Доклади на Българската академия на науките
Comptes rendus de l'Académie bulgare des Sciences

Tome 76, No 4, 2023

AGRICULTURAL SCIENCES

Plant breeding

TOPPING AT THE SEEDLING STAGE CHANGES THE PLANT MORPHOLOGY AND YIELD OF UNBRANCHED TYPE SOYBEAN

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Received on October 28, 2022
Presented by H. Najdenski, Corresponding Member of BAS, on November 29, 2022

Abstract

The crop will be free from the control of apical dominance and the axillary buds will develop into branches after topping. However, there are relatively few studies on this subject of soybean. In order to further improve soybean grain yield, unbranched type high-yield soybean variety was used as test material, and the effects of topping at the first trifoliate stage on soybean plant growth, dry matter accumulation, yield and yield components of five planting densities [15 (D1), 18 (D2), 21 (D3), 25 (D4) and 30 (D5) × 104 plants ha^{-1}] were systematically investigated in this study. The results showed that, the dry matter accumulation increased after topping. Flower number per plant, seed number per plant, pod number per plant, and single-plant yield decreased in conventional-cultivation planting density (D4, topping), but they all increased as the planting density was reduced. D2 achieved the highest yield, with 100-seed weight and yield increased by 8.92% and 5.90% compared to CK (D4, non-topping). The number of branches per plant was significantly and positively correlated with podding node number per plant, flower number per plant, pod number per plant, and seed number per plant. This study demonstrates that the more branches formed after topping, the more conducive to increasing the flower number per plant, pod number per plant under lower density.

Key words: soybean, topping, branching, photosynthesis, yield and yield components

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This article was supported by the National Natural Science Foundation of China (32160520).
DOI:10.7546/CRABS.2023.04.16

Introduction. Soybean [*Glycine max* L. (Merr.)] is one of the most important sources of protein and vegetable oil for both human and animal nutrition [1]. Along with societal development and population accretion, the demand for soybean is gradually increasing, especially in China [2]. Increasing soybean yield per unit area is the key to stabilizing domestic soybean production capacity and solving the demand gap.

Crop production has the property of population, the production formation at various groups' cultivation not only depends on the individual plant but also depends on the influence of the group structure. Planting density can affect the structure of crop population, affects the photosynthetic physiological indexes of soybean population. Changing planting density could effectively regulate canopy structure of soybean population [3, 4]. Suitable planting density can improve the light energy utilization and ventilation capacity of the colony. Shoot architecture is usually a plastic trait regulated by genetics, the environment, and interactions between the two [5–8]. The number of branches determine the increase of nutrient organs, resulting in increase of plant biomass, and plasticity in branching helps plants strengthen response to environmental changes [9, 10]. Soybean varieties with high branching plasticity can maintain stable yields, even when the number of main stem nodes per unit area is low because they produce more branches to compensate for the limited production of main stem nodes. Therefore, increasing the number of effective branches per plant to moderate dense planting is one of the ways to obtain a high yield in field production.

Plant apical dominance is a phenomenon where the plant-growing stem roof suppresses lateral bud growth and branching. Topping (decapitation-induced axillary bud outgrowth) is a vital mechanism whereby shoots can continue normal growth and development [11–15]. Topping at the seedling stage can alter canopy structure and increase branches number of the unbranched type high-yield soybean, thus increase crop yield and yield components in our recent studies. This characteristic has a certain research significance for tapping the yield potential of modern high-yield soybean varieties. However, the agronomic response of canopy structure of the unbranched type high-yield soybean to topping under different planting densities is still unclear. In this study, the unbranched type high-yield soybean variety was used as test material, and the effects of topping at the first trifoliate stage on soybean plant growth, dry matter accumulation, yield and yield components of five planting densities were systematically investigated. This study aimed: (1) To clarify the response of dry matter accumulation, yield and agronomic traits of unbranched soybean varieties to topping; (2) To clarify the population growth and yield changes of unbranched soybean after topping at different densities; (3) To provide a new method for further increasing soybean yield in field production.

Materials and methods. ***Site description.*** Experiments were conducted from April to October during 2018 soybean growing seasons, at the Sanping agron-

omy farm experimental field of Xinjiang Agricultural University (43°56′ North, 87°20′ West), Urumqi, Xinjiang, China. The soil texture was characterized by loam and sandy loam, and maize (*Zea mays* L.) was the previous crop planted in the experimental field. The straw stubble from the preceding maize crop was plowed into the cropland before sowing. The chemical characteristics of 0–20 cm soil samples were described as follows: organic matter 10.88 mg kg^{-1}, total N 110.0 mg kg^{-1}, available P 26.2 mg kg^{-1}, available K 328.2 mg kg^{-1} and pH 8.17. Total precipitation and total number of hours of sunshine during the growing season were 207.3 mm and 1731.7, respectively.

Experimental design. The unbranched type high-yield soybean variety Xindadou27 was used as the test material and five different planting densities (15 (D1), 18 (D2), 21 (D3), 25 (D4) and 30 (D5) $\times$ 10^4 plants ha^{-1}) were set up for topping, while the conventional-practice density (25×10^4 plants ha^{-1}) without topping was used as a control in this experiment. The design for growth data was a completely randomized block of three replicates. The plots were 7 m long and 4.8 m wide and consisted of 6 rows. The planting method was narrow row planting (50 + 30 cm). The seeds were sown manually on 28 April. During the growing period of soybean, no plastic film was covered, and drip irrigation pipe was laid in narrow row. Precise planting density was adjusted at two emerging true leaf stage. Irrigation was carried out six times during the growth period, with a total irrigation amount of 4500 m^3 ha^{-1}. Fertilization corresponding to 69 and 92 kg N ha^{-1} at R1 and R5, and the fertilizer application was the same in all treatments. The harvest time was from 5 September to 15 September. These growth stages were determined according to the method described by Fehr and Caviness [16].

Measurement items and methods. *Dry matter accumulation.* Dry matter accumulation was measured at the V7, R1, R3, R5, R6, and R7 stages. Three adjacent plants from the same inside row were selected from each pot and they were separated into leaves, petioles, stalks and pods. The aboveground parts were placed into an aluminum box, at 105 °C for 30 min, and then dried at 60 °C for 24 h until a constant weight was reached.

Flowers, pods and cavities, yield and yield components. Starting from R1, five consecutive plants were selected from each plot, and the number of flowers on each node of the main stem and branches was surveyed every two days until the end of flowering. Starting from R3, the number of pods on each node was surveyed every four days until the number of pods on the whole plant was stable without any addition. After maturation, the marked spikes from ten plants were harvested and brought back to the laboratory for pods, seed cavities, and 100-seed weight measurement. The yield traits were investigated at the mature stage. The plants were collected in the middle 4 rows (1.6×3 m = 4.8 m^2) of each plot for yield components determination. Soybean yield and moisture content were measured, and the actual yield was adjusted by the grain water content of 13% before data analysis. At the end of this trial, growth parameters were determined.

Statistical analysis. Excel 2019 and SPSS 19.0 software were used for statistical analysis. All data are reported as mean ± SD. The data was the average of the three repeats, Duncan's multiple range test was applied to the separate mean values. When the analysis was statistically significant (LSD), significance was considered for $P < 0.05$. Pearson correlation and linear regression were performed to understand the relationships among grain yield and characteristics of soybean plants.

Results and discussion. ***Dry matter accumulation.*** The dry matter accumulation of D4 increased by 5.91% compared with CK. The increase of dry matter accumulation in all organs was mainly in stem, followed by leaf. Compared with CK, the proportion of dry matter accumulation in vegetative organs increased, while the proportion of reproductive organs decreased (Table 1). The dry matter accumulation increased with the increase of planting density, and decreased with decreasing density. The logistic growth curves (Table 2) showed that time to maximum growth rate, time to entering the rapid growth period, and time to ending the rapid growth period were all delayed in D4. Increasing the density, they all went ahead. The maximum growth rate showed no significant difference among all treatments, while the duration of rapid growth showed a trend of increasing first and then decreasing with the increase of planting density. D2 had the highest dry matter accumulation and the rapid growth stage, outperforming CK by 10.05% and 15.12%, respectively. This change may be caused by the fact that the new shoots after topping developed later than the main stem.

Main agronomic traits and grain yield. The number of branches and podding nodes per plant decreased with increased planting density. The number of pods per node, the number of pods and seeds per plant decreased by 31.07%, 5.38%, and 11.26%, while the number of podding nodes per plant increased by 37.02% in D4 compared to CK. The number of flowers, pods, and cavities per plant, and single-plant yield decreased by 6.44%, 5.38%, 7.55%, and 12.47% compared to CK in D4, but they all increased after decreasing planting density. The

T a b l e 1

Dry matter accumulation and its partitioning of soybean after topping under different planting densities

Treatment	Dry matter accumulation (g m^{-2})					Allotment ratio (%)				
	Leaf	Petiole	Stem	Pod shell	Seed	Leaf	Petiole	Stem	Pod shell	Seed
CK	351.42	210.37	245.63	190.56	446.63	24.33	14.56	17.00	13.19	30.92
D1	364.69	191.14	271.24	211.30	438.46	24.69	12.94	18.37	14.31	29.69
D2	368.21	201.81	336.85	235.52	472.99	22.79	12.49	20.85	14.58	29.28
D3	331.42	207.65	399.06	221.26	426.04	20.90	13.10	25.17	13.96	26.87
D4	365.65	210.05	364.61	198.65	391.02	23.90	13.73	23.83	12.98	25.56
D5	397.52	240.34	334.57	188.02	381.03	25.79	15.59	21.70	12.20	24.72

Table 2

Logistic regression analysis of soybean after topping under different planting densities. y, dry matter accumulation of soybean; t, number of days after soybean seedling emergency; V_m, maximum growth rate; t_0, days after the maximum accumulation rate occurred; t_1, the inflection point of rapid growth into the time; t_2, the end time of the inflection point of rapid growth; Δt, duration of rapid growth. **, significant at the 0.01 probability level

Treatment	t_0 (d)	t_1 (d)	t_2 (d)	t (d)	V_m (g d^{-1} m^{-2})	Function	R^2	F
CK	46.95	26.18	67.72	41.54	23.96	$y = 1502.3101/(1 + e(3.1947 - 0.067633t))$	0.982	111.26^{**}
D1	53.93	36.04	71.83	35.79	28.07	$y = 1544.1626/(1 + e(4.2367 - 0.079329t))$	0.994	349.44^{**}
D2	55.14	35.25	75.04	39.79	27.58	$y = 1666.7757/(1 + e(3.6504 - 0.066197t))$	0.996	532.61^{**}
D3	52.42	33.73	71.12	37.39	28.71	$y = 1630.3665/(1 + e(3.6927 - 0.070438t))$	0.996	497.90^{**}
D4	48.26	30.24	66.27	36.04	28.86	$y = 1572.0419/(1 + e(3.4741 - 0.073208t))$	0.995	392.71^{**}
D5	46.00	28.67	63.32	34.65	30.03	$y = 1585.7185/(1 + e(3.6311 - 0.075489t))$	0.992	244.51^{**}

Table 3

Effects of topping on flowering traits, fruiting traits and yield of soybean under different planting densities. Different lowercase letters indicate significant differences at the 5% level

Treatment	Plant number (10^4 plant ha^{-1})	Stalk number (10^4 plant ha^{-1})	Branch number per plant	Podding node number per plant	Flower number per plant	Total number of flowers (per m^2)	Pod number per node	Pod number per plant	Total number of pods (per m^2)	Seed number per plant	Total number of seeds (per m^2)	100-seed weight (g)	Yield (kg ha^{-1})	Growth (d)
CK	25.83b	25.83f	0	10.40a	129.25d	3338.91a	3.83a	39.79c	1005.43a	99.77d	2577.47a	20.85c	5163.59b	130
D1	15.42e	38.40e	2.49a	19.40b	212.53a	3277.15a	3.10b	39.96a	924.54b	152.82a	2356.04bc	22.32a	5050.80b	136
D2	17.92d	40.52d	2.07b	16.83c	174.41b	3125.41b	3.33b	56.00a	1003.51a	139.89b	2506.29a	22.71a	5468.40a	136
D3	20.97c	41.85c	2.00b	15.74d	145.21c	3045.15c	2.90c	44.43b	931.70b	110.51c	2317.65bc	22.12a	4925.55b	136
D4	25.00b	44.62b	1.78c	14.25e	120.92d	3023.01cd	2.64d	36.83c	921.25b	88.54e	2213.42c	21.29b	4520.40c	138
D5	29.93a	48.36a	1.62c	12.23f	99.12e	2966.65d	2.47e	30.19d	903.60c	73.24f	2192.09c	20.92bc	4405.65c	138

total number of flowers showed a decreasing change, and the total number of pods showed an increasing and then decreasing change with increasing planting density. D2 has the highest total number of pods among all treatments and the 100-seed weight and yield were 8.92% and 5.90% higher than CK, respectively (Table 3). The result indicated that the significant decrease in the number of plants in D2 and the significant increase in yield were mainly the result of a significant increase in the number of branches, leading to a significant increase in the number of pods, seeds, and 100-seed weight per plant compared to CK.

Correlation analysis and principal component analysis of yield and its contributing traits. The correlation analysis (Fig. 1a) showed that the yield was significantly positively correlated with podding node number per plant, flower number per plant, pod number per plant, seed number per plant, pod number per node, total number of flowers, total number of pods, total number of seeds, and 100-seed weight. The correlation coefficient with pod number per node was the highest (0.99**). Total number of plants and total number of stalks were significantly negatively correlated with yield and other agronomic traits. Dry matter accumulation was positively correlated with pod number per node, total number of pods, total number of seeds, yield, and 100-seed weight. Principal component analysis (Fig. 1b) shows that the first two principal components explained 89.8% of the variation. The scores of principal components 1 and 2 were 74.0% and 15.8%, respectively. Among the corresponding traits of principal component 1,

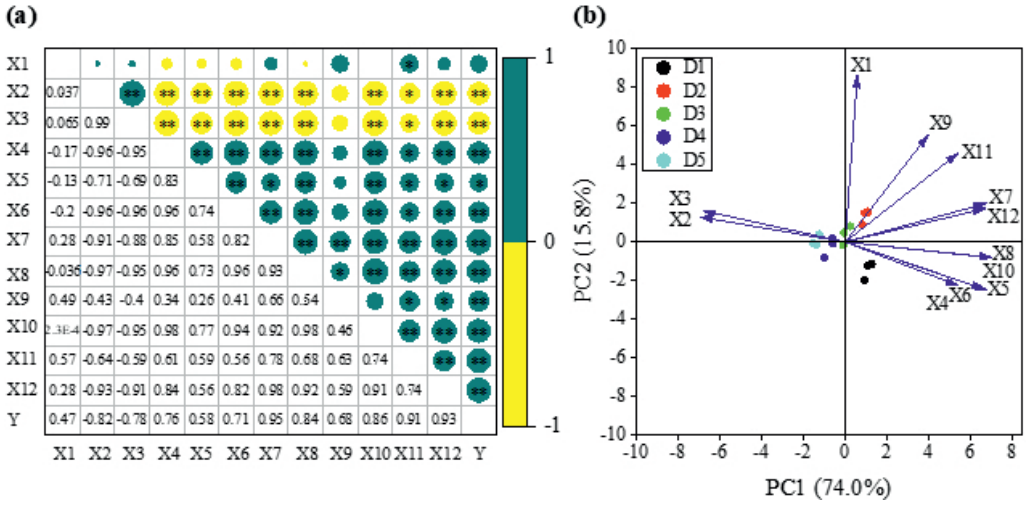


Fig. 1. Correlation analysis (a) and principal component analysis (b) of soybean yield with the major traits after topping. X1, dry matter. X2, plant number. X3, stalk number. X4, flower number per plant. X5, total number of flowers. X6, podding node number per plant. X7, pod number per node. X8, pod number per plant. X9, total number of pods, X10, seed number per plant. X11, total number of seeds. X12, 100-seed weight. Y, Yield. *, significant at the 0.05 probability levels; **, significant at the 0.01 probability levels, respectively

the load values of plant number and stalk number were negative, and the load values of other traits were positive. The load values of individual plant traits were 0.32–0.33, and the load values of population traits were 0.19–0.26. The population trait load value of principal component 2 was positive, and the trait load value per plant was negative. The results showed that the change of individual traits had a decisive effect on yield. Under this density condition, D2 has the highest comprehensive score, indicating that the effect of topping is the best under this density condition, followed by D1. These results indicate that excessive branches formed after topping are not conducive to yield, and increasing flower number and pod number per node are important ways to increase yield.

Yield is a consequence of individual-based interactions with the population. Moderate densification could promote dry matter accumulation (especially total dry matter and post-anthesis dry matter of soybean), increase the proportion of reproductive organs and crop yield [17,18]. Excessive increase of branches number is not conducive to increased soybean yield, and appropriate planting density and branch number are the key to achieve high yield.

Conclusions. The findings of this study show that topping at the first trifoliate leaf stage changed the canopy structure of the unbranched type high-yield soybean. Topping eliminates the apical dominance of soybean plants and promotes the formation of multiple effective axillary branches and yields. The compensation effect of branching on yield under low density is mainly the result of the newly added branching promoting the significant increase in the number of pod nodes per plant and the number of pods and seeds per plant. Our study helped a decision on whether to replant or promote the plant to grow new branches to compensate for the decrease in yield caused by the decrease in density according to the degree of injury while the top bud of soybean is subjected to insect-eating or hail disasters at the seedling stage.

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