Influence of Cropping System Intensity on Dry Matter Yield and Nitrogen Concentration in Different Parts of Soybean Plant

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Summary

Two-year investigations were conducted within the three-year maize-soybean-wheat crop rotation with the aim to assess the influence of two cropping systems, conditionally marked as high-input and reduced-input systems, on soybean dry matter yield and nitrogen concentration in its different plant parts. The high-input system was characterized by: ploughing at 30-32 cm, fertilization with 80 kg N and 130 P_2O_5 and K_2O kg ha^{-1}, weed control based on oxasulfuron and, if required, a corrective treatment with propachizafop and bentazone. The reduced-input system involved: ploughing at 20-22 cm, fertilization with a total of 40 kg N and 130 kg P_2O_5 and K_2O kg ha^{-1}, and only oxasulfuron-based weed control.

Investigations involved two soybean genotypes: L 940596 and L 910631, vegetation group I. An identical monofactorial trial with four replications was set up in each cropping system.

Cropping system intensity had a positive effect on leaf and stem dry matter mass in 2002, and on leaf and stem nitrogen concentration, whereas it had no effect on pod dry matter, seed yield and seed nitrogen concentrations in either year.

The highest leaf dry matter was recorded in R_4 development stage and that of stem and pod without seeds in R_7 development stage. In both trial years, the highest nitrogen concentrations in leaf and stem were recorded in R_1 development stage.

In both trial years, higher pod nitrogen concentration was achieved in R_4 development stage than in the R_7 stage.

Key words

soybean; cropping system; yield; dry matter; nitrogen concentration

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Introduction

A major role in determination of seed yield of field crops is that of the total yield of biomass and partitioning of particular plant parts in it. It is taken that each subsequent yield increase can be a result of increased assimilate partitioning in harvest parts (Loomis et al., 1979). Harvest index defined at harvest is often used as a criterion of assimilate partitioning; the harvest index, however, does not reveal the changes of and differences between vegetative and generative plant organs in the growing period. In indeterminate soybean genotypes, growth and development of vegetative and generative plant organs proceed simultaneously during flowering. During seed filling, however, the largest part of assimilate is exported into seed, and carbon and nitrogen from plant vegetative parts are also exported into seed (Egli et al., 1980; Zeiher et al., 1982). Total plant dry matter increases up to R_5/R_6 development stages when it reaches its maximum, and then diminishes during the seed filling stage along with a decrease of the leaf area index (Kumudini et al., 2001).

Seed yield is a result of the total dry matter and harvest index, and is consequently affected by their separate or simultaneous changes (Kumudini et al., 2001). Yield components, number of pods and seeds, depend on the assimilate availability to reproductive organs during flowering and fruit and seed formation (Heitholt et al., 1985).

Egli et al., 1985, report that the number of pods with developing seed increased up to the R_6 development stage, which means the formation of new nodes stopped before the total number of pods was formed. Also, these authors mention that differences in the number of pods and seeds may result from differences in the degree of crop growth rather than from translocation of assimilate between vegetative and generative plant parts.

Since soybean nitrogen requirements during seed development and formation are very high, daily nitrogen accumulation is not sufficient and translocation of a large amount of nitrogen from the vegetative parts is needed for full seed development (Sinclair and de Wit, 1976). It is estimated that the amount of nitrogen translocated from soybean vegetative parts is 20-60% of total seed nitrogen (Hanway and Weber, 1971; Egli et al., 1978; Zeiher et al., 1982).

Influence of different cropping systems on dry matter accumulation and protein content in different plant parts of the new soybean genotypes, as well as the correlation of these processes with the increase in seed yield, are of great significance for their evaluation. Of special importance is nitrogen fertilization, which due to soybean physiological characteristics plays a major role for this crop.

Higher nitrogen levels have an adverse effect on its symbiotic fixation, thereby thwarting soybean's ability to satisfy part of its nitrogen requirements from its symbiotic relation with Bradyrhizobium japonicum (Varga et al., 1988, Redžepović et al., 1990, Redžepović et al., 1991).

Soybean response to nitrogen fertilization is especially weak on fertile soils (Varga, 1988). However, Wood et al. (1993) achieved increased soybean yield with nitrogen fertilization; the increase depended on the nitrogen rate applied and on the development stage in which it was applied.

The research objective was to assess the influence of different cropping systems on seed yield, dynamics of dry matter accumulation in particular plant parts of two soybean genotypes, and their nitrogen concentrations.

Material and methods

Investigations were conducted over two years (2000 and 2002) in field trials set up at the Experimental Facility of the Faculty of Agriculture in Zagreb. Two genotypes were investigated: L 940596 and L 910631, vegetation group I. The high-input cropping system was characterized by: ploughing at 30-32 cm, fertilization with 80 kg N and 130 P_2O_5 and K_2O kg ha^{-1}, weed control based on oxasulfuron (25 g a.i. ha^{-1}) and, if required, a corrective treatment with propachizafop (100 ml a.i. ha^{-1}) and bentazone (960 ml a.i. ha^{-1}), and sowing density of 55 germinated seeds m$^{-2.}$ The reduced-input system involved: ploughing at 20-22 cm, fertilization with a total of 40 kg N and 130 kg P_2O_5 and K_2O kg ha^{-1}, only oxasulfuron-based (25 g a.i. ha^{-1}) weed control, sowing density of 45 germinated seeds m^{-2}. The trial was laid out according to the randomized block scheme with four replications. The main plot size was 8.64 m^2 (6 rows x 0.18 m inter-row spacing x 8 m row length). Narrow inter-row spacing was based on previous research (Varga et al., 1991). After emergence, the plot was shortened by 0.25 m on each side so that the plot size at harvest was 8.1 m^2. The overall state of the production system and the trial area required high phosphorus levels in fertilizers applied in both cropping systems.

During the growing period, plant samples were taken at the following development stages: R_1, R_3, R_4 and R_7 (Fehr et al. 1971). A sample of 10 plants per plot was taken in each development stage. In dependence on the development stage, each plant was partitioned into the following parts: stem, leaves with petioles (all leaves on a plant), pods and seeds. Particular plant parts were dried at 70°C; dry matter and nitrogen concentration were determined. Nitrogen concentration was determined by the Kjeldahl-AOAC method. Yield from each plot was assessed at harvest and expressed as yield per hectare at 13% moisture level. Obtained data were processed by the analysis of variance. Mean separation was obtained using a LSD test at the 0.05 probability level when significant F-tests ($P<0.05$) were observed.

Results and discussion

Leaf dry matter mass and nitrogen concentration

In both trial years, leaf dry matter mass was significantly reduced in the R_7 development stage (Table 3). The great difference in dry matter mass of soybean leaf between trial years is a result of higher precipitation during the growing period in 2002 (Table 2). The April-September period of 2002 had 318 mm more precipitation than the same period in 2000. Besides, temperatures in the same period were favourable for soybean growth and development (Table 1). Cropping systems had no influence on leaf dry matter of either genotype in 2000, whereas larger leaf dry matter mass was achieved in the high-input system in 2002. Under the high-input cropping system, genotype L 940596 produced 354 g m^{-2}, and genotype L 910631 376 g m^{-2} of leaf dry matter (Table 3).

In both trial years, nitrogen concentration of soybean leaf was the highest in the R_1 development stage, i.e., at the start of flowering, amounting to 3.92% in 2000, and to 3.53% in 2002. Leaf nitrogen concentration was the same in R_3 and R_4 development stages of both trial years, while it was significantly the lowest in the R_7 development stage in 2000 (1.79%) and in 2002 (1.75%), Table 4. These values are somewhat higher compared to the nitrogen concentration of soybean leaf during ripening reported by Streeter (1978).

Table 2.
Decadal and monthly precipitation in Zagreb - Maksimir in 2000 and 2002 year

Month	Precipitation, mm 2000	2002	Mean (1963-1992)
April	53.5	131.4	59.0
May	39.3	85.9	75.0
June	46.6	70.6	98.0
July	79.3	123.5	79.0
August	10.0	142.5	96.0
September	84.9	77.9	78.0
Total	313.6	631.8	485.0

Table 1.
Average decadal and monthly air temperature in 2000 and 2002 year and years-long average

Month	Mean			Mean minimum (°C)		Mean maximum (°C)	
	2000	2002	1963-1992	2000	2002	2000	2002
April	14.2	10.8	10.5	8.6	6.5	20.2	15.4
May	17.5	18.4	15.3	11.1	12.5	23.9	24.2
June	21.6	21.1	18.6	14.8	15.0	28.1	27.1
July	20.9	21.9	20.4	14.8	16.5	26.9	27.6
August	23.1	20.8	19.5	16.0	16.7	30.4	26.2
September	16.6	15.4	15.8	11.7	11.8	23.1	20.5
Mean	19.0	18.1	16.7	12.8	13.2	25.4	23.5

Table 3.
Leaf dry matter mass (g m^{-2}) of soybean genotypes studied under low- and high-input cropping systems in different development stages in 2000 and 2002

Genotype	Cropping system	2000					2002				
		R_1	R_3	R_4	R_7	Mean	R_1	R_3	R_4	R_7	Mean
L 940596	reduced-input	89.8	283.5	382.3	139.0	223.7	131.0	383.2	526.4	291.9	333.2 ab
	high-input	127.1	240.2	427.1	177.6	243.0	171.3	431.4	658.9	154.3	354.0 a
L 910631	reduced-input	86.5	251.5	352.5	83.1	193.4	126.8	330.2	546.7	141.3	286.2 b
	high-input	106.8	249.0	285.1	118.6	189.9	143.5	474.6	670.2	215.5	375.9 a
Mean		102.6 c	256.1 b	361.8 a	129.6 c		143.2 d	404.8 b	600.6 a	200.7 c	

Values followed by the same letter within the year are not significantly different at the 5% level of probability

Table 4.
Leaf nitrogen concentration of soybean genotypes studied under low- and high-input cropping systems in different development stages in 2000 and 2002 (%)

Genotype	Cropping system	2000 R_1	2000 R_3	2000 R_4	2000 R_7	2000 Mean	2002 R_1	2002 R_3	2002 R_4	2002 R_7	2002 Mean
L 940596	reduced-input	3.92	3.15	3.26	1.88	3.06	3.31	3.17	2.91	1.65	2.76 b
	high-input	3.90	3.30	3.45	1.84	3.12	3.65	3.42	3.35	1.84	3.07 a
L 910631	reduced-input	4.01	3.31	3.16	1.70	3.04	3.40	3.07	3.02	1.74	2.81 b
	high-input	3.86	3.28	3.16	1.74	3.01	3.77	3.51	3.32	1.75	3.09 a
Mean		3.92 a	3.26 b	3.25 b	1.79 c		3.53 a	3.29 b	3.15 b	1.75 c	

Values followed by the same letter within the year are not significantly different at the 5% level of probability

Table 5.
Stem dry matter mass (g m^{-2}) of soybean genotypes studied under low- and high-input cropping systems in different development stages in 2000 and 2002

Genotype	Cropping system	2000 R_1	2000 R_3	2000 R_4	2000 R_7	2000 Mean	2002 R_1	2002 R_3	2002 R_4	2002 R_7	2002 Mean
L 940596	reduced-input	47.7	161.3	201.8	244.4	163.8	57.2	267.6	444.4	645.7	353.7 bc
	high-input	69.4	140.4	216.4	259.9	171.5	80.6	325.5	633.2	603.9	410.8 ab
L 910631	reduced-input	45.2	149.8	172.0	219.3	146.6	54.9	286.5	457.0	486.7	321.3 c
	high-input	58.3	156.4	203.0	219.7	159.4	68.2	442.8	609.5	692.3	453.2 a
Mean		55.2 d	152.0 c	198.3 b	235.8 a		65.2 d	330.6 c	536.0 b	607.2 a	

Values followed by the same letter within the year are not significantly different at the 5% level of probability

Table 6.
Stem nitrogen concentration of soybean genotypes studied under low- and high-input cropping systems in different development stages in 2000 and 2002 (%)

Genotype	Cropping system	2000 R_1	2000 R_3	2000 R_4	2000 R_7	2000 Mean	2002 R_1	2002 R_3	2002 R_4	2002 R_7	2002 Mean
L 940596	reduced-input	2.11	2.16	1.61	0.58	1.62 a	1.56	1.49	1.21	0.61	1.21 b
	high-input	1.92	1.77	1.21	0.80	1.43 b	1.63	1.55	1.35	0.67	1.10 c
L 910631	reduced-input	1.94	1.93	1.29	0.81	1.49 b	1.53	1.13	1.12	0.62	1.30 ab
	high-input	2.44	1.96	1.46	0.73	1.65 a	1.54	1.60	1.63	0.66	1.36 a
Mean		2.10 a	1.95 b	1.39 c	0.73 d		1.56 a	1.44 b	1.33 b	0.64 c	

Values followed by the same letter within the year are not significantly different at the 5% level of probability

Cropping systems had influence on leaf nitrogen concentrations only in 2002. Genotypes L 940596 and L 910631 achieved higher leaf nitrogen concentration in the high-input system, 3.07 and 3.09%, respectively. That indicates that both genotypes had positive reactions on higher nitrogen input in year with sufficient precipitation.

Stem dry matter mass and nitrogen concentration

In both trial years, stem dry matter mass increased up to the R_7 development stage: 236 g m^{-2} in 2000 and 607 g m^{-2} of stem dry matter in 2002 (Table 5). Like in the case of leaf dry matter, the considerably higher leaf mass in 2002 is a result of higher precipitation during the soybean growing period. Cropping system intensity had no influence on stem dry matter mass in 2000 whereas larger stem dry matter mass was achieved in the high-input system in 2002. Under the high-input system in 2002, genotype L 910631 produced 453 and genotype L 940596 411 g m^{-2} of stem dry matter.

In both trial years, the highest nitrogen concentration of soybean stem was recorded in the R_1 development stage (2.10% in 2000, 1.56% in 2002, being thus inversely proportional to stem dry matter mass). In 2000, stem nitrogen concentration decreased in the subsequent development stages, amounting to 1.95% in R_3, 1.39% in R_4, and 0.73% in R7 development stages. In 2002, after its maximum in the R_1 stage, nitrogen concentration of

Table 7.
Pod walls dry matter mass (g m^{-2}) of soybean genotypes studied under low- and high-input cropping systems in different development stages in 2000 and 2002

Genotype	Cropping system	2000 R_4	2000 R_7	2000 Mean	2002 R_4	2002 R_7	2002 Mean
L 940596	reduced-input	35.7	173.3	104.5	24.7	265.3	145.0
	high-input	36.6	170.9	103.8	29.9	240.0	135.0
L 910631	reduced-input	46.4	173.7	110.1	34.4	196.1	115.3
	high-input	46.5	159.0	102.8	30.9	269.5	150.2
Mean		41.3	169.2*		30.0	242.7*	

* Significant difference between means at P= 0.05

Table 8.
Pod walls nitrogen concentration of soybean genotypes studied under low- and high-input cropping systems in different development stages in 2000 and 2002 (%)

Genotype	Cropping system	2000 R_4	2000 R_7	2000 Mean	2002 R_4	2002 R_7	2002 Mean
L 940596	reduced-input	3.28	0.96	2.12 b	3.48	1.05	2.26
	high-input	3.41	0.94	2.17 ab	3.58	1.05	2.31
L 910631	reduced-input	3.35	0.92	2.13 b	3.20	1.14	2.17
	high-input	3.51	0.97	2.24 a	3.66	1.08	2.37
Mean		3.39*	0.94		3.48*	1.08	

Values followed by the same letter within the year are not significantly different at the 5% level of probability
* Significant difference between means at P= 0.05

soybean stem dropped in R_3 and R_4 stages to approximately the same level (1.44 and 1.33%, respectively) and decreased to 0.64% in the R_7 development stage (Table 6). Symbiotic nitrogen fixation cannot compensate for the reduction of available nitrogen in soil and meet the demands of intensive crop growth. Streeter (1978) obtained similar results and reported that soybean plants with normal nitrogen supply had a stem nitrogen concentration of 0.64% during ripening.

Differences in stem nitrogen concentrations in particular plant development stages decreased with the course of the growing period to be the lowest in the R_7 development stage irrespective of the characteristics of the growing period. In the wetter, for growth and development more favourable growing period, stem nitrogen concentration at the start of flowering was lower compared to the dry 2000, but the difference diminished in the R_7 development stage.

In 2000, genotype L 940596 achieved, averaged over all development stages, a higher stem nitrogen concentration under the reduced-input cropping system (1.62%), whereas genotype L 910631 had a higher nitrogen concentration under the high-input system (1.65%); the obtained values were not significantly different.

In 2002, genotype L 910631 achieved a higher stem nitrogen concentration compared to genotype L 940596. Nitrogen concentrations of genotype L 910631 were not significantly different under high-input and reduced-input cropping systems: 1.36 and 1.30%, respectively. Genotype L 940596 had the significantly lowest nitrogen concentration (1.10%) under the high-input cropping system. It may be assumed that there are morphological or physiological differences between these two lines of different origin that enable better utilization of soil nitrogen or a more efficient symbiotic relation of a genotype.

Pod dry matter mass and nitrogen concentration

In both trial years, dry matter mass of pod without seed reached its maximum in the R_7 development stage: 169 g m^{-2} in 2000, and 243 g m^{-2} in 2002 (Table 7). Cropping system intensity had no influence on pod dry matter mass. In 2002, genotype L 940596 produced a somewhat larger mass of pod dry matter under the reduced-input system compared to high-input system (145 and 135 g m^{-2}, respectively), but the difference was not statistically significant. In the same year, genotype L 910631 produced a larger mass of pod dry matter under the high-input cropping system (150 g m^{-2}) compared to the reduced-input system (115 g m^{-2}), but the difference was not statistically significant either.

In both trial years, nitrogen concentration in pod without seed was higher in the R_4 development stage – 3.39% in 2000, and 3.48% in 2002 (Table 8). After ni-

Table 9.
Seed yield (kg ha^{-1}) of soybean genotypes studied under low- and high-input cropping systems in different development stages in 2000 and 2002

Genotype	2000 Cropping system reduced-input	2000 Cropping system high-input	2000 Mean	2002 Cropping system reduced-input	2002 Cropping system high-input	2002 Mean
L 940596	3618	3410	3514	4772	4928	4850
L 910631	3382	3372	3377	4957	4809	4883
Mean	3500	3391		4864	4868	

Table 10.
Seed nitrogen concentration (%) of soybean genotypes studied under low- and high-input cropping systems in different development stages in 2000 and 2002

Genotype	2000 Cropping system reduced-input	2000 Cropping system high-input	2000 Mean	2002 Cropping system reduced-input	2002 Cropping system high-input	2002 Mean
L 940596	5.74	5.76	5.75	5.93	5.98	5.95
L 910631	5.83	5.83	5.83*	6.00	6.04	6.02
Mean	5.78	5.79		5.96	6.01	

* Significant difference between means at P= 0.05

trogen translocation from pod to seed, pod nitrogen concentration in the R_7 development stage was 0.94% in 2000, and 1.08% in 2002 (Table 8). Streeter (1978) obtained somewhat lower results in the ripening stage – 0.62%.

Nitrogen concentration in soybean pods without seed of both genotypes was higher under the high-input system in 2000, while cropping system intensity had no influence on pod nitrogen concentration in 2002.

Yield of soybean seed and seed nitrogen concentration

Cropping system intensity had no influence on soybean seed yield in either trial year, and the differences between the genotypes were not statistically significant either. Yields of 3500 and 3391 kg ha^{-1}, respectively, were achieved in low- and high-input systems in 2000, and yields of 4864 and 4868 kg ha^{-1}, respectively, in 2002 (Table 9). Higher seed yields of 2002 were due to more favourable weather conditions in the growing period, notably to higher precipitation. Similar results were obtained by Varga et al. (1992) and Hons and Saladino (1995), indicating that it is only slightly, or not at all, possible to increase soybean seed yield by applying higher nitrogen rates. Soybean response to nitrogen fertilization is particularly weak on fertile soils (Varga, 1988). However, Wood et al. (1993) and Gan et al. (2003) achieved increased yields of soybean seed by nitrogen fertilization, but the increase depended on the weather and the nitrogen rate applied.

Cropping system intensity had no influence on nitrogen concentration in soybean seed in either trial year. Nitrogen concentrations of 5.78 and 5.79%, respectively, were recorded in reduced-input and high-input systems in 2000, and concentrations of 5.96 and 6.01%, respectively, in 2002 (Table 10). Similar results were obtained by Bullock, 1990; Redžepović et al., 1990, Varga et al., 1992, and Pospišil, 1998, indicating that average nitrogen rates, applied before sowing or with topdressing during full soybean flowering, have a low or no effect on protein content in soybean seed. However, Varga et al., 1988, found that application of higher nitrogen rates in the V3 and R2 development stages can increase the protein content of soybean seed. Similar results were reported by Gan et al. (2003).

In 2000, genotype L910631 achieved higher seed nitrogen concentration (5.83%) compared to genotype L 940596 (5.75%) whereas no statistically significant difference between genotypes was recorded in 2002. Similar results were obtained by Pospišil et al. (2002), while Streeter (1978) achieved higher nitrogen concentration in soybean seed: 6.55%.

The results point to the conclusion that seed has a dominant role in translocation and that the cropping system, notably fertilization, has little influence, except in cases of limiting factors.

Conclusions

The highest mass of leaf dry matter was reached in the R_4 development stage. The highest mass of stem dry matter was in the R_7 development stage. Cropping system intensity had no influence on dry matter mass of leaf and stem in 2000, while higher dry matter mass of leaf and stem was recorded in 2002 in the high-input system. In both trial years, averaged over both cropping systems, the highest nitrogen concentration in leaf and stem was achieved in the R_1 development stage.

Dry matter mass of pod without seed reached its maximum in the R_7 development stage. Cropping system intensity had no influence on pod dry matter mass. In both trial years, higher nitrogen concentrations were recorded in the R_4 development stage compared to the R_7 stage: 3.39% in 2000 and 3.48% in 2002.

Cropping system intensity had no influence on yield of soybean seed in either trial year, and the differences between genotypes were not statistically significant either. Likewise, the cropping system intensity had no influence on seed nitrogen concentration.

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