直播旱作水稻的吸氮特征与土壤氮素表观盈亏

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摘要:水稻旱作是水稻节水栽培中最有效的方式。通过田间试验研究旱作直播条件下水稻对氮素的吸收利用特征以及土壤矿质氮的动态变化,并对土壤氮素的表观盈亏量进行了估算。结果表明,直播旱作水稻较水作水稻更注重中后期对氮素养分的吸收,尤其是对土壤氮素的吸收;幼穗分化后水稻的土壤吸氮量占阶段吸氮总量的 69.5%,比水作水稻多 17.8%。对 0~40cm 土层土壤矿质氮含量时空变化的研究表明,直播旱作水稻生育前期土壤表层矿质态氮大量累积,在灌水和降雨的影响下,向下层的迁移增加,基肥施用后裸地处理 20~40cm 土层的矿质氮高达 104kgN/hm²。对水稻各生育期土壤氮素盈亏的计算结果表明,自分蘖盛期后旱作各处理都表现出土壤氮素不同程度上的表观亏缺,然而就全生育期土壤氮素盈余量而言,旱作处理平均高达 127 kg N/hm²,生育前期氮肥的大量投入是氮素盈余的主要原因。本试验结果表明,直播旱作水稻生育前期对施用的肥料氮吸收很少,提高直播旱作水稻氮肥利用效率的关键在于减少生育前期肥料氮的投入。

关键词:旱作水稻;吸氮量;土壤矿质氮;土壤氮素表观盈亏

Absorption and apparent budget of nitrogen by direct-seeding rice cultivated in aerobic soil with or without mulching

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Abstract: Rice production in aerobic soil with mulching is one of the most important cropping systems for water-saving agriculture. In this system, the rice plant (not upland variety but traditional paddy rice variety with high yield potential) is grown during whole growth stage in soil with water content being 70%~90% of water holding capacity (WHC). The total shift of the growth environment from traditional waterlogged to aerobic conditions greatly changes rice growth, i. e. the characteristics of rice growth and development, the yield formation and the nitrogen forms that the rice takes up. The objective of the present study is to determine the effects of direct-seeding rice cultivated in aerobic soil with mulching on characteristics of nitrogen uptake and apparent budget to provide the basis for nitrogen management practices for rice cultivation in aerobic soil condition.

A field experiment was carried out in sandy loam soil in Yancheng, Jiangsu province (33°27′N, 120°11′E) in 2001. There were three treatments in rice cultivation in aerobic soil, including the soil being covered with plastic film (PF), with rice straw (RS) and the soil without any mulching (B). The control for the experiment was the rice grown in waterlogged soil (W). The main field experiment, which was subdivided into one waterlogged area and one large aerobic area, was constructed in a one-factorial block design with three replications each treatment. The experimental block of waterlogged rice production was separated from the aerobic block by a strong plastic foil vertically inserted into depth of 60 cm for hydrological isolation. After

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sowing, plastic film was used to cover all surface of aerobic treatments to ensure seedling emergence. At the 3-leaf stage, the plastic film was removed in RS and B treatments. The soil surface in RS treatment was then covered with semi-decomposed rice straw (about 6000 kg dry straw/hm^2). Two water tensionmeters with tips at 18 cm depth were installed in each plot to indicate that soil water content was maintained round 75%～90% of water holding capacity (WHC), that is to say, as soon as soil water content was lower than 75%～90% of WHC, irrigation would be made immediately and then stopped when the water at the soil surface reached the expected values. The ^{15}N sub-plots were laid out within each treatment and thus the application of 225 kg N/hm^2 (^{15}N-labeled urea with 2% ^{15}N abundance) was homogeneously added into soil by hand. Plant samples were taken in ^{15}N sub-plots at four growth stages: maximum tillering, panicle initiation, heading and harvest of the rice plant. All the samples were dried at 70℃ for 72h after kept at 105℃ for 20 min to stop the biological activity. Delta C continuous flow mass spectrometer was coupled to Carlo Erba elemental analyzer 1108 by Conflo II interface to measure total plant N content and ^{15}N abundance. Soil sampling at the depths of 0～20cm and 20～40cm from fields was done every two weeks during the experimental duration. The soil mineral N (including NO_3^--N and NH_4^+-N) was determined as follows: 0.01mol/L $CaCl_2$ were used as extraction on a horizontal shaker for 1h, and Nmin in the filtrate was analyzed by using a flow-analyzer (CFAAA3). At the same time the soil water content of each sample was determined by oven drying.

Estimating of apparent budget of soil N (ABSN) was followed by Zhou Shun-Li's method that was based on the balance of available N to plant (including Nmin and fertilizer-N). ABSN＝(Total amount of original Nmin ＋ Rate of applied N)-(Total amount of residual Nmin ＋ Rate of uptake N by crop).

The main results of this study are as follow. Large nitrogen uptake and accumulation of rice plant cultivated in an aerobic condition happened mostly during the later growing stage, while they occurred soon after transplanting stage in waterlogged conditions. About 69.5% of nitrogen uptake by rice plants was from aerobic soil after the panicle-initiation (PI) process, whereas the rate was only 51.7% in waterlogged soil. A large amount of mineral N was accumulated in the surface layer in aerobic conditions during the early growing stage of rice. As a result of irrigation and precipitation, the nitrate could be leached into sub-layers and the mineral N concentration, for example, could be as high as 104 kg N/hm^2 in the layer of 20～40 cm in B treatment. Thus there could be a possibility that soil mineral N would leach out of the root zones since rice roots were usually distributed in the top 20 cm soil layer. On the other hand, a decrease of 57.7 kg N/hm^2 was found in surface layer in RS treatment because of the immobilization by the semi-decomposed straw compared to B treatment at the time of one week after tillering fertilizer application. This immobilized N could facilitate the uptake of N by the rice in the latter growing stage. The estimated results of apparent budget of soil nitrogen (ABSN) indicated that surplus soil mineral nitrogen was found in the soil of aerobic cultivation system from the seeding to the maximum tillering stage but after then the available nitrogen in soil (inorganic-N ＋ fertilizer-N) could not meet the requirements of the rice plants. During the whole vegetation period, the average apparent surplus of soil nitrogen in aerobic treatments was 127 kg N/hm^2, which was due to the large nitrogen fertilizer input during the early growing stage.

Key words: rice cultivation in aerobic soil with mulching; nitrogen uptake; soil mineral nitrogen; apparent nitrogen budget

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近年来水稻旱种作为在节水种稻基础上发展起来的一种高效节水新模式而受到越来越多的关注,其中地膜覆盖旱作和利用半腐解秸秆替代地膜的覆盖旱作都受到了广泛的重视[1,2]。在传统的水稻高产栽培模式中,针对水稻移栽后生长旺盛,后期易贪青的生长习性,往往采取"前促后控"、强调基肥施用的水肥管理模式[3,4]。而水稻旱作后,整个生育期不建立水层,土壤含水量显著降低,势必会对水稻的生长发育产生很大的影响。研究发现,水稻旱作后表现为"前慢、中猛"的生长发育特性[2,5]。而目前旱作水稻的生产上仍沿袭水作水稻的施肥模式,因此研究旱作水稻的吸氮特征是建立符合旱作水稻生育进程的氮肥运筹模式所必需的基础工作。

水稻旱作后稻田水分含量的降低也会影响土壤氮素的运移。在水田环境中土壤氮素以铵态氮为主要存在形式,生长季中的氮素淋溶损失明显小于玉米、小麦等其它旱地作物[6～8]。而水稻旱作后土壤中矿质氮以硝态氮为主[9],加上生育期适逢雨季,如何减少氮素淋失便成为建立对环境友好的水稻旱作氮肥施用模式的挑战所在。

本试验在大田条件下,以传统水作水稻作为对照,研究地膜覆盖、半腐解秸秆覆盖以及裸地3种旱作方式下直播水稻生育过程中的氮素吸收特征,同时监测0～20cm和20～40cm土层土壤矿质氮的动态变化,并对不同生育阶段土壤氮素的表观盈亏

量进行估算,旨在为进一步建立适于旱作水稻需氮规律的氮肥合理运筹模式提供理论依据。

1　材料与方法

1.1　试验地点和供试土壤

试验在盐城市东郊江苏省沿海地区农业科学研究所试验场内进行。供试水稻品种为中熟杂交稻特优 559,供试土壤是黄泛冲积物母质发育而成的潮盐土,其基本理化性质见表 1。

表 1　水稻播种前试验地土壤基本性状

Table 1　Soil characteristics of experimental field before sowing

土壤层次 Soil depth (cm)	容重 Bulk capacity (g/cm^3)	pH (H_2O)	全氮 Total N (g/kg)	有机质 Organic matter (g/kg)	NH_4^+-N (mg/kg)	NO_3^--N (mg/kg)
0～20	1.46	8.42	0.744	11.8	3.51	6.90
20～40	1.54	8.73	0.581	7.8	1.67	7.48

1.2　试验设计

以常规水作水稻作为对照(代号 W),试验分为水作与旱作两个区,中间有一深为 60 cm、宽为 20 cm 的沟,埋上厚塑料膜填土筑埂,用以隔水隔肥,且在埂的两侧各设有 6 m 宽的过渡小区。旱作区设地膜覆盖(代号 PF)、半腐解秸秆覆盖(代号 RS)和裸露(代号 B)3 个处理,每个处理重复 3 次,随机区组排列。各处理小区面积为 72 m^2(12m×6m),小区内设有采样亚区(3m×4m),收获亚区(2m×4m),^{15}N 亚区由 1.8m×2m×0.4m 的金属框围成,埋入土中 25cm 深。水作稻 5 月 13 日落谷,6 月 13 日移栽;旱作各处理于 5 月 9 日播种后均用地膜覆盖,待秧苗长至 2～3 叶期后,再进行不同的覆盖处理。其中,地膜覆盖处理破膜放苗,覆草处理则揭去地膜用半腐解秸秆覆盖,其用草量为 6000 kg hm^{-2};裸地旱作处理则在揭膜后按旱作物种植方式进行管理。各处理行、株距为 25cm×15cm,每穴定苗 3 株。

1.3　水肥管理

各处理均施尿素氮肥 225 N kg/hm^2,^{15}N 微区等量施用丰度为 2%的^{15}N 尿素(由上海化工研究院所提供丰度为 10.3%的尿素稀释而成)。氮肥分基肥、分蘖肥和穗肥 3 次按 4∶3∶3 比例施用,磷、钾肥用量分别为 90 P kg/hm^2 和 90 K kg/hm^2,以普钙和氯化钾作为基肥一次施入。各旱作处理水稻生长期内通过各小区中埋在土壤深度为 18cm 的两支张力计来指导灌溉。当张力计读数指示土壤含水量低于田间持水量(由试验地土壤水分特征曲线获得)的 90%时即进行灌水,至田面出现浅水层后为止并保证浅水层在灌水后即刻消失。

1.4　土壤及植株样品的采集

水稻生育期间,每两周一次分别采集 0～20cm 和 20～40cm 土壤混合样品。在水稻生长的四个生育时期,即分蘖盛期(7 月 18 日)、幼穗分化期(8 月 1 日)、抽穗期(8 月 29 日)和成熟期(9 月 26 日)在 1.8m×2m 的^{15}N 微区内,分别随机取植株小样,分析含氮量和^{15}N 丰度;同时,在采样亚区内采取破坏性的取样方式,在 0.3m^2 上取 8 穴植株样品,剪取地上部样品,称鲜重后随机取小样烘干,以计算水稻生育期内群体生物产量。收获时,各收获亚区收割地上部,脱粒。秸秆称鲜重,随机取小样烘干计算秸秆产量并分析含氮量;籽粒风干称重计产,随机取小样烘干,分析含氮量。

1.5　测定方法

1.5.1　土壤矿质氮的测定　新鲜土壤充分混匀,过 2mm 筛,土壤含水量较大时,尤其是水田样品,过 5mm 筛。称取 25.00g 土壤样品,加入 200ml 0.01mol/L 的 $CaCl_2$,振荡 60min 后过滤,浸提液中的铵态氮和硝态氮用连续流动分析仪(AA3 Continuous Flow Analytical System,Bran&Luebbe Inc Germany)测定。同时,烘干法测定土壤样品含水量。

1.5.2　^{15}N 丰度的测定。将^{15}N 植株和土壤样品磨细后,用 Delta C 连续流动质谱仪联合 Carlo Erba 元素分析仪同时测定全氮含量和^{15}N 丰度。

1.6　数据分析

肥料^{15}N 的作物吸收量 Ndff (kgN/hm^2)=籽粒%Ndff × 籽粒吸氮量 + 秸秆% Ndff × 秸秆吸氮量,土壤氮素的作物吸收量 Ndfs(kgN/hm^2)=作物吸氮量-作物 Ndff[10];单位面积土层重量(kg/m^2)=土壤容重×土层厚度,单位面积土壤 Nmin 总量(kgN/hm^2)=土壤矿质氮浓度 × 单位面积土层重量;土壤氮素表观盈亏量 =(土壤 Nmin 起始总量+施氮量)-(土壤 Nmin 残留总量+作物吸氮量)[7]。

文中表内数据均采用 SPSS 统计软件进行 ANOVA 方差分析,并进行 SSR 多重比较。

2　结果与分析

2.1　不同处理水稻生育期内群体氮素累积动态

综观水稻一生,水作水稻全生育期氮素累积总量明显高于旱作,水作比覆膜、覆草和裸地处理分别多吸收 22%、24%和

31%的氮素;而3个旱作处理的氮素累积总量差异不明显(表2)。比较不同处理水稻各生育阶段的氮素累积动态发现,水作水稻对氮素的吸收利用主要集中在生育前期,从播种-分蘖盛期的吸氮量约占其总吸氮量的一半,显著高于各旱作处理;而旱作覆草和裸地处理在此阶段吸收的氮只有水作稻的1/4,阶段吸氮量仅占其一生吸氮总量的15%~18%。旱作覆膜处理水稻在播种-分蘖盛期的阶段吸氮量占其一生总吸氮量的43%,明显高于其它旱作处理;但在分蘖盛期-幼穗分化期,覆膜旱作水稻对氮素的吸收明显下降,阶段吸氮量仅占其一生总吸氮量的6%;而覆草和裸地处理此阶段的吸氮量则与前一阶段大致持平。在幼穗分化-抽穗期水稻吸氮量有所增加,虽然各处理水稻在此阶段的吸氮量差异不显著,然而就其占整个生育期吸氮总量的比例来看,旱作水稻各处理显著高于水作处理。在抽穗-成熟期所有处理水稻的阶段吸氮量都回落,其中以覆草处理的回落幅度最小,其它3个处理的回落差异不明显。从不同旱作处理的氮累积高峰来看,覆草和裸地处理均出现在幼穗分化-抽穗期,而覆膜旱作水稻则有播种-分蘖盛期和幼穗分化-抽穗期两个吸氮高峰,反映了不同旱作栽培水稻氮素营养特性上的差异。

表2 不同处理水稻不同生育阶段氮素累积量及累积比例

Table 2 Nitrogen accumulation rate in rice crop at different stages

处理 Treatment	播种-分蘖盛期 Vegetative phase		分蘖盛期-幼穗分化期 Vegetative-lag phase		幼穗分化-抽穗期 Reproductive phase		抽穗-收获期 Ripening phase		累积总量 Total
	NAR① (kg/hm^2)	PNA② (%)	NAR (kg/hm^2)	PNA (%)	NAR (kg/hm^2)	PNA (%)	NAR (kg/hm^2)	PNA (%)	NAR (kg/hm^2)
PF	59.4b③	42.9a	8.0b	5.8b	55.4a	40.0a	15.7b	11.4b	138b
RS	20.9c	15.5b	22.8a	16.9a	56.3a	41.8a	34.6a	25.7a	134bc
B	21.2c	17.3b	20.1a	16.4a	61.7a	50.5a	19.3b	15.7ab	122c
W	86.1a	48.5a	16.2ab	9.1ab	53.4a	30.1b	21.7ab	12.2b	177a

①NAR:阶段氮累积量 N accumulation rate;②PNA:占总量 Percentage of N accumulated at different stages;③同列中不同字母表示差异显著(SSR test, $P<0.05$, $n=3$)Means followed by different letters on the same column indicate significant difference at 5% level by SSR test

2.2 不同处理水稻生育期内对肥料氮和土壤氮吸收利用的差异

施氮条件下水稻吸收的氮素主要源自土壤氮和肥料氮。^{15}N示踪法计算所得的水稻地上部不同生育阶段对肥料^{15}N和土壤氮吸收累积量的变化趋势表明(图1),水作水稻对肥料氮的吸收随生育期的推移逐渐增加(图1a),而旱作处理则明显不同,其中覆草与裸地处理水稻对基肥和分蘖肥的吸收量远低于覆膜处理,肥料氮的吸收高峰出现在施用穗肥后,而覆膜处理因前期生长旺盛,则呈现出分段吸肥的趋势。在对土壤氮素的吸收利用方面,与水作水稻生育后期土壤氮素吸收速率趋缓不同的是,旱作各处理水稻对土壤氮的吸收随着生育期的推移而逐渐增加(图1b),尤其是在穗肥施用以后,植株对土壤氮的吸收持续增加。旱作水稻从幼穗分化后直到收获的整个生殖生长过程中,对土壤氮的吸收占此阶段吸氮总量的69.5%,比水作处理高17.8%,说明与水作相比旱作水稻生育后期土壤氮素对作物氮素营养的贡献远大于肥料氮。

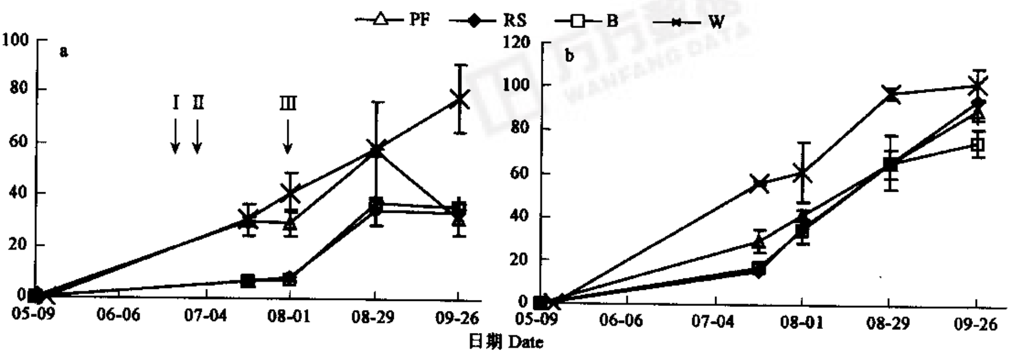

图1 不同处理水稻各生育期吸收肥料^{15}N(a)和土壤氮(b)的动态过程

Fig.1 The changes of N absorbed from ^{15}N-fertilizer(a) and soil(b) by rice plant in different treatments

图中小竖线表示标准误 Error bars indicates ±S.E.M, $n=3$; I 旱作水稻分蘖肥及水作水稻基肥 Urea applied at tillering stage in upland rice and as basal fertilizer in paddy rice II 水作水稻分蘖肥 Urea applied at tillering stage in paddy rice III 旱作和水作水稻穗肥 Urea applied at booting stage

2.3 不同处理水稻生育期内土壤矿质氮的动态变化

不同处理水稻生育期内每两周0~20cm、20~40cm土层土壤矿质氮的动态变化研究表明(图2),旱作水稻生育前期表层

0～20cm土层中的矿质氮含量在施用氮肥后1～2周内迅速出现高峰,然后随着作物的吸收、灌溉和雨水的淋洗而急剧下降(图2a);而在穗肥施用后,因旱作水稻进入旺盛生长阶段,对氮素的吸收强度较大而使后期土壤中矿质氮一直维持在一个相对较低的水平。分蘖肥施用后,覆草处理由于半腐解稻草的覆盖而出现了明显的生物固持的现象,矿质氮数量与旱作裸地处理相比下降了57.7kg/hm^2,说明半腐解稻草的覆盖有利于肥料氮在土壤中的固持,减少生育前期肥料氮的损失。

比较生育期内20～40cm土壤中矿质氮的变化趋势可以发现,土壤矿质氮在亚表层20～40cm的变化没有表层剧烈(图2b),基肥施用后在灌水的作用下,表层的矿质氮迅速向下迁移,其中裸地处理土壤亚表层矿质氮的含量高达104kgN/hm^2,几乎等于施入基肥的总量,显著高于旱作覆盖处理,说明旱作覆盖可以有效地减少土壤中矿质氮的淋洗损失。

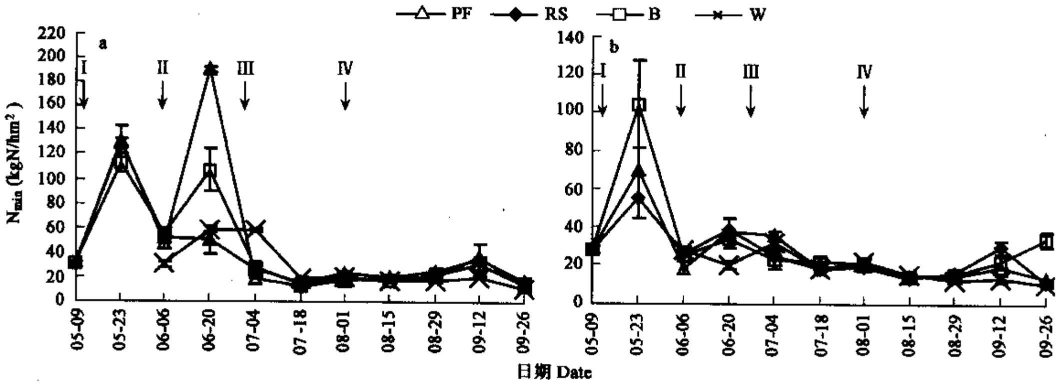

图2　不同处理0～20cm(a),20～40cm(b)土层矿质氮的动态变化

Fig. 2　The changes of soil inorganic nitrogen in different treatments in0～20cm(a), 20～40cm(b) soil layer

图中小竖线表示标准误 Error bars indicates ± S. E. M, $n=3$; I　旱作水稻基肥 Urea applied as basal fertilizer in upland rice　II　旱作水稻分蘖肥及水作基肥 Urea applied at tillering stage in upland rice and as basal fertilizer in paddy rice　III　水作水稻分蘖肥 Urea applied at tillering stage in paddy rice　IV　旱作和水作水稻穗肥 Urea applied at booting stage

2.4　不同处理水稻生育期内土壤氮素盈亏量的表观估算

氮肥施入后减去被作物吸收和残留在土壤中矿质氮外的那部分氮素被称作氮素的表观盈余[7],水稻全生育期0～40cm土层土壤氮素表观盈亏量(各生育阶段盈余量之和)的估算结果显示,各处理均表现为土壤氮素的表观盈余(表3),但从各生育阶段来看,不同处理间差异较大。从播种-分蘖盛期,由于氮肥的大量施用,各处理均表现为土壤氮素的大量盈余,而旱作覆草与裸地处理其土壤氮素表观盈余量显著高于覆膜旱作水稻和水作水稻;在水稻进入分蘖盛期后,生长迅速,各处理迅速表现为土壤氮素的亏缺,尤其是对于生育前期生长迅速的水作处理水稻来讲,更为明显;而在穗肥的施用下,水作处理水稻的土壤亏缺得以缓解,而旱作除覆草处理水稻外,依然表现为土壤氮素的亏缺;抽穗以后,各处理仍然表现不同程度地亏缺。

表3　不同处理水稻生育期内土壤氮素的表观盈亏量(0～40cm 土层)

Table 3　Apparent budget of soil N at different stages of rice in different treatments (N kg/hm^2)

处理 Treatment	播种-分蘖盛期 Vegetative phase	分蘖盛期-幼穗分化期 Vegetative-lag phase	幼穗分化-抽穗期 Reproductive phase	抽穗-收获期 Ripening phase	全生育期 Growth duration
PF	132 b*	−8.1 a	−5.8 ab	−3.7 ab	98.4 b
RS	162 a	−31.1 ab	11.4 ab	−6.4ab	135 a
B	156a	−20.5 ab	−9.7 b	3.1 a	147 a
W	128 b	−56.8 b	26.9 a	−22.0 b	75.6 c

* 同列中不同字母表示差异显著(SSR test, $P<0.05$, $n=3$)Means followed by different letters on the same column indicate significant difference at 5% level at SSR test

3　讨论

3.1　不同处理水稻各生育阶段氮素吸收的差异及土壤氮素的表观盈余

与其他旱作水稻相比,覆膜处理水稻播种到分蘖盛期氮素累积迅速,可能是因为覆膜对土壤的增温作用使水稻发苗早,分蘖旺盛,地上部的干物质积累迅速所致[11];但是由于水稻光合生产能力有限,旱作覆膜处理水稻又不能象水作水稻那样通过烤田控制无效分蘖,往往出现单株分蘖数多但成穗率不高的情况[5,12],而分蘖的大量死亡使分蘖盛期后覆膜水稻的氮素累积量显著低于其它旱作处理,最终表现为覆膜水稻在前期大量累积的氮素被无效利用而损失。而半腐解秸秆覆盖和裸地旱作处理水稻

由于生育前期生长缓慢，对基肥和分蘖肥的吸收量远低于地膜覆盖处理，作为基肥和分蘖肥施用的氮肥在被水稻吸收利用前会有较多的损失。因而，就旱作各处理而言，在生产实践中的施肥模式应有别于注重基肥的传统水作水稻，适度减少前期肥料 N 的投入；同时在前期直播旱育秧苗阶段（3 叶期前）适当增加水分补给，以争取全苗壮秧[13]，并辅以其他土肥管理措施，促进旱作水稻前期的生长发育，增加对基施氮肥的吸收，进而提高氮肥利用效率。

水作处理水稻生育前期氮素累积量明显高于旱作各处理，而旱作水稻则相对更注重中后期对氮素养分的吸收利用。这是因为移栽水作水稻生育前期生长发育迅速，根系干物质的积累在拔节前明显高于旱作水稻[14]；同时，水作条件下土壤中的有效态氮素向水稻根系的迁移较快，能很好的满足水稻生长的需要，因而生育前期氮素累积量显著高于旱作各处理。由于水作水稻中后期根系衰老速度较快，使其对氮素的吸收速率下降；而旱作条件下水稻根系干物质累积量较多，抽穗后根系衰老相对缓慢，根系活力依然较高[15,16]，因而对氮素的吸收速率不减，氮素积累的高峰出现在幼穗分化到抽穗期。^{15}N 示踪的研究结果也表明，地表覆盖旱作处理水稻在抽穗后对土壤氮的吸收速率不减，与水作处理差异明显。这是因为生育前期水稻植株较小，所需氮量相对较少，而随着生育期的推移，水稻不断生长发育，所需氮素逐渐增加；施用穗肥后，旱作土壤中可利用的肥料氮减少了，对土壤氮的吸收就表现出不断增加的趋势。

虽然旱作水稻在一生中表现为 0～40cm 土层土壤氮素的盈余，但这种表观盈余是由早期大量施用氮肥以及前期旱作水稻生长缓慢所致。幼穗分化后，旱作水稻进入生殖生长阶段，吸氮量急速增加，旱作各处理均表现出不同程度的氮素亏缺，土壤中可利用氮素供应不足。由上文分析可知，旱作水稻在生育后期对土壤氮素不断增加，则从侧面说明旱作水稻从土壤中吸收的氮在一定程度上可以缓解旱作水稻中后期的供氮问题。杨建昌等研究发现，覆膜旱作水稻在生长过程中易因无效分蘖过多而使后期肥水供应不足，进而引起早衰减产[5]。因而，在实际操作中应适度加大旱作直播水稻穗肥的施用力度，或在不增加穗肥氮施用量的基础上采取后期叶面喷施氮肥以防止穗肥氮过多造成的贪青迟熟，以实现增产增效的目的。

3.2 直播旱作水稻生育期间的氮素损失与氮肥运筹

尿素施入土壤后，无论是水作还是在旱作条件下，均很快水解，在好气条件下施入土壤中的尿素会迅速转化为 NO_3^--N[17]。旱作直播条件下水稻幼苗生长缓慢，前期对肥料氮的吸收利用较少，此时肥料的大量施用会使土壤中的无机氮过量存在，在降雨和灌溉的条件下会带来较多的淋洗损失。而水稻在传统移栽水作条件下，提倡多施基肥，是因为水稻移栽后适逢旺盛生长期，对氮素的需求量大。旱作好气条件下表层土壤中过量存在的无机氮同时还使 N_2O 的排放大大增加，根据同期监测不同处理水稻施肥后 N_2O 排放通量的结果表明，旱作处理 N_2O 在施肥后 1 周左右会出现排放高峰，其排放通量均显著高于水作处理[18]。

本试验中半腐解秸秆覆盖处理对施用的分蘖肥发生了明显的生物固持现象，覆草处理表层土壤中无机氮含量明显低于其它旱作处理，类似的固持现象在秸秆还田试验中也有报道[19,20]，因而采用半腐解秸秆覆盖可以有效的减少无机氮在土壤表层的积累，进而减少氮素的损失。因此，在直播覆盖旱作水稻的栽培中，基肥少施的基础上，加强旱育秧苗阶段的水土管理，争取全苗壮秧；将地膜覆盖与半腐解秸秆相结合，适度延长地膜覆盖的时间，以利早发苗、促分蘖，揭膜后用半腐解秸秆覆盖，增加对前期所施氮素的固持，为水稻后期对土壤氮的大量吸收打下基础，达到增加产量、提高肥效的目的。

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