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Influence of Magnesium on Photosynthetic Characteristics and Growth Effects of Sugarcane at Seedling Stage

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Abstract: In this study, the effects of different concentrations of magnesium on photosynthetic characteristics and growth of sugarcane cultivars Roc22 and YT00-236 at seedling stage were investigated by combined cultivation of sand culture with nutrient solution. The results showed that under the stress of low magnesium, the synthesis and photosynthesis of chlorophyll are blocked with significantly decreased biomass accumulation, increased root-shoot ratio and slowed growth rate. Appropriate treatment of magnesium (0.1mmol/L) can promote sugarcane photosynthesis with maximal biomass, significantly decreased root-shoot ratio and increased growth rate. Excess With excessive treatment of magnesium (1mmol/L), the photosynthetic rate is lower than the value under low magnesium stress; Once the overall growth of sugarcane is inhibited, however, the growth is better than low magnesium stress. It is found that the photosynthesis and growth effects of ROC22 are stronger than that of YT00-236. It is preliminarily deduced that ROC22 is a sensitive variety of magnesium.

Keywords: Sugarcane, Magnesium, Photosynthetic Characteristics, Growth Effect

Introduction

Magnesium is an essential element for plant growth and a component of chlorophyll molecules, accounting for 2.7% of chlorophyll molecular weight (Kasinath *et al*., 2014). Magnesium can maintain the structural stability of chloroplast thylakoid membrane. Its main function is to maintain a certain conformation of natural pigment, action center and membrane at the molecular level, maintain the close relationship between the electronics carriers and ensure the effective absorption, transfer and transformation of light energy (Kong *et al*., 2016; Sun *et al*., 2017). Farhat thought magnesium deficiency hindered protein synthesis and reduced chlorophyll content. If photosynthesis is blocked, the harvest of crops will be reduced (Farhat *et al*., 2016). The tropical and subtropical regions of southern China are the main sugarcane producing areas, where it is hot and rainy and the leaching loss of magnesium is serious. The effective magnesium content is low and the soil magnesium supply potential is also low in these regions (Yu, 2015). Under the condition of soil available magnesium deficiency, the application of magnesium fertilizer to sugarcane is very effective and the economic benefit is higher (Liu *et al*., 2013). In addition, because magnesium is a metal ion and when the concentration of magnesium in the environment is too high, excessive magnesium ions would not only poison the plants but also inhabit the absorption and transport of plant to potassium and calcium, which would lead to the decrease of yield and quality (Huda and Ibrahim, 2010; Domingues *et al*., 2016). In this study, the effects of magnesium on photosynthetic characteristics and growth of sugarcane at seedling stage are investigated through a combination of sand culture and nutrient solution culture and a theoretical basis for the nutrition physiology of sugarcane is provided.

Materials and Methods

Experiment Designs

Varieties of culture seedlings of sugarcane: ROC22 and YT 00-236.

Culture medium: particle size selected is 0.6mm-2mm of river sand after cleaning and removing the soil and silt with clean water, washing with hydrochloric acid (in order not to dissolve salts from sands or adsorb salts from culture medium during the test). Wash it to neutral and then wash two times using deionized water after hydrochloric acid washing. A plastic bucket with small holes at the bottom has 8-12 kg sand, dried for sugarcane seedlings transplant. The nutrient solution of the test is the standard solution after proper improvement of Hoagland (Tocquin *et al*., 2003). The nutrient solution of P and Mg were separately prepared in this experiment.

The test was conducted at the glass house of the Institute of Biotechnology, Guangdong Ocean University from Aug.12 to Oct.27, 2016. The plastic bucket was immersed in the nutrient solution with 5cm depth for cultivation. Under the condition of 0.1mmol/L phosphorus level, test set treatments (Mg_0, Mg_1, Mg_2) on three magnesium levels (0, 0.1 and 1 mmol/L) and with three times of repetition, 18 buckets in all with three plants in each bucket. The test was managed according to the greenhouse test. The deionized water was supplemented every day to maintain the nutrient concentration of nutrient solution, adjusting the pH of nutrient solution to 6.0. The nutrient solution was replaced 1-2 times weekly and the moss both inside and outside the bucket was removed. The plant height of sugarcane was investigated every 15 days during the growth period. After 75 days of cultivation, the chlorophyll content and biomass of the plants were determined.

Determination Items and Methods

Determination of chlorophyll content: Referring to the method of Zhang *et al*. (2015), which was improved to use 1:1 volume ratio between acetone and absolute ethyl alcohol; Digesting leaves 24 h in the dark, 721 UV spectrophotometer respectively measured the extraction solution at 646 nm and 663 nm absorbance and calculated the chlorophyll a and b content of the unit mass with the formula of Lichtenthaler (Lichtenthaler and Wellburn, 1983).

Determination of photosynthetic parameters: The portable LI-6400 type photosynthetic measurement system produced by the US LI-COR company was used to determine the net photosynthetic rate (Pn, $CO_2\mu mol/m^2s$), transpiration rate (Tr, H_2Omol/m^2s), stomatal conductance (Gs, mol/m^2s) and CO_2 concentration in intercellular space (Ci $\mu mol/m^2s$) in sufficient light.

Determination of agronomic traits: Agronomic traits such as plant height, leaf number and stem diameter of sugarcane were measured every 15 days during the growth of sugarcane.

Determination of fresh weight, dry weight and root-shoot ratio: After 75 days of transplant, the above-ground and below-ground of sugarcanes were harvested and the fresh weights of them were weighed. Finally, they were put into the oven for fixation at 105°C for 30 min and the body matter was weighed at 80°C after constant temperature drying. Root-shoot ratio Root/Shoot） = the below-ground biomass/ the above-ground biomass × 100%.

Data Reduction

SPSS17.0 and Excel 2003 software were used to make statistics and drawings. The Duncan's method was used for significant comparison and the significant level was α = 0.05.

Results

Effects of Magnesium on Photosynthetic Characteristics of Sugarcane

Effects on the Chlorophyll Content of Sugarcane Leaves

Table 1 showed that under the condition of sufficient supply of phosphorus, the chlorophyll content of sugarcane increased with the increase of magnesium level. Especially in the variety of ROC22, the chlorophyll content increased by 4.28 mg/g from level of Mg_0 to level of Mg_2. Under the treatment of each magnesium level, the total chlorophyll content of ROC22 was higher 1.72~4.67 mg/g than YT00-236. Based on the results of multiple comparisons, it was preliminarily deduced that Mg_1 level was the most suitable for YT00-236 chlorophyll synthesis; Mg_2 level was the most conducive to chlorophyll synthesis of ROC22 and ROC22 was more sensitive to magnesium than YT00-236. Additionally, chlorophyll content of ROC22 was restricted by chlorophyll a, while YT00-236 was restricted by chlorophyll b.

Table 1: Effect of different magnesium treatments on chlorophyll content in sugarcane leaves

Varieties	Treatments	Chl a (mg/g)	Chl b (mg/g)	Total content (mg/g)
ROC22	Mg_0	13.08c	3.98c	17.06c
	Mg_1	14.17b	4.21b	18.38b
	Mg_2	16.25a	5.09a	21.34a
YT00-236	Mg_0	1.28a	14.06b	15.34b
	Mg_1	1.37a	15.56a	16.93a
	Mg_2	1.34a	15.33a	16.67a

Chl a, Chlorophyll a; Chl b, Chlorophyll b. Values followed by the same letter(s) are not significantly different at 5%, the below is same.

Effects of Magnesium on Photosynthetic Parameters of Sugarcane

The results (Table 2) also showed that the values of photosynthetic parameter of ROC22 were obviously higher than those of YT00-236. It was speculated that the photosynthetic intensity of ROC22 was larger than that of YT00-236 under most treatments with different magnesium levels. At Mg_1 level, all the values of photosynthetic parameter reached the maximum in two sugarcane varieties, except for the value of Ci in ROC22. Especially, the inhibition of photosynthetic rate in YT00-236 was more obvious. The photosynthetic inhibition under excess magnesium stress was stronger than that under low magnesium stress both in ROC22 and ROC22 and it was likely that excessive magnesium ions inhibited the absorption and transport of sugarcane to potassium and calcium, thus inhibiting the photosynthesis of sugarcane.

Influences of Magnesium on the Growth Effect of Sugarcane

Influences of Magnesium on the Growth Rate of Sugarcane

Magnesium had significant effects on plant height of two varieties, especially with the extension of cultivation time (Fig. 1). After 45 days of treatment, the plant height of Mg_1 level began to be larger than that of Mg_0 level and Mg_2 level in ROC22. After 30 days of treatment, the plant height of Mg_1 level was significantly different from that of Mg_0 level and Mg_2 level in YT00-236. The test results showed that a moderate amount of magnesium (0.1mmol/L) promoted the growth of sugarcane, while excessive amount (1mmol/L) of magnesium inhibited sugarcane growth. This was similar with the research of Xu *et al*. (2009) that a proper amount of magnesium fertilizer had a significant effect on the growth and development of flue-cured tobacco, while too low or too high magnesium can both inhibit the growth and development of flue-cured tobacco. Under the treatment of each magnesium level, the plant height of ROC22 was greater than that of YT00-236 and the difference was more obvious with the prolongation of treatment time, which was also in accordance with the trend of the effects of different magnesium levels on photosynthesis.

Effects of Magnesium on Biomass Accumulation of Sugarcane

It can be seen from Table 3 that in the case of sufficient phosphorus supply, biomass of the two varieties was $Mg_1>Mg_2>Mg_0$, indicating that magnesium could promote biomass accumulation of sugarcane. No matter it was ROC22 or YT00-236, both of their fresh and dry weight increased with the improvement of magnesium level. Moreover, under the treatment of Mg_1 level, the promoting effect was the most obvious, the difference was significant with Mg0 treatment and the biomass accumulation was the most. The treatment with Mg_2 level inhibited biomass accumulation.

Table 2: Effect of different magnesium treatments on photosynthetic parameters in sugarcane leaves

Varieties	Treatments	Pn (CO2μmol/m2s)	Gs (H2Omol/m2s)	Ci (mol/m2s)	Tr (μmol/m2s)
ROC22	Mg_0	18.68 b	0.204 b	179.41 a	4.93 b
	Mg_1	21.41 a	0.226 a	157.67 b	6.09 a
	Mg_2	20.41 a	0.171 c	144.33 b	5.69 a
YT00-236	Mg_0	15.99 a	0.116 b	109.90 b	3.39 a
	Mg_1	15.73 a	0.150 a	169.89 a	3.72 a
	Mg_2	10.75 b	0.077 c	103.16 b	2.32 b

Pn, Net photosynthetic rate, Gs, Stomatal conductance, Ci, CO2 concentration of intercellular space, Tr, Transpiration rate

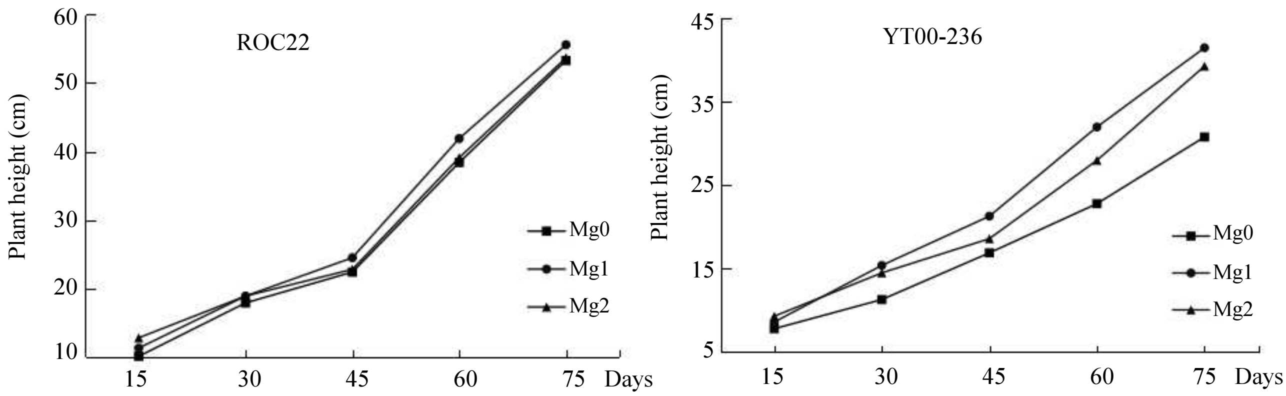

Fig. 1: Effect of different magnesium treatments on plant height in sugarcane

Table 3: Effect of different magnesium treatments on biomass in sugarcane

Varieties	Treatments	Fresh weight (g)	Dry weight (g)
ROC22	Mg_0	84.28b	20.12b
	Mg_1	126.93a	31.74a
	Mg_2	112.45ab	29.34ab
YT00-236	Mg_0	111.58b	23.80b
	Mg_1	192.13a	42.60a
	Mg_2	162.30ab	38.20a

Table 4: Effect of different magnesium treatments on root-shoot ratio in sugarcane

Varieties	Treatments	Root dry weight (g)	Shoot dry weight (g)	Root/shoot (%)
ROC22	Mg_0	4.34c	19.46b	22.31b
	Mg_1	7.42b	35.18a	21.09b
	Mg_2	7.72a	30.48a	25.33a
YT00-236	Mg_0	2.84b	17.28c	16.44c
	Mg_1	5.65a	26.09a	21.66b
	Mg_2	6.71a	22.63b	29.64a

That indicates an appropriate amount of magnesium can promote the growth and development of sugarcane, which was conductive to the accumulation of bio-synthesis matter, thus contributing to the formation of yield. In addition, the biomass of ROC22 was higher than that of YT00-236. This was consistent with the fact that the output of ROC22 was higher than YT00-236 in actual production.

Effect of Magnesium on the Root-Shoot Ratio of Sugarcane

It can also be seen from Table 4 that magnesium can promote the growth of the root and above-ground both in ROC22 and YT00-236, however, the trend is different. In the treatment of ROC22, the growth rate of above-ground is higher than that of the roots at Mg_1 level, resulting in a decrease of root-shoot ratio. While in the treatment of YT00-236, the root-shoot ratio is at a minimum due to the growth stagnation of root caused by the treatment of low magnesium stress at Mg_0 level. At Mg_2 level, because magnesium can promote the growth of roots and inhibit the growth of above-ground, resulting in the maximum root-shoot ratio of the two varieties. It is possible that the high magnesium treatment inhibited the transportation of root nutrients to the above-ground, resulting in the accumulation of root nutrient and the growth of root system.

Discussion

According to the result of the test of the yield, sucrose content and benefits of sugarcane growing in acidic soil with deficiency of available Mg content, Hu *et al*. (2017) put forward that the application of magnesium fertilizer to sugarcane was conducive to improving plant height, stem diameter and etc, which was conducive to the improvement of yield. Yin *et al*. (2009) generalized the advances in the research progress of tobacco magnesium nutrition that magnesium can promote photosynthesis and physiological metabolism of tobacco leaves, thus promoting the growth of tobacco plants and improving the quality of tobacco leaves. Moreover, magnesium deficiency would lead to block in photosynthesis and physiological metabolism of leaves and had adverse effects on the growth of tobacco plants and leaves. Similar results have been found in this sugarcane test. When the concentration of magnesium was 0.1mmol/L, the photosynthetic rate, transpiration rate and stomatal conductance of the two varieties reached their best and the accumulation of biomass was the most. Because the condition for plant height and tiller growth was optimal, growth of the above-ground is faster than the below-ground and then the root-shoot ratio decreased significantly. When there was no magnesium supply, the growth and development of sugarcane were obviously hindered.

In the effect of magnesium deficiency stress on the growth and ion balance of maize seedlings, Xiong *et al*. (2010) proposed that that magnesium deficient stress reduced the plant height, root length, dry and fresh weight of maize seedlings and weakened the vigor of each strain. Moreover, the distribution imbalance of N elements in the above-ground and root parts interfered with the metabolism of N elements and destroyed the ion balance in maize seedlings and inhibited the growth of corn seedlings. Farhat *et al*. (2016) also showed that the chlorophyll content of plants was reduced under the condition of magnesium deficiency and photosynthesis was blocked, which seriously affected the growth and development. The chlorophyll content of soybean also decreased significantly under magnesium deficiency, however, appropriate amount of magnesium could effectively increase the chlorophyll content of soybean (Wang *et al*., 2004). This experiment shows that sugarcane also has the corresponding performance. When there was no magnesium supply, the content of chlorophyll a and b in sugarcane both decreased; photosynthesis was blocked; biomass accumulation decreased obviously; growth rate slowed, plant dwarfed and less tillered. Meanwhile, in order to adapt to the magnesium stress environment, the root of ROC22 is developed and the root-shoot ratio is higher, while the root and the above-ground of YT00-236 are inhibited, especially the decrease of the root material accumulation and the root- shoot ratio. In addition, whether or not the growth and development of sugarcane is hindered due to the imbalance of N elements needs further study.

The rational application of magnesium nutrition and magnesium fertilizer is also very important for the growth of tobacco. The appropriate amount of magnesium (75-100 kg/hm^2) can increase the yield and quality in flue-cured tobacco leaves. Moreover, the higher magnesium application level (100-125 kg/hm^2) resulted in a significant increase in the content of nonvolatile organic acids and the deterioration in upper and middle leaves of tobacco quality (Yao *et al*., 2017). Similarly, the excessive magnesium treatment in soil reduced the plant height, root length and chlorophyll content in bean leaves. The higher the concentration of magnesium was, the more severe the physiological indexes were (Huda *et al*., 2010). The practice of sugarcane production proves that the balanced efficiency of magnesium fertilizer has economic significance for high yield of sugarcane. This test showed that in the case of excess magnesium treatment (1mmol/L), the photosynthetic rate was lower than the magnesium deficiency stress; the toxicity of magnesium ions inhibited root absorption and transport of nutrients, which makes the root growth developed. The root-shoot ratio was significantly higher than that of Mg0 treatment, but its overall growth trend was still better than that under low magnesium stress. This is different from the nutritional effects of magnesium on soybean tobacco and tomato. Therefore, only a moderate amount of magnesium is beneficial to the growth of sugarcane.

It was found that the photosynthesis and growth effects of ROC22 were stronger than those of YT00-236, which was the reason of the higher yield of ROC22 in actual production. According to the response of ROC22 to different magnesium nutrition levels, it was preliminarily inferred that ROC22 was a magnesium sensitive variety. However, the study on the migration and metabolic pathway of magnesium in two sugarcane genotypes is not enough. The basic research on effects of magnesium on enzyme activity of photosynthesis, physiological characteristics of root system, absorption kinetics and transporter expression should be carried out to construct the theoretical research system of magnesium nutrition in sugarcane. According to the results of the sand culture experiment, the absorption efficiency of magnesium was different between the two genotypes of sugarcane, but when magnesium level was about 0.1mmol/l, the growth of sugarcane was most affected and too low or too much was not good for biomass increase efficiency. Therefore, it is necessary to make suitable magnesium fertilizer application scheme according to different sugarcane varieties and different soil magnesium supply conditions and to determine the best magnesium fertilizer application rate in the production practice.

Conclusion

Under the stress of low magnesium, the synthesis and photosynthesis of chlorophyll are blocked with significantly decreased biomass accumulation, increased root-shoot ratio and slowed growth rate. Appropriate treatment of magnesium (0.1mmol/L) can promote sugarcane photosynthesis, make biomass reach the maximum, root-shoot ratio decrease significantly and growth rate increase. With excess treatment of magnesium (1mmol/L), the photosynthetic rate is lower than the value under low magnesium stress; the overall growth of sugarcane is inhibited, however, the growth is better than low magnesium stress. The effects of magnesium on ROC22 and YT00-236 were significantly different. The photosynthesis and growth effects of ROC22 are stronger than that of YT 00-236 (YT00-236). It is preliminarily deduced that ROC22 is a sensitive variety of magnesium.

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Author’s Contributions

Chao Zheng: Designed and performed the numerical experiments. Revised the manuscript.

Yong-Xiang Huang: Performed the numerical experiments, analyzed the data and wrote the paper.

Ke-Xing Liu: Designed experiments and revised the manuscript.

Ethics

The authors declare their responsibility for any ethical issues that may arise after the publication of this manuscript.

Conflict of Interest

The authors declare that they have no competing interests. The corresponding author affirms that all of the authors have read and approved the manuscript.

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