



Title	Possible solubilization of various mineral elements in the rhizosphere of <i>Lupinus albus</i> L
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Table S1. pH and concentration of total nitrogen and total carbon in the field bulk soils before fertilization.

	pH(H <sub>2</sub> O)	Total N (mg g <sup>-1</sup> )	Total C (mg g <sup>-1</sup> )
-N	6.03 ±0.03 a	2.11 ±0.02 c	31.6 ±0.24 c
-P	5.38 ±0.02 c	2.35 ±0.02 bc	34.0 ±0.32 b
-K	5.38 ±0.01 c	2.91 ±0.01 a	41.2 ±0.21 a
+NPK	5.49 ±0.02 b	2.64 ±0.16 ab	34.7 ±0.36 b

-N, fertilization without N; -P, fertilization without P; -K, fertilization without K; +NPK, complete fertilization.

Values are means (n = 3) ± standard errors. Different letters indicate a significant difference ( $P < 0.05$ ) using Tukey's multiple-comparison test following a one-way ANOVA.

Table S2. Dry weight (g plant<sup>-1</sup>) of each organ of lupin and soybean under nitrogen, phosphorus, and potassium deficient conditions.

Species	Treatment	Leaf		Pod		Stem	
		Mono-culture	Co-culture	Mono-culture	Co-culture	Mono-culture	Co-culture
Soybean	-N	8.42 ±0.48 a	** 13.76 ±1.06 a	28.61 ±1.61 a	* 37.55 ±2.12 a	10.28 ±1.04 a	11.16 ±0.94 a
	-P	5.05 ±0.45 b	* 7.87 ±0.61 b	14.18 ±1.32 b	* 25.21 ±2.69 ab	4.21 ±0.43 b	*** 8.40 ±0.46 ab
	-K	7.72 ±0.93 ab	7.40 ±0.76 b	15.12 ±1.96 b	16.26 ±0.66 b	7.31 ±1.05 ab	8.17 ±0.58 b
	+NPK	7.83 ±0.76 ab	9.82 ±1.39 ab	31.30 ±2.46 a	35.32 ±7.19 a	10.97 ±0.61 a	** 6.37 ±0.60 b
Lupin	-N	9.06 ±0.42 a	*** 4.35 ±0.33 a	9.12 ±1.02 a	*** 1.63 ±0.61 a	17.77 ±0.42 a	*** 10.29 ±0.89 a
	-P	7.06 ±0.54 a	6.21 ±0.60 a	6.06 ±1.97 a	2.57 ±0.76 a	12.00 ±0.97 a	10.71 ±0.53 a
	-K	5.91 ±0.74 a	4.34 ±0.22 a	4.28 ±2.04 a	3.14 ±0.60 a	10.65 ±1.46 a	9.69 ±0.56 a
	+NPK	6.41 ±0.67 a	4.64 ±1.19 a	7.85 ±1.38 a	3.82 ±0.90 a	11.04 ±1.71 a	10.60 ±1.78 a

-N, fertilization without N; -P, fertilization without P; -K, fertilization without K; +NPK, complete fertilization.

Values are means (n = 4) ± standard errors. Different letters indicate a significant difference ( $P < 0.05$ ) among the treatments using Tukey's multiple-comparison test following a one-way ANOVA.

Asterisks indicate statistically significant differences between mono-cultures and co-cultures in each treatment and each organ (Student's t-test, \*, \*\*, and \*\*\*:  $P < 0.05$ , 0.01, and 0.001, respectively).

Table S3. Leaf concentration of each element in soybean and lupin grown as mono-culture and co-culture in the field.

Species	Cultivation	Treatment	Na ( $\mu\text{g g}^{-1}$ )	K ( $\text{mg g}^{-1}$ )	Cs ( $\mu\text{g g}^{-1}$ )	Rb ( $\mu\text{g g}^{-1}$ )	Mg ( $\text{mg g}^{-1}$ )	Ca ( $\text{mg g}^{-1}$ )	Sr ( $\mu\text{g g}^{-1}$ )	Ba ( $\mu\text{g g}^{-1}$ )	P ( $\text{mg g}^{-1}$ )	N ( $\text{mg g}^{-1}$ )	Fe ( $\mu\text{g g}^{-1}$ )	As ( $\mu\text{g g}^{-1}$ )	Al ( $\mu\text{g g}^{-1}$ )
Soybean	Mono-culture	-N	38.2 $\pm$ 1.3 b	15.1 $\pm$ 0.6 a	0.34 $\pm$ 0.07 c	6.2 $\pm$ 0.3 bc	0.82 $\pm$ 0.06 c	17.1 $\pm$ 0.5 c	46.4 $\pm$ 1.5 b	15.4 $\pm$ 2.5 a	1.99 $\pm$ 0.10 b	30.9 $\pm$ 0.5 a	141 $\pm$ 3 b	0.38 $\pm$ 0.00 a	34.0 $\pm$ 2.6 b
		-P	33.1 $\pm$ 5.6 b	9.5 $\pm$ 0.1 a	0.79 $\pm$ 0.07 c	5.4 $\pm$ 0.2 c	1.59 $\pm$ 0.14 bc	17.7 $\pm$ 1.2 bc	49.8 $\pm$ 3.4 a	17.6 $\pm$ 2.9 a	0.90 $\pm$ 0.06 c	23.4 $\pm$ 0.9 b	142 $\pm$ 9 b	0.21 $\pm$ 0.01 b	70.3 $\pm$ 4.5 b
		-K	55.8 $\pm$ 3.2 a	2.6 $\pm$ 0.1 d	4.60 $\pm$ 0.20 a	15.0 $\pm$ 0.4 a	10.17 $\pm$ 0.50 a	31.0 $\pm$ 1.4 a	81.7 $\pm$ 3.8 a	17.7 $\pm$ 3.6 a	3.39 $\pm$ 0.25 a	28.9 $\pm$ 0.8 a	229 $\pm$ 24 a	0.40 $\pm$ 0.06 a	127.6 $\pm$ 24.9 a
		+NPK	17.1 $\pm$ 3.1 c	6.5 $\pm$ 0.7 c	1.36 $\pm$ 0.09 b	7.5 $\pm$ 0.6 b	2.35 $\pm$ 0.18 b	23.2 $\pm$ 1.8 b	49.2 $\pm$ 4.6 b	11.6 $\pm$ 3.3 a	1.26 $\pm$ 0.06 c	22.0 $\pm$ 1.1 b	133 $\pm$ 5 b	0.22 $\pm$ 0.01 b	58.9 $\pm$ 5.6 b
Soybean	Co-culture with lupin	-N	45.2 $\pm$ 5.2 a	14.5 $\pm$ 0.3 a	0.33 $\pm$ 0.02 d	5.8 $\pm$ 0.2 c	1.08 $\pm$ 0.06 c	21.1 $\pm$ 0.9 b	57.0 $\pm$ 2.5 b	20.8 $\pm$ 3.3 ab	1.82 $\pm$ 0.04 b	29.5 $\pm$ 0.8 a	200 $\pm$ 8 a	0.42 $\pm$ 0.02 a	56.7 $\pm$ 2.5 a
		-P	42.6 $\pm$ 2.7 a	12.1 $\pm$ 0.1 ab	0.86 $\pm$ 0.04 c	7.4 $\pm$ 0.2 bc	2.79 $\pm$ 0.28 b	23.5 $\pm$ 1.6 b	65.9 $\pm$ 4.3 b	28.7 $\pm$ 1.7 a	1.38 $\pm$ 0.09 b	32.1 $\pm$ 2.3 a	151 $\pm$ 6 a	0.15 $\pm$ 0.01 b	60.7 $\pm$ 7.5 a
		-K	69.8 $\pm$ 12.1 a	3.2 $\pm$ 0.2 c	5.31 $\pm$ 0.20 a	17.4 $\pm$ 1.1 a	11.29 $\pm$ 0.23 a	30.7 $\pm$ 1.2 a	89.0 $\pm$ 2.8 a	26.1 $\pm$ 5.0 a	4.11 $\pm$ 0.49 a	28.7 $\pm$ 0.7 a	252 $\pm$ 16 a	0.39 $\pm$ 0.03 a	120.5 $\pm$ 13.3 a
		+NPK	53.0 $\pm$ 12.8 a	8.2 $\pm$ 1.2 b	1.85 $\pm$ 0.06 b	10.3 $\pm$ 1.4 b	2.84 $\pm$ 0.31 b	14.6 $\pm$ 1.8 c	54.1 $\pm$ 5.5 b	11.6 $\pm$ 0.7 b	1.61 $\pm$ 0.18 b	22.0 $\pm$ 1.4 b	219 $\pm$ 62 a	0.37 $\pm$ 0.10 a	147.6 $\pm$ 60.4 a
Lupin	Mono-culture	-N	677 $\pm$ 59 c	17.0 $\pm$ 0.5 a	34 $\pm$ 7 b	41.6 $\pm$ 5.0 a	2.26 $\pm$ 0.14 a	8.2 $\pm$ 0.2 bc	35.1 $\pm$ 0.6 ab	3.3 $\pm$ 0.3 a	2.22 $\pm$ 0.19 a	40.9 $\pm$ 2.6 a	281 $\pm$ 14 ab	1.18 $\pm$ 0.09 ab	61.3 $\pm$ 8.8 a
		-P	1325 $\pm$ 131 bc	16.4 $\pm$ 1.0 a	127 $\pm$ 10 a	72.4 $\pm$ 5.6 a	2.22 $\pm$ 0.15 a	7.2 $\pm$ 0.2 c	31.3 $\pm$ 1.0 b	2.5 $\pm$ 0.1 a	1.93 $\pm$ 0.21 a	49.3 $\pm$ 1.9 a	352 $\pm$ 19 a	1.47 $\pm$ 0.06 a	49.7 $\pm$ 6.5 a
		-K	4368 $\pm$ 894 a	9.0 $\pm$ 1.9 b	105 $\pm$ 21 a	56.7 $\pm$ 11.8 a	2.43 $\pm$ 0.10 a	10.9 $\pm$ 0.6 ab	42.6 $\pm$ 2.6 a	3.6 $\pm$ 0.5 a	2.40 $\pm$ 0.14 a	48.5 $\pm$ 2.1 a	225 $\pm$ 30 b	0.88 $\pm$ 0.20 b	78.2 $\pm$ 7.6 a
		+NPK	3075 $\pm$ 421 ab	11.8 $\pm$ 1.2 ab	104 $\pm$ 15 a	64.6 $\pm$ 7.7 a	2.28 $\pm$ 0.07 a	12.6 $\pm$ 1.5 a	40.1 $\pm$ 4.5 ab	3.2 $\pm$ 0.2 a	2.29 $\pm$ 0.13 a	46.4 $\pm$ 2.4 a	226 $\pm$ 24 b	0.93 $\pm$ 0.09 b	71.2 $\pm$ 11.7 a
Lupin	Co-culture with soybean	-N	583 $\pm$ 62 c	14.9 $\pm$ 1.5 ab	38 $\pm$ 4 b	44.4 $\pm$ 0.9 c	2.63 $\pm$ 0.15 ab	9.3 $\pm$ 0.6 ab	32.0 $\pm$ 2.6 ab	2.0 $\pm$ 0.2 b	1.62 $\pm$ 0.11 a	28.2 $\pm$ 1.2 b	239 $\pm$ 15 a	1.08 $\pm$ 0.07 ab	39.5 $\pm$ 3.5 a
		-P	1326 $\pm$ 77 c	17.6 $\pm$ 0.3 a	135 $\pm$ 4 a	71.5 $\pm$ 4.6 a	2.47 $\pm$ 0.02 ab	9.3 $\pm$ 0.4 ab	35.5 $\pm$ 1.7 ab	3.1 $\pm$ 0.3 a	2.03 $\pm$ 0.16 a	41.2 $\pm$ 0.8 a	298 $\pm$ 21 a	1.43 $\pm$ 0.18 a	48.6 $\pm$ 7.2 a
		-K	4212 $\pm$ 342 a	8.9 $\pm$ 0.5 bc	138 $\pm$ 7 a	59.4 $\pm$ 3.0 ab	2.88 $\pm$ 0.09 a	10.9 $\pm$ 0.4 a	39.4 $\pm$ 1.6 a	2.8 $\pm$ 0.3 ab	1.92 $\pm$ 0.14 a	34.6 $\pm$ 2.5 b	210 $\pm$ 16 a	0.97 $\pm$ 0.10 ab	47.1 $\pm$ 3.2 a
		+NPK	2761 $\pm$ 260 b	12.4 $\pm$ 0.6 b	110 $\pm$ 11 a	55.6 $\pm$ 3.1 bc	2.13 $\pm$ 0.17 b	8.4 $\pm$ 0.6 b	27.9 $\pm$ 2.2 b	1.9 $\pm$ 0.2 b	1.52 $\pm$ 0.07 a	33.0 $\pm$ 1.0 b	227 $\pm$ 31 a	0.79 $\pm$ 0.04 b	43.3 $\pm$ 6.3 a

Species	Cultivation	Treatment	Mn ( $\mu\text{g g}^{-1}$ )	Cr ( $\mu\text{g g}^{-1}$ )	Co ( $\mu\text{g g}^{-1}$ )	Ni ( $\mu\text{g g}^{-1}$ )	Zn ( $\mu\text{g g}^{-1}$ )	Cd ( $\mu\text{g g}^{-1}$ )	Cu ( $\mu\text{g g}^{-1}$ )	Mo ( $\mu\text{g g}^{-1}$ )	V ( $\mu\text{g g}^{-1}$ )	B ( $\mu\text{g g}^{-1}$ )	S ( $\text{mg g}^{-1}$ )	Se ( $\mu\text{g g}^{-1}$ )
Soybean	Mono-culture	-N	71 $\pm$ 2 c	2.44 $\pm$ 0.09 a	0.106 $\pm$ 0.001 c	2.07 $\pm$ 0.04 b	47.7 $\pm$ 2.0 b	0.132 $\pm$ 0.005 b	3.07 $\pm$ 0.14 bc	0.229 $\pm$ 0.093 a	0.213 $\pm$ 0.013 ab	26.0 $\pm$ 1.3 c	1.35 $\pm$ 0.03 b	0.080 $\pm$ 0.009 a
		-P	242 $\pm$ 47 bc	1.25 $\pm$ 0.24 b	0.269 $\pm$ 0.046 ab	1.72 $\pm$ 0.11 b	117.7 $\pm$ 11.6 a	0.205 $\pm$ 0.027 ab	5.86 $\pm$ 0.17 a	0.073 $\pm$ 0.004 a	0.252 $\pm$ 0.021 ab	37.6 $\pm$ 2.5 b	1.46 $\pm$ 0.04 b	0.081 $\pm$ 0.008 a
		-K	464 $\pm$ 64 a	1.92 $\pm$ 0.36 ab	0.362 $\pm$ 0.042 a	3.10 $\pm$ 0.38 a	153.3 $\pm$ 8.1 a	0.335 $\pm$ 0.037 a	2.52 $\pm$ 0.20 c	0.167 $\pm$ 0.039 a	0.320 $\pm$ 0.066 a	65.9 $\pm$ 2.3 a	2.00 $\pm$ 0.15 a	0.063 $\pm$ 0.012 a
		+NPK	311 $\pm$ 45 ab	1.89 $\pm$ 0.20 ab	0.203 $\pm$ 0.022 bc	1.97 $\pm$ 0.09 b	115.6 $\pm$ 12.8 a	0.301 $\pm$ 0.044 a	3.52 $\pm$ 0.17 b	0.112 $\pm$ 0.028 a	0.139 $\pm$ 0.008 b	29.1 $\pm$ 1.4 c	1.12 $\pm$ 0.02 b	0.044 $\pm$ 0.007 a
Soybean	Co-culture with lupin	-N	85 $\pm$ 4 c	9.00 $\pm$ 0.66 a	0.211 $\pm$ 0.008 a	5.54 $\pm$ 0.26 a	45.0 $\pm$ 5.0 c	0.135 $\pm$ 0.016 b	3.44 $\pm$ 0.21 b	0.147 $\pm$ 0.005 a	0.237 $\pm$ 0.010 a	32.7 $\pm$ 1.3 b	1.42 $\pm$ 0.02 b	0.057 $\pm$ 0.016 a
		-P	297 $\pm$ 46 b	0.84 $\pm$ 0.16 b	0.229 $\pm$ 0.028 a	1.73 $\pm$ 0.09 b	152.6 $\pm$ 12.3 a	0.268 $\pm$ 0.033 a	8.94 $\pm$ 0.86 a	0.095 $\pm$ 0.023 a	0.160 $\pm$ 0.023 a	38.3 $\pm$ 1.2 b	1.68 $\pm$ 0.11 ab	0.022 $\pm$ 0.004 a
		-K	459 $\pm$ 18 a	1.83 $\pm$ 0.24 b	0.294 $\pm$ 0.006 a	3.35 $\pm$ 0.23 ab	178.5 $\pm$ 5.9 a	0.359 $\pm$ 0.004 a	2.46 $\pm$ 0.16 b	0.117 $\pm$ 0.005 a	0.260 $\pm$ 0.036 a	72.1 $\pm$ 6.9 a	1.92 $\pm$ 0.04 a	0.046 $\pm$ 0.014 a
		+NPK	313 $\pm$ 41 b	3.30 $\pm$ 1.26 b	0.266 $\pm$ 0.051 a	3.81 $\pm$ 1.26 ab	105.6 $\pm$ 11.4 b	0.282 $\pm$ 0.041 a	3.57 $\pm$ 0.27 b	0.097 $\pm$ 0.020 a	0.316 $\pm$ 0.181 a	32.2 $\pm$ 1.9 b	1.21 $\pm$ 0.12 b	0.016 $\pm$ 0.015 a
Lupin	Mono-culture	-N	5128 $\pm$ 589 b	1.73 $\pm$ 0.25 a	0.645 $\pm$ 0.037 ab	3.65 $\pm$ 0.21 ab	32.0 $\pm$ 2.5 a	0.031 $\pm$ 0.002 b	7.48 $\pm$ 0.28 a	0.247 $\pm$ 0.056 b	0.156 $\pm$ 0.032 a	20.1 $\pm$ 0.8 a	1.97 $\pm$ 0.18 a	0.536 $\pm$ 0.088 ab
		-P	8869 $\pm$ 334 a	2.23 $\pm$ 0.48 a	0.747 $\pm$ 0.017 a	4.76 $\pm$ 0.42 a	39.4 $\pm$ 5.4 a	0.036 $\pm$ 0.003 ab	9.56 $\pm$ 1.50 a	1.278 $\pm$ 0.264 a	0.131 $\pm$ 0.022 a	19.5 $\pm$ 0.9 a	2.01 $\pm$ 0.14 a	0.569 $\pm$ 0.060 a
		-K	3860 $\pm$ 891 b	2.22 $\pm$ 0.29 a	0.492 $\pm$ 0.107 b	3.54 $\pm$ 0.26 ab	41.7 $\pm$ 4.4 a	0.033 $\pm$ 0.003 ab	8.60 $\pm$ 0.98 a	0.351 $\pm$ 0.097 a	0.192 $\pm$ 0.030 a	20.6 $\pm$ 1.3 a	2.38 $\pm$ 0.10 a	0.276 $\pm$ 0.076 ab
		+NPK	5386 $\pm$ 457 b	1.69 $\pm$ 0.15 a	0.537 $\pm$ 0.032 ab	3.25 $\pm$ 0.23 b	36.7 $\pm$ 3.1 a	0.047 $\pm$ 0.005 a	7.97 $\pm$ 0.27 a	0.513 $\pm$ 0.183 a	0.133 $\pm$ 0.006 a	19.3 $\pm$ 0.3 a	2.55 $\pm$ 0.33 a	0.266 $\pm$ 0.049 b
Lupin	Co-culture with soybean	-N	4449 $\pm$ 396 c	6.41 $\pm$ 2.27 a	0.605 $\pm$ 0.035 bc	5.52 $\pm$ 1.27 a	23.4 $\pm$ 1.5 c	0.018 $\pm$ 0.001 c	8.16 $\pm$ 0.74 ab	0.221 $\pm$ 0.051 b	0.104 $\pm$ 0.013 a	23.4 $\pm$ 0.6 b	1.63 $\pm$ 0.16 b	0.390 $\pm$ 0.058 ab
		-P	9285 $\pm$ 390 a	1.11 $\pm$ 0.20 b	0.807 $\pm$ 0.048 a	3.83 $\pm$ 0.28 a	39.3 $\pm$ 1.0 a	0.039 $\pm$ 0.003 a	8.93 $\pm$ 0.27 a	1.112 $\pm$ 0.154 a	0.092 $\pm$ 0.015 a	24.6 $\pm$ 0.7 b	2.32 $\pm$ 0.12 a	0.410 $\pm$ 0.027 a
		-K	6962 $\pm$ 707 b	2.41 $\pm$ 0.41 ab	0.619 $\pm$ 0.051 b	3.45 $\pm$ 0.34 a	31.0 $\pm$ 1.7 b	0.029 $\pm$ 0.001 ab	9.40 $\pm$ 0.36 a	0.242 $\pm$ 0.035 b	0.092 $\pm$ 0.006 a	30.8 $\pm$ 1.4 a	2.58 $\pm$ 0.21 a	0.354 $\pm$ 0.015 ab
		+NPK	3188 $\pm$ 495 c	2.02 $\pm$ 0.12 ab	0.425 $\pm$ 0.036 c	3.34 $\pm$ 0.34 a	23.2 $\pm$ 0.9 c	0.024 $\pm$ 0.003 bc	6.66 $\pm$ 0.25 b	0.301 $\pm$ 0.078 b	0.076 $\pm$ 0.008 a	19.9 $\pm$ 1.8 b	1.54 $\pm$ 0.06 b	0.245 $\pm$ 0.031 b

–N, fertilization without N; –P, fertilization without P; –K, fertilization without K; +NPK, complete fertilization.

Values are means (n = 4)  $\pm$  standard errors.

Different letters indicate a significant difference ( $P < 0.05$ ) among the treatments using Tukey's multiple-comparison test following a one-way ANOVA.

Note that soil chemical properties, including the elemental profile, varies somewhat among the treatments due to the long-term fertilizer treatment.

Table S4. Leaf concentration of each element in soybean and lupin grown in hydroponics.

Species	Na ( $\mu\text{g g}^{-1}$ )	K ( $\text{mg g}^{-1}$ )	Cs ( $\mu\text{g g}^{-1}$ )	Mg ( $\text{mg g}^{-1}$ )	Ca ( $\text{mg g}^{-1}$ )	P ( $\text{mg g}^{-1}$ )	N ( $\text{mg g}^{-1}$ )
Soybean	8.9 $\pm$ 1.1 **	31.4 $\pm$ 2.3 *	77 $\pm$ 6	4.57 $\pm$ 0.13 **	13.2 $\pm$ 0.3 ***	3.62 $\pm$ 0.31 *	56.2 $\pm$ 0.4 **
Lupin	470 $\pm$ 95	14.4 $\pm$ 0.6	92 $\pm$ 4	3.51 $\pm$ 0.16	8.4 $\pm$ 0.1	2.18 $\pm$ 0.09	76.8 $\pm$ 3.2

  

Species	Fe ( $\mu\text{g g}^{-1}$ )	Mn ( $\mu\text{g g}^{-1}$ )	Zn ( $\mu\text{g g}^{-1}$ )	Cu ( $\mu\text{g g}^{-1}$ )	Mo ( $\mu\text{g g}^{-1}$ )	B ( $\mu\text{g g}^{-1}$ )	S ( $\text{mg g}^{-1}$ )
Soybean	110 $\pm$ 5	206 $\pm$ 13 ***	152 $\pm$ 6 *	16.6 $\pm$ 0.4	16.68 $\pm$ 1.16 ***	66.3 $\pm$ 1.5	2.58 $\pm$ 0.07 ***
Lupin	92 $\pm$ 9	3153 $\pm$ 333	93 $\pm$ 10	17.9 $\pm$ 1.5	3.34 $\pm$ 0.63	62.2 $\pm$ 31.1	3.58 $\pm$ 0.09

Values are means ( $n = 3$ )  $\pm$  standard errors.

Asterisks indicate statistically significant differences between soybean and lupin (Student's t-test, \*, \*\*, and \*\*\*:  $P < 0.05$ , 0.01, and 0.001, respectively).