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Nitrogen, Phosphorus, and Potassium Interactive Effects for Improving Drought Resistance on Mung Bean Varieties

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Abstract

The planting areas of mung bean are mostly arid and semi-arid areas, and lack of irrigation conditions. Many studies have reported that fertilization can increase drought resistance. In our previous research, optimized nitrogen (N), phosphorus (P) and potassium (K) combined fertilization model was established in mung bean. In the present study, the optimal fertilization was conducted in pot trails, and mung bean varieties Bailv9 and Bailv11 were used as materials, while the four water regimes, and three fertilization ratios of F120 (optimal fertilization), F100 (conventional fertilization), F50 (half of conventional fertilization) treatments were set, to compare each fertilization ratio effects and non-fertilization condition under each water regimes respectively. Under different water conditions, the investigation of N, P, and K effects of optimal fertilization showed that the yield of Bailv9 was not sensitive to water stress and had strong drought resistance; their water sensitivity index and drought resistance coefficient were BaiLv9 as Di = 0.89 and DC = 0.79. The yield of Bailv11 was sensitive to water stress, and their drought resistance was weak; their water sensitivity index and drought resistance coefficient were BL11 Di = 1.76 DC = 0.59, and under different water treatment conditions, Bailv9 and Bailv11 all had the best yield and other related traits increase in the F120 fertilization mode compared with other fertilization and non-fertilization conditions, and the average yield increases were 31.56% and 28.08%, respectively. The pot trails conduct the drought stress treatments in mung bean varieties Bailv9, Bailv11, Bailv935 and Bailv985 to determine the function of

NPK optimized fertilization for improving plants growth in drought stress condition. Compared with the mung bean varieties treated with F50, F100, and F120, the yield of Bailv9 increased by 56.20%, 81.27%, and 107.22%, respectively; compared with that of F0, the yield of Bailv11 increased by 10.18%, 19.42%, and 45.88%, respectively; Bailv935 increased by 26.52%, 61.90%, 74.16% respectively, and Bailv985 increased by 23.78%, 56.92%, 87.62% respectively. The significant performances of optimized fertilization were also verified in 20 mung bean varieties in our filed trails. The research establishes a theoretical basis for introducing the model into production practice in the next step.

Keywords

Mung Bean, Water Sensitivity, Fertilization Sensitivity, Optimal Fertilization, Drought Improvement

1. Introduction

Drought caused by climate change and water shortages will become more serious, which will drastically affect growth and survival of plants and crops in many parts of the world [1]. The application of urea provides sufficient N to promote the synthesis and accumulation of chlorophyll in crops, thereby promoting photosynthesis, enhancing dry matter production, and promoting crop growth [2]-[4]. This is associated with physiological and cellular effects, including enhanced leaf water potential, increased photosynthetic efficiency and antioxidant enzyme activity, and enhanced accumulation and elevation of infiltrates [5]-[9]. P application alleviates dryness when drought negatively affects the relative water content, net photosynthetic rate, carbohydrate metabolism, and soluble protein content of legume crops [10]. Moreover, P fertilization improves the N fixation rate [11] [12], and a higher P content can alleviate drought-induced soybean yield reduction owing to increased water and nutrient uptake [13]. On the other hand, K fertilizer application can enhance the ability of crops to resist disease and adverse weather conditions and increase chlorophyll content, thereby enhancing the rate of photosynthesis [14].

Within a certain range, the N, P, and K fertilizers promoted plant vegetative growth, increased the chlorophyll, soluble sugar, and soluble protein concentrations, and enhanced nutrient accumulation [15]. The experiment employed various fertilization and irrigation levels to examine the effects of fertilization on plant growth. [16]. The N-fertilizer white oak showed maximum stomatal conductance than N-deficit condition. Differences in stomatal conductance changed between nitrogen fertilization treatments and drought levels [17] [18]. Several potassium fertilization ratios and well-watered and water-stressed regimes were set to conduct drought sensitivities [19]. Potassium (K), a major essential nutrient of plants can alleviate water stress tolerance in plants, and for relieving the harmful impact of drought in response to water use efficiency, growth, yield attributes, nutrient content, and yield of mung bean [20]. More intensified cropping with large amounts of fertilizer input has been conducted to obtain higher yields. However, inappropriate soil fertilization is common, and increases the negative impacts on soil environment. The excessive and imbalanced application of fertilizers has resulted in low nutrient use efficiency and high environmental risks [21] [22]. Therefore, irrigation and fertilization are two important factors influence agriculture productions, fertilization and irrigation balance play important role in agriculture [23]-[25].

Shabbir *et al.* demonstrated that combination or single application of NPK fertilizers to barley (*Hordeum vulgare*) had significant effects, with combination application being superior to single application. In different varieties of barley, NPK fertilizers significantly increased the response of drought resistance morphological indicators under water stress, including plant height, root length, dry matter mass, and root-to-shoot ratio. The combined application of NPK fertilizers can enhance the physiological and biochemical mechanisms of drought resistance in barley, including increased osmotic adjustment substances and antioxidant enzymes, as well as their activities under drought conditions. During the flowering stage, NPK enhances the regulation of stress resistance mechanisms to maintain later crop growth, ultimately improving yield and yield components under drought conditions [26] [27]. In our study, the optimal fertilization methods of mung bean were conduct to drought stress with similar performance rules, and the performance of different plant traits was different. The application of this method under different water regimes and drought conditions should consider the differential performance of plant responses.

2. Materials and Methods

2.1. Experimental Materials

Pots Test Varieties: Bailv9, Bailv11, Bailv935, Bailv985.

Field Test Varieties: Bailv9, Bailv11, Bailv935, Bailv985, Bailv12, Bailv10, Bailv8, Bailv6, Bailv14, Bailv15, Bailv522, Zhonglv5, Zhonglv8, Zhonglv11, Jilv03083, Liaolv8, Liaolv3, Tonglv918, Jilv7, Jilv9.

The seeds used in the experiment were provided by the Edible Bean Research Institute of Baicheng Academy of Agricultural Sciences. Nitrogen fertilizers (urea containing 46%N), phosphate fertilizers (superphosphate containing 12% P_2O_5) and potassium fertilizers (potassium sulfate containing 50% K_2O) were purchased from Sinochem Jilin Changshan Fertilizer Co., Ltd. (Songyuan, Jilin Province, China).

2.2. Experimental Location and Management

The experiment was conducted at the Baicheng Academy of Agricultural Sciences in Jilin Province during May to September in 2017 - 2018. Baicheng City (123˚ east longitude, 45˚ north latitude) has a temperate semi-arid continental monsoon climate. During the 2017 - 2018 test years, the average rainfall from May to September in the crop growing season was 404.93 mm, the average daily temperature was 20.03˚C, and the average sunshine duration was 1243.2 hours . At the growth periods of the trails in 2017 - 2018, the temperature and sunshine duration were not affected yield production, with the proper management. During the flowering stage of July 2017 and August 2018, there was less rainfall than there had been in previous years. Consequently, irrigation was applied once in July 2017 and in August 2018.

The soil type is chernozem (pH = 7.5) with a layer thickness of about 15 mm. The soil layer organic matter content was 2.21%, total nitrogen content was 0.19%, total phosphorus content was 0.14%, and total potassium content was 1.93%, of which available nitrogen was 120 ppm, available phosphorus was 82 ppm, and available potassium was 140 ppm.

2.3. Experimental Treatments

2.3.1. Water Regimes Treatments

Water treatment 1 (X_0): 3 times of water stress treatment after severe wilting at flowering stage (3 times of rehydration); Water treatment 2 (X_1): 5% PEG6000 water stress treatment after 1 - 2 times of normal irrigation; X_0 and X_1 were water stress treatments.

Water treatment 3 (X_2): 3 times of normal irrigation, with normal plant growth and development as the water control standard; Water treatment 4 (X_3): irrigated in case of drought, 2 - 3 times more water than the normal irrigation X_2 treatment, simulating a climate with more rainfall condition. X_2 and X_3were non-stress treatments. The water in the four treatments (X_0, X_1, X_2, and X_3) and control was increased sequentially.

2.3.2. Drought Stress Treatments

Drought stress treatment: 1) 3 times of drought stress treatment (3 times of rewatering) were carried out at the beginning of flowering, full flowering and pod setting. The drought conditions were recorded when severe drought was encountered during the flowering period, and the leaves were wilted for two consecutive days in the afternoon and then rehydrated. At each rewatering time, 80% of the leaves of the plants began to wilt, but before they curled and fell off, the water supply was 100%.

2) Natural drought conditions in the field, select plots without irrigation conditions.

2.3.3. Fertilization Treatments

Fertilizer treatment: treatment F120 (F1): optimized fertilization method of N:P:K = 1:0.55:1.16; treatment F100 (F2): for conventional fertilization, the ratio of N, P and K was 1:1.18:0.94; treatment F50 (F3): reduced fertilization, and the amount of fertilizer was reduced by half compared with treatment F100; treatment F0 (CK): no fertilization (**Table 1**).

Table 1. Fertilizer experiment formula of Mung bean.

Test Item	Fertilization treatments	Test area (m^2)	Fertilization amounts (g)	N (N46%) g	P_2O_5 (N17%, P47%) g	K_2O (K50%) g	N:P:K
Fields							
(3 replicates)	F120	1	45	15	10	20	1:0.55:1.16
	F100	1	45	10	20	15	1:1.18:0.94
	F50	1	22.5	5	10	7.5	1:1.18:0.94
	F0 (ck)	1	0	0	0	0	
Pots							
(3 replicates)	F120	0.09	4.05	0.9	1.35	1.8	1:0.55:1.16
	F100	0.09	4.05	1.8	0.9	1.35	1:1.18:0.94
	F50	0.09	2.03	0.9	0.45	0.68	1:1.18:0.94
	F0 (ck)	0.09	0	0	0	0	

2.4. Pots Experiment Design

The open-air cultivation potted experiments were conducted, and a cylindrical plastic pot was used, the bottom diameter was 25 cm, the mouth diameter was 30 cm, and the height was 38 cm. Ordinary field soil was used, the same amount of soil was loaded into each pot, watering was performed before sowing, and seedlings were thinned after emergence, leaving 8 seedlings in each pot. Four levels of fertilizer treatments and four water treatments were performed on each variety. A completely randomized design was used with 3 replicates. The rest of the time is managed normally to ensure that there is no excessive drought and growth and development are not seriously affected. Sampling at the full blooming stage for investigation and statistics of fertility traits; yield testing at the mature stage.

The yield changes of mung bean varieties Bailv9 and Bailv11 were test under X_0, X_1, X_2, X_3 water regimes respectively, to calculate the water stress sensitivity index and drought resistance coefficient, and to analyze the sensitivity and drought resistance of mung bean varieties [28]. Also, the interactions effects of water regimes and fertilization modes were tested, to evaluate the optimal fertilization performances compared with other fertilization modes under each water water treatments. Moreover, the mung bean varieties of Bailv9, Bailv11, Bailv935, Baiv985 were used to investigate the optimal fertilization responses in drought stress condition. The formula for calculating the water stress sensitivity index (Di) was as follows:

$$Di = (1 - Yd/Yp)/(1 - \text{sum } Yd/\text{sum } Yp)$$

where Yd is the yield (trait value) under water stress, and Yp is the yield without water stress (trait value). The drought resistance coefficient (Dc) is typically an important indicator for measuring the drought resistance of crop varieties and is calculated as follows:

$$Dc = Yd/Yp$$

where Dc and Di are negatively correlated with each other.

2.5. Field Verified Test Design

Variety identification test under natural drought conditions in the field. The proven and effective optimized fertilization treatment in pots was adopted, and 20 varieties of mung bean and red bean were tested under natural drought in the field. The field area was 4 m^2 and the plant spacing was 15 cm. Each cultivar was treated with 2 levels (F0 and F120) of fertilizer in a split-plot design with 3 replicates.

And set up a rain shelter, which is conducive to moisture control and eliminates the influence of rainfall. The rest of the time is managed normally to ensure that there is no excessive drought and growth and development are not seriously affected. Sampling was carried out at the full flowering stage to investigate the fertility traits, and the yield was uniformly measured at the mature stage.

2.6. Measurements Methods

Plant height: The height from the cotyledon node to the point where the petiole of the last compound leaf of the main stem is attached (apex). Number of main stem nodes: the number of nodes from the cotyledon node to the last compound leaf-bearing node at the top of the plant. Root dry weight: Randomly take all the root systems of 5 plants, weigh the fresh weight centrally, and calculate the average value. Then air dry or weigh after oven drying to calculate dry weight. The error is not more than 0.5 g, and the unit is expressed in g. Stem dry weight: All the stems of 5 plants were randomly taken, and then weighed after drying in the oven, and the dry weight was calculated. The error is not more than 0.5 g, and the unit is expressed in g. Number of pods per plant: 5 plant samples were randomly taken from each plot, and the average number of pods per plant was calculated. Number of seeds per pod: The number of seeds per pod was calculated by randomly counting the seeds in ten mature pods using the average number of seeds. Hundred seed weight: 100 seeds were weighed, repeated 3 times, and the average weight was calculated. The error is not allowed to exceed 0.5 grams, expressed in g. Plot yield: All mature plants within 6 m^2 (two rows of 5 m long) were taken from each experimental plot, and the pods were harvested manually. When the harvested grains were dried to less than 13% moisture, the plot yield was measured by weighing and expressed in kg. It is then converted into hectares of yield. Randomly select 5 single plants and excavate them with their roots, rinse with water to remove the soil from the roots, put them in a cool place to air dry and weigh the fresh weight, and calculate the average value, in g. Randomly take the root system of 5 individual plants, measure the length of the main root, and take the average value in cm.

2.7. Data Analysis

Excel was used for raw data processing and analysis, and table preparation; DPS was used for significant variance analysis, and $P < 0.05$ was considered significant difference.

3. Results

3.1. Analysis of Water Stress Sensitivity Index and Drought Resistance of Mung Bean

As shown in Table 2, the average water sensitivity indexes of the main morphological

Table 2. Analysis of water stress sensitivity index and drought resistance of mung bean.

Varieties	Traits	Water Stress Treatments			Non Stress Treatments				
		X0	X1	Average	X2	X3	Average	Di	Dc
Bailv9	Chlorophyll content	49.51	54.39	51.95	54.46	54.20	54.33	1.13	0.96
	Plant height (cm)	77.40	86.69	82.05	103.07	120.86	111.97	1.03	0.73
	100-seeds weight (g)	5.91	6.48	6.20	6.10	6.32	6.21	1.00	1.00
	Stem fresh weight (g)	36.18	49.32	42.75	85.95	55.20	70.58	1.00	0.61
	Plant pods (number)	11.01	18.94	14.97	26.24	16.53	21.39	0.99	0.70
	Lateral Roots	10.79	12.15	11.47	14.46	13.44	13.95	0.99	0.82
	Plant fresh weight	10.90	15.54	13.22	20.35	14.99	17.67	0.98	0.61
	Main stem Branches	5.12	3.92	4.52	3.53	2.46	2.99	0.98	1.51
	Leaf fresh weight (g)	27.77	26.77	27.27	52.05	33.02	42.53	0.94	0.64
	Root fresh weight	3.55	5.30	4.43	8.33	5.27	6.80	0.93	0.65
	Seeds per Pod (seeds)	12.00	13.31	12.65	14.01	13.56	13.79	0.92	0.92
	Yields kg/ha	856.8	1567.2	1212	1592.4	1473.15	1532.7	0.89	0.79
	Average							0.98	0.83
Bailv11	Chlorophyll content	49.96	52.01	50.99	51.13	49.64	50.39	−0.31	1.01
	Plant height (cm)	71.58	87.27	79.42	91.86	102.68	97.27	0.71	0.82
	100-seeds weight (g)	5.06	6.11	5.59	5.87	5.76	5.82	1.95	0.96
	Stem fresh weight (g)	40.57	56.30	48.43	99.29	63.19	81.24	1.02	0.60
	Plant pods (number)	11.09	15.64	13.37	25.89	14.38	20.13	1.11	0.66
	Lateral Roots	10.73	12.47	11.60	14.94	12.69	13.82	0.95	0.84
	Plant fresh weight	64.77	87.07	75.92	158.25	94.68	126.47	1.02	0.60
	Main stem Branches	5.09	4.16	4.62	3.29	2.45	2.87	1.18	1.61
	Leaf fresh weight (g)	27.68	32.56	30.12	59.96	34.09	47.03	0.97	0.64
	Root fresh weight	3.51	5.40	4.45	9.13	5.74	7.43	1.07	0.60
	Seeds per Pod (seeds)	12.08	12.96	12.52	12.96	12.89	12.92	0.97	0.97
	Yields kg/ha	900	1379.1	1139.55	2073.3	1797.9	1935.6	1.76	0.59
	Average							1.03	0.82

Note: Water stress sensitivity index Di = (1 − Yd/Yp)/(1 − sum Yd/sum Yp), Yd was the yield of water stress (trait value), Yp was the yield of non-water stress (trait value), Dc = Yd/Yp was the drought resistance coefficient, and Ddc was negatively correlated with Di.

indicators of Bailv9 were in the following order: chlorophyll content > plant height > 100-grain weight > fresh stem weight > pod number per plant > lateral root number > plant fresh weight > main stem branch > leaf fresh weight > root fresh weight > single pod number of grains > the yield; the average water sensitivity coefficients of the main morphological indicators of Bailv11 were in the following order: yield > 100-grain weight > main stem branch > number of pods per plant > root fresh weight > stem fresh weight > plant Fresh weight > fresh leaf weight > number of seeds per pod > number of lateral roots > plant height > chlorophyll (Table 2). The water sensitivity and drought resistance index of Bailv9 were Di = 0.89 and DC = 0.79; and Bailv11 had a Di of 1.76 and DC of 0.59 , these results indicated that Bailv9 was not sensitive to water, and its drought resistance was significantly stronger than that of Bailv11 (Table 2).

3.2. Analysis of Water and Fertilization Effect of Mung Bean

Bailv9 and Bailv11 were sensitive to fertilization effects, the yield increased under stress conditions compared with no fertilization condition. The yield of Bailv9 increased under the stress conditions in the order of F0 (ck), F120 (39.34%) > F100 (26.39%) > F50 (26.21%), with fertilizer efficiency sensitivity index of Di = 1.21; the yield of Bailv11 increased under stress conditions in the order of F100 (29.88%) > F120 (28.04%) > F50 (22.75%), with the fertilizer efficiency sensitivity index of Di = 0.71; The sensitivity index of fertilization effect was Bailv9 > Bailv11 (Table 3). Under non-stress conditions, the three fertilization treatments of Bailv9 had an increased yield compared with no fertilization F0 treatment, in the order of F50 (28.50%) > F120 (23.77%) > F100 (10.17), with the fertilizer efficiency sensitivity index of Di = 0.91; each fertilization treatment increased the yield of Bailv11, compared with no fertilization F0 treatment by order of F120 (45.37) > F100 (36.00%) > F50 (18.15%), with the fertilizer efficiency sensitivity index of Di = 1.05; the two varieties were sensitive to fertilization effect in order of Bailv11 > Bailv9. Under non-drought conditions, the halved fertilization mode of mung bean increased yield by 23.52%, compared with no fertilization, and the yield increase was smaller than that under drought conditions (Table 3).

The optimized fertilization model increased the yield of Bailv9 and Bailv11, by 33.37% and −6.98% respectively, compared with that for F100 under stress conditions, and the effects of optimized fertilization increased the yield of Bailv9 and Bailv11 by 57.21% and 20.65% respectively, compared with F100 under non-stress conditions. The above test results further illustrated that the varieties with stronger drought resistance not only had a significant yield increase under non-stress conditions; even under stress conditions, the optimized fertilization mode could still be more effective than conventional fertilization. There was a large yield increase effect, and it was more cleared that the yield increase of the optimized fertilization mode was very significant (Table 3).

The highest yields of mung bean varieties Bailv9 and Bailv11 all appeared in the F120 fertilization mode, and Bailv9 had higher yields in the two treatments of

F120X1 and F120X2. The yield of Bailv11 was higher in both treatments F120X1 and F120X2. In addition, the yield of Bailv9 for each fertilization treatment were ranked in order of F120 > F50 > F100 > F0; the yield of Bailv11 were in order of F120 > F100 > F50 > F0. Under different water treatments, the yields of the two mung bean varieties showed a trend of first increasing and then decreasing with the increase or decrease of the water gradient; and mung bean yield were significantly higher than the control (X0). The yield differences among the water treatments were significantly greater than the yield differences within the water treatments due to the different fertilizer treatments (Table 3).

Table 3. Comparative analysis of fertilization effects of mung bean yield under different water treatments.

Varieties	Water Treatments	Fertilization Treatments(Yield kg/ha)					Fertilization Effects					
		F_0	F50 (F1)	F100 (F2)	F120 (F3)	Average	(F1)%	(F2)%	(F3)%	Average	F3 increased by F2%	Di
Bailv9	X0 (ck1)	652.05	909.6	921.3	944.4	925.05	39.48	41.29	44.81	41.86	7.87	1.56
	X1 (ck2)	1367.85	1549.8	1520.1	1831.05	1633.65	13.31	11.13	33.86	19.43	67.12	0.86
	Drought Average	1009.95	1229.7	1220.7	1387.65	1279.35	26.39	26.21	39.34	30.65	33.37	1.21
	X2	1405.65	1601.7	1649.4	1712.7	1654.65	13.95	17.34	21.84	17.71	20.63	0.80
	X3	1249.05	1786.95	1286.7	1570.2	1547.85	43.06	3.01	25.71	23.92	88.30	1.02
	Non-drought Average	1327.35	1694.25	1468.05	1641.45	1601.25	28.50	10.17	23.77	20.82	57.21	0.91
	X Average	1168.65	1462.05	1344.3	1514.55	1440.3	27.45	18.19	31.56	25.73	42.35	1.06
	Total	4674.75	5848.05	5377.5	6058.2	5761.2	109.79	72.76	126.22	102.93	42.35	4.25
Bailv11	X0 (ck1)	671.85	880.35	1029.6	1017.9	976.05	465.9	53.27	51.53	45.29	−3.37	0.44
	X1 (ck2)	1295.85	1483.05	1383	1354.8	4220.85	216.75	6.72	4.55	8.57	−47.90	0.98
	Drought Average	983.85	1181.7	1206.3	1186.35	2598.45	341.25	29.99	28.04	26.93	−6.98	0.71
	X2	1851.9	1944.45	2123.25	2373.6	6441.3	75	14.65	28.17	15.94	47.99	1.01
	X3	1304.7	1713	2052.9	2121	5886.9	469.5	57.34	62.56	50.40	8.35	1.10
	Non-drought Average	1578.3	1828.8	2088	2247.3	6164.1	272.25	36.00	45.37	33.17	20.65	1.05
	X Average	1273.2	1435.95	1512	1582.05	3879.3	252.6	24.88	28.08	23.27	11.40	0.81
	Total	5124.15	6021	6588.6	6867.3	17524.95	1227	131.98	146.81	120.20	10.10	3.53

3.3. Correlation Analysis of Main Plant Traits and Yield of Mung Bean

As shown in Table 4, the results of correlation analysis between various trait indicators and yield results showed that the correlation coefficients between mung bean yield and various plant traits and yield components were as follows: the number of pods per plant (r = 0.70**) > the number of lateral roots (r = 0.0.57**) > the number of nodes in the main stem (r = 0.54**) > the number of grains per pod (r = 0.49**) > the main stem branch (r = 0.44**) > Main root length (r = 0.43**) >

chlorophyll content (r = 0.42*). The correlation coefficient between the number of pods per plant and other characters were in the order of yield (r = 0.70**) > number of lateral roots (r = 0.61**) > number of nodes in main stem (r = 0.59**) > chlorophyll content (r = 0.59**). The correlation coefficients between the number of grains per pod and other traits were in the order of number of main stem nodes (0.68**) > chlorophyll content (r = 0.59**) > yield (r = 0.49**) > main stem branches (r = 0.47 **) > plant height (r = 0.46**). The correlation coefficient between 100-grain weight and other traits were plant height (0.57**) > chlorophyll content (r = 0.53**) > main root length (r = 0.42*) > main stem node number (r = 0.42*). The size of the correlation items among other traits of mung bean were shown in Table 4.

Table 4. Correlation analysis of main traits, yield factors and yield of mung bean.

Relative Cofficients	Yields	Plant Pods	Seeds per Pod	100-seeds weight	Plant height	Main Root	Lateral Roots	Main stem Branches	main stem node number (node)	Chlorophyl l content
Yields	1	0.70**	0.49**	0.27	0.2	−0.43*	0.57**	−0.44**	0.54**	0.42*
Plant Pods	0.70**	1	0.31	0.1	0.01	−0.19	0.61**	−0.19	0.59**	0.36*
Seeds per Pod	0.49**	0.31	1	0.21	0.46**	−0.29	0.34	−0.47**	0.68**	0.59**
100-seeds weight	0.27	0.1	0.21	1	0.57**	−0.42*	0.34	−0.26	0.42*	0.53**
Plant height	0.2	0.01	0.46**	0.57**	1	−0.43*	0.43*	−0.62**	0.53**	0.35*
Main Root	−0.43*	−0.19	−0.29	−0.42*	−0.43*	1	−0.43*	0.48**	−0.3	−0.28
Lateral Roots	0.57**	0.61**	0.34	0.34	0.43*	−0.43*	1	−0.41*	0.70**	0.41*
Main stem Branches	−0.44**	−0.19	−0.47**	−0.26	−0.62**	0.48**	−0.41*	1	−0.32	−0.23
main stem node number (node)	0.54**	0.59**	0.68**	0.42*	0.53**	−0.3	0.70**	−0.32	1	0.65**
Chlorophyll content	0.42*	0.36*	0.59**	0.53**	0.35*	−0.28	0.41*	−0.23	0.65**	1

Note: $^{*}P < 0.05$, $^{**}P < 0.01$.

3.4. Correlation Analysis of Various Morphological Indicators and Yield of Mung Bean

As shown in Table 5, the correlation coefficients between the yield of mung bean and various morphological indicators were in the order, root fresh weight (r = 0.69**) > stem fresh weight (r = 0.59**) > stem dry weight (0.57**) > fresh weight of plants (r = 0.56**) > dry weight of plants (r = 0.54**) > ratio of root to shoot (0.48**) > fresh weight of leaves (r = 0.43*) > dry weight of roots (0.37*). The correlation coefficients between plant fresh weight and other morphological indicators and yield were stem fresh weight (r = 0.99**) > leaf fresh weight (r = 0.95**) > root fresh weight (0.89**) > yield (r = 0.56 **) > plant dry weight (r = 0.45**) > leaf dry weight (r = 0.43*) > stem dry weight (0.43*). The order of correlation coefficient between root fresh weight and other traits were plant fresh weight (r = 0.89**) > stem fresh weight (r = 0.88**) > leaf fresh weight (r = 0.81**) > yield (r = 0.69**) > plant dry weight (0.537**) > root/shoot ratio (r = 0.53**) > leaf dry weight (r = 0.51**). The correlation coefficients between other traits were shown in Table 5.

Table 5. Correlation analysis results between main morphological indicators and yield of mung bean.

Relative Cofficients	Yields	Fresh Plants	Root fresh weights	Stem fresh weights	Leaf fresh weights	Plant dry weights	Root dry weights	Stem dry weights	Leaf dry weights	Root/Shoot Ratio (Fresh)%
Yields	1	0.56**	0.69**	0.59**	0.43*	0.54**	0.37*	0.57**	0.45**	0.48**
Fresh Plants	0.56**	1	0.89**	0.99**	0.95**	0.45**	0.33	0.43*	0.43*	0.13
Root fresh weights	0.69**	0.89**	1	0.88**	0.81**	0.53**	0.42*	0.51**	0.51**	0.53**
Stem fresh weights	0.59**	0.99**	0.88**	1	0.88**	0.42*	0.25	0.40*	0.43*	0.13
Leaf fresh weights	0.43*	0.95**	0.81**	0.88**	1	0.43*	0.44*	0.42*	0.39*	0.05
Plant dry weights	0.54**	0.45**	0.53**	0.42*	0.43*	1	0.83**	0.97**	0.93**	0.22
Root dry weights	0.37*	0.33	0.42*	0.25	0.44*	0.83**	1	0.80**	0.74**	0.21
Stem dry weights	0.57**	0.43*	0.51**	0.40*	0.42*	0.97**	0.80**	1	0.81**	0.2
Leaf dry weights	0.45**	0.43*	0.51**	0.43*	0.39*	0.93**	0.74**	0.81**	1	0.2
Root/Shoot Ratio (Fresh)%	0.48**	0.13	0.53**	0.13	0.05	0.22	0.21	0.2	0.2	1

Note: $^{*}P < 0.05$, $^{**}P < 0.01$.

3.5 Response of Mung Bean NPK Optimal Fertilization Model Under Drought Stress

Under the condition of potted drought stress, the response results of various mung bean varieties under different fertilization modes showed that the plant height, main root length, main stem node number, and the yield of Bailv9, Bailv11, Bailv935, and Bailv985 were all equal. The best performance was under F120 (optimized fertilization mode), and the difference was significant compared with other treatments ($P <$ 0.05). Compared with other treatments, the difference was significant ($P < 0.05$), while the fresh weight of Bailv985 was not the best in F120, and the difference was significant compared with F0 and F50. There was no significant difference ($P > 0.05$) with the conventional fertilization treatment F100 ratio. The chlorophyll content of each variety was the best under the condition of F120, and was significantly ($P <$ 0.05) higher than that of F0 and F50, but had no significant difference compared with conventional fertilization treatment F100. Under different fertilization conditions, the root-shoot ratio of Bailv9 was F0 > F50 > F120 = F100. The condition was significantly ($P < 0.05$) higher than other treatments; the effect of different fertilization on the root-shoot ratio of Bailv11 and Bailv935 was F0 > F50 > F120 > F100, and there was no significant ($P > 0.05$) difference between F50 and F120 on Bailv11 , and the ratio of F0 was significantly different; F50, F100 and F120 had no significant($P > 0.05$) effect on Bailv935, but had a significant difference with F0; the response of the root-shoot ratio of Bailv985 under different fertilization conditions was, F0 > F120 > F50 > F100, and the performance of F50, F120 and F100 were not significantly different, but significantly different from F0 (Table 6). Compared with the mung bean varieties treated with F50, F100, and F120, the yield of Bailv9 increased by 56.20%, 81.27%, and 107.22%, respectively; compared with that of F0, the yield of Bailv11 increased by 10.18%, 19.42%, and 45.88%, respectively; Bailv935 increased by 26.52%, 61.90%, 74.16% respectively, and Bailv985 increased by 23.78%, 56.92%, 87.62% respectively (Table 6).

Table 6. Mung bean potted fertilizer experiment in 2017.

Varieties	Treatments	Plant heights (cm)	Main roots (cm)	Nodes number of main stem (Node)	Total fresh weight (g)	Root shoot ratio	Chlorophyll (SPAD)	Field yields (g)	Increasing yield by F0 (%)
Bailv9	F0	28c	9.83c	6c	18.07c	0.15a	42.5b	14.68d	-
	F50	31c	11.67b	8bc	25.68bc	0.12b	44.7b	22.93c	56.20
	F100	34.67b	10.67bc	10b	35.58ab	0.09c	50.2a	26.61b	81.27
	F120	42.17a	13a	12.67a	45.27a	0.09c	51.8a	30.42a	107.22
Bailv11	F0	22.67c	12.33c	5.67b	14.17c	0.24a	40.37c	14.93d	-
	F50	30b	13.33c	6b	17.27bc	0.18b	43.47b	16.45c	10.18
	F100	25c	15.33b	6.33b	25ab	0.14c	47.53a	17.83b	19.42
	F120	36.5a	17.67a	7.67a	25.93a	0.16b	47.9a	21.78a	45.88
Bailv935	F0	23.17d	10.83c	7.33b	12.03c	0.27a	45.13c	14.67d	-
	F50	28c	12bc	6.33b	32.93b	0.16b	48.57b	18.56c	26.52
	F100	33.33b	13.17b	7.83b	41.58b	0.11b	50.33ab	23.75b	61.90
	F120	36.33a	16a	9.67a	54a	0.14b	52.5a	25.55a	74.16
Bailv985	F0	24.67b	12.17b	5.33c	17.37b	0.19a	44.1c	10.26d	-
	F50	27b	13.67b	7.67b	22.2b	0.11b	46.7b	12.7c	23.78
	F100	26.33b	13.33b	7.33b	54a	0.09b	50.83a	16.1b	56.92
	F120	35.67a	17.67a	9.67a	52.9a	0.13b	52.37a	19.25a	87.62

Note: F0 is no fertilization, F50 is half of conventional fertilization, F100 is conventional fertilization, and F120 is optimal fertilization.

3.6. Response of NPK Optimization Model under Drought Stress of Multiple Varieties

Under the conditions of field drought stress, the yield of each variety with optimized fertilization treatment increased significantly compared with the control non-fertilization. In addition, among the 20 mung bean varieties treated with F0 and F120, the plant height, main root length, main stem node number and plant fresh weight of each variety treated with F120 showed significance ($P < 0.05$) or extremely significance ($P < 0.01$) compared with control treatment performance. Compared with the control treatment, the plant height of Liaolv8 and Jilv 9 increased the most, with an increase of 107.14% - 105.46%, respectively; the main root length of Zhonglv5 and Bailv14 increased the most, with an increase of

164.42% and 109.78% respectively; the number of main stem nodes of Zhonglv11, Liaolv3 and Jilu7 increased the most, increased by 81.43%, 76.14% and 76.37%, respectively. The fresh weight of plants of Zhonglv11, Liaolv3 and Liaolv8 increased significantly, which increased by 404.34%, 832.99% and 522.22%, respectively. The root-shoot ratio of each mung bean cultivar was significantly lower under the F120 condition, and the response under the F0 condition, which may be due to the significant increase in the root-shoot ratio under drought stress. There was no significant difference in the increase in the root-shoot ratio of F120 of each variety compared with the control (Table 7).

Table 7. Mung bean field fertilizer experiment in 2018.

Varieties	Plant height (cm)		Main root (cm)		main stem node number (node)		Total Fresh weights (g)		Root/shoot ratio		Yields (kg)		
	CK	F120	CK	F120	CK	F120	CK	F120	CK	F120	CK	F120	Increasing by CK(%)
Bailv9	59.33	90.33**	12	16.33*	9	11.67*	77.87	133.76*	0.137	0.093*	0.30	0.81*	171.37
Bailv11	55	77*	22	26.67**	8.67	10.33*	94.37	184.1*	0.173	0.049**	0.42	0.86**	104.97
Bailv935	73.67	83.67**	10.33	17.67**	9.33	11.33*	77.07	167.97*	0.146	0.047**	0.24	0.48**	98.33
Bailv985	98	129.33*	12.67	17*	10	12.67**	71.87	103.07**	0.137	0.037**	0.30	0.52**	73.72
Bailv12	53.33	74.33**	13.67	20**	7.67	11*	48.33	108.27**	0.145	0.04**	0.19	1.12*	477.89
Bailv10	63.67	108*	15.67	19**	8.6	10.33*	57.83	112.07*	0.163	0.042**	0.26	0.79**	199.67
Bailv8	82.67	105.67**	15	20.33*	9.67	12.67*	222.3	176.17*	0.137	0.036**	0.29	0.82*	188.17
Bailv6	70.33	104.33*	16.67	22.33*	10	13*	108.13	142.1*	0.15	0.037**	0.28	0.58**	110.66
Bailv14	94.67	110**	13.67	21.67*	9.67	12.33*	89.33	151.23*	0.147	0.027**	0.23	0.6*	162.73
Bailv15	86.33	127.33*	15.33	19.67*	10.33	13.1**	116.57	153.7*	0.087	0.038**	0.39	0.81*	108.29
Bailv522	72.67	80.67	13.33	18*	9.67	11.67*	99.33	112*	0.069	0.034*	0.33	0.86*	160.78
Zhonglv5	40.67	73**	9.33	24.67**	7	8.67	21.5	68**	0.147	0.08*	0.43	0.91**	114.28
Zhonglv8	57.33	75*	14.33	19.67*	8	10.33*	49.27	68.57*	0.176	0.086*	0.27	0.97*	265.51
Zhonglv11	48	70.33**	12	18*	5.33	9.67*	17.74	89.47**	0.429	0.069**	0.28	0.76*	173.15
JL03083	78.33	101.67**	14	18*	7	10.17*	37.13	95.53*	0.1	0.036**	0.21	0.74**	250.92
Liaolv8	42	87**	12	15.33**	8.33	9.33**	77.3	96.03*	0.12	0.04**	0.37	0.61*	66.89
Liaolv3	57.33	73**	13	22.67*	7	12.33**	26.37	246.03*	0.293	0.036**	0.33	0.71**	118.25
Tonglv918	51	73.33*	10.33	21.67*	6.33	9*	37.47	58.6*	0.123	0.073**	0.24	0.6*	153.66
Jilv7	42.67	87.67**	11.33	14.67**	5.67	10*	20.6	128.2*	0.115	0.051**	0.23	0.71**	215.40
Jilv9	60.67	85.33**	15	18.67*	7	10*	59.67	88.47*	0.14	0.065*	0.38	0.78*	103.36

Note: CK was non-fertilization, F120 was optimal fertilization.

4. Discussion

Crops have different response mechanisms to water stress during the seed germination, seedling, flowering, and fruit-bearing stages. Studies have found that the germination rate and potential of tomato at the germination stage are inhibited under different water stress conditions [29] [30]. Soybean under water stress at the flowering stage, the material distribution in each organ is affected at different stages, altering the source-sink relationship and affecting yield [31] [32]. Water stress at the soybean pod setting stage affects phase morphology and physiological characteristics [33]. During the vegetative growth and flowering periods of chickpeas, all measured physiological indicators have been observed to be affected by water stress, among which chlorophyll *a* and *b* and total chlorophyll are significantly affected by drought [34]. The chlorophyll content of adzuki bean varieties was significantly lower under drought. A study on drought stress reported that the investigated indicators were all affected by drought, and the plants responded in a specific manner, wherein plant height and root fresh weight both decreased [35]. In different mung bean varieties, from the flowering to maturity stages, water control stress, seed pod, grain yield, and other indicators showed that the yield under drought stress decreased by approximately 22% [36]. In the present study, yield composition and yield under drought stress were significantly lower than those in the other treatments. With the intensification of drought stress, the root-to-shoot ratio of different adzuki bean varieties increases significantly [28] [35]. Correspondingly, in the current study, the root-to-shoot ratios of adzuki bean varieties under drought conditions were higher than those in other treatments [37]. Fertilization can increase drought resistance in crops [38] [39] [40].

In this study, it was found that mung bean under different fertilization patterns under drought conditions, had the worst performance when the conventional fertilization rate was halved (F50). The chlorophyll and yield components of mung bean (the number of pods per plant, the number of grains per pod, and the weight of 100 grains), root-shoot ratio, under the conditions of conventional fertilization (F100) and optimized fertilization (F120), were all superior and had no significant difference, while there were no significant differences in the number of seeds per pod and the weight of 100 seeds in the three fertilization modes. Under drought stress of mung bean, optimal fertilization (F120) treatment had significantly higher plant height, main root length, main stem node number, plant fresh weight, and yield than other treatments, showing the superiority of optimal fertilization method. To sum up, the optimal fertilization methods of mung bean respond to drought stress with similar performance rules, and the performance of different plant traits is different. Therefore, the application of this method under drought conditions should consider the differential performance of plant responses. In the multi-variety verification experiment, the optimized fertilization model achieved good performance for mung bean varieties, but the performance of different varieties was significantly different. Therefore, in future research, comprehensive factors such as species differences and environmental differences should be further considered.

Under the condition of water stress, the optimized fertilization study of mung bean with N, P, and K clarifies that Bailv 9 is not sensitive to water, and its drought resistance is significantly stronger than that of Bailv 11, while Bailv 9 and Baihong 6 are semi-full creeping and infinite pod-bearing cultivars, which further proves that The drought resistance of cultivars is closely related to growth habit and pod-setting habit. In particular, when comparing the fertilization patterns of the four varieties under stress and non-stress conditions for yield indicators, it was found that the three fertilization treatments significantly increased the yield compared with no fertilization treatments, and under drought conditions, the optimized fertilization method of mung bean increased the yield by up to 34.57%; These test results further indicated that the optimized fertilization method enhanced the drought resistance of the plants.

The water stress sensitivity index and drought resistance coefficient are the main indicators for measuring drought resistance in crops in the field [40]. Through the water stress sensitivity index, drought resistance coefficient, fertilization effect analysis and correlation analysis, the number of pods per plant, fresh stem and root dry weight, and chlorophyll content, which are significantly related to the yield of mung bean, have a large contribution rate to the response to water stress. It can be used for the main technical indicators of water and fertilizer regulation and identification. Especially in the flowering stage, the chlorophyll content in the leaves of mung bean is significantly different from the water sensitivity among the varieties. In addition, the field measurement of this index is simple, easy and accurate, and can be used as one of the main physiological indicators for the identification of drought resistance during the growth period of mung bean.

Fertilizer to water, water to fertilizer, water and fertilizer coordination is one of the main strategies in crop cultivation. With the warming of the climate and the shortage of water resources, more and more attention has been paid to the balanced fertilization and water-fertilizer coupling technology in the research and development and production of modern agricultural cultivation technology.

In the fertilization effect analysis in this study, it was found that under stress conditions, the average yield of mung bean was increased by 24.59% compared with no fertilization; The other main characters, such as the number of pods per plant, 100-grain weight, the number of lateral roots and the fresh weight of stems, also showed an obvious increasing trend. However, under non-drought conditions, the halved fertilization mode of mung bean increased yields by 23.52% and 21.28%, respectively, and the yield increases were smaller than those under drought conditions.

The number of pods per plant, the number of nodes in the main stem, the number of grains per pod, the branches of the main stem, the length of the main root, the fresh weight of the root, the fresh weight of the stem, the dry weight of the stem, the dry weight of the plant, and the fresh weight of the stem were selected. weight, and the chlorophyll content and plant height that are easily affected by water and fertilizer factors; According to the correlation analysis results, under the same drought stress, The other main characters, such as the number of pods per plant, 100-grain weight, the number of lateral roots and the fresh weight of stems, also showed an obvious increasing trend.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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