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膜下滴灌追肥种类对花生结荚期茎叶干物重、矿质养分吸收和产量的影响

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摘 要: 为明确不同肥料种类及其相互配合追施提高花生产量的效应, 确定适宜的追施肥料种类和相互配施, 为花生科学施肥提供理论依据和技术指导。本研究在大田覆膜滴灌条件下, 于花针期设置追施氮、钙、硼肥及其相互配施处理, 研究了膜下滴灌追肥种类对花生结荚期茎叶干物重、矿质养分吸收和产量的影响。结果表明, 花针期追施氮、硼、钙肥及其相互配施均可不同程度地提高花生茎叶干物重、含氮量和积累量、含钙量和积累量、荚果产量, 但单独追施氮、硼、钙肥效果不如氮、硼、钙肥配合施用, 其中以追施氮硼钙或氮钙提高茎叶干物重、含氮量和积累量、含钙量和积累量、荚果产量的效果好。追施硼肥可提高花生茎秆、叶片含硼量和积累量, 而与氮、钙肥配施则可促进花生对硼素的吸收积累。花生产量与茎叶干物重、氮积累量、钙积累量和叶片硼积累量均呈显著正相关关系, 茎叶干物重与茎叶氮积累量、茎叶钙积累量均呈显著正相关关系, 茎叶氮积累量与茎叶含氮量呈显著正相关关系, 茎叶钙积累量与茎叶含钙量呈显著正相关关系, 茎叶硼积累量与茎叶含硼量呈显著正相关关系。说明氮硼钙配施促进了花生对氮、硼、钙的吸收积累, 增加了干物质量, 进而提高了产量。

关键词: 花生; 追肥种类; 干物重; 养分含量; 产量

Effects of drip irrigation and topdressing on dry matter weight, mineral nutrient absorption and yield of pod-bearing stage in peanut

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Abstract: This study was designed to clarify the effects of different fertilizer types and their mutual application on improving peanut yield, to determine the appropriate type of topdressing fertilizer and mutual application, and provide theoretical basis and technical guidance for scientific fertilization of peanut. Nitrogen (N), calcium (Ca), and boron (B) fertilizer were applied at the pod-pin stage under the condition of mulching drip irrigation in the field and the effects of different types of drip irrigation topdressing on dry matter weight, mineral nutrient absorption and yield of peanut in pod-bearing stage were analyzed. The results showed that the dry matter weight, nitrogen content and accumulation, calcium content and accumulation, and pod yield of peanut stems and leaves were significantly increased by topdressing of N, B, and Ca fertilizer in the pod-pin stage, however, the effect of topdressing of N, B, and Ca fertilizer alone was not as good as that of the combination of N, B, and Ca fertilizer, and the effect of topdressing of N, B, and Ca fertilizer on stem and leaf dry matter weight, nitrogen content and accumulation, calcium content and accumulation, and pod yield was better. Topdressing boron fertilizer could improve the boron content and its accumulation in peanut stems and leaves, while the combination of nitrogen and calcium fertilizer could promote the absorption and accumulation of boron in peanut. Peanut yield and stem (matter weight, nitrogen accumulation, calcium accumulation and leaf boron accumulation) were significantly positively related, stem (stem leaf nitrogen accumulation and leaf weight and the calcium accumulation)

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were significantly positive correlation, stem leaf nitrogen accumulation and stem leaf nitrogen content were significantly positive correlation, the calcium content in the stem leaf calcium accumulation and leaf were significantly positive correlation, stem leaf boron accumulation with stem and leaf boron content were significantly positive correlation. These results suggest that the application of N, B, and Ca promoted the absorption and accumulation of N, B, and Ca, increased the quality of dry matter, and consequently increased the yield of peanut.

Keywords: peanut; topdressing species; dry matter weight; nutrient content; yield

花生是我国重要的油料作物和经济作物,持续提高花生产量对保障我国食用油脂安全具有重要意义^[1]。科学施肥是持续提高花生产量的重要技术措施^[2-3]。花生的膜下滴灌施肥技术作为一项现代的农业技术,有效缓解了花生施肥存在的问题,例如肥料利用率低、产量低。目前关于膜下滴灌施肥的研究大多集中在作物产量、品质、水氮耦合和氮肥利用效率^[4-7],而关于多种肥料配合追施的研究则少见报道。因此,研究膜下滴灌花生物质积累和养分吸收规律,进行科学施肥对实现花生高产和提高肥料利用率具有重要意义。

有关施肥与花生物质积累、养分吸收和产量方面报道较多。施肥能显著增加花生对氮磷钾的吸收量^[8]。适量增施氮或钾肥能促进花生对氮磷钾的吸收和生长而增产,过量施氮或钾肥反而导致花生养分吸收减少,产量降低^[9-10]。施硝酸钙可促进花生对氮磷钾的吸收,而抑制钾的吸收^[11]。氮是花生生长发育必需的大量元素之一,对花生产量形成和品质提高有重要作用^[12]。花生虽为豆科作物,但仅靠根瘤菌所固定的氮肥和土壤氮,尚不能满足花生对氮的需求,因此,仍需要施用氮肥来保证花生生长发育的正常进行^[13]。钙是花生生长发育中所需要的中量元素之一,钙对花生植株生长、荚果发育、光合特性、产量形成等方面具有重要作用^[14-15]。硼是花生必需的微量元素之一,硼素对改善光合产物在各器官中的分配和运转有重要作用,施用硼肥能够促进荚果膨大、增加干物质积累,增加花生单株结荚数和双仁果数、饱果数、百果重,而增产^[16-17]。缺硼可导致花生空荚率高,糖分含量降低,从而影响花生产量^[18]。综上所述,目前关于花生单施氮、钾、钙、硼肥的研究相对较多,但是鲜有研究报道氮、钙、硼肥配合追施对花生干物质积累、养分吸收和产量的影响。花针期是花生生长发育水肥需求最敏感时期^[19],而结荚期则是吸收矿质元素最旺盛时期^[20],且叶片尚未开始脱落,该期营养器官干物质积累量、矿质元素含量和积累量的多少,反映了植株生长是否正常和吸收矿质元素的丰缺^[21]。为此,

本研究在大田覆膜滴灌条件下,于花生花针期追施不同种类的肥料,研究了氮、硼和钙单施及其配合施用对花生结荚期茎叶干物质积累、养分吸收和产量的影响及其相关关系,以期花生科学施肥提供理论依据和技术指导。

1 材料与方法

1.1 供试材料

试验于2017年和2018年在青岛农业大学胶州现代科技示范园进行。该站地处北温带季风区域,属暖温带半湿润季风区大陆性气候,2年相关气象数据如表1。供试土壤为沙姜黑土,2017年0~20 cm土层土壤包含有机质1.15%、碱解氮55.93 mg kg⁻¹、速效磷31.84 mg kg⁻¹、速效钾80.38 mg kg⁻¹、交换性钙3.46 mg kg⁻¹、有效硼0.87 mg kg⁻¹, pH 7.68; 2018年0~20 cm土层土壤包含有机质1.15%、碱解氮566.76 mg kg⁻¹、速效磷30.39 mg kg⁻¹、速效钾75.50 mg kg⁻¹、交换性钙3.21 mg kg⁻¹、有效硼0.80 mg kg⁻¹, pH 7.53。花生品种为大花生品种青花7号。肥料为尿素(总氮46.4%)、硝酸钙(Ca(NO₃)₂·4H₂O 99.0%)和硼沙(Na₂B₄O₇·10H₂O 99.0%)。

1.2 试验设计

在统一按公顷基施复合肥(N P K=15 15 15) 300 kg的基础上,采用膜下滴灌方式,在花针期设置8个处理,分别为处理1 (CK): 只灌水不追肥,处理2 (N): 追施氮肥,处理3 (B): 追施硼肥,处理4 (Ca): 追施钙肥,处理5 (NB): 追施氮硼肥,处理6 (NCa): 追施氮钙肥,处理7 (BCa): 追施硼钙肥,处理8 (NBCa): 追施氮硼钙肥。各处理具体追肥种类、数量及灌水量见表2。于花生适宜播种期(2017年5月8日,2018年5月9日)进行机播,一垄双行,垄距90 cm,垄上小行距30 cm,穴距15 cm,每穴2粒。小区面积20.0 m × 2.7 m = 54.0 m²,随机排列,重复3次,共24个小区。分别于2017年9月13日和2018年9月11日收获。其他田间管理同大田生产。

1.3 测定项目与方法

于结荚期(追肥后30 d, 2017年8月3日, 2018

表 1 2017 年和 2018 年全年相关气象数据

Table 1 Relevant meteorological data in 2017 and 2018

年份 Year	月份 Month	平均温度 Average temperature ()	降水量 Precipitation (mm)	日照时数 Sunshine hours (h)
2017	1	-0.5	0	129.7
	2	1.9	0	162.7
	3	6.8	0	195.0
	4	15.2	13.3	249.0
	5	20.1	30.3	265.3
	6	22.9	73.6	234.5
	7	27.7	138.1	187.5
	8	25.9	144.1	180.2
	9	22.4	103.0	206.7
	10	14.3	39.2	116.4
	11	6.9	1.6	196.4
	12	0.5	0	181.6
	年平均 Annual mean	13.7	45.3	192.1
2018	1	-2.3	0	126.3
	2	0.2	1.1	178.6
	3	8.0	26.3	206.7
	4	13.6	16.5	210.7
	5	18.4	82.4	231.8
	6	22.7	93.6	237.1
	7	26.2	155.2	207.2
	8	27.5	178.0	234.5
	9	21.5	102.4	201.3
	10	16.1	14.9	240.7
	11	10.8	17.8	145.5
	12	2.2	27.7	111.3
	年平均 Annual mean	13.7	59.7	194.3

表 2 各处理施肥和灌水情况

Table 2 Fertilization and irrigation of each treatment

处理 Treatment	追肥量 Top dressing amount (kg hm ⁻²)			灌水量 Irrigation quantity (mm)
	尿素 Carbamide urea	硼沙 Borax	硝酸钙 Calcium nitrate	
CK	0	0	0	10
N	130.5	0	0	10
B	0	15	0	10
Ca	0	0	132.3	10
NB	130.5	15	0	10
NCa	130.5	0	132.3	10
BCa	0	15	132.3	10
NBCa	130.5	15	132.3	10

年 8 月 6 日)每小区取代表性植株 5 穴, 将叶、茎分开, 装于牛皮纸袋中, 于 105℃杀青 0.5 h, 后 75℃烘干至恒重, 称量其干物重, 并用于测定氮、硼、钙含量。用浓硫酸等催化剂消解法, 半自动凯氏定氮仪测定全氮含量^[22], 用硝酸和高氯酸联合消煮法, 等

1.4 数据处理

采用 Microsoft Excel 2010 分析数据, 在利用 DPS 数据处理系统 LSD 进行统计分析和差异显著性检验。

2 结果与分析

2.1 追肥种类和配施对花生茎叶干物重的影响

由表 3 可以看出, 各追肥处理结荚期花生叶片、

茎秆干物重均高于对照, 其中除 B 和 Ca 处理与对照差异不显著外, 其他处理均达显著水平。追肥处理间比较, NBCa 处理叶片、茎秆干物重最高(除 2018 年叶片干重略低于 NCa 处理外)。两两配施处理花生叶片、茎秆干物重均高于相应单施处理。两两配施处理中, NCa 处理花生叶片、茎秆干物重最高, NB 处理次之, BCa 处理最低。单施处理中以 N 处理为最高, 有时与 B 处理达到显著水平, 除 2017 年叶片外, B 和 Ca 处理差异均不显著。说明花针期追肥均可不同程度地提高花生茎叶干物重, 但单独追施氮、硼、钙肥效果不如氮、硼、钙肥配合施用, 其中以追施氮硼钙或氮钙提高茎叶干物重的效果较好。

2.2 追肥种类和配施对花生茎叶含氮量和积累量的影响

由表 4 可以看出, 各追肥处理花生茎秆、叶片

表 3 追肥种类和配施对花生茎叶干物重的影响

Table 3 Effects of topdressing types and combined application on dry matter weight of stem and leaf in peanut (g plant⁻¹)

处理 Treatment	叶片 Leaf		茎秆 Stem	
	2017	2018	2017	2018
CK	18.84 e	17.86 d	15.00 c	14.48 d
N	21.09 bc	20.03 bc	17.97 ab	16.19 bc
B	18.61 e	18.22 cd	16.18 bc	15.80 bcd
Ca	19.26 cd	18.93 cd	16.71 bc	15.40 bcd
NB	21.22 bc	20.97 ab	18.25 ab	16.56 bc
NCa	22.82 ab	22.80 a	19.12 a	17.29 ab
BCa	20.74 cd	19.03 bc	17.79 ab	16.09 bc
NBCa	23.22 a	22.63 a	19.59 a	18.96 a

数据后面的不同小写字母表示处理间差异显著($P < 0.05$)。处理同表 2。

Different lowercase letters within a growing season indicate significant difference at the 0.05 probability level. Treatments are the same as those given in Table 2.

表 4 追肥种类和配施对花生茎叶含氮量和积累量的影响

Table 4 Effects of topdressing types and combined application on nitrogen content and accumulation of stem and leaf in peanut

处理 Treatment	含氮量 Nitrogen content (%)				氮素积累量 Nitrogen accumulation (mg plant ⁻¹)			
	叶片 Leaf		茎秆 Stem		叶片 Leaf		茎秆 Stem	
	2017	2018	2017	2018	2017	2018	2017	2018
CK	2.63 b	2.78 bc	1.28 c	1.45 bc	495.38 de	495.82 f	191.94 e	209.43 ef
N	2.75 ab	3.08 a	1.54 ab	1.72 a	579.67 bc	616.82 cd	276.60 ab	278.47 bc
B	2.66 b	2.90 b	1.28 c	1.49 bc	495.07 e	527.67 ef	207.10 de	234.84 de
Ca	2.71 ab	3.06 a	1.38 c	1.53 bc	521.88 cde	578.73 de	230.47 cd	235.11 de
NB	2.77 ab	3.10 a	1.56 a	1.72 a	587.03 bc	649.27 bc	284.01 a	284.83 bc
NCa	2.82 a	3.15 a	1.57 a	1.74 a	643.09 ab	718.31 a	299.37 a	300.91 ab
BCa	2.73 ab	3.05 a	1.40 bc	1.60 ab	565.61 cd	580.32 de	248.52 bc	257.49 cd
NBCa	2.87 a	3.13 a	1.56 a	1.76 a	666.41 a	707.57 ab	306.42 a	334.39 a

数据后面的不同小写字母表示处理间差异显著($P < 0.05$)。处理同表 2。

Different lowercase letters within a growing season indicate significant difference at the 0.05 probability level. Treatments are the same as those given in Table 2.

含氮量和积累量均高于对照,有的达到显著水平。追肥处理间比较,NBCa、NCa 处理茎秆、叶片含氮量和积累量互有高低,但均未达到显著水平,两处理均高于其他处理,有的达到显著水平。两两配施处理茎秆、叶片含氮量和积累量大多高于相应单施处理。两两配施处理中,各处理茎秆、叶片含氮量和积累量均表现为 $\text{NCa} > \text{NB} > \text{BCa}$ 。单施处理中,各处理茎秆、叶片含氮量和积累量表现为 $\text{N} > \text{Ca} > \text{B}$, N、Ca 处理有时与 B 处理差异达显著水平。说明花针期追肥均可不同程度地提高花生茎秆、叶片含氮量和积累量,但单独追施氮、硼、钙肥效果不如氮、硼、钙肥配合施用,其中以追施氮钙或氮硼钙肥提高茎秆、叶片含氮量和积累量的效果较好。

2.3 追肥和配施对花生茎叶含钙量和积累量的影响

由表 5 可以看出,各追肥处理花生茎秆、叶片含钙量和积累量均高于对照,有的达到显著水平。追肥处理间比较,NBCa 处理花生茎秆、叶片含钙量和积累量(除 2018 年叶片钙积累量外)均最高,有的达到显著水平。两两配施处理茎秆、叶片含钙量和积累量大多高于相应单施处理。两两配施处理中,各处理茎秆、叶片含钙量和积累量均表现为 $\text{NCa} > \text{BCa} > \text{NB}$ 。单施处理中,各处理茎秆、叶片含钙量表现为 $\text{Ca} > \text{B} > \text{N}$,茎秆、叶片钙积累量表现为 Ca 与 N 差异较小,B 处理最低。说明花针期追肥均可不同程度地提高花生茎秆、叶片含钙量和积累量,但

单独追施氮、硼、钙肥效果不如氮、硼、钙肥配合施用,其中以追施氮钙或氮硼钙肥提高茎秆、叶片含钙量和积累量的效果较好。

2.4 追肥种类和配施对花生茎叶含硼量和积累量的影响

由表 6 可以看出,追施硼肥或硼肥与氮、钙肥配施茎秆、叶片含硼量和积累量均显著高于对照。追肥处理间比较,叶片含硼量以 NB 处理最高,但与 B、BCa 处理差异不显著,茎秆含硼量以 B 处理最高,但与 NB、BCa、NBCa 处理差异不显著,茎秆、叶片硼积累量除 2017 年叶片外均以 NBCa 处理最高,其次为 NB,再次为 BCa,说明追施硼可提高花生茎秆、叶片含硼量和积累量,而与氮、钙肥配施则可促进花生对硼素的吸收积累。

2.5 追肥种类和配施对花生生产量的影响

由表 7 可以看出,各追肥处理花生生产量均显著高于对照。追肥处理间比较,花生生产量以 NBCa 处理为最高,比对照增产 26.38%~27.28%,但与 NCa 处理的产量差异不显著,显著高于其他处理。两两配施处理花生生产量也均高于相应单施处理。两两配施处理中,以 NCa 处理花生生产量为最高,比对照增产 21.55%~22.05%。单施处理中花生生产量以 N 处理为最高,比对照增产 10.80%~12.46%。说明花针期追肥均可不同程度地提高花生生产量,但单独追施氮、硼、钙肥效果不如氮、硼、钙肥配合施用,其中以追施氮硼钙或氮钙提高产量的效果较好。

表 5 追肥种类和配施对花生茎叶含钙量和积累量的影响

Table 5 Effects of topdressing and combined application types on calcium content and accumulation of stem and leaf in peanut

处理 Treatment	含钙量 Calcium content (%)				钙素积累量 Calcium accumulation (mg plant ⁻¹)			
	叶片 Leaf		茎秆 Stem		叶片 Leaf		茎秆 Stem	
	2017	2018	2017	2018	2017	2018	2017	2018
CK	2.03 e	1.90 de	1.03 d	0.97 cd	382.36 d	338.68 e	154.44 e	139.94 ef
N	2.13 de	1.97 cd	1.08 d	1.02 bcd	448.93 bc	394.53 cd	193.93 d	165.14 cd
B	2.15 de	2.00 cd	1.04 d	0.96 cd	400.12 cd	364.40 de	168.26 e	151.12 de
Ca	2.30 bc	2.19 ab	1.18 bc	1.06 abc	442.98 bc	414.57 bc	197.05 d	162.73 cd
NB	2.21 cd	2.08 bc	1.10 cd	1.01 bcd	468.96 bc	436.13 bc	200.05 cd	167.25 bcd
NCa	2.54 a	2.33 a	1.24 ab	1.09 ab	578.51 a	531.32 a	236.27 ab	188.50 b
BCa	2.39 b	2.31 a	1.26 ab	1.09 ab	495.69 b	439.59 b	224.20 bc	175.42 bc
NBCa	2.57 a	2.33 a	1.28 a	1.12 a	596.75 a	528.03 a	251.55 a	213.02 a

数据后面的不同小写字母表示处理间差异显著($P < 0.05$)。处理同表 2。

Different lowercase letters within a growing season indicate significant difference at the 0.05 probability level. Treatments are the same as those given in Table 2.

表 6 追肥种类和配施对花生茎叶含硼量和积累量的影响
Table 6 Effects of topdressing types and combined application on boron content and accumulation of stem and leaf in peanut

处理 Treatment	含硼量 Boron content (%)				硼素积累量 Boron accumulation (mg plant ⁻¹)			
	叶片 Leaf		茎秆 Stem		叶片 Leaf		茎秆 Stem	
	2017	2018	2017	2018	2017	2018	2017	2018
CK	0.042 e	0.052 cd	0.025 bc	0.027 c	0.79 d	0.94 c	0.38 d	0.39 d
N	0.043 e	0.052 cd	0.023 c	0.033 b	0.90 d	1.04 c	0.42 cd	0.53 c
B	0.069 ab	0.070 ab	0.031 a	0.041 a	1.29 c	1.23 b	0.49 ab	0.65 b
Ca	0.048 de	0.052 d	0.024 c	0.028 c	0.93 d	0.98 c	0.40 d	0.43 d
NB	0.074 a	0.073 a	0.029 ab	0.039 a	1.57 a	1.54 a	0.52 ab	0.65 b
NCa	0.056 cd	0.057 c	0.025 bc	0.033 b	1.27 c	1.30 b	0.48 bc	0.57 c
BCa	0.067 abc	0.067 b	0.026 bc	0.041 a	1.39 bc	1.32 b	0.47 bc	0.67 b
NBCa	0.063 bc	0.070 ab	0.028 ab	0.039 a	1.46 ab	1.58 a	0.55 a	0.74 a

数据后面的不同小写字母表示处理间差异显著($P < 0.05$)。处理同表 2。
Different lowercase letters within a growing season indicate significant differences at the 0.05 probability level. Treatments are the same as those given in Table 2.

表 7 追肥种类和配施对花生产量的影响
Table 7 Effect of topdressing types and combined application on yield in peanut

处理 Treatment	产量 Yield (kg hm ⁻²)	
	2017	2018
CK	4318.83 e	4278.70 f
N	4785.20 cd	4811.67 cd
B	4613.50 de	4510.37 ef
Ca	4694.25 cd	4707.41 de
NB	5024.89 bc	5027.97 bc
NCa	5249.56 ab	5222.04 ab
BCa	4860.16 cd	4857.22 cd
NBCa	5496.89 a	5407.41 a

数据后面的不同小写字母表示处理间差异显著($P < 0.05$)。处理同表 2。
Different lowercase letters within a growing season indicate significant difference at the 0.05 probability level. Treatments are the same as those given in Table 2.

2.6 花生茎叶干物重、养分含量和积累量与产量的相关性

由表 8 可以看出,花生产量与茎叶干物重、氮积累量、钙积累量和叶片硼积累量均呈显著正相关关系,茎叶干物重与茎叶氮积累量、茎叶钙积累量均呈显著正相关关系,茎叶氮积累量与茎叶含氮量呈显著正相关关系,茎叶钙积累量与茎叶含钙量呈显著正相关关系,茎叶硼积累量与茎叶含硼量呈显著正相关关系。说明氮硼钙配施促进了花生对氮、硼、钙的吸收积累,增加了干物质量,进而提高了产量。

3 讨论

作物较高的生物积累量是实现高产、优质生产的前提,而生物量积累则以养分吸收为基础^[24]。本试验相关分析结果表明,花生产量与茎叶干物重、氮积累量、钙积累量和叶片硼积累量均呈显著正相关关系,茎叶干物重与茎叶氮积累量、茎叶钙积累量均呈显著正相关关系。

虽然地膜覆盖技术的应用提高了作物的产量及水肥利用率,但是由于花生地下结果的特性,使地膜覆盖花生无法进行追肥,只能一次性施用速效底肥。在花生生育后期,由于根系的衰老和一次性速效底肥流失,且荚果发育对氮的需求量大,叶片氮转移到荚果中,从而引起叶片早衰,降低了叶片光合能力,进而导致减产^[25]。而膜下滴灌追肥较地膜覆盖条件下的普通施肥具有提高作物的水肥利用率和提高作物产量等优点^[26-29]。施肥能显著增加花生对氮磷钾的吸收量^[8]。于俊红等^[9]认为,在一定的施氮量范围内,增施氮肥能促进花生对氮磷钾的吸收和生长而增产,过量施氮反而导致花生养分吸收减少,产量降低。在施一定氮磷肥的基础上,增施钾肥能促进植株对氮磷钾的吸收,显著提高花生干物质积累,而增产^[30-31]。彭智平等^[10]则认为,在一定范围内,随施钾量增加花生氮磷钾吸收增多产量提高,过量施钾导致花生养分吸收减少,产量下降。施硝酸钙促进花生对氮磷镁的吸收,抑制钾的吸收^[11]。孙俊丽等^[32]认为,氮磷钾配施促进了花生对氮磷钾养分的吸收利用,

表 8 花生茎叶干物重、养分含量、积累量、产量间的相关性

Table 8 Correlation among dry matter weight, nutrient content, accumulation and yield in peanut

	Y	LDW	SDW	NCL	NAL	NCS	NAS	CCL	CAL	CCS	CAS	BCL	BAL	BCS	BAS
Y	1	0.931**	0.877**	0.479	0.906**	0.665	0.928**	0.778*	0.918**	0.628	0.788*	0.396	0.722*	0.181	0.521
LDW		1	0.900**	0.317	0.877**	0.549	0.895**	0.723*	0.928**	0.637	0.790*	0.182	0.566	-0.054	0.307
SDW			1	0.076	0.658	0.348	0.832*	0.788*	0.913**	0.759*	0.928**	0.364	0.621	-0.026	0.356
NCL				1	0.733*	0.899**	0.586	0.054	0.193	-0.240	-0.020	0.279	0.373	0.685	0.712
NAL					1	0.852*	0.938**	0.538	0.759*	0.339	0.524	0.268	0.592	0.311	0.583
NCS						1	0.830*	0.128	0.351	-0.094	0.129	0.463	0.609	0.599	0.735*
NAS							1	0.600	0.797	0.459	0.670	0.304	0.641	0.234	0.580
CCL								1	0.927**	0.922**	0.894**	0.201	0.474	-0.162	0.130
CAL									1	0.840*	0.920**	0.203	0.556	-0.120	0.232
CCS										1	0.931**	0.087	0.335	0.413	-0.151
CAS											1	0.238	0.514	-0.201	0.112
BCL												1	0.908**	0.665	0.686
BAL													1	0.528	0.696
BCS														1	0.914**
BAS															1

Y: 产量; LDW: 叶干重; SDW: 茎干重; NCL: 叶含氮量; NAL: 叶氮积累; NCS: 茎含氮量; NAS: 茎氮积累量; CCL: 叶含钙量; CAL: 叶钙积累量; CCS: 茎含钙量; CAS: 茎钙积累量; BCL: 叶含硼量; BAL: 叶硼积累量; BCS: 茎含硼量; BAS: 茎硼积累量。*和**分别表示在 0.05 和 0.01 水平上差异显著。

Y: yield; LDW: leaves dry weight; SDW: stems dry weight; NCL: nitrogen content in leaves; NAL: nitrogen accumulation in leaves; NCS: nitrogen content in stems; NAS: nitrogen accumulation in stems; CCL: calcium content in leaves; CAL: calcium accumulation in leaves; CCS: calcium content in stems; CAS: calcium accumulation in stems; BCL: boron content in leaves; BAL: boron accumulation in leaves; BCS: boron content in stems; BAS: boron accumulation in stems. * and ** indicate significant difference at the 0.05 and 0.01 probability levels, respectively

而提高产量。潮土区高产夏播花生氮磷钾肥配比能够显著提高产量和养分吸收利用效率^[33]。蔡苗等^[34]研究认为, 与不施肥及偏施氮钾肥处理相比, 氮磷配施、氮磷钾平衡施肥、有机无机配施均能够显著提高玉米氮磷钾养分含量及积累量。氮钙配施有提高氮素回收率和改善地上部氮素营养的作用, 促进氮素吸收、积累及运转, 而提高其利用率^[35]。赵朋^[36]研究也表明, 适量增施氮钙促进黄瓜对氮磷钾的吸收和积累, 适量施氮对钙的吸收也具有一定的促进作用。这与本研究结果表现一致, 即花针期追施氮、钙肥处理可不同程度地提高花生茎叶氮、钙含量和积累量, 而两两配施或氮硼钙肥同施效果好于单施处理, NCa 或 NBCa 处理的花生茎叶含氮量均明显高于单施氮、钙肥处理。说明花针期追施氮、钙肥均有利于花生茎叶氮、钙含量及积累量的提高, 且单独追施氮、钙肥效果不如氮、硼、钙肥配合施用。在追施氮肥基础上, 配合施用硼、钙肥对氮的吸收具有一定的促进作用。其中以追施氮钙或氮硼钙肥提高花生茎叶含氮量、含钙量、氮积累量和钙积累量效果较好。

Reeve 等^[37]研究发现, 缺硼条件下水培番茄植株的缺硼症状会因施入钙而加重, 但高硼条件下的毒害症状会减轻, 且硼、钙及腐植酸配合施用能够显著提高番茄的株高、果数、单果重及产量^[38]。配施钙锰硼肥对地稔分枝数、结果数和干物质量均有明显促进作用^[39]。于俊红等^[40]在南方酸性土上单施钙能促进营养物质从营养体向荚果转运调节花生生长, 单施硼增产效果明显, 钙硼配施促进各种营养元素吸收和积累, 增产效果显著。本试验研究结果表明, 花针期追施氮、硼肥可不同程度地提高花生茎叶含硼量, 氮硼肥同施效果好于单施处理。追施氮、硼、钙肥可不同程度地提高花生茎叶硼积累量, 而两两配施或氮硼钙肥同施效果好于单施处理。BCa 和 NBCa 处理的茎叶含硼量虽低于 B 或 NB 处理, 但差异并未达到显著水平, 即在本试验条件下, 硼钙肥同施未出现拮抗现象。说明花针期追施氮、硼、钙肥及氮硼钙肥配合施用有利于花生茎叶含硼量及积累量的提高。

4 结论

花针期追施氮、硼、钙肥及其相互配施均可不

同程度地提高花生茎叶干物重、含氮量和积累量、含钙量和积累量、荚果产量,但单独追施氮、硼、钙肥效果不如氮、硼、钙肥配合施用,其中以追施氮硼钙或氮钙提高茎叶干物重、含氮量和积累量、含钙量和积累量、荚果产量的效果好。追施硼可提高花生茎秆、叶片含硼量和积累量,而与氮、钙肥配施则可促进花生对硼素的吸收积累。花生产量与茎叶干物重、氮积累量、钙积累量和叶片硼积累量均呈显著正相关关系,茎叶干物重与茎叶氮积累量、茎叶钙积累量均呈显著正相关关系,茎叶氮积累量与茎叶含氮量呈显著正相关关系,茎叶钙积累量与茎叶含钙量呈显著正相关关系。本研究表明氮硼钙肥配施促进了花生对氮、硼、钙的吸收积累,增加了干物质量,进而提高了产量。

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