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有机无机结合施肥对红壤稻田土壤氮素供应和水稻生产的影响

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摘要:1999 年以不同施肥制度对红壤稻田系统生产力和土壤环境影响的长期定位试验的为依托,比较研究了 9a 定位试验后,不施肥、单施无机肥、有机物循环和有机无机结合施肥对红壤稻田生态系统土壤供氮能力、水稻吸氮特性和水稻生产的影响。结果表明:红壤稻田系统长期不施肥(CK)土壤速效氮含量低,最高为 16.7mg/kg,平均为 14.2mg/kg,水稻累积吸收氮量较少,早稻为 32.84kg/hm^2,晚稻为 59.79kg/hm^2,系统生产力低,早稻生物量为 3887kg/hm^2,稻谷产量为 2180kg/hm^2,晚稻生物量为 7164kg/hm^2,稻谷产量为 3719kg/hm^2;施用 N 肥可以改善土壤供氮状况,提高土壤速效氮含量,且 N、NP、NK、NPK 处理间没有显著差异,土壤速效氮含量最大可达到 29.7mg/kg,平均为 21.4mg/kg,而水稻累积吸收氮量与系统生产力随着 NPK 配合程度的增加而提高, NPK 处理的早稻累积吸收氮量、生物量和稻谷产量分别比 CK 处理增加 122.6%、87.1%和 65.4%,晚稻分别增加 85.0%、48.2%和 46.0%;系统内有机物循环利用(C)水稻各生育期土壤速效氮含量显著提高,最高为 30.2mg/kg,平均为 20.8mg/kg,水稻累积吸收氮量早、晚稻分别比 CK 增加 111.1%和 48.9%,早稻生物量与稻谷产量显分别比 CK 高 85.6%和 55.2%,晚稻分别高 28.9%和 35.2%;有机无机结合施肥土壤速效氮含量最大为 43.1mg/kg,平均为 29.1mg/kg,且 N+C、NP+C 和 NPK+C 处理间没有显著差异,但水稻累积吸收氮量和系统生产力有随着有机肥与 NPK 配合程度增加而提高的趋势。

关键词:有机无机结合;养分循环;水稻;氮;供应特征;生产效益

Some effects of inorganic fertilizer and recycled crop nutrients on soil nitrogen supply and paddy rice production in the red earth region of China

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Abstract: A field study was conducted at the Taoyuan Experimental Station of Agro-ecosystem Observation, to investigate the long-term (9 years) effects of different fertilization systems on rice productivity, nitrogen absorption by the crops at different growth stages and the nitrogen supplying

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Biography: ZHOU Wei-Jun, Ph. D., Associate professor. Mainly engaged in the research of transformation and cycling of matter in agro-ecosystem. E-mail: Wjzh@sia.ac.cn capacity of soils in the red earth region of China.

The experiment had a total of ten treatments. (1) A control treatment 'CK', in which no fertiliser or recycled crop nutrients were applied; (2) treatment 'C', in which crop nutrients were recycled but no fertiliser was applied; (3) treatment 'N', in which nitrogen fertiliser (urea) alone was applied at N 262.5kg/(hm^2 · a) (pre-1997) and at N 182.3kg/(hm^2 · a) (post-1997) with no recycling of crop nutrients; (4) treatment 'N+C', which was simply treatments N and C combined; (5) treatment 'NP', which was treatment N plus P39.3 kg(hm^2 · a) as single-superphosphate; (6) treatment 'NP+C', which was treatments NP and C combined; (7) treatment 'NK', which was treatment N plus K 197.0 kg/(hm^2 · a) (post-1997) as potassium chloride (K 137.0 kg/(hm^2 · a) (pre-1997); (8) treatment 'NP', which was treatment NK plus P 39.3 kg/(hm^2 · a) as single-superphosphate; (9) treatment 'NPK+C', which was treatment NPK plus treatment C; (10) treatment 'F+1/2C', which was nitrogen, phosphorus and potassium applied at rates N 121.5 kg/(hm^2 · a) (N 175.5 kg/(hm^2 · a)(pre 1997), P 26.2 kg/(hm^2 · a) and K 65.7 kg/(hm^2 · a) (K 45.7 kg/(hm^2 · a) (pre-1997), respectively, and only 1/2 the rice straw recycled to the plots.

Each treatment had three replicates, which were arranged in fully randomized blocks. For the treatments in which there was no recycling of crop nutrients, Chinese milk vetch was cultivated in winter from 1990 to 1994 (but not after 1994) and the upper parts of the green manure harvested and removed from the field before spring plowing. For the treatments in which there was recycling of crop nutrients (C), Chinese milk vetch was cultivated in winter and ploughed into the field. Rice straw was also fully returned to the field after harvesting and 80% of the full grains (50% after 1995) and all of the empty or blighted grains were fed to pigs, and the pig muck subsequently spread on the field.

Soil samples were collected from all plots at seven growth stages: (1) prior to early rice transplanting, (2) at transplanting-tillering, (3) at tillering-heading (4) at heading-maturity (5) at late rice transplanting (6) at tillering-heading, (7) at heading-maturity. Multiple soil cores were taken from each plot with an auger to a depth of 200mm and mixed to form composite samples. Fresh soil samples were extracted with 2mol/L KCl and analysed for mineral nitrogen (NO_3^--N and NH_4^+-N) by steam distillation and titration. Soil moisture contents were determined to convert the nitrogen results to units of nitrogen per kilogram of dry soil. Samples of rice plants were collected from each plot on the same dates that the soil samples were collected. The samples were oven-dried at 80℃, milled, and analysed for total nitrogen by the Kjeldahl digestion method.

Based on the soil mineral nitrogen results, the treatments can be divided into four different groups. The lowest level of soil mineral nitrogen (14mg N/kg on average over all 7 samplings) was found in the control treatment CK. The next lowest level (21mg N/kg on average over all 7 samplings), however, encompassed the four full rate fertiliser treatments (N, NP, NK, and NPK), and also treatment C, in which crop nutrients alone had been recycled and no fertiliser had been applied. This is interesting because it implies that recycling of crop nutrients alone had supplied as much nitrogen as the full N application rate. The second highest level of mineral nitrogen (N26mg/kg on average over all 7 samplings) was found in treatment F+1/2C, in which only 2/3 of the N application rate had been applied and only half the straw had been recycled. The highest level (N31mg/kg on average over all 7 samplings) was found in the three treatments (N+C, NP+C and NPK+C) in which the full N application rate had been applied in combination with recycled crop nutrients (C).

The results of nitrogen uptake by the rice crops at the 6 different stages were somewhat different to the soil mineral nitrogen results. At the tillering and heading stages, for both early and late crops,

nitrogen offtakes in the three full N treatments with recycling (N＋C, NP＋C and NPK＋C) were significantly ($P<0.05$) higher than those in any other treatments, whereas at the heading and maturity stage nitrogen offtake in treatment NPK＋C (N9.72 kg/hm^2 for the early crop and N12.98 kg/hm^2 for the late crop) was the highest over all ($P<0.05$). Total rice grain yield over both crops (9719kg grain/hm^2) was likewise significantly greater in treatment NPK＋C than in any other treatment. In keeping with the soil mineral nitrogen results, however, treatments N, NP, NK and NPK had plant nitrogen offtakes and rice grain yields for each crop which did not differ significantly from those in treatment C. Equally, in treatment F＋1/2C, nitrogen offtakes at maturity, (N5.61 kg/hm^2 for the early crop and N8.30 kg/hm^2 for the late crop), and rice grain yield for both crops (5259 kg grain/hm^2 for the early crop and 8644 kg grain/hm^2 for the late crop) were as great as those in treatments N, NP, NK and NPK.

In conclusion, full or partial recycling of crop nutrients provides a substantial level of nitrogen to crops and significantly reduces the requirement for fertiliser nitrogen to achieve very reasonable total levels of rice grain production over early and late crops (＞8000kg grain/hm^2). Alternatively, very high levels of production (＞9500kg grain/hm^2), and maximum profits, may be achieved by applying the highest rates of fertiliser nitrogen, phosphorus and potassium in combination with nutrient recycling (C). However, such high levels of nitrogen and phosphorus usage could be of detriment to the environment and to drinking water quality.

Key words: recycling of crop nutrients; rice; soil mineral nitrogen; profits of rice production

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氮是限制农业生态系统生产力最重要的营养元素,氮肥的效益可达到作物增产的76%[1]。在水稻的氮素营养中,土壤氮素的供应起着十分重要的作用。研究表明,施用氮肥与否,水稻对土壤氮素的依存率都在50%以上[2~4],而目前我国氮肥的当季利用率约为30%～35%[5]。因而,近20年来,人们围绕提高氮肥利用率、减少氮肥的损失及其对作物产量的影响进行了大量的研究,并取得了丰硕的成果,其中有很多已用于实际,如氮肥深施、以水带肥、推荐施肥、平衡施肥、包膜控释肥的施用等[6~10],但是,有关经过长期不同施肥处理后,红壤稻田系统土壤氮素供应特征、水稻吸氮特性及其水稻生产效应差异的报道则不多见。本文以中国科学院桃源农业生态试验站布置的中长期定位试验——不同施肥制度对红壤稻田系统生产力及土壤环境的影响为依托,进行了相关研究。

1 试验材料和方法

1.1 试验设计与田间管理

田间试验设置在中国科学院桃源农业生态站农业生态试验区内,自1990年开始,以“稻-稻-绿肥”耕作制为基础,代表区域为红壤丘陵单、双季稻作带。早稻为当地的常规稻,晚稻为杂交稻,并每3年更换1次水稻品种。共设10个处理,3次重复,小区面积4.1m×8.1m,随机区组排列。小区间用水泥埂隔开,其地下埋深0.5m,高出地表0.2m。

试验处理 ① 不施肥(CK),收获产品全部移出;② 有机物循环(C),不施化肥,收获产品中有机物循环再利用(简称“循环”以C表示,下同);③ N;④ N＋C;⑤ NP;⑥ NP＋C;⑦ NK;⑧ NPK;⑨ NPK＋C;⑩ F＋1/2C,2/3化学NP肥＋1/3化学K肥＋1/2秸秆还田。其中处理1与2、处理3与4、处理5与6、处理8和9为4对配对的无有机物循环和有有机物循环处理。

供试化肥为尿素(N 450.0g/kg)、过磷酸钙(P 52.4g/kg)和氯化钾(K 498.1g/kg)。施用量为处理①～⑨,1990～1996年,N262.5kg/hm^2,P39.3kg/hm^2,K137.0kg/hm^2;从1997年起,N182.3kg/hm^2,P39.3kg/hm^2,K197.2kg/hm^2;处理⑩,1990～1996年,N175.5kg/hm^2,P26.2kg/hm^2,K45.7kg/hm^2;从1997年起,N121.5kg/hm^2,P26.2kg/hm^2,K65.7kg/hm^2。

循环(处理2、4、6和9)是指将收获稻谷的80%(1995年后改为50%)及全部空瘪谷喂猪,猪粪尿还田,

水稻秸秆和绿肥全部还田；处理⑩的稻谷不喂猪，无猪粪尿还田，但一半水稻秸秆和全部绿肥还田。无循环处理（处理①、③、⑤、⑦和⑧）1994 年前种植绿肥，以后不再种植，绿肥移出小区，收获稻谷和稻草全部移出小区。

供试土壤为第四纪红色粘土发育的水稻土，基础肥力性状为：有机质 23.2g/kg，全 N1.39g/kg，全 P0.60g/kg，全 K14.9g/kg，速效 N53.4mg/kg，速效 P14.7mg/kg，速效 K67.7mg/kg，pH5.74。

1.2　测定项目与分析方法

1.2.1　土壤速效氮（NH_4^+-N 和 NO_3^--N）的测定　分别在 1999 年 4 月 5 日（春耕前）、5 月 24 日（早稻分蘖期）、6 月 27 日（早稻齐穗期）、7 月 22 日（早稻成熟期）、8 月 6 日（晚稻分蘖期）、9 月 15 日（晚稻齐穗期）和 10 月 20 日（晚稻成熟期），采集 0～20cm 表层土壤。新鲜土壤样品立即带回实验室，捏碎大土块，混匀，称 25g 新鲜土壤，加 100ml 2mol/LKCl 溶液，振荡 30min，过滤，吸 25ml 滤液，加 10ml 12% MgO 和 1g $FeSO_4$-Zn 粉还原剂，蒸馏法测定土壤速效氮。同时另称 1 份 40g 左右土壤，用烘干法测定土壤水分。

1.2.2　生物量与植株全氮的测定　采集土壤样品的同一天，每小区调查 20 蔸水稻的茎蘖数，根据平均茎蘖数每小区采集 4 蔸水稻，在 80℃条件下烘干测定生物量。植株样品经粉碎作分析用。植株全氮测定用凯氏半微量法。

1.3　统计分析方法

试验数据采用 Excel 2000 进行统计分析，并采用 Duncan's 新复极差法（LSR）进行显著性检验。

2　结果与分析

2.1　土壤速效氮的变化特征

从图 1 可以看出，土壤速效氮（NH_4^+-N＋NO_3^--N）在水稻生长期间的波动是较大的，且不同处理间有明显的差异，各生育期均以 NPK＋C 处理最高，不施肥（CK）处理最低。总的变化趋势呈一双峰曲线，春耕前（4 月 5 日）最低，两个峰值分别出现在早稻分蘖期（5 月 24 日）和晚稻分蘖期（8 月 6 日），两个谷值分别出现在早稻成熟期（7 月 22 日）和晚稻齐穗期（9 月 15 日）。春耕前湘北土温较低，微生物的活力较弱，土壤氮素的矿化较缓慢[11,12]，而早稻移栽前基肥（氮肥、有机肥等）的施用，则因刚移栽的水稻，根系吸收养分的能力较弱，导致速效氮在土壤中大量积累，因而在分蘖期出现一峰值；而后水稻生长速率加快，吸收氮量增加，加之还有少部分 NH_4^+-N 挥发及 NO_3-N 的渗漏损失[14]，Shiga 和 Ventura 报道[13]，在温带地区，水稻土速效氮大部分是在淹水后的 4 周内分解释放的，因而土壤速效氮持续降低，至早稻收获期降至最低点。晚稻移栽时由于施用基肥，土壤速效氮又升高，而后随着水稻的生长而降低，至于晚稻成熟期土壤速效氮的略微升高，可能是该期田间排水，土壤自然落干，干土效应所致。

从图 1a 可以看出，CK 处理土壤速效氮的波动性虽然较小，但含量较低，最高为 16.7mg/kg，最低为 10.0mg/kg，平均为 14.2mg/kg。采取稻田系统有机物循环（C）可以明显提高稻田土壤速效氮含量，早稻分蘖期比 NPK 处理略高，其它时期均比 NPK 处理低。这与 C 处理早稻还田有机物即有稻草又有猪粪、紫云英，且量较大有关，但是比 F＋1/2C 和 NPK＋C 处理土壤速效氮的含量低，可见，在稻田系统保持有机物循环利用的同时，配合施用一定量的化学氮肥，对维持土壤氮素供应有重要作用。NPK 化肥配合施用可以较好的改善稻田土壤氮素的供应，提高土壤各生育期土壤速效氮的含量，但是其土壤速效氮含量比 F＋1/2C 处理低，且显著地低于 NPK＋C 处理，显见，在红壤稻田系统中采取系统内有机物循环利用有利于提高土壤氮素供应强度。

从图 1b 可以看出，在红壤稻田系统施用化学氮肥可以较好地改善土壤的供氮性能，提高土壤速效氮含量，且 N 与 P 或 K 配合施用与单施 N 肥没有显著性差异。在保持稻田系统有机物循环的基础上，配合施用无机化肥时，土壤速效氮含量显著地高于单施化肥处理，且与 NPK 肥的配合程度无关，即土壤速效氮的含量并不随着有机肥与 NPK 配合度的增加而提高。

2.2　水稻不同生育期累积吸收氮量

表 1 列出了水稻不同生育阶段水稻累积吸收氮量，从中可以看出，无论早稻还是晚稻，水稻累积吸收氮量为：分蘖-齐穗期＞移栽-分蘖期＞齐穗-成熟期。分蘖期至齐穗期是水稻吸收氮素的主要时期，齐穗期

至成熟期由于水稻根系老化，吸收养分能力较弱，主要为植株体内养分在各组织器官之间的迁移与重新分配，水稻累积吸收氮量较小。

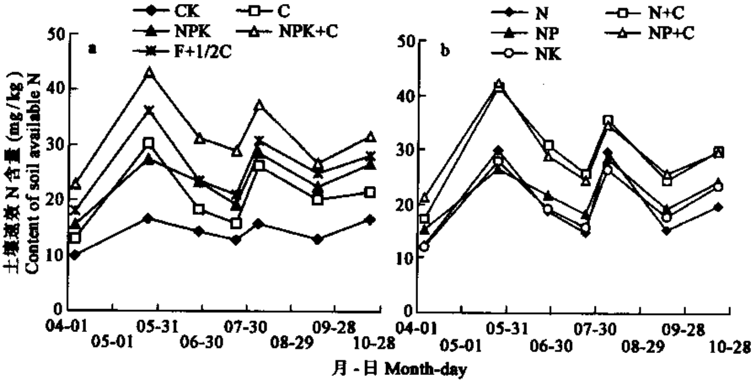

图 1　水稻不同生育期土壤速效 N 含量

Fig. 1　Content of soil available N on different growth stage of rice

表 1　水稻不同生育期吸收氮量

Table 1　The amount of absorption N in different growth stage of rice (kg/hm²)

处理 Treatments	早稻 Early rice			晚稻 Late rice		
	移栽-分蘖 Transplanting-tillering	分蘖-齐穗 Tillering-heading	齐穗-成熟 Heading-maturity	移栽-分蘖 Transplanting-tillering	分蘖-齐穗 Tillering-heading	齐穗-成熟 Heading-maturity
CK	8.54g	20.95e	3.35e	12.83g	40.96f	6.00fg
C	22.80cd	42.52b	4.00de	25.60e	54.08d	9.36cd
N	11.78f	24.65d	3.56e	20.48f	48.55e	4.61g
N＋C	23.73cd	45.97a	5.23cde	33.37c	84.93a	11.77ab
NP	22.30d	37.38c	5.16cde	29.66d	55.02d	7.36ef
NP＋C	27.74b	46.68a	6.86bc	40.11b	79.53b	10.45bc
NK	18.54e	35.08c	4.39de	33.00c	55.43d	6.01fg
NPK	23.94cd	41.79b	7.37b	38.76b	64.31c	7.52def
NPK＋C	31.07a	47.58a	9.72a	47.40a	87.25a	12.98a
F＋1/2C	25.45bc	41.18b	5.61bcd	33.26c	65.96c	8.30de

同一列中不同英文字母表示有显著差异（$P=0.05$）Different English letter of the same line indicate significant difference among treatments ($P=0.05$)

从表 1 可以看出，施用 N 肥改善了土壤的供氮状况，使水稻各阶段氮素的累积吸收量增加，但是单施 N 水稻氮累积吸收量和累积速率的增加较少，如早稻分蘖-齐穗期累积吸收氮量仅比 CK 高 17.7%，晚稻高 18.5%，这可能是长期(10a)偏施氮肥，而其它营养元素(P、K 等)未得到有效补充，而成了限制水稻生长的障碍因子，致使其水稻生长受到遏制的缘故。随着 P 与 K 进入稻田系统，水稻的氮素营养得到进一步的改善，不同生育期氮素累积吸收量和累积速率迅速提高，且有随 NPK 配合程度增加而增加的趋势，如，早稻分蘖-齐穗期累积吸收氮量，NPK 处理比 NP 和 NK 两处理分别高 11.8%和 19.1%，而后两者比 N 处理又分别高 51.6%和 30.1%。保持稻田系统内有机物循环利用可以显著地提高水稻不同生育阶段氮素累积吸收量和累积速率，但是以有机无机结合效果最佳，有有机物循环各处理水稻各生育阶段累积吸收氮量显著地高于对应的无有机物循环处理，且除 N＋C 处理在早稻移栽-分蘖期比 NPK 处理低但没有显著差异外，N＋C、NP＋C 和 NPK＋C 处理各生育期水稻累积吸收氮量均显著高于 NPK 处理。可见，在红壤稻作区在保持系统内有机物循环利用的基础上，配合施用一定量的无机化肥是必要的，有机无机结合施肥可以

较好的改善水稻的氮素营养，促进水稻对氮素的吸收。

2.3　稻田系统的生产力

2.3.1　生物量的累积　从表 2 可以看出，早、晚稻不同生育阶段生物量的累积为：分蘖-齐穗期＞移栽-分蘖期＞齐穗-成熟期，产生这一差异的原因主要是因为在湘北地区，早稻移栽后，气温和土温较低，影响了水稻的生长，早稻成熟阶段，气温和土温往往较高，水稻高温逼熟，而晚稻移栽后，正处于湘北的高温阶段，不利于水稻生长发育，而成熟阶段温度适宜，有利于水稻生物量的积累。

表 2　水稻不同生育期生物量的累积量

Table 2　The accumulation amount of biomass in different growth stage of rice (kg/hm^2)

处理 Treatments	早稻 Early rice			晚稻 Late rice		
	移栽-分蘖 Transplanting-tillering	分蘖-齐穗 Tillering-heading	齐穗-成熟 Heading-maturity	移栽-分蘖 Transplanting-tillering	分蘖-齐穗 Tillering-heading	齐穗-成熟 Heading-maturity
CK	478e	2088e	1127c	1194f	3106f	2512e
C	884c	4689abc	1448b	1760e	4520cd	2600de
N	561de	2341e	1383b	1533e	3867e	2601de
N+C	894c	4811ab	1440b	2646bc	5097b	3260a
NP	1090bc	3677d	1414b	2166d	4368d	2501e
NP+C	1256ab	4569bc	1369b	2788ab	4908bc	2927bc
NK	817cd	3717d	1407b	2298d	4543cd	2348e
NPK	1212ab	4376c	1491ab	2839ab	4974b	2453e
NPK+C	1359a	4983a	1680a	3083a	5831a	3223a
F+1/2C	1049bc	4555bc	1688a	2430cd	5271b	2856cd

同一列中不同英文字母表示有显著差异($P=0.05$) Different English letter of the same line indicate significant difference among treatments ($P=0.05$)

经过 9a 不同施肥处理后，不同处理间水稻生物量的累积量和累积速率有显著差异。CK 处理水稻生物量累积量和累积速率较低，施肥可以提高水稻生物量的累积量和累积速率，并且有随着 NPK 配合程度提高而提高的趋势(表 2)，如，分蘖-齐穗阶段，NPK 处理的水稻生物量累积量显著地高于 NP、NK 处理，早稻分别高 19.0%和 17.7%，晚稻分别高 13.9%和 9.5%，而后两者又显著地高于 N 处理，早稻分别高 57.1%和 58.8%，晚稻分别高 13.0%和 17.5%。保持稻田系统有机物循环利用有利于水稻生物量地积累，C 处理虽然除了系统内有机物循环利用外，再没有补充其它外源养分，但是其生物累积量显著地高于 CK 和 N 处理。有机无机结合施肥可更进一步提高水稻各生育期的生物累积量，且有有机物循环利用处理均显著地高于对应的无循环的单施无机肥处理。

2.3.2　稻谷产量　表 3 列出了定位试验 1999 年的稻谷产量，从中可以看出，经过 9a 不同施肥处理的定位试验研究，各处理间的稻谷产量有了显著差异，从全年稻谷产量的统计结果看，可以将其分为 4 个水平档次，其中 NPK+C 处理最高；第 2 水平档次为 NPK、N+C、NP+C、F+1/2C 和 C 5 处理；第 3 水平档次为 NK 和 NP 2 处理；第 4 水平档次为 CK 和 N 2 处理。早、晚稻的稻谷产量变化与全年的虽有一些差异，但基本变化趋势是一致的。

表 3　不同施肥制度的稻谷产量(1999 年)

Table 3　Rice grain yield (1999) of different fertilization systems (kg/hm^2)

处理	CK	C	N	N+C	NP	NP+C	NK	NPK	NPK+C	F+1/2C
早稻①	2180c	3383ab	2075c	3400ab	3260ab	3225ab	2970ab	3605a	3435ab	3385ab
晚稻②	3719e	5027bc	3717e	5335b	4107de	5455b	4584cd	5428b	6284a	5259b
全年③	5899e	8410c	5792e	8735bc	7367d	8680bc	7554d	9033b	9719a	8644bc

① Early rice，② Late rice，③ Annual；同一行中不同英文字母表示有显著差异($P=0.05$) Different English letter of the same row indicate significant difference among treatments ($P=0.05$)

CK 处理由于自试验开始一直未再施肥，因而其稻谷产量较低，早稻 2180kg/hm^2，为 NPK 处理的 60.5%，晚稻 3719kg/hm^2，为 NPK 处理的 68.5%。随着 NPK 化肥依次进入稻田系统，稻谷产量逐渐提高，至 NPK 完全配合时达到最高产量。在保持稻田系统有机物循环利用的基础上，配施化肥可以显著提高系统稻谷产量，有随着 NPK 配合程度增加而增加的趋势，且有有机物循环处理除 NPK+C 早稻稻谷产量比 NPK 处理低且没有显著差异外，其它均比对应的无循环单施无机肥处理的高，并达到显著或极显著差异水平，但是，仅采用系统内有机物循环，虽然稻谷产量有较大提高，但并不能达到最佳产量效果，C 处理的稻谷产量显著地高于 CK 和 N 处理，高于 NP 和 NK 且晚稻和全年均达到 1%的极显著差异水平，但比 NPK 和 F+1/2C 处理低。

3 结论

通过对不同施肥处理经过 9a 定位试验后，土壤供氮能力、水稻吸收氮素差异和水稻生产效益的比较研究，得到如下结论：

（1）稻田系统长期不施肥，土壤速效氮含量低，供氮能力弱，水稻累积吸收氮量少，系统生产力及稻谷产量低；采用稻田系统有机物循环利用可以充分利用生态系统内的有效资源，增强土壤的供氮能力，增加水稻累积吸收氮量，提高系统的生产力，但并不能达到最佳产量效果。

（2）施用氮肥可以改善土壤的供氮状况，提高土壤速效氮的含量，但在偏施氮肥的情况下，并不利于水稻对氮素的吸收利用和系统生产力的提高，只有在 NPK 配施的条件下，才有利于改善稻田土壤肥力环境条件，促进水稻对氮的吸收，提高稻田系统的生产力。

（3）在保持稻田系统有机物质循环利用的基础上，配施 NPK 化肥，即所谓有机无机结合施肥制度，这种施肥制度可以使土壤供氮能力大大增强，土壤速效氮的含量高，水稻生长的土壤环境得到进一步改善，有利于水稻对氮素的吸收和系统生产力的提高。

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