting; no supplemental fertilizer was applied in 2011 or 2012. In 2010, weeds were controlled with Pursuit TM (imazethapyr-ammonium) and Select Max TM herbicides (dimethenamid-P and atrazine) plus hand hoeing. In 2011 and 2012, weeds were controlled by hoeing and mulching with corn stover before flowering. In 2011 and 2012, natural rainfall was supplemented with irrigation. Selected plots were covered at the start of seed filling until physiological maturity with 50% black shade netting (EasyShade) deployed 1 m above the plants. The shade netting reduced photosynthetically active radiation (PAR) reaching the canopy by an average of 48.5% as determined by measuring PAR above and below the shade on a clear day at noon using an ACCUPAR LP-80 PAR sensor (Decagon Devices).

At physiological maturity, plants from 1 m^2 were harvested from the inner rows of each treatment plot to quantify bean yield (kg/ha), number of pods per plant, seeds per pod, 100-seed weight (g), pod harvest index (PHI %) = (seed weight/pod wall + seed weight)x100, and Harvest Index (HI %) = (seed weight/total biomass at harvest)x100. Samples were dried at 60°C for 72 h and weighed. Seed composition was determined using seeds sampled from a uniform set of pods tagged at the start of seed filling. Seeds for mineral analysis were washed with double distilled water, dried and ground with a 30-mesh sieve with a steel mill. Seed mineral concentration was determined ICP spectroscopy. Seed nitrogen was determined by combustion. Seed oil was determined gravimetrically by hexane extraction. Total starch was determined enzymatically using a total starch kit (Megazyme International) following AOAC Method 996.11/ AACC Method 76.13. Total protein, starch and oil concentration and content are reported at 130 g/kg (13 %) moisture basis.