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不同水分条件下常规尿素和控释尿素对玉米根冠生长及产量的影响

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摘 要: 为了进一步探讨控释尿素在玉米上的应用效果, 于 2006—2007 年在防雨棚中, 应用郑单 958 进行了池栽试验。在不同水分条件下, 比较了施用常规尿素和控释尿素后, 玉米各生育阶段的根系活力、植株生长及籽粒产量。与常规尿素(全部基施和基施+小喇叭口期追施)相比, 地上部干重、叶面积指数开花前较低, 开花后较高; 成熟期籽粒产量显著高于不施氮对照和两个常规尿素处理, 生物产量显著高于不施氮对照和常规尿素全部基施处理。从籽粒产量看, 维持土壤田间最大持水量的 50% 时, 控释尿素处理分别比常规尿素全部基施处理和分次施处理高 27.3% 和 12.1%; 维持土壤田间最大持水量的 75% 时, 分别比常规尿素全部基施处理和分次施处理高 17.4% 和 8.1%。相同氮肥处理, 土壤田间最大持水量维持 75% 处理比维持 50% 处理籽粒产量和生物产量平均分别高 20.6% 和 17.0%, 差异均达极显著水平。与常规尿素处理相比, 控释尿素处理花前根系数量、活性和根冠比均较低, 但花后三者能维持较高水平。可见, 控释尿素对玉米生长具有明显的“前控后保”效果; 控释尿素与水分对玉米产量的耦合效应高于常规尿素, 其原因是生育后期能维持较高的根系数量及活性, 促进地上部干物质积累和转移。

关键词: 田间持水量; 常规尿素; 控释尿素; 玉米; 根冠比; 产量

Effects of Normal Urea and Release-Controlled Urea on Root and Shoot Growth and Yield of Maize in Different Water Conditions

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Abstract: As a prosperous fertilizer in crop production, release-controlled urea (CU) promotes the yield of maize (*Zea mays* L.) and nitrogen use efficiency with less environmental pollution than normal fertilizers. However, the interaction effects of CU and soil water content on the growth and development of maize have been rarely reported. In this study, the maize cultivar Zhengdan 958 was used to compare the differences of root activity, root and shoot growth, and yield between treatments with normal urea and CU under two water soil moisture conditions. The experiments were carried out in pools (10 m in length, 60 cm in width, and 1.2 m in depth) under a mobile water-proof shelter in 2006–2007. The normal urea was applied with basal (100% applied before sowing, NU) and split (40% applied before sowing and 60% applied at pretasselling stage, NS) dressing methods, whereas, the CU was totally applied before sowing. No urea applied was taken as the control. The results showed that the shoot dry weight and leaf area index of CU treatments were higher after anthesis and lower before anthesis than those of NU and NS treatments. As a result, the grain yield of CU treatment was significantly higher than those of NU and NS treatments, and the biomass of CU treatment was significantly higher ($P < 0.05$) than those of NU treatment and control. Under the condition of soil moisture at 50% of field capacity (W1), the grain yield of CU treatment was higher than those of NU and NS treatments by 27.3% and 12.1%, respectively. Under the condition of soil moisture at 75% of field capacity (W2), the grain yield of CU treatment was higher than those of NU and NS treatments by 17.4% and 8.1%, respectively. In the same urea treatment, the average values of grain yield and

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biomass were higher by 20.6% and 17.0% under W2 than those under W1, respectively. Root weight, root activity, and root/shoot ratio were lower before anthesis in CU treatment than in NU and NS treatments, but higher after anthesis in CU treatment than in NU treatment. The results suggest that the CU could have a remarkable early-decrease-and-late-increase effect on maize growth, and its coupling effect with soil moisture was higher than that of normal urea. The positive coupling effect of CU might be caused by the higher root activity and root/shoot ratio after anthesis, which could increase the accumulation and transportation of dry matters in the aboveground organs.

Keywords: Field water capacity; Normal urea; Controlled release urea; Maize; Root/shoot ratio; Yield

水分和氮素调控是作物高产优质栽培技术体系的重要组成部分。水分胁迫影响根系的生长和分布, 并通过协调根冠关系对地上部的生长和发育进行调控^[1-2]。施氮可以显著促进作物生长, 降低根冠比, 提高产量, 但是施氮量较大时氮素利用率却显著降低^[3-4]。水分和氮素对根、冠生长不仅存在单独效应, 也存在耦合效应^[5-7]。在水分和常规尿素对玉米根冠生长的影响方面, 前人研究主要集中在对产量的影响上, 而对根冠生长的报道较少。已有研究表明, 在土壤干旱状况下增施氮肥, 或者在低肥条件下增加灌水量, 均可显著提高玉米产量; 在节水节肥条件下, 通过氮水耦合也可以实现玉米高产^[8-10]。但水分和控释尿素对玉米根冠生长及产量的耦合效应鲜见报道。与常规肥料相比, 控释肥料可显著提高玉米产量和肥料利用率, 并减少对环境的污染^[11-13]。Shoji 等^[14]研究指出, 控释氮肥不仅能提高玉米产量和氮素利用率, 而且能提高玉米氮素吸收总量。随着控释尿素生产成本的降低和产量的增加, 控释尿素在生产中的应用成为化学肥料发展的重要趋势之一。本研究旨在探讨不同土壤水分条件下, 常规尿素和控释尿素对玉米根系数量与活性分布、根冠生长及产量影响的差异, 为控释尿素在玉米高产优质高效实践中安全合理利用提供理论依据和技术借鉴。

1 材料与方法

1.1 试验设计

为了克服盆栽试验与大田种植差异较大、而大田种植根系取样较难等不足, 2006 年和 2007 年在山东农业大学农学实验站活动式防雨棚内进行池栽试验。试验池水泥砌成, 长 10 m, 宽 60 cm, 深 1.2 m, 将玉米植株按照 25 cm 株距用 PVC 板固定防水膜隔开, 然后从田间逐层取土填实。土壤为棕壤土, 0~20 cm 土层含有机质 12.9 g kg⁻¹、全氮 1.0 g kg⁻¹、碱解氮 89.8 mg kg⁻¹、速效磷 52.6 mg kg⁻¹、速效钾 88.9 mg kg⁻¹。

两年均设 2 个水分处理, 分别于开花后维持土

壤田间最大持水量的(50±5)%(W1)和(75±5)%(W2)。2006 年设 3 个氮肥处理, 即不施氮对照、常规尿素基施 150 kg N hm⁻²(NU)和包膜控释尿素基施 150 kg N hm⁻²(CU); 2007 年增加常规尿素 150 kg N hm⁻²分次施处理(基施 40%, 其余 60%于小喇叭口期追施, NS)。控释尿素(含氮 43.47%)由山东金正大生态工程股份有限公司提供。

玉米品种为郑单 958, 6 月 11 日播种, 每池中央播 3 粒, 三叶期每池定苗 1 株, 其他管理同高产田。为了尽量模拟大田种植情况, 每个处理播 3 行, 仅在中间行取样, 3 次重复。

1.2 生长指标和产量测定

于大喇叭口期、开花期、乳熟期和成熟期取样, 3 次重复, 每重复取 2 株。用叶长×叶宽×0.75 法测定叶面积。取植株地上部, 分成籽粒、秸秆两部分, 于 105℃杀青 30 min, 80℃烘至恒重后测定各部分干物质质量。将已取地上部样品的池中土分 6 个层次, 0~50 cm 土层每 10 cm 为一个层次, 50~120 cm 为一个层次, 每个层次的土全部取出, 把根小心地完全冲出, 快速洗净、去杂, 并挑除死根后, 测定根系活力和根干重。用 TTC 还原法测定根系活力^[15], 每个样品随机取样, 测定 3 次。

1.3 数据处理

用 DPS 7.05 软件分析数据, 用最小显著极差法(LSD_{0.05})进行平均数显著性检验, 取 $P = 0.05$ 。用 ORIGIN PRO 8.0 软件作图。两年的试验结果趋势基本一致, 除 NS 处理数据外, 其他均为两年的平均数。

2 结果与分析

2.1 玉米叶面指数动态

施氮处理玉米叶面积指数均高于对照。大喇叭口期, W1 条件下表现为 NU>NS>CU>CK; W2 条件下 NS、CU>NU>CK。开花期与大喇叭口期基本一致, 不同的是在 W1 条件下 NS>CU>NU>CK, 说明大喇叭口期追施尿素已发挥作用(图 1)。乳熟期至成熟期, 叶面积指数均表现为 CU、NS>NU>CK。与 W1 相比, W2 处理玉米前期叶面积指数较高, 且花后叶

面积指数降低的速率较慢,从而更有利于植株干物质的积累。表明控释尿素和适宜的水分可以维持较高的花后叶面积指数,利于夏玉米产量的提高。

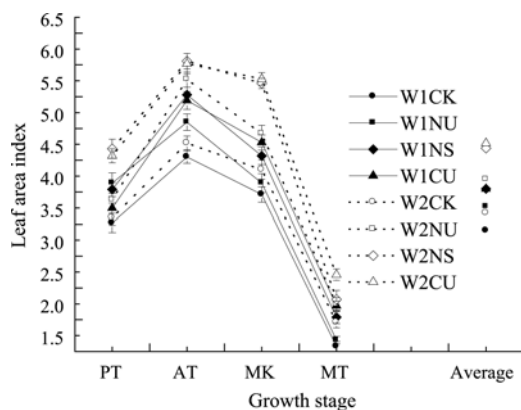


图 1 玉米不同处理的叶面积动态变化

Fig. 1 Dynamic change of leaf area index of maize in different treatments

W1: soil moisture at 50% of field capacity; W2: soil moisture at 75% of field capacity. CK: no urea applied; NU: 150 kg N hm⁻² normal urea, totally applied before sowing; NS: 150 kg N hm⁻² normal urea, 40% applied before sowing and 60% applied at pre-tasselling stage; CU: 150 kg N hm⁻² controlled release urea, totally applied before sowing. PT: pretasselling; AT: anthesis; MK: milking; MT: maturity.

2.2 玉米地上部干物质积累动态

施氮能显著提高玉米花后的干物质量,在水分充足的条件下增幅更显著。与常规尿素处理相比,包膜控释尿素处理开花期前干物质积累量较小,低于 NU 和 NS 处理;但开花期高于 NU 处理,而低于 NS 处理;乳熟期和成熟期均表现为 CU>NS>NU>CK。与 W1 处理相比, W2 处理的花后干物质量均提高(图 2)。

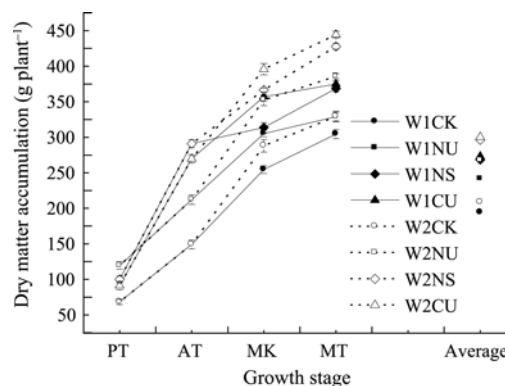


图 2 不同处理玉米干物质积累动态

Fig. 2 Dry matter accumulation of maize in different treatments

Treatments described as in Fig. 1.

2.3 籽粒产量

土壤水分状况和尿素类型直接影响作物产量(表 1)。统计分析表明,氮肥、水分以及水氮耦合作用对籽粒产量和生物产量的影响均达显著水平。在相同的水分条件下施氮具有极显著的增产效果,籽粒产量和生物产量均为 CU>NS>NU>CK。W1 时 CU 处理的籽粒产量分别比 NS 和 NU 处理高 12.1%和 27.3%; W2 时 CU 处理的籽粒产量分别比 NS 和 NU 处理高 8.1%和 17.4%。氮肥和水分对生物产量的影响与对籽粒产量的影响基本一致。相同的氮肥处理, W2 比 W1 籽粒产量和生物产量平均分别提高 20.6%和 17.0%,均达极显著水平。表明氮肥和水分具有良好的耦合效应,相同水分条件下包膜控释尿素的耦合效应均高于常规尿素。两个水分条件下, CU 和 NS 处理的秸秆产量差异不显著,但籽粒产量均达显著水平,这得益于收获指数的提高。

表 1 不同处理的玉米产量

Table 1 Yield of maize in different treatments (g plant⁻¹)

处理 Treatment	籽粒产量 Grain yield	秸秆产量 Straw yield	生物产量 Biomass yield
W1CK	147.6 f	156.0 d	303.7 f
W1NU	166.1 e	170.0 c	336.0 e
W1NS	188.5 d	180.1 bc	368.6 d
W1CU	211.4 c	190.8 b	402.1 c
W2CK	159.7 ef	168.8 c	328.4 e
W2NU	214.9 c	192.0 b	406.9 c
W2NS	233.5 b	213.1 a	446.6 b
W2CU	252.4 a	215.5 a	467.9 a

Values followed by different letters within a column are significantly different at $P<0.05$. Treatments described as in Fig. 1.

2.4 根系数量和活性的时空分布

2.4.1 根系的数量的时空变化 0~20 cm 土层玉

米根干重最高,占总根干重的 55.0%~69.9%,随着土层深度的增加,根干重所占比例呈下降趋势,但

仍有 7.0%~22.6% 的根干重分布在 50~120 cm 土层 (表 2)。开花期, 总根干重为 NU>NS>CU>CK, 各土层中均以 NU 的根干重最高; 在乳熟期, W1 条件下总根干重为 NS>CU>CK、NU, 而 W2 时则为 CU>NS>NU、CK。成熟期, W1 和 W2 条件下总根干重均为

CU>NS>NU>CK。说明施用控释尿素利于玉米后期维持较多的活性根系。在 50~120 cm 土层中, CU 处理花后根干重高于 NU 和 NS 处理。同一施氮处理, 灌水量增加时总根干重降低, 且更多地分布在较浅的土层中。

表 2 玉米根干重的时空分布
Table 2 Temporal and spatial distribution of root dry weight of maize (g)

时期 Growing stage	处理 Treatment	土壤层次 Soil layer						合计 Total
		0-10 cm	10-20 cm	20-30 cm	30-40 cm	40-50 cm	50-120 cm	
开花 Anthesis	CK	11.36 d	2.56 bc	2.03 b	1.40 b	2.22 a	5.73 b	25.30 c
	NU	17.89 a	2.90 a	2.55 a	1.83 a	1.89 ab	7.20 a	34.26 a
	NS	14.62 b	2.70 b	2.44 a	1.53 b	1.61 b	5.36 b	28.26 b
	CU	13.10 c	2.45 c	2.38 a	1.45 b	1.55 b	4.91 c	25.84 c
乳熟 Milking	W1CK	10.79 bc	3.13 c	2.10 bc	1.49 bc	1.83 bc	5.39 bc	24.72 b
	W1NU	11.16 bc	3.40 bc	1.98 c	1.13 cd	1.75 bc	4.57 c	23.98 b
	W1NS	13.15 ab	3.47 ab	2.51 ab	1.86 ab	2.44 a	6.12 ab	29.54 a
	W1CU	15.30 a	3.78 a	2.72 a	2.11 a	2.63 a	6.65 a	33.18 a
	W2CK	9.45 c	1.63 e	1.22 d	1.02 cd	0.93 e	2.34 d	16.59 c
	W2NU	9.18 c	1.91 de	1.35 d	0.91 d	1.06 de	2.32 d	16.73 c
	W2NS	10.91 bc	1.81 e	1.39 d	1.47 bc	1.42 cd	3.05 d	20.05 bc
	W2CU	13.25 ab	2.18 d	1.87 c	1.81 ab	1.88 b	4.57 c	25.54 b
成熟 Maturity	W1CK	6.54 e	1.61 c	1.21 d	0.98 de	0.94 cd	1.18 de	12.45 de
	W1NU	7.49 d	1.59 c	1.76 b	1.21 c	1.03 bc	1.42 bc	14.50 c
	W1NS	8.65 ab	2.42 b	1.52 c	1.28 c	1.03 bc	1.53 ab	16.42 b
	W1CU	9.02 a	2.83 a	2.06 a	1.88 a	1.32 a	1.67 a	18.77 a
	W2CK	6.50 e	1.55 c	0.96 e	0.88 e	0.88 d	0.98 ef	11.74 e
	W2NU	7.82 cd	1.51 c	1.09 de	0.99 de	1.01 bc	0.93 f	13.34 cd
	W2NS	8.02 bcd	1.60 c	1.29 d	1.04 d	1.06 b	1.27 cd	14.28 c
	W2CU	8.39 abc	2.64 ab	1.91 ab	1.51 b	1.09 b	1.59 ab	17.12 b

In each growth stage, values followed by different letters within a column are significantly different at $P<0.05$. Treatments described as in Fig. 1.

2.4.2 根系活性的时空变化 不同层次根系活力均随生育期的推进先增加后降低, 呈单峰曲线变化 (图 3)。在 0~50 cm 土层中, 玉米根系活力在 0~10 cm 的活性最强, 10~20 cm 其次, 在其他层次则相对较弱。相同水分条件下, 开花期各土层中根系活力基本表现为 NU>NS>CU>CK; 而花后各时期各土层的根系活力基本表现为 CU>NS>NU>CK。相同氮素条件下, W2 处理的花后的根系活力均高于 W1 处理。表明花后保持适宜的水分条件或施用控释尿素则利于维持较强的根系活力。

2.5 根冠比动态

由图 4 可知, 相同水分条件下, 玉米大喇叭口期根冠比 CK>NS>NU>CU, 开花期各处理根冠比则为 CK>NU>NS>CU。乳熟期 W1 条件下 CK、NU>NS、CU, 而 W2 时 CU>CK>NS、NU。成熟期, 相同水分条件下, 根冠比均以 CU 处理最高。这表明施氮降低了玉米的根冠比, 相同施氮量时常规尿素处理的根冠比要高于控释尿素处理, 但控释尿素处理在乳熟期后仍能维持较高的根冠比。与 W1 处理相比, W2 处理各时期的根冠比较低。上述结果表明, 在干旱、

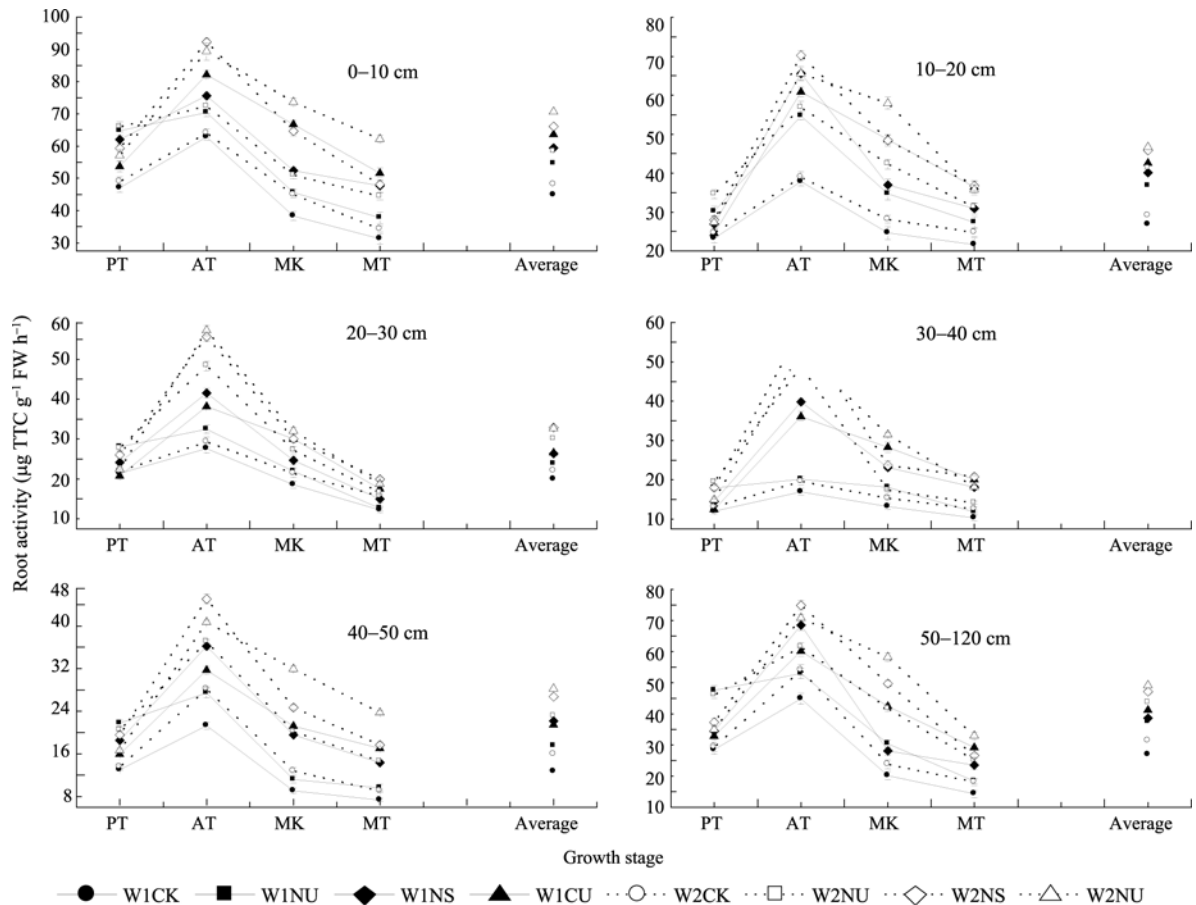


图 3 玉米根系活力的时空变化
Fig. 3 Temporal and spatial changes of root activity of maize
Abbreviations as in Fig. 1.

低肥条件下, 玉米可以通过提高根冠比来增加对水分和养分的吸收。

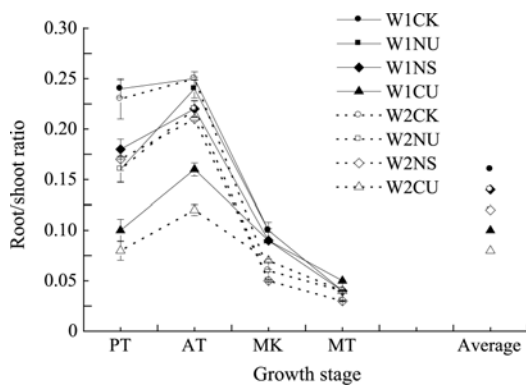


图 4 不同处理玉米根冠比的动态
Fig. 4 Dynamic changes of root to shoot ratio in different treatments
Abbreviations as in Fig. 1.

3 讨论

与常规尿素全部基施和分次施肥处理相比, 控

释尿素处理开花前玉米的叶面积指数、地上部干重较小, 但花后增长较快, 乳熟期至成熟期已超过各常规尿素处理, 因而成熟期籽粒产量和生物产量均较高, 表现出明显的“前控后保”效果。干旱时, 控释尿素的“前控后保”效果更显著。这种“前控后保”效果与根系数量和活性及根冠比等的变化密切相关。大喇叭口期和开花期, 控释尿素处理的根冠比低于常规尿素全部基施和分次施肥各处理, 但成熟期控释尿素处理仍保持较高的根冠比。由于前期的大量吸收和淋失, 施用常规尿素的玉米花后氮素和水分供需矛盾加重^[14,16-17], 为了获得足够氮素和水分, 玉米根系所占的比例增大, 但这种调整是以消耗光合产物为代价的, 因此产量降低。而控释尿素前期释放较慢^[16], 玉米长势较弱, 花后氮素供应较充足, 根系相对数量较多、活力较强, 促进了地上部干物质量的积累和转移, 成熟期籽粒产量和生物产量高于常规尿素全部基施和分次施肥各处理。

氮素与水分对产量的影响存在显著的互作效

应^[5-7]。改善水肥条件, 促进根系与地上部分均衡生长是获得高产的有力措施^[6,18]。本研究表明, 氮素和水分在玉米产量上存在显著的正耦合效应, 施用包膜控释尿素将显著提高这种正耦合效应。与水分适宜相比, 干旱条件下控释尿素的增产效果更显著。上述影响均可用根冠协调生长来解释。作物根系具有自我调控能力, 当少量根系能维持作物水分与养分的供需平衡时, 作物将把能量更多地用于地上部的生长, 而不是用于根系的生长; 当水分或养分不足时, 作物会增加根系数量、活性及根冠比来加强对水分和养分的吸收^[2,4], 但并不能弥补肥水缺乏造成的产量下降。由于控释尿素更好地协调了作物的根冠关系, 特别是生育后期能维持较高的根系总活力, 因而耦合效应更显著。

4 结论

控释尿素对玉米生长具有明显的“前控后保”效果, 成熟期籽粒产量和生物产量均较高。控释尿素与水分对植株生长及产量的耦合效应高于常规尿素与水分的耦合效应。其原因是生育后期能维持较高的根系数量及活性, 协调了根冠关系, 促进了地上部干物质积累和转移, 产量显著增加, 而且在干旱条件下增产幅度更大。

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