

Macro and Micro-Nutrient Accumulation and Partitioning in Soybean Affected by Water and Nitrogen Supply

Ingrid Silva Setubal ¹, Aderson Soares de Andrade Júnior ², Silvestre Paulino da Silva ¹, Artenisa Cerqueira Rodrigues ¹, Aurenívia Bonifácio ³, Evandro Henrique Figueiredo Moura da Silva ⁴, Paulo Fernando de Melo Jorge Vieira ², Rafael de Souza Miranda ^{5,*}, Nicolas Cafaro La Menza ⁶ and Henrique Antunes de Souza ²

¹ Postgraduate Program in Agronomy, Agricultural Science Center, Federal University of Piauí, Teresina 64048-550, Brazil;

ingrid.s.setubal@gmail.com (I.S.S.); silvestre.mapito@gmail.com (S.P.d.S.); artenisacerqueira@ufpi.edu.br (A.C.R.)

² Embrapa Mid North, Brazilian Agricultural Research Corporation, Teresina 64008-780, Brazil; aderson.andrade@embrapa.br (A.S.d.A.J.); paulofernando.vieira@embrapa.br (P.F.d.M.J.V.)

³ Department of Biology, Center of Nature Science, Federal University of Piauí, Teresina 64600-000, Brazil; aurenivia@ufpi.edu.br

⁴ Luiz de Queiroz College of Agriculture, University of São Paulo, Piracicaba 13418-900, Brazil; ehfmsilva@gmail.com

⁵ Campus Profa. Cinobelina Elvas, Federal University of Piauí, Bom Jesus 64900-000, Brazil

⁶ West Central Research, Extension and Education Center, University of Nebraska-Lincoln, Lincoln, NE 68588, USA; ncafarolamenza2@unl.edu

* Correspondence: rsmiranda@ufpi.edu.br

Table S1. Partitioned dry biomass accumulation (kg ha⁻¹) of soybean plants under different water regimes and with and without nitrogen supplementation.

Leaf dry biomass				
Full Irrigation			Deficit irrigation	
DAE	With N	Without N	With N	Without N
16	94.1 aA ¹	143.9 aA	130.5 aA	80.1 aA
23	291.6 aA	203.8 aA	292.4 aA	341.8 aA
30	1041.3 aA	844.0 bA	948.0 aB	860.0 aA
37	1186.0 aA	962.0 bA	1044.0 aA	698.0 bB
44	1332.7 aA	1536.0 aA	1384.0 aA	1002.0 bB
58	1671.3 aA	1730.0 aA	1237.3 aB	1226.0 aB
65	2316.0 aA	1403.3 bA	1000.0 aB	970.0 aB
79	1742.0 aA	1222.7 bA	982.0 aB	608.0 bB
86	604.0 aA	444.0 aA	688.0 aA	330.0 bA
Stem dry biomass				
16	39.0 aA	51.9 aA	41.3 aA	34.8 aA
23	133.0 aA	142.8 aA	174.2 aA	134.4 aA
30	388.0 aA	334.6 aA	289.3 aA	322.7 aA
37	826.0 aB	1006.0 aA	1222.0 aA	322.7 aA
44	1714.0 aA	1438.0 bA	1578. aA	614.0 bB
58	3094.0 aA	3126.0 aA	1546.0 aB	1148.0 bB
65	3160.0 aA	1549.3 bA	1370.0 aB	2268.0 bB
79	2670.7 aA	1841.3 bA	1726.0 aB	1130.7 aB
86	2490.0 bA	2894.0 aA	1330.0 aB	1042 aB
Reproductive structures dry biomass				
37	112.6 aA	70.3 bB	123.6 aA	107.1 aA
44	340.2 aA	278.6 aA	134.4 aB	117.5 aB
58	992.0 aA	1240.0 aA	558.0 aB	458.0 aB
65	880.0 aA	1088.0 aA	336.0 aB	569.3 aB
79	1794.0 aA	1668.0 aA	1106.0 aB	930.0 aB
86	1850.0 aA	1836.0 aA	1354.0 aB	1080.0 bB
Seed dry biomass				
58	346.6 aA	257.3 aA	284.0 aA	356.0 aA
65	1340.0 bA	2002.0 aA	518.0 aB	670.0 aB
79	4901.3 aA	4274.0 aA	2514.7 aB	1476.0 aB
86	6070.0 aA	5392.0 aA	2110.0 aB	2352.0 aB

¹Same lowercase letters indicate that there was no significant difference concerning nitrogen fertilization (with and without nitrogen). Same uppercase letters indicate that there was no difference concerning the application of different water regimes (full and deficient WR) (t test at 5 % probability).

Table S2. Estimation of the model parameters fitted for the accumulation of dry matter, N, P, K, Ca, Mg, S and the respective inflection point (IP) and coefficient of determination (R^2) of soybean plants under different water regimes with and without nitrogen supplementation.

	Full irrigation					Deficit irrigation					Model
	a ⁽²⁾	b ⁽³⁾	x ₀ ⁽⁴⁾	IP	R ²	a ⁽²⁾	b ⁽³⁾	x ₀ ⁽⁴⁾	IP	R ²	
	kg ha ⁻¹	----- DAE -----				kg ha ⁻¹	----- DAE -----				
Dy matter											
Leaves											
With N	2045.34**	21**	60**	40	0.84	1340.38**	22**	54**	32	0.83	Gaussian
Without N	1730.46**	20**	57**	37	0.91	1176.71**	21**	54**	33	0.89	Gaussian
Stem											
With N	3339.88**	20**	68**	48	0.98	1733.23**	26**	66**	40	0.81	Gaussian
Without N	3900.35**	19**	71**	52	0.81	2247.39**	16**	62**	46	0.95	Gaussian
Reproductive structure											
With N	1856.80**	21**	81*	60	0.99	1350.58*	20*	86*	66	0.97	Lorentzian
Without N	1782.22*	22*	83*	60	0.93	1066.22*	19*	85**	66	0.98	Lorentzian
Seeds											
With N	6435.94*	9 ^{ns}	85*	76	0.98	2925.76*	11 ^{ns}	85*	74	0.99	Gaussian
Without N	5399.08 ^{ns}	12 ^{ns}	85*	73	0.95	1518.83*	14**	83**	69	0.99	Gaussian
Total											
With N	11548.42**	21**	80**	59	0.98	6456.52**	27**	80**	53	0.94	Lorentzian
Without N	10152.37**	25**	84**	59	0.94	4501.36**	29*	79**	50	0.93	Lorentzian
Nitrogen											
Leaves											
With N	79.21**	20**	55**	35	0.85	54.55**	21**	50**	29	0.84	Gaussian
Without N	66.34**	18**	54**	36	0.97	42.14**	20**	51**	31	0.95	Gaussian
Stem											
With N	58.59**	15**	62**	46	0.99	40.70**	19**	60**	42	0.83	Gaussian
Without N	41.22**	16**	60**	44	0.93	20.22**	16**	56**	40	0.88	Gaussian
Reproductive structure											
With N	28.22**	11 ^{ns}	53*	42	0.87	19.11 ^{ns}	19 ^{ns}	74*	55	0.83	Gaussian
Without N	21.11**	17*	62*	45	0.83	8.12**	27 ^{ns}	66**	39	0.98	Gaussian
Seeds											
With N	364.08*	8**	84**	76	0.98	129.19**	10 ^{ns}	83*	73	0.99	Lorentzian
Without N	276.32 ^{ns}	11 ^{ns}	84**	73	0.97	71.42**	13**	83**	70	0.99	Lorentzian
Total											
With N	380.54**	22**	85**	63	0.98	214.71**	22**	70**	48	0.99	Lorentzian
Without N	313.57**	21**	82**	61	0.98	133.11**	33**	85**	52	0.92	Lorentzian
Phosphorus											
Leaves											
With N	6.24**	17**	52**	35	0.90	4.92**	13**	46**	33	0.87	Gaussian
Without N	5.03**	16**	50**	34	0.90	3.52**	15**	47**	32	0.93	Gaussian
Stem											
With N	5.74**	15**	60**	45	0.98	3.91**	17**	58**	41	0.89	Gaussian
Without N	5.08**	17**	57**	40	0.94	4.57**	12**	55**	44	0.97	Gaussian
Reproductive structure											
With N	2.19**	15**	66**	51	0.87	1.41**	11*	52**	41	0.90	Gaussian
Without N	2.89*	15**	60**	45	0.84	1.05*	14*	65**	51	0.85	Gaussian

	Full irrigation					Deficit irrigation					Model
	a ⁽²⁾	b ⁽³⁾	x ₀ ⁽⁴⁾	IP	R ²	a ⁽²⁾	b ⁽³⁾	x ₀ ⁽⁴⁾	IP	R ²	
	kg ha ⁻¹	----- DAE -----				kg ha ⁻¹	----- DAE -----				
Seeds											
With N	15.55**	10**	80**	70	0.99	9.98**	9*	74**	65	0.88	Gaussian
Without N	18.60**	9**	78**	69	0.99	7.06**	9**	77**	68	0.99	Gaussian
Total											
With N	19.37**	25*	75**	50	0.95	12.23**	22**	67**	45	0.87	Gaussian
Without N	19.46**	25**	75**	50	0.92	9.42**	23**	66**	43	0.94	Gaussian
Potassium											
Leaves											
With N	28.63**	20**	55**	35	0.93	23.96**	20**	51**	31	0.82	Gaussian
Without N	26.45**	19**	54**	35	0.80	20.09**	19**	51**	32	0.90	Gaussian
Stem											
With N	50.08**	18**	59**	41	0.93	36.43**	19**	55**	36	0.80	Gaussian
Without N	54.26*	18**	56**	38	0.72	37.98**	15**	56**	41	0.85	Gaussian
Reproductive structure											
With N	25.83**	29*	91**	59	0.98	31.02 ^{ns}	12 ^{ns}	83*	71	0.99	Gaussian
Without N	23.22*	21 ^{ns}	78*	57	0.98	13.37**	18*	71**	53	0.89	Gaussian
Seeds											
With N	73.94**	10*	82**	72	0.98	77.65**	30**	72*	42	0.86	Lorentzian
Without N	59.62 ^{ns}	12 ^{ns}	82*	70	0.97	25.56**	16**	85**	69	0.99	Lorentzian
Total											
With N	143.12**	31**	84**	53	0.96	77.65**	30*	72**	42	0.86	Gaussian
Without N	136.49**	29*	79**	50	0.91	72.74**	22**	64**	42	0.89	Gaussian
Calcium											
Leaves											
With N	45.28**	30**	81**	51	0.96	19.74**	27**	63**	36	0.84	Gaussian
Without N	26.24**	21**	61**	40	0.94	16.97**	24*	58**	34	0.81	Gaussian
Stem											
With N	47.52**	8**	71**	63	0.82	11.05**	20**	62**	42	0.84	Gaussian
Without N	18.82**	22**	64**	42	0.80	10.40**	19**	58**	39	0.95	Gaussian
Reproductive structure											
With N	9.52*	22*	79*	57	0.96	7.98**	16 ^{ns}	83**	67	0.92	Gaussian
Without N	9.71*	20*	73**	53	0.82	5.65**	23*	79**	56	0.93	Gaussian
Seeds											
With N	17.73**	11**	82**	71	0.99	6.68**	13 ^{ns}	86**	73	0.82	Gaussian
Without N	15.77 ^{ns}	16 ^{ns}	85*	69	0.92	3.90**	19*	80**	61	0.99	Gaussian
Total											
With N	91.92**	20**	71**	51	0.90	41.56**	27*	68*	41	0.86	Gaussian
Without N	62.05*	23**	69**	46	0.97	33.93**	26**	67**	41	0.96	Gaussian
Magnesium											
Leaves											
With N	13.72**	20**	59**	39	0.92	7.95**	21**	54**	33	0.92	Gaussian
Without N	11.40**	16**	51**	35	0.89	6.06**	21**	49**	28	0.78	Gaussian
Stem											
With N	12.04**	22**	69**	47	0.87	7.66**	22**	61**	39	0.84	Gaussian
Without N	6.20**	12**	46**	34	0.90	9.35**	17**	61**	44	0.97	Gaussian

	Full irrigation					Deficit irrigation					Model
	a ⁽²⁾	b ⁽³⁾	x ₀ ⁽⁴⁾	IP	R ²	a ⁽²⁾	b ⁽³⁾	x ₀ ⁽⁴⁾	IP	R ²	
	kg ha ⁻¹	----- DAE -----				kg ha ⁻¹	----- DAE -----				
Reproductive structure											
With N	27.53**	10**	81**	71	0.96	15.78**	8**	80**	72	0.95	Gaussian
Without N	30.42**	5*	74**	69	0.80	6.27**	18**	82**	8	0.95	Gaussian
Seeds											
With N	20.09**	8**	79**	71	0.99	5.52**	11**	83**	72	0.97	Gaussian
Without N	22.84**	8*	79**	71	0.99	4.27**	14**	83**	69	0.98	Gaussian
Total											
With N	58.24**	26**	85**	60	0.93	41.47**	21**	69**	48	0.99	Gaussian
Without N	39.85**	30 ^{ns}	86*	56	0.88	22.36**	25*	69**	44	0.98	Gaussian
Sulphur											
Leaves											
With N	4.21**	14**	64**	50	0.92	1.89**	25**	58**	33	0.80	Gaussian
Without N	3.25**	18**	61**	43	0.83	2.03**	17**	54**	37	0.87	Gaussian
Stem											
With N	4.13**	18**	67**	49	0.95	3.65**	14**	58**	44	0.93	Gaussian
Without N	2.71**	20**	65**	45	0.94	2.18*	16**	54**	38	0.88	Gaussian
Reproductive structure											
With N	1.08**	16**	63**	47	0.92	0.76**	13**	62**	49	0.97	Gaussian
Without N	1.39**	14**	62**	48	0.94	0.39**	18**	62**	44	0.91	Gaussian
Seeds											
With N	5.59*	8*	77**	69	0.99	3.29**	8 ^{ns}	78**	70	0.98	Gaussian
Without N	3.27 ^{ns}	13 ^{ns}	79*	66	0.87	2.20 ^{ns}	12 ^{ns}	79*	67	0.90	Gaussian
Total											
With N	11.55**	19**	70**	51	0.89	5.98**	24**	68**	44	0.91	Gaussian
Without N	9.28**	19**	68**	49	0.97	5.10**	21**	63**	42	0.92	Gaussian

(2) Value of maximum dry matter accumulation. (3) Amplitude in the value of x in DAE between the inflection point and the maximum point. (4) Days after emergence (DAE) that provided the maximum accumulation. **, *, and ns: significant at 1 %, 5 %, and not significant by the t test, respectively.

Table S3. Estimation of the model parameters fitted for the accumulation of Cu, Fe, Mn, Zn, B, and the respective inflection point (IP) and coefficient of determination (R^2) of soybean plants under different water regimes with and without nitrogen supplementation.

Full irrigation						Deficit irrigation					Model
a ⁽²⁾	b ⁽³⁾	x ₀ ⁽⁴⁾	IP	R ²	a ⁽²⁾	b ⁽³⁾	x ₀ ⁽⁴⁾	ID	R ²		
g ha ⁻¹	----- DAE -----				g ha ⁻¹	----- DAE -----					
Copper											
Leaves											
With N	29,92**	16**	56**	40	0,88	19,37**	15**	52**	37	0,84	Gaussian
Without N	23,55**	16**	57**	41	0,90	22,44**	18**	43**	25	0,79	Gaussian
Stem											
With N	25,39**	17**	59**	42	0,80	24,11**	4**	39**	35	0,84	Gaussian
Without N	47,31*	8**	53**	45	0,86	14,21**	15**	57**	42	0,77	Gaussian
Reproductive structure											
With N	15,04*	14*	60**	46	0,74	7,55**	19**	62**	43	0,96	Gaussian
Without N	9,21**	16**	68**	52	0,94	7,55**	19**	62**	43	0,96	Gaussian
Seeds											
With N	45,03**	10**	84**	74	0,99	29,95**	7**	78**	71	0,99	Gaussian
Without N	45,79*	12 ^{ns}	84*	72	0,98	29,95**	7**	78**	71	0,99	Gaussian
Total											
With N	77,16**	23**	70**	47	0,89	30,65**	31*	70**	39	0,85	Gaussian
Without N	78,78**	21*	69**	48	0,87	30,65**	31*	70**	39	0,85	Gaussian
Iron											
Leaves											
With N	369,60**	18**	59**	41	0,91	218,31**	25**	59**	34	0,86	Gaussian
Without N	249,04**	20**	58**	38	0,92	149,03**	22**	56**	34	0,91	Gaussian
Stem											
With N	123,79**	16**	68**	52	0,97	144,31**	21**	73**	52	0,91	Gaussian
Without N	83,73**	27**	71**	44	0,92	240,70*	6*	52**	46	0,85	Gaussian
Reproductive structure											
With N	69,35**	8**	51**	43	0,91	35,66**	21**	83**	62	0,98	Lorentzian
Without N	115,56**	15*	75**	60	0,74	56,88**	19*	84**	65	0,94	Lorentzian
Seeds											
With N	486,66**	8**	80**	72	0,99	181,85*	7*	77**	70	0,89	Lorentzian
Without N	231,93*	11 ^{ns}	82**	71	0,98	61,40**	16*	82*	66	0,99	Lorentzian
Total											
With N	734,20**	25*	77**	52	0,91	441,47**	31 ^{ns}	79**	48	0,85	Lorentzian
Without N	577,39**	27**	78**	51	0,99	296,45**	27*	64**	37	0,88	Lorentzian
Manganese											
Leaves											
With N	286,66**	20*	59**	39	0,88	179,24**	18**	54**	36	0,87	Gaussian
Without N	217,69**	12**	46**	34	0,95	86,01**	19**	51**	32	0,82	Gaussian
Stem											
With N	92,28*	16**	68**	52	0,84	34,66**	23**	60**	37	0,87	Gaussian
Without N	85,54**	15**	65**	50	0,99	33,25*	16*	59*	43	0,77	Gaussian
Reproductive structure											
With N	32,25**	14**	63**	49	0,85	31,63**	16**	71**	55	0,87	Gaussian
Without N	31,67*	7*	55**	48	0,84	10,17**	20**	72*	52	0,84	Gaussian

Full irrigation						Deficit irrigation					Model
a ⁽²⁾	b ⁽³⁾	x ₀ ⁽⁴⁾	IP	R ²	a ⁽²⁾	b ⁽³⁾	x ₀ ⁽⁴⁾	ID	R ²		
g ha ⁻¹	----- DAE -----				g ha ⁻¹	----- DAE -----					
Seeds											
With N	60,17*	14*	79**	65	0,91	41,61**	9 ^{ns}	78*	69	0,99	Gaussian
Without N	59,57 ^{ns}	12 ^{ns}	78*	66	0,82	18,71 ^{ns}	18 ^{ns}	79*	61	0,85	Lorentzian
Total											
With N	437,62**	21*	64**	43,0	0,89	230,05**	22**	60**	38,0	0,84	Gaussian
Without N	308,53**	20**	60**	40,0	0,93	130,70*	24*	58**	34,0	0,87	Lorentzian
Zinc											
Leaves											
With N	111,38**	16**	54**	38	0,91	57,61**	21**	49**	28	0,86	Gaussian
Without N	54,65**	8**	50**	42	0,87	53,19**	18**	49**	31	0,94	Gaussian
Stem											
With N	44,16**	15**	57**	42	0,92	46,94**	16**	59**	43	0,89	Gaussian
Without N	21,05**	18**	63**	45	0,92	23,05**	16**	54**	38	0,95	Gaussian
Reproductive structure											
With N	40,29**	8**	54**	46	0,91	28,25*	12*	61*	49	0,87	Gaussian
Without N	21,05**	18**	63**	45	0,92	11,86*	20*	67*	67	0,95	Gaussian
Seeds											
With N	155,42**	13*	79**	66	0,89	106,59 ^{ns}	8 ^{ns}	79*	71	0,97	Gaussian
Without N	147,90 ^{ns}	13 ^{ns}	79*	66	0,91	20,57 ^{ns}	12 ^{ns}	76*	64	0,84	Gaussian
Total											
With N	245,12**	24**	67**	43	0,95	131,10**	31**	75**	44	0,86	Gaussian
Without N	216,34**	18**	57**	39	0,81	85,18**	21**	57**	36	0,95	Gaussian
Boron											
Leaves											
With N	42,40**	23**	56**	33	0,92	53,41**	15**	45**	30	0,83	Lorentziano
Without N	38,85*	21**	45**	24	0,85	36,72**	17**	50**	33	0,92	Lorentziano
Stem											
With N	50,24**	17**	65**	48	0,91	29,13**	12**	49**	37	0,83	Lorentziano
Without N	42,85*	10 ^{ns}	52**	42	0,76	33,89**	15**	63**	48	0,95	Lorentziano
Reproductive structure											
With N	57,45**	9**	74**	65	0,89	26,42**	27**	89**	62	0,96	Gaussian
Without N	55,72**	12*	71**	59	0,97	34,09**	11**	73**	62	0,89	Gaussian
Seeds											
With N	97,39*	10**	82*	72	0,99	27,51**	9**	80**	71	0,93	Gaussian
Without N	76,01**	11*	82**	71	0,99	34,79**	9**	79**	70	0,94	Gaussian
Total											
With N	198,02**	18**	78**	60	0,94	114,99**	26**	68**	42	0,82	Gaussian
Without N	160,53**	27*	82**	55	0,86	108,12**	21**	69**	48	0,93	Gaussian

(2) Value of maximum dry matter accumulation. (3) Amplitude in the value of x in DAE between the inflection point and the maximum point. (4) Days after emergence (DAE) that provided the maximum accumulation. **, *, and ns: significant at 1 %, 5 %, and not significant by the t test, respectively.

Table S4. Total accumulation and accumulation in the grain of dry biomass (DM), macronutrients, micronutrients, and corresponding harvest indexes (HI) in soybeans under full irrigation with N (FIWN), full irrigation without N (FINN), deficit irrigation with N (DIWN), and deficit irrigation without N (DINN).

	Total accumulation				Accumulation in the grain				Harvest index (HI)			
	FIWN	FINN	DIWN	DINN	FIWN	FINN	DIWN	DINN	FIWN	FINN	DIWN	DINN
					kg ha ⁻¹				%			
DM	11.014	10.566	5482	4.804	6.070	5.392	2.110	2.352	55	51	38	49
N	383	309	170	145	343	270	125	125	89	87	73	86
P	15	15	6	6	14	12	5	5	93	80	83	83
K	149	144	74	53	91	77	30	31	60	53	40	58
Ca	53	44	32	26	34	16	6	10	64	36	19	38
Mg	50	36	36	17	14	20	12	8	28	55	33	47
S	6	4	3	2	3	3	2	1	50	75	66	50
					g ha ⁻¹				%			
Cu	64	60	29	20	44	45	17	12	73	75	59	60
Fe	562	535	383	213	370	232	101	115	66	43	26	54
Mn	181	126	122	52	108	61	31	26	59	48	21	50
Zn	232	220	106	39	206	185	73	21	88	84	69	54
B	154	145	69	62	96	87	25	26	62	60	36	42