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Net assimilation rate dynamics of cotton during the growth stages under zinc element regulation

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ABSTRACT

It is well known that zinc can promote plant growth and enhance its resistance, but the influence of zinc on cotton net assimilation rate has not been reported. The change rule of cotton's net assimilation rate under the application of zinc element is studied by means of field trial, which provides a scientific basis for reasonable application of zinc fertilizer for cotton. The results show that cotton net assimilation rate (NAR) is associated with growth period and consumption of zinc. NAR shows a tendency of rising first and then decreasing with the growing period; the maximum NAR appears during bud stage ~ flowering stage (LH). NAR shows an obvious rising tendency with the increase of zinc dosage during the earlier growth stage (seedling stage ~ full blossom stage), and the NAR is obviously decreased with the increase of zinc dosage during the middle and later growth stage (flowering stage ~ boll opening stage). After the later growth stage (boll-forming stage), NAR is not obviously responded to zinc. And the NAR in the experiment group at all stages is lower than that of the control group (no zinc treatment). During full blossom stage ~ boll-forming stage, zinc dosage and NAR are significantly associated in the linear relationship, exponential relationship and quadratic curve relationship; Quadratic curve of one variable is more significant (R^2 = 0.7349). Cotton production firstly raises and then falls with the increase of zinc consumption. When $ZnSO_4 \cdot 7\ H_2O$ is 20 kg/hm^2, cotton production reaches the highest.

KEYWORDS

Zinc element; Cotton; Net assimilation rate; Dynamic change; Regulation.

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INTRODUCTION

Net assimilation rate (NAR) refers to the net efficiency of plant photosynthesis, therefore, it is also known as Photosynthetic produce rate of plants. Gregory et al. defines net assimilation rate as the increment of leaf dry weight in a unit area within a certain period[1]. Then scholars from all countries set NAR as an important indicator for the plants' growth status to carry out studies. In addition, it can also indicate the critical conditions of plants' absorption of mineral nutrition[2, 3], thus providing new thought for diagnosing the enrichment and the paucity of mineral nutrition. Abundant carbon dioxide assimilation is needed to complete photosynthetic metabolism during the growth stage of cotton; when the absorptive amount of carbon dioxide decreases, it will affect the growth of cotton plant and the increase of yield[4]. The apparent results can be measured by net assimilation rate. Some researchers think that water deficit and overweight of soil salinity will severely restrain the photosynthesis and breath of wheat and corn[5,6], and applying potash fertilizer can effectively increase the net assimilation rate of potatoes[7], thus relieving the influence of water and salinity on the crops. As zinc element is an essential mineral element for cotton's growth, whether the enrichment and the paucity of zinc element can be indicated by net assimilation rate is a significant research topic. Therefore, study on the influence of zinc element application on the net assimilation rate of cotton in different growth stages can provide theoretical reference for rational application of fertilizer as well as high-yield cultivation and management for cotton.

MATERIAL AND METHOD

The experiment was carried out in Alar, Xinjiang during 2008~ 2009, where the soil was sandy soil. The organic content was 10.9g/ kg (potassium dichromate volumetric method), total nitrogen content was 1.01 g/kg (kjeldahl method), alkali-hydrolyzale nitrogen was 98.3 mg/kg (alkali-hydrolyzed reduction diffusing method), rapidly available phosphorus content was 12.1 mg/kg (Mo-Sb colorimetric method), rapidly available potassium content was 168 mg/kg (digestion by neutral ammonium acetate - flame photometry), available zinc content in the soil was 0.613 mg/kg (digestion by DTPA- AAS method), the content was low (the critical value of the zinc in the soil was 0.5 mg/kg, however, for the calcareous soil in Xinjiang, the content of available zinc would be deemed as deficit if it was less than 1.0 mg/kg).

Randomized blocks design was completely adopted in the experiment, with single factor and six levels adopted, which was repeated for 3 times. Zinc fertilizer ($ZnSO_4 \cdot 7H_2O$) shall be pure analytical chemical reagent, basal application (mix each part of fertilizer and 5kg fine grained soil, then uniformly scatter the mixture in the ditching between lines, with the fertilizing depth of 10 cm) dosage was 0kg/ hm^2 (CK), 10 kg/ hm^2, 20 kg/ hm^2, 30 kg/ hm^2, 40kg/ hm^2 and 50 kg/ hm^2 respectively; the area of the plot was 38.4 m^2. The tested cotton cultivar was Zhongmiansuo No. 49 (Zhongmiansuo referred to Institute of Cotton Research of CAAS), with no fertilizer topdressed and no mepiquat chloride sprayed during the growth stage, topping after measured during boll opening stage. Measure the leaf area and the dry matter weight of an entire cotton during seedling stage ~ full bud stage (indicated by ML), full bud stage ~ full blossom stage (indicated by LH), full blossom stage and boll forming stage (indicated by HL) as well as boll-forming stage ~ boll opening stage (indicated by LX), with each measurement carried out between two irrigations. The leaf area shall be measured for the 10 designated cottons in the plot, so as to obtain the leaf area of a single plant, then obtain the successive 5 plants in the middle line and border line respectively (10 plants in total) in a random manner to measure and obtain the dry matter weight of a single plant. The leaf area shall be calculated by length-width method. The net assimilation rate (NAR) shall be calculated in line with Radford[8] formula.

$$NAR = \frac{(DM_2 - DM_1) / \ln LA_2 - \ln LA_1)}{(LA_2 - LA_1)(t_2 - t_1)}$$

Where $DM1$ and $DM2$ are the dry matter weight at t 1 and t 2 respectively; $LA1$ and $LA2$ are the average leaf area of a single plant at t 1 and t 2 respectively.

The theoretically measured yield shall be the test result, and it shall be measured according to the following measuring method:

$$SCY(kg/hm^2) = [\mathrm{NPH} \times \mathrm{ABQ} \times \mathrm{A}SCW]/1000$$

In the above formula, SCY is abbreviation of seed cotton yield, NPH means number of plants per hectare, ABQ means average boll quantity of a single plant, and ASCW is abbreviation of average seed cotton weight of a single boll (g).

Measurement of boll quantity of a single plant: measure 30 plants of mature boll quantity in each plot, and obtain the average boll quantity of a single plant to be the result (where the young bolls and buds are not calculated).

Measurement of seed cotton weight of a single boll: designate 30 cotton plants in each plot, collect them after boll opening on a regular basis, accumulate the weight of the seed cotton collected in each plot after many collections to obtain the seed cotton weight of the 30 plants, then calculate the weight of a single boll of each plant, and divide the boll quantity of a single plant to obtain the average seed cotton weight of a single boll.

Measurement of line spacing: count 11 lines (10 line spacing) at one site, measure the total width and divide 10 to obtain a line spacing. Measurement of plant spacing: take 21 plants in a line in a site (20 plant spacing), measure the total length and divide 20 to obtain a plant spacing. Measure 3 sample sites of line spacing and plant spacing in each spot to obtain the average value as the results.

$$\text{Plant quantity per hectare} = \frac{1000\text{m}^2}{\text{Line spacing (m)} \times \text{Plant spacing (m)}}$$

Carry out basic processing and tendency analysis on the data via Microsoft Excel 2003, and carrying out data analysis via SAS9. 0.

RESULT AND DISSCUSS

With the increase of zinc element dosage, cotton yield shall rise before decrease, and progressively increase when $ZnSO_4 \cdot 7H_2O$ increases from 0 kg/ hm^2 to 20 kg/ hm^2. As shown in Figure 1, the marginal yield of zinc during this level section of zinc application (refers to the increment of the total yield due to the increase of unit fertilizer application input under the condition that the input of other production factors stays unchanged) shall rise before decrease, and decrease to the minimum when $ZnSO_4 \cdot 7H_2O$ reaches about 20 kg/ hm^2, the cotton yield shall reach the maximum at this moment. With the increase of $ZnSO_4 \cdot 7H_2O$ dosage, the marginal yield shall be a negative value. During the level section of zinc application from 20 kg/ hm^2 to 60 kg/ hm^2 of $ZnSO_4 \cdot 7H_2O$ dosage, with the increase of zinc application, cotton yield shall become lower and lower; however, the marginal yield becomes abnormal, i.e., the absolute value of marginal yield shall decrease gradually. Under the set processing, the zinc element level and the yield have certain quadratic correlation. The fitted equation for fertilizer effect shall be y =-0. 1625 x^2 + 7. 8751 x + 280. 56, multiple correlation coefficient R^2 =0. 7349, which reaches the significant level of 0.05 as verified. Rational and effective zinc application can not only achieve higher economic yield of cotton, but also increase the biological yield of cotton, i.e., dry matter accumulation. High biological yield of cotton is the premise of high yield, and also the building for high yield frame in cotton production. Net assimilation rate calculated through biomass (amount of dry matter) is closely linked to the economic yield of cotton to a great extent.

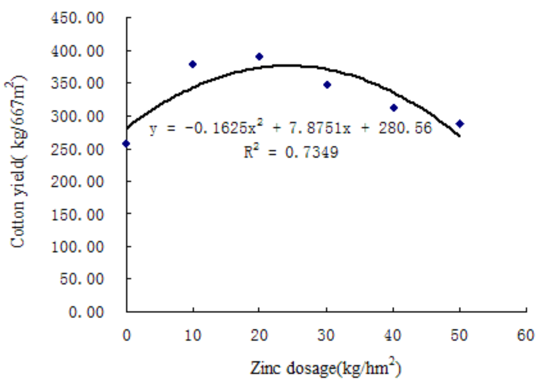

Figure 1 : Dynamic of cotton yield by zinc regulation

As shown in Figure 2, in the four periods of seedling stage ~ bud stage (indicated by ML), bud stage~ flowering stage (indicated by LH), flowering stage and boll-forming stage (indicated by HL) as well as boll-forming stage ~ boll opening stage (indicated by LX), net assimilation rates under different zinc application levels see the same tendency, i.e., NAR rises before decreases with the cotton's growth, and reaches the maximum value during full bud stage and full blossom stage. Without zinc fertilizer application, net assimilation rate reflects rising tendency after flowering stage ~ boll-forming stage; however, this is significantly different from that under the condition of zinc application, where the more zinc element is applied, the faster NAR will decrease.

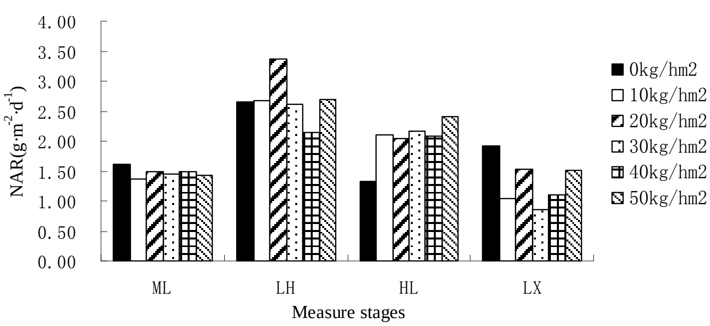

Figure 2 : Dynamics of NAR in different growth stages by zinc fertilized

(Note: The cifferent letters of sort marks show notable siversity of 5%)

Seen from the variation tendency of NAR, during cotton's vegetative growth stage and early reproductive growth stage (seedling stage ~ bud stage, bud stage ~ flowering stage), zinc element can effectively increase NAR, while during full vegetative growth stage (flowering stage ~ boll-forming stage, boll-forming stage ~boll opening stage), with the increment of zinc dosage, NAR decreases obviously. The reasons for the decrease of NAR may include: firstly, the falling of the leaves on the lower part of the plants and falling of some cotton bolls during the cotton's late growth stage; secondly, the coordination mechanism among individuals adopted by the plants to adapt to group growth after mass propagation. Through SAS8.0 variance analysis and DUNCAN multiple comparisons, it can be known that the cotton's NARs in each stage all have significant differences, where the maximum NAR appears during the period from full bud stage to full blossom stage, followed by the period from full blossom stage to boll-forming stage; then NAR starts to decrease as the cotton bolls become mature. During the period from boll-forming stage ~ boll opening stage (LX), there is no significant difference between the NAR from that during full vegetative growth stage (ML) (See Figure 2).

Applying zinc can effectively increase the cotton's NAR, in particularly during the period from bud stage ~ boll-forming stage. During seedling stage ~ full bud stage (ML), the effect of zinc on cotton's NAR is not so significant, with no significant difference among the NAR values measured under all zinc dosage levels. During the period from full bud stage ~ full blossom stage (LH), when $ZnSO_4 \cdot 7H_2O$ reaches 20 kg/ hm^2, the cotton's NAR can be significantly increased. During the period from full blossom stage ~ boll-forming stage (HL), applying zinc has very significant effect on NAR: under the several set processing levels, with the increase of $ZnSO_4 \cdot 7H_2O$ dosage, NAR reflects increasing tendency, with the maximum value appearing at 50 kg/ hm^2 of $ZnSO_4.7H_2O$. During late reproductive growth stage, the cotton's NAR becomes abnormal, when NARs are all less than the comparison values under zinc processing, and poisoning to cotton appears. The reasons for such results may be related to the cotton's absorption law for zinc element. During bud stage ~ boll-forming stage, its growth is the most vigorous, with high photosynthesis and high zinc use ratio; while after boll-forming stage, the nutrition needed by the cotton decreases, and the metabolism inside it weakens. As the irrigation for cotton reduces during the late stage, the conversion and transformation of zinc element in the soil which has a slow conversion speed further slows down, which results in surplus zinc element within a short time.

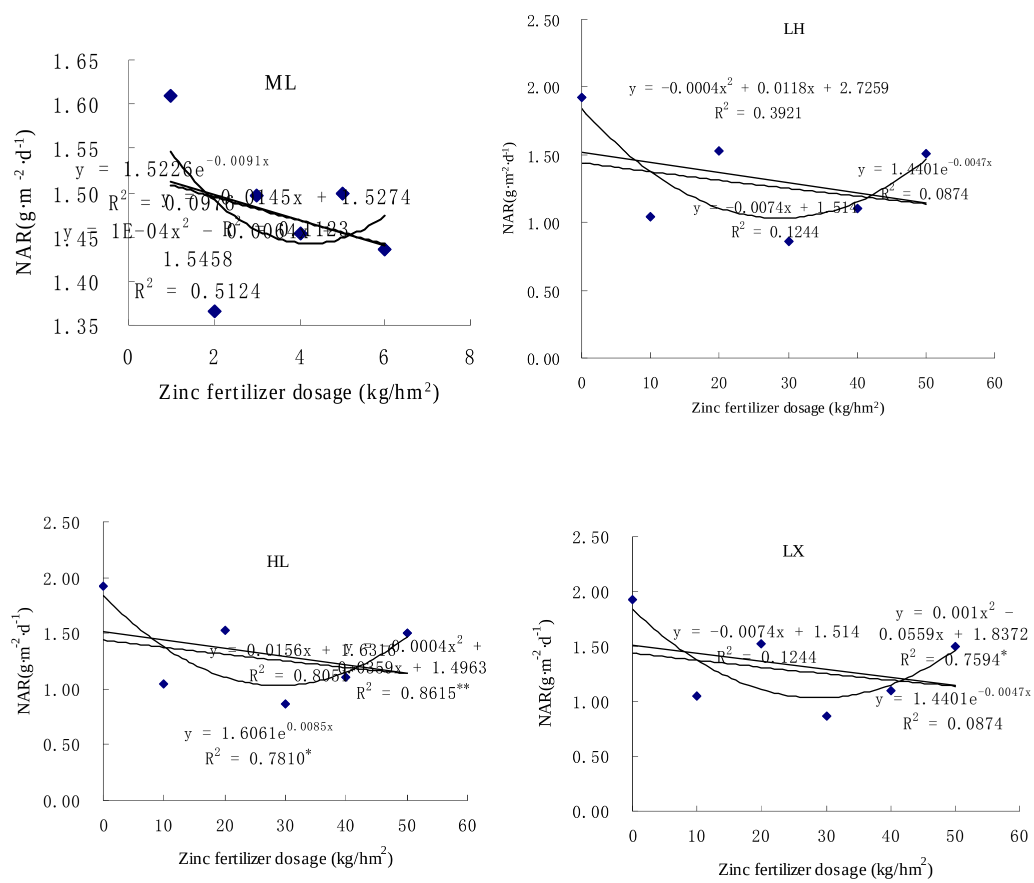

Figure 3 : The relationship between cotton NAR and zinc amount applied in different stages

During the 4 growth stages of ML, LH, HL and LX as measured in the experiment, the zinc element dosage and NAR all have linear relationship, exponential linear relationship and quadratic curve relationship; however, during ML, LH and LX stage, the relationships all reflect certain negative linear correlation, but the correlation is not significant. However, positive linear correlation occurs during HL stage, and R^2, the multiple correlation coefficient of linear equation $y = 0.0156\, x + 1.6316$ can reach 0.8051, which is the significant level of 0.05; the correlation coefficient of exponential equation $y = 1.6061e^{0.0085\, x}$ also reaches the significant level of 0.05 ($R^2 = 0.7810$), and the quadratic curve $y = -0.0004\, x^2 + 0.0359\, x + 1.4963$ reaches the significant level of 0.01 (multiple correlation coefficient $R^2 = 0.8615$). During LX stage, zinc element dosage and NAR also have significant quadratic curve relation, but the correlation at this moment decreases (See Figure 3).

Figure 3 evidently shows that the contribution rate of zinc dosage to the cotton's NAR is small during cotton's vegetative growth stage and early reproductive growth stage, with poor correlation between the two. During late reproductive growth stage, its contribution rate increases vigorously, in particularly during the period from flowering stage to boll-forming stage, when linear relationship, exponential linear relationship and quadratic curve relationship all reach significant level, which shows that during HL stage, cotton's absorptive and metabolic activities for zinc are both the most exuberant. The two appear significant quadratic curve relationship till maturation stage (LX), which all indirectly proves that nutrient absorptive amount, absorption efficiency and photosynthetic metabolism of the plants all weaken evidently during mature period.

NAR is not only an important indicator of plants' respiratory metabolism, but also a scale to measure photosynthesis. Singh M and Singh S think that additional sodium source ($NaHCO_3$) not only has significant negative correlation with pea's growth rate and yield, but also has significant negative correlation with its NAR, however, this varies greatly among different breeds[9]. Geok-Yong Tan finds that during the dry matter accumulation of medicago sativa, nitrogen assimilation rate contributes most to the plants' photosynthetic productivity, that's because medicago sativa can efficiently convert luminous energy into the contribution to dry matter yield after biological nitrogen fixation[10]. Xia Gengshou et al. also found that potassium could also effectively increase potato's NAR[7]. Therefore, the influences of some nutrient elements on plants' NAR have been proved; however, there has been rarely any report on the study on the influence of zinc element both home and abroad.

CONCLUSIONS

Cotton's economic yield is highly related to its high yield frame (high biomass accumulation), therefore, it is also closely related to NAR which is calculated by amount of dry matter. This experimental study finds that with the increase of zinc element dosage, cotton yield rises before decreases. During cotton's growth and development period, NAR reflects the tendency of rising before decreasing all the time, with the maximum value appearing at early reproductive growth stage (bud stage ~ flowering stage), then it will decrease to the level at vegetative growth stage as the cotton grows and develops, and even to a lower level. Generally, the crops' NARs all have the variation tendency of quadratic convex parabola of one variable; however, the growth stage when the zenith appears differs due to the difference of crop varieties and genes. During each growth stage of the cotton, zinc can all effectively affect the NAR. During early growth stage (seedling stage ~ full blossom stage), with the increase of zinc dosage, NAR reflects evident increasing tendency, while during middle and late growth stage (flowering stage ~ boll opening period), with the increase of zinc dosage, NAR will obviously decrease. Seen from the experimental results, cotton yield and the variation of NAR reflects certain synergistic effect under different zinc element dosages, with both reaching the maximum when zinc element reaches approximately 20 kg/hm^2. This shows that certain amount of zinc element can increase cotton's biomass accumulation and NAR, which is conducive to increasing the yield, therefore, reasonable zinc application can provide favorable guarantee for high yield by promoting carbohydrate accumulation for cotton.

The study finds that during late growth stage, in particularly boll-forming stage, the cotton appears to be zinc poisoned due to high zinc concentration in the soil solution and the plants. During this period, no matter how much the dosage is, NAR will always be less than the comparison values, with the difference reaching extremely significant level. The reasons for this result may be related to cotton's absorption law for zinc element. After boll-forming stage, as various metabolisms in the cotton plants weaken, the cotton needs less nutrition, which reduces the use ratio of zinc; therefore, the zinc applied in the soil will present increased zinc concentration in the surface soil under the condition of relatively less water in the soil during the late growth stage of the cotton. It is this short-term "gathering" of zinc element that poisons the cotton which needs little zinc during its late growth stage, moreover, the irrigation frequency and irrigation amount in maturation period is artificially reduced to avoid boll falling and promote boll opening, which leads to the results indicated in the experiment.

The contribution rate of zinc element to cotton's NAR differs in different growth stages, and the relationship between the two also differs. However, seen from the results, during the period from full blossom stage ~ boll-forming stage, linear relationship, exponential relationship and quadratic curve relationship are all significant, but the fitting of quadratic curve of one variable is better. The multiple correlation coefficient R^2 of the regression equation can reach 0.8651**, therefore, it can be deemed that the cotton's absorptive and metabolic activities for zinc are both the most exuberant from full blossom stage to boll-forming stage. Applying zinc to the soil is adopted in this study. According to the experiment conclusion, we think that applying zinc to the soil has certain effect, however, as for cotton's growth; zinc fertilizer shall be applied by means of basal application and topdressing for the purpose of achieving the fundamental goal of high yield for exuberant biotic community. Topdressing during full blossom ~ boll-forming stage can not only increase the biomass of the cotton, but also effectively improve the assimilation and photosynthetic efficiency of carbon dioxide. In addition, it can also increase the contribution ratio of zinc element.

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