

土壤水吸力对控释尿素养分释放特征的影响^{*}

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摘 要 为探究不同土壤水吸力对控释尿素养分释放的影响, 根据供试壤质砂土的水分特征曲线设置了6种不同土壤水吸力的处理, 采用25℃恒温土壤模拟实验, 测定土壤中控释尿素的养分释放特征。结果表明, 土壤水吸力为0 kPa时恒温土壤培养法与静水浸提法测得的控释尿素养分释放特征无显著差异。土壤水吸力为75 kPa、30 kPa和0 kPa的3个处理, 测定的土壤孔隙中空气相对湿度均为95%以上, 土壤水汽饱和, 释放期基本相同, 表明在不考虑水分流动及养分扩散状况影响时, 土壤水分条件已不再是影响控释尿素养分释放的主要因素。土壤水吸力525 kPa和260 kPa(土壤孔隙中空气相对湿度分别为84%和91%)时释放期分别为416.4 d和120.0 d, 相对于土壤水饱和时释放期(63.6 d)的相对相差分别为146.8%和59.1%, 远超过《控释肥料》行业标准规定的允许差(20%), 表明控释尿素的释放率和释放期受到土壤水吸力过高的抑制。土壤水吸力大小直接影响土壤孔隙空气湿度的饱和与否, 土壤水吸力对控释尿素养分释放的影响通过土壤水汽作用于肥料颗粒实现。

关键词 控释尿素; 释放率; 土壤水分特征曲线; 土壤水吸力; 土壤空气相对湿度

中图分类号 S146⁺.2; S14-33; S143.1⁺4

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据世界粮农组织(FAO)统计, 在发展中国家粮食的增产55%归功于化肥的使用。但是, 目前我国氮肥当季利用率仅为30%~35%。提高肥料利用率、降低资源浪费、减少环境污染已成为国内外研究的热点^[1-3]。包膜控释肥料是可以使养分的释放与作物的需肥规律相同步的新型肥料^[1], 在增加作物产量、提高肥料利用率、节肥增效以及减少面源污染的可持续农业发展中正发挥着重要作用, 在棉花和花生等经济作物上广泛使用^[4-5]。控释肥的养分释放受到肥料本身和环境条件(包括气候条件、土壤温度及水分含量等)的影响^[6-8]。静水浸提测定的释放率在实验室及生产中均被广泛使用,

但与实际应用中的释放规律仍有所偏差。从农业应用的角度看, 作物根系从土壤中吸收养分, 实际养分释放率应该是控释肥料在土壤中所表现的养分释放率^[9-11]。

土壤水分作为水资源的一种存在形式, 同时也是控释肥养分溶出及转化的重要影响因素。土壤水可汽化为水蒸气, 使施入土壤的控释肥在土壤水不饱和的情况下, 仍处在土壤孔隙水汽饱和的状态下, 水蒸气可通过膜壳微孔缓慢进入膜内, 导致膜内膨压增大而使膜壳微孔变大, 水蒸气进一步通过膜壳进入并溶解肥料核心养分, 养分在水蒸气压差作用下不断扩散到膜壳之外^[12-13]。土壤水汽进入

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膜壳使膜内膨胀压增大需要一定时间, 表现为控释肥料初期释放缓慢, 不可逆的膜壳膨胀使养分溶出扩散呈现中期加快, 但是肥料核心养分的减少使得膜内溶液将会由过饱和或饱和状态转入不饱和状态, 进一步引起膜内外压差的降低, 导致养分溶出速率的降低, 释放率达到稳定^[14]。不同土壤水分对控释肥料的影响以及控释肥料在干旱地区的推广应用也受到越来越多的关注^[15-17]。大量深入的研究发现, 在低压力水头(0~100 kPa)时, 土壤结构和孔径分布(即容重和孔隙度)是影响土壤水分持留的主要因素; 而在高压力水头范围(大于100 kPa), 吸附作用则成为土壤水保持的主要因素, 质地、有机质含量以及黏土矿物等通过影响土壤比表面积等性质进而影响土壤水的吸附^[18-20]。土壤各吸力段水分蓄持能力均随容重增大递减, 比水容量也随容重增大递减, 土壤水分特征曲线也受到较大影响; 质地对土壤吸水持水能力的影响非常明显, 砂壤土持水能力显著低于粉壤土。

土壤水分可以使用土壤含水量或土壤水势进行表征。土壤水势又称土壤水吸力是指土壤水的负压力, 表征土壤基质对水分的吸附能力, 主要包括重力势、基模势和溶质势^[21]。本文探讨的土壤水吸力为土壤基模势, 表征土壤固-液界面上的界面张力和土壤矿质颗粒与有机质颗粒表面对水产生的张力, 这与土壤水分进入控释肥料膜壳之内及膜内养分析出膜外的过程有直接关系。虽然土壤含水量与土壤水吸力之间存在密切关系, 但相同含水量的土壤释水状态吸力大于吸水状态, 存在明显的滞后现象。而且, 土壤含水量测定时需要破坏性取样, 带回实验室105℃烘干测定, 较土壤水吸力利用张力计直接测定的方式存在滞后性和诸多不便。因此, 土壤水吸力表征的土壤水有效性或干湿程度较不同质量含水量更具科学意义^[21-24]。本研究采用恒温土壤培养实验, 研究不同土壤水吸力对控释尿素氮素溶出特性的影响, 探明限制控释尿素养分释放的土壤水吸力阈值以及影响其养分在土壤中释放的相关因素, 为控释尿素在干旱区作物上的合理施用提供科学依据。

1 材料与方法

1.1 供试材料

供试土壤采自山东省泰安市宁阳县汶河河谷,

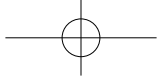
土壤类型为潮土, 在中国土壤系统分类中为淡色潮湿锥形土(Ochri-Aquic Cambosols), 砂粒含量830.7 g kg⁻¹, 粉粒125.2 g kg⁻¹, 黏粒44.1 g kg⁻¹, 土壤质地类型为壤质砂土(美国制); 容重1.32 g cm⁻³, 孔隙度48.70%, 有机质含量4.30 g kg⁻¹, pH 7.32。为了对比土壤质地对水分特征曲线的影响, 选取质地为粉壤土的土壤进行对比, 采自山东泰安南郊的棕壤, 在中国土壤系统分类中为简育湿润淋溶土(Hapli-Udic Argosols), 砂粒含量344.1 g kg⁻¹, 粉粒523.9 g kg⁻¹, 黏粒131.6 g kg⁻¹, 质地为粉壤土; 有机质含量为12.61 g kg⁻¹, pH 7.30。

供试肥料为山东农业大学土肥资源高效利用国家工程实验室研制的作物秸秆液化改性树脂包膜尿素, 由众德肥料(平原)有限公司生产, 含氮量44.15%, 在25℃静水中测得累积释放率为80%时的释放期为56 d。试验于2015年3月至6月在山东农业大学土肥资源高效利用国家工程实验室进行。

1.2 试验方法

控释尿素静水浸提实验按照《控释肥料》行业标准(HG/T 4215-2011)进行。称取肥料样品10.00 g(精确至0.01 g)放入100目尼龙纱网做成的小袋中, 将小袋放入250 ml玻璃瓶中, 加入200 ml蒸馏水, 加盖密封, 重复3次, 置于25℃恒温培养箱中。取样时间为第24小时(第1天)、第5、10、20、30、40、50、60、70天(养分溶出率达80%以上)。取样时, 将玻璃瓶上下颠倒3次, 使瓶内的液体浓度一致, 然后保存于10 ml指形管中, 注意密封, 并注明取样时间及编号, 以备测定。然后, 重新加入200 ml的蒸馏水, 封口后放入培养箱。控释尿素氮素释放量测定采用凯氏定氮法。

室内模拟实验根据实验所需供试土壤田间持水量19.5%以及预设相对含水量100%、70%、40%、20%、5%和0%, 得出相应的质量含水量分别为19.5%、13.7%、7.8%、3.9%、1.0%和0%。从土壤水分特性曲线计算不同的土壤水吸力, 6个处理分别为: 1) ADS, 风干土; 2) SWS525(土壤水吸力为525 kPa); 3) SWS260(土壤水吸力为260 kPa); 4) SWS75(土壤水吸力为75 kPa); 5) SWS30(土壤水吸力为30 kPa); 6) SWS0即土壤饱和水处理。6个处理分别加入不同量的蒸馏水, 将300.0 g供试土壤装入自封塑料袋, 将水土充分混匀后测定实际含水量, 根据测得供试土壤田间持



水量 (19.5%) 计算得到相对含水量 (表1)。同时将5.0 g控释尿素装入尼龙网指形袋, 分别放入不同土壤水吸力处理的自封袋土壤中, 密封后放入25℃恒温培养箱中。每个处理30次重复, 每次破坏性取样3个尼龙网指形袋, 测定控释尿素的养分释放率。

土壤水分会以水蒸气形态弥散在土壤孔隙中, 进一步对控释尿素养分溶出释放起作用, 用干燥器封闭水汽达到平衡, 模拟土壤孔隙中空气相对湿

度, 可以用温湿度计进行测定。将6个水分处理的土壤称取500.0 g于干燥器底部, 将温湿度计 (T&H meter, 凯隆达, 天津) 放置垫板之上, 用凡士林封口, 确保温湿度计密封, 装置安顿好之后, 将干燥器整体置于25℃的恒温培养箱中, 不打开干燥器, 隔着玻璃进行读数并记录相对湿度, 记录间隔为1 h, 直至读数恒定, 6个处理的土壤空气相对湿度分别为38%、84%、91%、95%、98%和99% (表1)。

表1 模拟实验中不同土壤水分处理

Table 1 Treatments of soil moisture in the simulated experiment

处理代号 Treatment No.	相对含水量 Relative water content (%)	预设质量含水量 Designed gravimetric water content (%)	实测质量含水量 Measured gravimetric water content (%)	加入的水量 Volume of water addition (ml)	土壤水吸力 Soil water suction (kPa)	土壤孔隙空气相对湿度 Relative humidity of soil pore air (%)
ADS	0	0	0.4	0	—	38
SWS525	5	1.0	1.7	45	525	84
SWS260	20	3.9	3.9	175	260	91
SWS75	40	7.8	8.0	350	75	95
SWS30	70	13.7	13.1	650	30	98
SWS0	100	19.5	19.9	875	0	99

注: ADS, 风干土; SWS525、SWS260、SWS75、SWS30和SWS0分别表示土壤水吸力525 kPa、260 kPa、75 kPa、30 kPa和0 kPa。下同 Note: ADS: air dried soil; SWS525, SWS260, SWS75, SWS30 and SWS0 mean soil water suction 525 kPa, 260 kPa, 75 kPa, 30 kPa and 0 kPa, respectively. The same below

1.3 测定项目与方法

采用1500 F1型 15 Bar压力膜仪 (SEC, 美国) 测定供试土壤的水分特征曲线: 首先用橡皮筋将滤纸固定于配套的塑胶环刀上, 将过2 mm筛的风干土壤样品小心装入环刀中, 使土壤约与环刀上沿齐平, 整体成为土样环并称重记录。将土样环置于提前浸好的陶土板上并小心在陶土板上加水, 使土壤样品吸水达到充分饱和, 然后用吸管吸掉陶土板上多余的水分。将压力室组装好, 调节压力调节阀, 逐渐加到所需压力。若出水管口不再滴水则可认为达到平衡。反向转动调压阀到1个标准大气压, 打开压力室后立即称量土样环的质量。设定0、100、300、500和1 500 kPa共5个压力, 测定各平衡时的土样环重量, 根据初始的风干土重计算每次的质量含水量, 最终得出土壤水分特征曲线^[23]。

控释尿素的养分释放率测定: 分别于实验开始后第1、5、10、20、30、40、50、60、70天取自封袋中的肥料袋, 用自来水冲洗2~3次, 去除表面的土粒, 将肥料置于铝盒于60℃烘箱中烘至恒重。冷却后用万分之一天平称重。用差减法计算控释尿素养分的释放量并求出释放率。

1.4 数据处理

试验相关数据通过Excel 2003和SAS 8.2软件完成单因素方差分析 (ANOVA) 及邓肯 (Duncan) 差异显著性检验, 并用Excel 2003 软件进行作图。

2 结果与讨论

2.1 两种土壤的水分特征曲线

土壤水分特征曲线为含水量和基质吸力的关系曲线, 随着含水量的变化, 吸力也发生变

化^[23]。两种供试土壤的水分特征曲线如图1所示, 可以看出, 质地对土壤水分特征曲线影响显著。在土壤水吸力1 500 kPa时壤质砂土质量含水量仅为1.6%, 粉壤土的质量含水量高达5.9%; 在土壤水吸力100~300 kPa范围, 壤质砂土质量含水量为2.9%~3.9%, 而粉壤土的质量含水量为10.7%~12.7%。土壤水分特征曲线受到质地的影响, 可为合理确定植物生长所需的水吸力提供理论依据。在相同水吸力时, 不同质地土壤对有效水的控制力不同; 相同的质量含水量在不同质地土壤中的有效性不同, 说明控制不同土壤质量含水量并不能够准确表示土壤水分的有效性。控制相同含水量时, 控释尿素的释放受到多方面影响, 而控制相同的土壤水吸力可以排除土壤基质对水的吸附影响, 使实验设计更符合田间土壤孔隙中空气的水汽压实际情况。壤质砂土在质量含水量1.7%与粉壤土质量含水量5.9%的土壤水吸力一致, 因此, 室内培养实验供试土壤选用壤质砂土 (LS)。

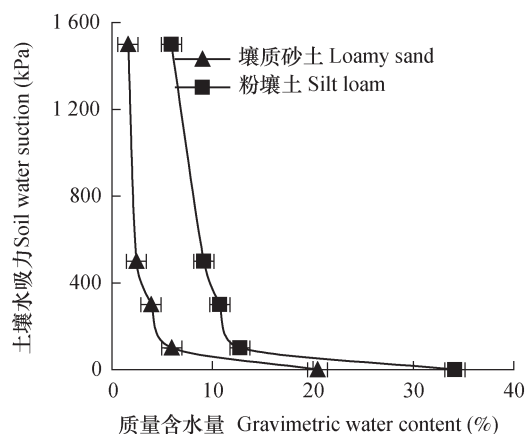
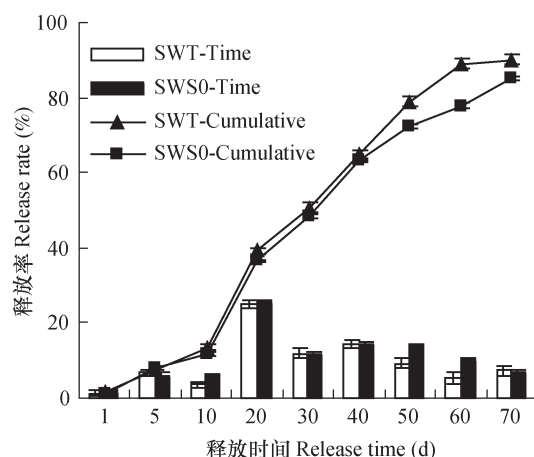


图1 供试土壤水分特征曲线

Fig. 1 Soil water characteristic curves of the experimental soils

2.2 土壤水饱和时控释尿素的养分释放特性

包膜控释尿素在25℃恒温培养静水浸提试验 (SWT: Still water test) 和土壤埋袋试验 (SWS0: Soil water suction=0 kPa) 饱和水条件下的释放曲线呈现基本一致的规律 (图2), 均呈现S形, 且养分释放率在1~7 d较慢, 7~14 d释放逐渐加快, 于21 d以后达到稳定。在静水浸提中第1天释放率为1.5%, 第30天累积释放率为50.7%, 符合《控释肥料》行业标准的要求。静水浸提中测得累积释放率达到80%时为55.9 d, 在土壤中测得累



注: SWT-Time为静水浸提试验 (SWT) 处理的时段释放率; SWS0-Time为SWS0处理的时段释放率; SWT-Cumulative为SWT处理的累积释放率; SWS0-Cumulative为SWS0处理的累积释放率 Note: SWT-Time, Time interval release rate of still water test (SWT); SWS0-Time, Time interval release rate of SWS0; SWT-Cumulative, Cumulative release rate of SWT; SWS0-Cumulative, Cumulative release rate of SWS0

图2 控释尿素氮素累积释放特征

Fig. 2 Cumulative nitrogen release characteristics of controlled-release urea (CRU)

积释放率达到80%时为63.6 d, 可能由于土壤中控释尿素的颗粒被装在网袋中, 通过失重法测定会产生较大的误差, 其相对相差为12.9%, 仍在《控释肥料》行业标准规定的20%误差范围之内。

2.3 不同土壤水吸力对控释尿素养分释放的影响

在恒温25℃的模拟实验中, 水分作为影响控释尿素养分释放的单一因素, 在前5天土壤水分对控释尿素释放率影响不显著 (图3)。土壤水不饱和时, 水分对控释尿素的作用是通过汽化成水蒸气进入控释尿素膜壳的微孔, 而进入微孔使膜内膨胀压增大并溶解养分需要一定的时间^[12], 控释尿素氮素第5天开始溶出释放。在土壤水吸力为525 kPa时, 土壤空气相对湿度为84%, 土壤水汽未达到饱和, 养分析出后未能及时转运出, 使得控释尿素释放受到明显抑制; 而风干土的处理, 土壤空气相对湿度为38%, 土壤孔隙中水蒸气不足以进入控释尿素膜壳, 控释尿素释放率始终为初期释放率, 而无后续的增加, 表明风干土中埋置的控释尿素未释放。

土壤水吸力在260 kPa时, 土壤空气相对湿度为91%, 进入控释尿素膜壳的水蒸气量增多, 但是由于未达饱和, 释放速度仍受到抑制。土壤水吸力

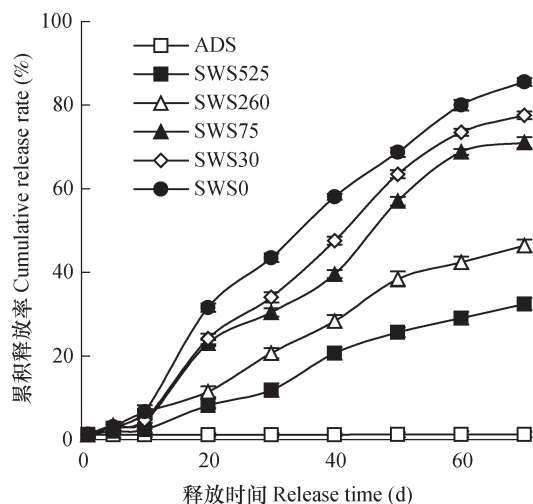


图3 恒温 (25℃) 模拟实验中控释尿素在不同土壤水吸力下的累积释放特征

Fig. 3 Cumulative N release characteristics of CRU in soils different in soil water suction in the simulated experiment under constant temperature (25℃)

低于75 kPa时, 土壤空气相对湿度均为95%以上, 土壤水汽达到饱和, 表现为水分条件对控释尿素释放产生的影响一致。

对土壤埋袋中包膜尿素在土壤不同水吸力下的氮素累积释放率曲线 (图3) 进行数学回归分析, 以氮素累积释放率为自变量 (x), 以释放天数 d 为因变量 (y) 建立回归方程 (表3)。用相应的多项式方程能很好地模拟和反映不同土壤水吸力时的氮素释放特征, 除SWS525处理拟合的方程 R^2 达0.95以外, 其余四个处理的方程拟合度较高, R^2 均达0.98以上。利用相应方程可以较准确地根据不同时段的氮素累积释放率计算出不同土壤水吸力时的控释尿素的释放期, 判断土壤水吸力对控释尿素释放期的影响, 进而在推广使用中根据实际的水分条件选择更加合适的控释尿素。

通过回归方程可以计算出不同土壤水吸力时的释放期 (表3), 饱和水分的土壤中释放期63.6 d,

表2 恒温 (25℃) 模拟实验中不同土壤水吸力处理的控释尿素氮素释放回归方程

Table 2 Regression equation of nitrogen release characteristics of CRU in soil different in soil water suctions in the simulated experiment under constant temperature (25℃)

处理代号 Treatment No.	回归方程 Regression equation	R^2
SWS525	$y=0.0071x^2+4.748x-8.931$	0.952 9
SWS260	$y=0.0051x^2+1.053x+0.0768$	0.985 1
SWS75	$y=0.0131x^2+0.028x+3.922$	0.989 9
SWS30	$y=0.0012x^2+0.0012x+3.783$	0.991 4
SWS0	$y=0.0084x^2+0.0752x+3.837$	0.993 7

注: 控释尿素养分在ADS (风干土) 处理中未释放, 故无拟合方程 Note: N release rate of CRU is nil in ADS (air dried soil) in the experiment

土壤水吸力在30 kPa时控释尿素释放期72.7 d, 相对相差为13.3%, 在行业标准规定的20%误差范围之内。土壤水吸力在75~525 kPa范围内, 随着土壤水吸力的增大, 控释尿素的养分释放减慢, 养分释放期逐渐变长。回归方程计算的SWS525和SWS260处理的释放期分别为416.4和117.0 d, 相对相差分别为146.8%和59.1%, 远超《控释肥料》行业标准规定的允许差 (20%), 说明控释尿素释放受到了土壤水吸力过高的限制, 土壤颗粒对水分的吸力远远大于肥料核心对水分的吸力。

2.4 不同土壤水吸力对氮素时段释放率的影响

土壤水吸力75 kPa、30 kPa和0 kPa的3种处理

中控释尿素的释放高峰均在20~30 d之间出现, 20 d的时段释放率分别为18.3%、22.2%和15.3%, 且在时间上呈现一致性 (图4)。30 d的时段释放率均为16.0%, 之后的释放趋于一致, 且在40 d以后达到缓慢释放。表明不考虑水分流动及养分扩散状况影响时, 土壤孔隙空气相对湿度高于95%, 土壤水汽达到饱和, 土壤水吸力不再是影响包膜控释尿素养分在土壤中释放的主要因素。

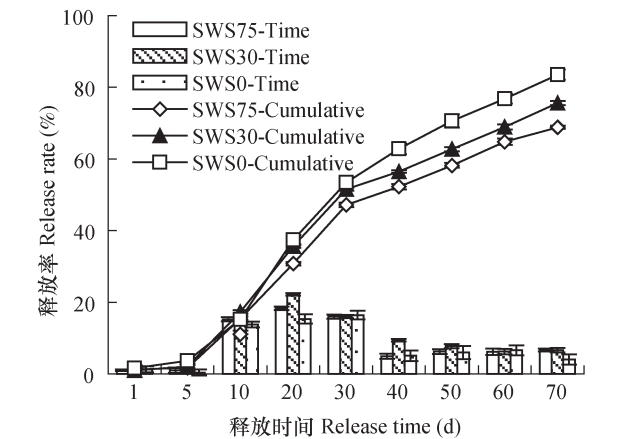
但是, 在土壤水吸力高于75 kPa时, 控释尿素养分释放开始受到土壤水吸力过高的影响 (图5), SWS260和SWS525的2个处理, 土壤孔隙空气相对湿度分别为91%和84%, 可以看出, 水汽减少

表3 恒温（25℃）培养实验中不同土壤水吸力处理的控释尿素氮素释放期

Table 3 Duration of N release of CRU relative to soil water suction in the simulated experiment under constant temperature (25℃)					
处理代号 Treatment No.	24小时累积释放率 Cumulative release rate of 24 h (%)	14天累积释放率 Cumulative release rate of 14 d (%)	28天累积释放率 Cumulative release rate of 28 d (%)	释放期 Duration of N release (d) ¹⁾	相对相差 Relative difference (%) ²⁾
ADS	1.3 ± 0.2ab	1.5 ± 0.2d	1.6 ± 0.5e	—	—
SWS525	1.7 ± 0.3a	3.7 ± 0.8c	9.4 ± 1.1d	416.4 ± 12.5a	146.8
SWS260	1.2 ± 0.1bc	12.4 ± 0.7b	28.2 ± 2.5c	117.0 ± 9.8b	59.1
SWS75	1.3 ± 0.1ab	15.4 ± 1.4ab	47.2 ± 1.4b	77.8 ± 7.6c	20.0
SWS30	1.0 ± 0.1c	17.3 ± 0.6a	51.6 ± 1.3ab	72.7 ± 7.3c	13.3
SWS0	1.6 ± 0.3ab	15.3 ± 0.5b	53.5 ± 0.7a	63.6 ± 7.1c	0

注：1) SWS0和SWS30为实测释放期，其他处理的释放期由表3拟合方程进行计算；2) 相对相差为不同土壤水吸力的释放期相对于SWS0的释放期的相对相差；3) 同一列中的平均数值用邓肯多重比较，标有相同字母的表示其差异不显著 ($p > 0.05$)

Note: 1) Release duration of CRU in SWS0 and SWS30 were measured values, and in the other treatments were fitted with the regression equation in Table 3; 2) Relative differences were release durations in the treatments relative to SWS0; 3) means followed by the same lowercase letters in the columns were not significant in difference according to the Duncan test at 5%



注：SWS75-Time、SWS30-Time、SWS0-Time分别为SWS75、SWS30和SWS0处理的时段释放率；SWS75-Cumulative、SWS30-Cumulative和SWS0-Cumulative分别为SWS75、SWS30、SWS0的累积释放率

Note: SWS75-Time, SWS30-Time, and SWS0-Time were the time interval release rates of SWS75, SWS30, and SWS0, respectively; SWS75-Cumulative, SWS30-Cumulative, and SWS0-Cumulative were the cumulative release rates of SWS75, SWS30, and SWS0, respectively

图4 土壤水吸力低于或等于75 kPa条件下控释尿素养分时段释放率

Fig. 4 Nutrient release rate in soils lower than or equal to 75 kPa in soil water suction relative to time interval

限制了控释尿素的养分释放。SWS525处理的释放高峰不明显，分别在30 d和70 d出现两次。SWS260的处理则在10 d、30 d和60 d出现释放高峰，时段

释放率分别为10.1%、11.8%和11.2%，表明在土壤水吸力260 kPa时控释尿素释放缓慢，整体上均匀增长，土壤空气相对湿度为91%，土壤水汽虽然未饱和，但是在后续能得到补充，使得释放时间延长。整体而言，土壤水分早期进入控释尿素膜壳越快越多，使得后期肥料核心尿素浓度变低，肥料膜壳内外浓度差变小，后期释放动力不足。土壤水吸力过高明显地限制了控释肥料养分溶出速率，进而使释放时间延长，表明水汽未达饱和时，控释尿素的释放率和释放期受到土壤水分含量过低的抑制。

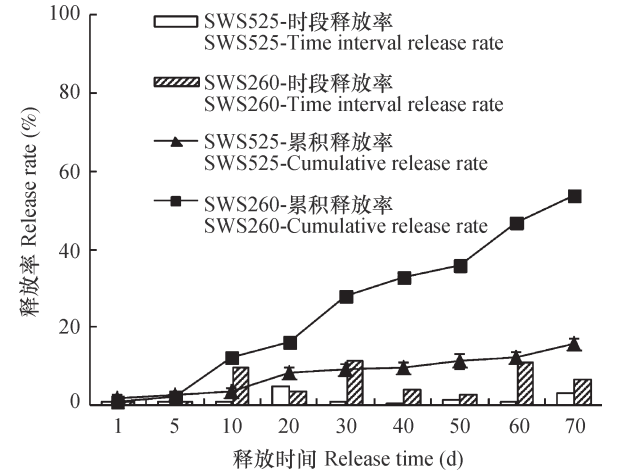


图5 土壤水吸力大于或等于260 kPa条件下养分时段释放率

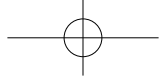
Fig. 5 Time interval nutrient release rate in soils more than or equal to 260 kPa in soil water suction

3 结 论

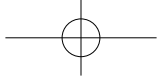
不同土壤水吸力对控释尿素释放的影响结果之间差异显著。本试验条件下土壤水吸力低于或等于75 kPa时,土壤水汽饱和,不考虑水分流动及养分扩散状况影响时,土壤水吸力不再影响控释尿素养分在土壤中释放;而土壤水吸力高于或等于260 kPa即土壤水汽未达饱和时,土壤颗粒对水分的吸力远远大于肥料核心对水分的吸力,控释尿素的释放受到抑制。土壤水吸力大小直接影响土壤孔隙空气湿度的饱和与否,土壤水汽是控释尿素释放影响因素的直观指标。

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Influence of Soil Water Suction on Nutrient Release Characteristics of Controlled-Release Urea

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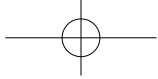
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Abstract 【Objective】 Nitrogen (N) release characteristics of controlled release urea (CRU) is affected by properties of the fertilizer per se and environmental conditions, such as climate, soil temperature and soil moisture etc. The static water extraction method is widely used for quality control of CRU. However, as a matter of fact, CRU is mainly applied to farm fields, where soil moisture is the major factor affecting N release from CRU. Soil moisture can be characterized by soil water suction, which is closely related to the process of nutrient transmembrane movement in CRU. So it is essential to explore threshold value of the soil water suction that controls N release rate of CRU so as to provide a scientific basis for proper application of CRU in arid regions. 【Method】 Static water extraction and soil culture experiments were carried out in this study to investigate N release characteristics of CRU in water and soil conditions, separately, under constant temperature of 25℃. The static water extraction experiment of CRU was performed following the industry standard for controlled release fertilizer (HG/T 4215-2011). In line with the soil water characteristic curves of the tested loamy sand soil (fluvo-aquic soil, Ochri-Aquic Cambosols), five levels (0, 30, 75, 260 and 525 kPa) of soil water suctions were designed for the soil culture experiment, and air-dried soil was used as control. And, vapors from the soils of the six treatments were measured with the simulated incubation method in the desiccator. 【Result】 Results show that N release of the CRU in static water was quite similar to that in the soil 0 kPa in soil water suction. Cumulative release rate in the first seven days increased very slowly, sped up from the 7th to the 14th day, and then leveled off after the 21st day. The CRU released 80% of its N in 55.9 days and 63.6 days, respectively, in water extraction and soil incubation. N release varied similarly in characteristics, peaked in the period from the 20th to the 30th day, and reached 18.3%, 22.2%, and 15.3%, respectively, in the treatments, 75 kPa, 30 kPa, and 0 kPa in soil water suctions, in 20 days. As the air in soil pores was >95% in relative humidity in all the tested soils, the soils were all the same in soil water vapor saturation and N release period, which indicates that in this case, excluding the impacts of flowing soil water and nutrient diffusion, soil moisture is no longer the major factor affecting N release from CRU. N release in the treatments, 525 kPa and 260 kPa in soil water suction and 84% and 91% in relative humidity of pore air, lasted for 416.4 d and 120.0 d, respectively, which was 146.8% and 59.1%, longer relative to that in the treatment saturated with water (63.6 days) and 20% longer relative to that set in the industry standards for controlled-release fertilizer, indicating that N release rate and N releasing period of the CRU is affected by too high soil water suction. 【Conclusion】 All the findings of this study demonstrate that the differences between the six treatments in N release characteristic of CRU are striking, when impacts



of water flow and N diffusion are not taken into account; Soil moisture is no longer the main factor affecting N release of CRU when the soil is less than 75 kPa in soil water suction; In soils with soil water suction being higher than 260 kPa, N release rate and duration of the CRU are restrained by soil moisture. Soil water suction is directly related to saturation of pore air in humidity. The influence of soil water suction on release characteristic of CRU is affected through the impact of vapor in the soil on fertilizer granules.

Key words Controlled-release urea; Release rate; Soil water characteristic curve; Soil water suction; Air relative humidity of soil interstices

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