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黄淮海平原玉米施氮量对后茬小麦土壤剖面硝态氮和产量的影响

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摘要:在冬小麦-夏玉米一年两熟模式下,玉米品种"郑单958"(植株密度9株/m^2)和小麦品种"93-9"(基本苗704株/m^2),冬小麦基施144 kg N/hm^2,研究了玉米5个施N量(0、90、180、270和360 kg/hm^2)对后茬小麦期间土壤剖面硝态氮含量、无机氮总量,以及小麦氮素吸收利用和产量的影响。结果表明:(1)与不施氮相比,玉米施氮显著增加小麦季0~200cm土壤硝态氮含量;自拔节起,0~40cm、0~130cm和0~200cm硝态氮含量均随施氮量增加而递增,在硝态氮含量较高的小区增幅也大。(2)轮作一周期后,不施氮和施氮360 kg/hm^{2}显著影响0~130cm和0~200cm无机氮总量,但在90~270 kg/hm^{2}之间,施氮量的影响不明显。(3)施氮小于180 kg/hm^{2}时,成熟期小麦植株氮素和籽粒氮素积累量、氮肥利用率均随施氮量增加而递增,但不明显。(4)与不施氮相比,施氮90 kg/hm^{2}的小麦产量和麦玉轮作总产均增加但不明显,施氮180 kg/hm^{2}均显著增加,施氮270kg/hm^{2}与180 kg/hm^{2}无明显差异。本试验条件下,夏玉米施氮90~180 kg/hm^{2}是适宜的。

关键词:冬小麦;施氮量;土壤硝态氮含量;籽粒产量

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Effect of N rates applied to summer maize on soil nitrate content during the following crop season and winter wheat grain yield in Huang-Huai-Hai Plains

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Abstract: Continuous applying N at high rate in crop production in China resulted in increasing basal soil N content and decreasing N fertilizer use efficiency. Moreover, it caused severe underground water pollution in many areas. Therefore, how to optimal use N fertilizer was facing scientists. There were lots of researches on the nitrate dynamics with N fertilizer treatments during winter wheat-summer maize rotation system, especially during summer-maize season. Due to high variation of rainfall and temperature during maize growth season in China, it was difficult to determine the optimal N fertilizer rate applied to maize only by studies on relationship of maize N requirements and soil nitrate dynamics. The objective of this study was to understand the effect of N rates applied to maize on soil nitrate content and crop yield during winter wheat growth season.

A field trial with the summer maize-winter wheat rotation was carried out in Huang-Huai-Hai Plain, North China, in 2002 ~ 2003. Five rates of nitrogen fertilizer (*i.e.* 0, 90, 180, 270 and 360 kg N hm^{-2}) were applied to maize with high-yield hybrid "Zhengdan 958" and the population of 9 plants m^{-2}. 2/3 of the total N fertilizer was applied at sowing stage and 2/3 of that at 10-

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unfolded leaf stage. After maize harvest, wheat as the following crop was planted in former crop plots with cultivar "97-3" and seed rate of 704 grain m^{-2}. N rate of 144 kg hm^{-2} was applied at wheat sowing. Except for precipitation of 112.1 mm during wheat season, two times of irrigation with 75 mm at each time were done on April 13, and May 9, 2003, respectively. The trial was completely randomized design with three replicates. Plot size was 6 m by 6 m. The vocation between maize harvest and wheat sowing was 15 days.

The soil in the trial field was light salted loam in 0 ~ 130 cm soil layers and loam in 130 ~ 200 cm soil layers. There was just ploughed during the vocation of the cropping system. In addition to N fertilizer, P_2O_5 and K_2O were dressed on the day of maize sowing at rate of 105 kg hm^{-2} and 120 kg hm^{-2}, and on the day of ploughing day at rate of 103 kg hm^{-2} and 75 kg hm^{-2}, respectively. Soil samples were taken three times (i.e. sowing, shooting and maturity) during wheat season and one time at maize sowing with a soil auger. The samples were divided into different soil layers in 20 cm increment from surface to 100 cm depth, 100 ~ 130 cm, 130 ~ 160 cm, and 160 ~ 200 cm at taking, pretreatment and analysis. Soil nitrate was determined by the Salicylic Acid Colorimetric Method and ammonium by the improved Ninhydrin Colorimetric Method. Considering of the nitrate mobility, we incorporated eight soil layers into three layers (i.e. 0 ~ 40 cm, 40 ~ 130 cm, and 130 ~ 200 cm) according to soil bulk density. At crop maturity, grain yield was measured in field and samples were taken at the same time. Total N content was analyzed with Kjeldahl Digestion Method.

The findings of the trial showed the nitrate content in the 0 ~ 200cm soil profile significantly increased during wheat season when N fertilizer applied. In the 0 ~ 40cm, 0 ~ 130cm and 0 ~ 200cm soil profiles, the nitrate content increased with the increment of N rates from wheat shooting to maturity. The higher the soil nitrate content, the more amount soil N increment caused by N fertilizer. The 0 ~ 200 cm inorganic amount in zero N fertilizer plots significantly decreased at wheat maturity by comparing to that at maize sowing, while that in the 360 kg hm^{-2} N fertilizer plots significantly increased. The 0 ~ 200 cm soil inorganic amounts in those plots with N rates of 90 kg hm^{-2} to 270 kg hm^{-2} little decreased after one maize season and one wheat season. The wheat plant N amount, grain N amount and grain NUE all slightly increased with increment of N rate when the N rate is less than 180 kg hm^{-2}. In comparison with zero N treatment, the 90 kg hm^{-2} treatment slightly increased the grain yield of winter wheat and that of maize plus wheat, but the 180 kg hm^{-2} treatment significantly increased it. The grain yields in the 270 kg hm^{-2} plots and those in the 180 kg hm^{-2} plots had no significant difference. So, the N fertilizer at rate of 90 ~ 180 kg hm^{-2} was optimal under trial conditions.

Key words: winter wheat (*Triticum aestivum* L.); N fertilizer rate; soil nitrate content; grain yield

匈牙利定位试验表明,长期高量施氮常造成土壤肥力递增[1]。土壤大量累积的 NO_3^--N 对地下水污染的威胁性增大[2]。我国粮食高产区常年大量使用氮肥,特别是玉米季超量十分严重,已使土壤肥力显著提高,玉米的氮肥增产效应愈来愈小[3],黄淮海平原夏玉米氮肥利用率仅约为 10%[4,5]。研究表明,若仅靠土壤供氮,既是在高肥力地块作物产量潜力也受到限制[6],且不持续[7,8];但若施氮量过高,也会造成产量下降[1]。J. Balázs 等认为,只有适宜的施氮量,作物产量才最高[1]。

氮肥问题一直是近年来的研究热点。国外集中在如何减少氮肥用量、减少污染[1,6,9~12],国内集中在如何减少氮肥用量的同时能确保作物产量[2,4,5,7,8,13,14],研究对象也从单季作物、周年轮作,又回到单季作物。在黄淮海平原冬小麦-夏玉米轮作体系中,与冬小麦季相比,夏玉米季的氮肥回收率显著降低而损失率显著增高[15]。为提高轮作体系的氮肥利用率、减少氮素损失,夏玉米季土壤氮素变化及其氮肥影响成为研究热点,并取得了大量结果[4,5,12,13],但因夏季温度和降水的多变性,规律性结果较少,研究仍较薄弱。为此,有人尝试在两季作物连接点上寻求突破,黄生斌等研究了玉米季不施氮的情况下,冬小麦施氮量对玉米氮素需求的影响[13]。目前,玉米季施氮对小麦季土壤氮素变化、小麦氮素吸收利用和产量的影响等方面的研究还较少,特别是在特定栽培技术体系。本试验充分考虑与当前冬小麦高产节水省肥栽培技术体系[16]衔接,研究了不同夏玉米施氮量对冬小麦季土壤剖面硝态氮含量和小麦氮素吸收、利用及产量的影响,以期为科学确定玉米氮

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肥用量、提高玉米季氮肥利用率提供理论依据。

1 材料与方法

本研究于2002~2003年在河北省吴桥实验站进行。在冬小麦-夏玉米一年两熟轮作模式下,先于2002年进行夏玉米氮肥试验,收获玉米后在所有试验小区上采用同一方式种植冬小麦,进行冬小麦试验。

玉米试验开始时的土壤基本情况是:冲积型盐化潮土,轻壤土质,有机质含量11.0 mg/g,全氮(N)0.7 mg/g,碱解氮(N)65.2mg/kg,速效磷(P)17.1 mg/kg,速效钾(K)74.9 mg/kg,地力中等偏上,pH 8.21。玉米氮肥试验设0、90、180、270、360 kg/hm^{2}共5个施氮量,完全随机区组设计,3次重复,小区面积为6 m×6 m;供试品种郑单958,植株密度9株/m^2。磷肥在无氮区用三料钙镁磷肥,在施氮区用磷酸二铵,钾肥用硫酸钾,磷肥(以P_2O_5计,105 kg·hm^{-2})和钾肥(以K_2O计,120 kg·hm^{-2})在播种期一次性施入。施氮量按播种期1/3、10叶展2/3分配,基施氮在扣除磷酸二铵的N后用尿素补足,追施氮用尿素,施肥方式均为侧行开沟条施。

小麦试验中,各对应小区均采用节水省肥高产栽培技术,即选用节水且对氮肥较敏感的小麦高产品种"93-9",10月18日播种,机播,基本苗704株/m^2;施尿素15kg、磷酸二铵15kg、硫酸钾10kg、硫酸锌1kg,所有肥料(其中,折合144 kg N/hm^2)全部基施。在浇足底墒水的基础上,采用春季二水灌溉模式,春一水4月13日,春二水5月9日(在开花~灌浆期之间),每次灌水75mm。冬小麦期间降水112.1mm。

1.1 土壤样品采集与分析方法

试验于夏玉米播种前,冬小麦播种期、拔节期(4月11日)和成熟期(6月8日)共采集了4次土壤样品。每小区选代表性的2个点,每点2钻,3次重复,在样点处用土钻分8层(0~20cm,20~40cm,40~60cm,60~80cm,80~100cm,100~130cm,130~160cm,160~200cm)取样,按采样点分层装入塑料袋,迅速于冰柜中保存。鲜土样处理如下:样品解冻后,将袋中土样充分混匀,称取20 g鲜土于180 ml塑料瓶,加入1 mol/L的KCL溶液100 ml,震荡1 h,用定量滤纸过滤到胶卷盒,过滤液需立刻冰冻保存或测定;同时,测定土壤含水量。将过滤液解冻后,用醋酸-硝酸试粉法[17]测定NO_3^--N含量,在530 nm下比色;用靛酚蓝比色法[18]测定NH_4^+-N含量,在625 nm下比色。

考虑到土壤NO_3^--N移动性较强,以20cm土层为分析单元误差较大,根据取样层的土壤容重,把无机氮的测定值进行了土层合并处理,分为0~40cm、40~130cm和130~200cm共3个层进行研究。土壤无机氮(N_{min})为NO_3^--N与NH_4^+-N之和,无机氮变化量=土壤$N_{min起始}$-土壤$N_{min结束}$[7]。

1.2 植物样品采集与分析方法

(1)干物质积累 每小区选取代表性样段10段,每段长0.5m,要求各样段基本苗一致。于拔节期、抽穗期和成熟期每小区各取样段30cm,所取样段按单茎株数与分蘖株数的比例,每小区选择考察10株,所取样段的植株全部烘干称重并粉碎留样。

(2)测产与考种 田间实际收获1m^{2}样区,每小区2个样点,测定冬小麦实际产量;夏玉米实际收获每小区中间3行,进行实测产量。

(3)样品全氮测定 植物和籽粒留样的全氮含量均采用半微量凯式定氮法[19]测定。氮肥利用率采用非同位素差值法计算,即氮肥利用率=作物从所施氮肥中的吸氮量/施氮总量×100%。氮转移效率=籽粒氮积累量/植物吸氮量×100%。

2 结果与分析

2.1 不同夏玉米施氮量下冬小麦生长季土壤硝态氮含量的变化

由图1知,与不施氮相比,玉米施氮处理显著增加小麦季0~200cm土壤硝态氮含量,施氮量之间差异明显。小麦播种期,施氮量对0~40cm土层硝态氮含量影响不明显;施氮90 kg/hm^{2}的40~130cm和130~200cm土层硝态氮含量均比不施氮增加,但不显著;施氮180 kg/hm^{2}的两土层均比施氮90 kg/hm^{2}明显增加;在施氮180~360 kg/hm^{2}之间,40~130cm土层硝态氮含量随施氮量增加而显著递增,130~200cm土层硝态氮含量在不同施氮量之间差异不明显。从0~130cm和0~200cm两土深看,随施氮量增加,土壤硝态氮含量均递增,其

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中施氮 90 kg/hm² 与不施氮差异不明显，比施氮 180 kg/hm² 显著降低。

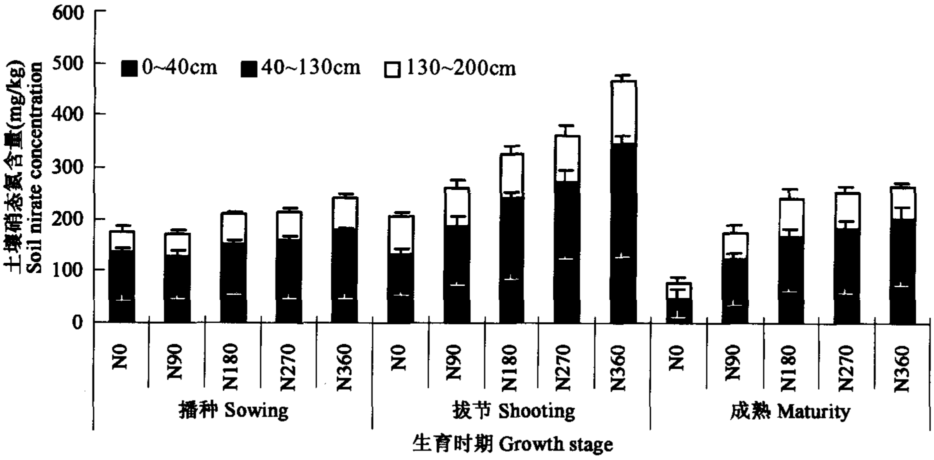

图 1 夏玉米施氮量对后季冬小麦生长期间土壤硝态氮含量的影响

Fig. 1 Effect of N rates applied in summer maize season on soil nitrate concentration during winter wheat season

小麦拔节期，随施氮量增加，0～40cm、40～130cm 和 130～200cm 三层土壤硝态氮含量均递增。其中，在 0～40cm 土层，施氮量小于 180 kg/hm² 时，随着施氮量增加，土壤硝态氮含量增加不明显；施氮 270 kg/hm² 比 180 kg/hm² 显著增加。在 40～130cm 土层，施氮量小于 180 kg/hm² 时，随施氮量增加，土壤硝态氮含量明显增加；施氮 270 kg/hm² 比 180 kg/hm² 增加不明显。在 130～200cm 土层，施氮量小于 270 kg/hm² 时，随施氮量增加，土壤硝态氮含量增加不明显，但施氮 360 kg/hm² 比 270 kg/hm² 增加显著。从 0～130cm 和 0～200 cm 两土深看，随着施氮量增加，土壤硝态氮含量显著递增。

小麦收获时，随施氮量增加，0～40cm、40～130cm 和 130～200cm 三土层硝态氮含量均递增。在 0～40cm 和 130～200cm 两层，施氮量小于 180 kg/hm² 时，随着施氮量增加，土壤硝态氮含量均递增明显，施氮量大于 180kg/hm² 时，随着施氮量增加，硝态氮含量均增加不明显。在 40～130cm 土层，随施氮量增加，硝态氮增加，其中施氮 90 kg/hm² 比不施氮增加显著。从 0～130cm 和 0～200cm 土壤硝态氮含量看，施氮 90 kg/hm² 比不施氮、施氮 180 kg/hm² 比施氮 90 kg/hm² 均显著增加。

2.2 夏玉米不同施氮量对麦玉轮作期土壤无机氮总量变化的影响

如表 1 所示，玉米施氮量对麦玉轮作周期 0～130cm 和 0～200cm 土壤无机氮（即，硝态氮与铵态氮之和）总量的变化有明显影响。经过一季玉米和一季小麦后，不施氮 0～40cm 和 40～130cm 土壤无机氮增加，分别为 89.6 kg/hm² 和 217.0 kg/hm²，但由于 130～200cm 土壤无机氮减少 513.1 kg/hm²，0～200cm 土壤无机氮共减少 206.5 kg/hm²。与此不同，施氮 360 kg/hm² 0～40cm 和 40～130cm 土壤无机氮分别减少 83.9 kg/hm² 和 61.0 kg/hm²，但由于 130～200cm 土壤无机氮增加 433.1 kg/hm²，0～200cm 土层无机氮也增加 288.2 kg/hm²。施氮 90～270 kg/hm² 范围内，施氮量对 0～130cm 和 0～200cm 土壤无机氮改变量的影响不明显。

2.3 不同夏玉米施氮量下冬小麦氮素积累与利用情况

从表 2 可知，随着玉米施氮量增加，成熟期小麦植株和籽粒氮素积累量均增加。施氮量小于 180 kg/hm² 时，随着施氮量增加，植株氮素积累量增加不明显；施氮量小于 270 时，随施氮量增加，籽粒氮素积累量增加不明显。与施氮 90 kg/hm² 和不施氮相比，施氮 270 kg/hm² 的植株积累氮量增加明显，但籽粒积累氮量增加不明显；施氮 360 kg/hm² 的植株氮量和籽粒

表 1 夏玉米施氮量对麦玉轮作期土壤无机氮改变量的影响

Table 1 Effect of N rates applied to maize on soil inorganic supplying amount during summer maize-winter wheat rotation (kg/hm²)

施氮量 N rates	0～40cm 土层 Soil layer	40～130cm 土层 Soil layer	130～200cm 土层 Soil layer	0～130cm 土层 Soil layer	0～200cm 土层 Soil layer
0	-89.6 a	-217.0 a	513.1 a	-306.6 a	206.5 a
90	-46.7 bc	18.3 c	8.9 b	-28.4 c	-19.5 b
180	24.2 c	-19.6 c	-24.8 b	4.6 c	-20.2 b
270	29.7 c	-5.0 c	-45.3 b	24.7 c	-20.6 b
360	83.9 a	61.0 b	-433.1 a	144.9 b	-288.2 a

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氮量均比施氮 270 kg/hm² 增加不明显,但比施氮 180 kg/hm² 显著增加,其中施氮 360 kg/hm² 的籽粒氮量分别比施氮 270 kg/hm² 和 180 kg/hm² 增加 4.2%和 7.2%。

随着玉米施氮量增加,小麦氮转移效率下降。其中,施氮量小于 180 kg/hm² 时,随施氮量增加,小麦氮转移效率素下降不明显;施氮 270 kg/hm² 的小麦氮转移效率比施氮 180 kg/hm² 下降 8.4%,差异显著。随着施氮量增加,小麦籽粒氮肥利用率增加,但差异不明显。

2.4 夏玉米不同施氮量对冬小麦及麦玉轮作期作物产量的影响

随着玉米施氮量增加,小麦籽粒产量(含水量 12%)和麦玉轮作期的籽粒总产(小麦产量和玉米产量之和,其中玉米籽粒含水量 14%)增加(图 2)。不施氮小麦籽粒产量和轮作总产均最低,分别为 5.74 t/hm² 和 15.4 t/hm²。与不施氮相比,施氮 90 kg/hm² 的小麦产量和轮作总产均增加,但不明显。施氮 180 kg/hm² 的小麦产量和轮作总产均比不施氮显著增加,分别达到 6.01 t/hm² 和 16.05 t/hm²;施氮 270 kg/hm² 的两产量均与 180 kg/hm² 无明显差异。施氮 360 kg/hm² 的轮作总产比施氮 270 kg/hm² 显著增加,但小麦产量差异不明显。

表 2　不同夏玉米施氮量对后季冬小麦氮素积累与利用的影响

Table 2　Influnces of N rates applied to maize on N accumulation and utilization by wheat

施氮量 N rates (kg/hm²)	植株积累氮量 Plant N amount (kg/hm²)	籽粒积累氮量 Grain N amount (kg/hm²)	氮转移效率 N transfering efficiency (%)	籽粒氮肥利用率 Grain N use efficiency(%)
0	170.01 c	108.98 b	64.1 a	
90	171.12 c	109.13 b	63.8 a	0.17 a
180	180.00 bc	111.40 b	61.9 a	1.35 a
270	202.21 ab	114.59 ab	56.7 b	2.08 a
360	215.08 a	119.41 a	55.5 b	2.90 a

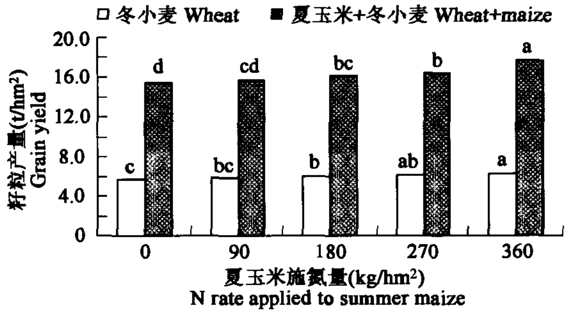

图 2　夏玉米施氮量对麦玉轮作期作物籽粒产量的影响

Fig.2　Effect of N rates applied to summer maize on grain yield of winter wheat and summer maize

3　讨论

研究表明,施氮能显著增加玉米季各土层硝态氮和无机氮量[4~7]。高施氮量(400 kg/hm²)的土壤硝态氮含量比常规施氮量(170 kg/hm²)显著增加[10]。施氮 90~270 kg/hm² 能明显增加夏玉米收获期 0~2m 土壤硝态氮积累,且随施氮量增加积累量递增[4]。本试验中,夏玉米的不同施氮量,同样造成了冬小麦播种前各处理小区的土壤硝态氮含量差异,且施氮量与播种期 0~200cm 土壤硝态氮含量呈明显线性关系,即 y(土壤硝态氮含量)= $0.189x$(施氮量)+ 168.63, $R = 0.942^{*}$。与此不同,黄生斌等发现[13],冬小麦季总施氮量与夏玉米播种前土壤无机氮残留量呈线性加平台关系,即施氮量少于 93.7 kg/hm² 时,0~90cm 土层土壤无机氮残留量为恒值,超过此量后,施氮量与土壤无机氮残留量呈线性关系($r = 0.857^{*}$)。在本试验条件下,玉米施氮量(特别是施用量小于 180 kg/hm² 时)对小麦吸氮量和氮素转移的影响已不明显,籽粒氮肥利用率仅为 0.17%~2.90%。这表明,在冬小麦节水省肥栽培技术体系中所施氮量(144 kg N/hm²)已能满足小麦对氮素的基本需求,玉米季施氮对小麦氮素吸收的贡献已很小。

本试验表明,不施氮处理 0~200cm 土壤无机氮总量经麦玉轮作周期后显著耗竭,小麦产量和轮作总产量均最低;施氮 90~270 kg/hm² 土壤无机氮略减但不明显,但从小麦产量和轮作总产看,施氮 90 kg/hm² 比不施氮增加不明显,施氮 180 kg/hm² 比不施氮显著增加,施氮 270 kg/hm² 与 180 kg/hm² 无明显差异;施氮 360 kg/hm² 土壤无机氮出现显著积累,轮作总产比施氮 270 kg/hm² 显著增加。这可能与高施氮量提高土壤硝态氮浓度的同时,还促进植物自身生长有关。Devienne BF 等认为,在快速生长期,作物能超量吸收 70%~80%[9]。即便如此,长期大量施用氮肥也将导致土壤和地下水污染。可见,在冬小麦季采用节水省肥技术时,若夏玉米不施氮肥,土壤肥力将逐渐衰竭,施氮 90~180 kg/hm² 可能是适宜的,这既能不对冬小麦季土壤供氮变化产生明显影响、基本维持地力水平,又能节约 1/2 生产成本[16],减少污染压力。

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减量施氮试验表明[12]，土壤硝态氮一旦进入1m以下土层，作物根系将很难再回收利用。事实上，夏玉米施氮量90～270 kg/hm^{2}已使120～200cm土壤硝态氮积累量比不施氮高出50～95.4 kg/hm^2[4]。张丽娟等发现，作物根长密度与相应土层标记硝态氮的利用率呈显著正相关[20]。小麦和玉米根系存在显著差异，这为研究玉米收获后残留根区以外的深层硝态氮对小麦有效性[4]提供了可能。本试验发现，冬小麦生长季相同方式施入等氮量后，不同土层硝态氮含量的改变各异，这说明在硝态氮含量不同的土壤中，既使引入相同的氮源，土壤矿化作用也是不同的[11]。另外，氮肥在土壤的转化与残留形态，以及残留氮肥当季外源氮素的互作和对植物的有效性等，还受温度、水分、土质等多因素影响[21]。冬小麦节水省肥技术体系中还有其它节水模式，需要进行多年、不同土质的深入、系统研究。

References:

[1] Balázs J, Németh I, Hoffmann. Effect of nitrogen fertilization on the yield of winter wheat and N-leaching. Achives of Agronomy and Soil Science, 2004, (50):85～90.

[2] Zhang W L, Tian Z X, Zhang N, *et al*. The investigation of ground water NO_3^--N pollution caused by N fertilizer in North China Plain. Plant Nutrition and Fertilizer Science, 1995, 1(2): 80～87.

[3] Zhang F S, Mi G H, Liu J A. Advances in the genetic improvement of nitrogen efficiency in maize. Journal of Agricultural Biotechnology, 1997, 5(2): 112～117.

[4] Wu Y C, Zhou S L, Wang Z M, *et al*. Dynamics and residue of soil nitrate in summer maize field of North China. Acta Ecologica Sinica, 2005,25(7): 1620～1625.

[5] Wang Q X, Wang P, Shen L X, *et al*. Effect of nitrogen application time on dynamics of nitrate content and apparent nitrogen budget in the soil of summer maize fields. Acta Ecologica Sinica, 2004,24(8): 1582～1588.

[6] Zebarth B J, Paul J W, Younie M, *et al*. Fertilizer nitrogen recommendations for silage corn in high-fertility environment based on pre-sidedress soil nitrate test. Communications in Soil Science and Plant Analysis, 2001, 32 (17,18): 2721～739.

[7] Wu J X, Chen X P, Jia L L, *et al*. Continuous nitrogen supplying capacity of the fertile soil in the winter wheat / summer maize rotation system. Plant Nutrition and Fertilizer Science, 2004, 10(1): 1～5.

[8] Ju X T, Liu X J, Zhang F S. Study on effect of nitrogen fertilizer and nitrogen balance in winter wheat and summer maize rotation system. Scientia Agricultura Sinica, 2002, 35(11):1361～1368.

[9] Devienne B F, Justes E, Machet J, *et al*. Integrated control of nitrate uptake by crop growth rate and soil nitrate availability under field conditions. Annals of Botany, 2000, 86(5): 995～1005.

[10] Liang B C, Remillard M, Mackenzie A F. Influence of fertilizer, irrigation, and non-growing season precipitation on soil nitrate-nitrogen under corn. Journal of Environmental Quality, 1991, 20(1): 123～128.

[11] Jenkinson D S, Fox R H, Rayner J H. Interaction between fertilizer nitrogen and soil nitrogen — the so-called "priming" effect. Journal of Soil Science, 1985, (36): 425～444.

[12] Liu X J, Ju X T, Zhang F S. Effect of reduced N application on Nutilization and balance in winter wheat-sumner maize cropping system. Chinese Journal of Applied Ecology, 2004, 15(3): 458～462.

[13] Huang S B, Chen X P, Zhang F S. Effect of residual nitrogen applied to winter wheat on the following summer maize. Journal of China Agricultural University, 2002, 7(1): 54～58.

[14] Li Z Z. Spatial variability of soil water and inorganic nitrogen at the different scales in the field. Ph.D Dissertation, China Agricultural University, 2000.

[15] Ju X T. Transformation and fate of soil-fertilizer nitrogen in winter wheat / summer maize rotation system. Ph.D Dissertation, China Agricultural University, 2000.

[16] Li J M, Zhou D X, Wang P eds. Principles of efficency use of water and fertilizer in winter wheat. Beijing: China Agricultural University Press, 2000. 3～16.

[17] Nanjing institute of soil sciences eds. Analysis of soil physiology and chemistry. Shanghai: Shanghai Science and Technology Press, 1978. 80～93.

[18] Bao S D eds. Analysis of soil agro-chemistry. Beijing: China Agriculture Press, 2000.54～56.

[19] Hunan agricultural college eds. Experiment guideline of crop cultivation. Beijing: Agriculture Press, 1988. 243～246.

[20] Zhang L J, Ju X T, Gao Q, *et al*. Recovery of labeled nitrate-N in different soil layers by two kind of crops. Scientia Agricultura Sinica, 2005, 38(2): 333～340.

[21] Zhu Z L. On some aspects in soil nitrogen research. Progress in Soil Science, 1989, (2): 1～9.

参考文献:

[3] 张福锁，米国华，刘建安．玉米氮效率遗传改良及其应用．农业生物技术学报，1997，5(2)：112～117．

[4] 吴永成，周顺利，王志敏，等．华北地区夏玉米土壤硝态氮的时空动态与残留．生态学报，2005，25(7)：1620～1625．

[5] 王启现，王璞，申丽霞，等．施氮时期对玉米土壤硝态氮含量变化及氮盈亏的影响．生态学报，2004,24(8)：1582～1588．

[7] 武俊喜，陈新平，贾良良，等．冬小麦/夏玉米轮作中高肥力土壤的持续供氮能力．植物营养与肥料学报，2004，10(1)：1～5．

[8] 巨晓棠，刘学军，张福锁．冬小麦与夏玉米轮作体系中氮肥效应及氮素平衡研究．中国农业科学，2002，35(11):1361～1368．

[12] 刘学军，巨晓棠，张福锁．减量施氮对冬小麦-夏玉米种植体系中氮利用与平衡的影响．应用生态学报，2004，15(3)：458～462．

[13] 黄生斌，陈新平，张福锁．冬小麦施氮对下茬夏玉米的后效．中国农业大学学报，2002，7(1)：54～58．

[14] 李子忠．不同尺度下农田土壤水分和无机氮的空间差异性．中国农业大学博士论文，2000．

[15] 巨晓棠．冬小麦/夏玉米轮作体系中土壤-肥料氮的转化及去向．中国农业大学博士学位论文，2000．

[16] 李建民，周殿玺，王璞主编．冬小麦水肥高效利用栽培技术原理．北京：中国农业大学出版社，2000．3～16．

[17] 中国科学院南京土壤研究所编．土壤理化分析．上海：上海科技出版社，1978．80～93．

[18] 鲍士旦主编．土壤农化分析．北京：中国农业出版社，2000．54～56．

[19] 湖南农学院主编．作物栽培学实验指导．北京：农业出版社，1988．243～246．

[20] 张丽娟，巨晓棠，高强，等．两种作物对土壤不同层次标记硝态氮利用的差异．中国农业科学，2005，38(2)：333～340．

[21] 朱兆良．关于土壤氮素研究中的几个问题．土壤学进展，1989，(2)：1～9．