稻田施氮水平对两种水稻热值变化特征影响

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摘要：对两种水稻类型（早稻、晚稻）在不同氮素水平下植株的热值动态进行了分析。结果表明，水稻植株的热值不仅因品种、器官而存在着差异，而且随着水稻生长发育的进程不同也存在着差异。两种水稻的热值最低值出现在小花分化期，最大值出现在分蘖期或开花灌浆时期。不同氮素水平对水稻热值的影响规律为，随着氮素水平的增加，水稻各组织器官的热值也增加，同一器官下，高氮素水平下的水稻组织热值高于低氮下组织的热值，不同器官热值（根、茎、叶、穗）之间在相同及不同氮素水平下存在显著差异。通过分析表明，没有氮素投入下的两种水稻基础热值为 16979 J/g，早稻每增加 1kg/hm^2 N，可以提高植株热值 1.72 J/g；晚稻每增加 1kg/hm^2 N，可以提高植株热值 1.24 J/g，这说明，氮素使用对早稻的热值效应影响要大于晚稻。因此，在运用热值指标进行能量分析时，必须考虑氮素使用水平对热值的影响。

关键词：热值；水稻；氮素；稻田

The Quantitative Analysis of the Caloric Value Dynamics of Two Rice Varieties Under Different Nitrogen Application Levels

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Abstract: This paper presents an analysis of the quantitative caloric energy characteristics and the dynamic variation of two rice varieties under different N levels in paddy fields in Hangzhou, Zhejiang Province, China. Field experiments were conducted at the Experimental Farm of Zhejiang University, Hua-Jia-Chi Campus, Hangzhou (latitude 30.2° N, longitude 120° E), China at 43.2m above sea level. The experimental site had an area of 1085.5 m^2. The early crop rice, Jiayu 948, was sown on 1st April, and transplanted on 2nd May 1999 while the late crop rice, Jiayu 93390, was sown on 24th June, and transplanted on 26th July 1999. The experiment plot was 8m×4m with complete random design and 4 replications. The planting hill density was 20cm×15cm with 5～6 seedlings for each hill. Nitrogen treatments with Urea fertilizers were at five levels: 0 (T0), 80 (T1), 120 (T2), 160 (T3), 200(T4) kg/hm^2. The application was done 3 times during the growth duration, 55% of the total N was applied before transplanting of seedlings, 35% in the tillering stage and 15% in panicle initiation stage. Adequate ecological and agronomic measures (e.g. pest and disease management) were undertaken to ensure optimal plant growth conditions. Water supply to the fields was appropriately regulated.

During the experiment, 10 hills of the plants were sampled at 10 and 7 days interval for vegetative and reproductive stages respectively. Each sample was separated into respective organs: root, stem, leaf, ear, grain and husk for measurement of each organs' dry matter weight and then ground into powder samples. Caloric values of the rice were measured by sampling 1～2g of organs' mixed dry matter and put them into the oven to dry for 2～3h, then the rice sample was placed into an Oxygen Bomber and pure oxygen (99.5%) with air pressure maintained at 30 kg/cm^2 was added. Using Caloric Measurer device GR-3500,

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which was produced by Changsa Instrument Cooperation Company, the caloric values of the organs were derived according to instructions in the instrument manual. The final value of each rice sample at different growth stages was determined by means of two parallel measurements of the values' difference not exceeding the 80 J/g as actual value. If the two parallel measurement values exceeded the standard difference, then a new sample was taken and tested again. Nitrogen contents of organs were determined using the Kjeldahl digestion method followed by colorimetric determination at an optical density of 490 nm. This was done in accordance with the procedure outlined by Yoshida *et al.* (1976). The results of caloric energy of rice were statistically analyzed using the random model aided by the data processing system (DPS) computer software (Tang & Feng, 1997).

The results indicated that the difference in caloric values of rice existed not only between varieties and rice organs, but also during the different development stages of the two rice cultivars. The lowest caloric value was recorded at the panicle initiation stage of both varieties, the highest was at the maximum tillering for Jiayu 948, flowering or grain-filling stage for Jiayu 93390. Roots had the lowest values and the highest was in grain and ear organs of rice under different nitrogen regimes. There existed a significant difference of caloric values among the different organs (see table 5).

The characteristics of N effects on the caloric values of the two rice crops showed that the caloric values increased with the increase of N application amount. Higher N levels produced higher caloric value as compared to lower N levels, but there were no significant differences in the same organs for the two varieties. The results indicated that the caloric value in the stems of early crop rice, Jiayu 948 under low nitrogen level had no significant difference with the root's caloric value under the higher nitrogen application. In the late crop rice, this trend was not evident as there were bigger differences between different organs under whatever N regimes were at higher or lower levels (see table 6).

N effect on the caloric values of the early crop rice had stronger influence than on the value of the late crop rice variety. The rice caloric value under higher nitrogen application level was greater than that under lower doses of nitrogen. This indicates that nitrogen had important effects on yield and energy formation and accumulation in the reproductive stage of the two rice varieties. Sun (1993) obtained similar results through their experiments.

The analysis of caloric values of the two rice varieties presented a significant linear relationship between caloric value and nitrogen application amounts as follows:

For early cultivars Jiayu 948 $Y=16980.7+1.721\,N$ ($r=0.9856^{**}$ $n=16$)

For late cultivars Jiayu 93390 $Y=16979.1+1.238\,N$ ($r=0.9921^{**}$ $n=16$)

where Y represents the caloric value and N is pure nitrogen amount (kg/hm^2) which was applied to the rice crops. From the equation, it showed that under this experiment the basic caloric value of early and late crop rice varieties without nitrogen application was generally 16979 J/g. This value is almost the same with the figure obtained by Sinclair (1990) who got the caloric value (16970 J/g) based on the calculation of the components' percent and their energy values among the rice plant (protein 8%, fat 2% and carbohydrate 88% etc). With a 1 kg/hm^2 increase of the pure nitrogen, the caloric value will increase by 1.721 J/g for Jiayu 948 and 1.238 J/g for Jiayu 93390. This indicated that nitrogen application effect on the caloric value of early crop rice Jiayu 948 was greater than that of late crop rice Jiayu 93390. The nitrogen application amounts in rice production in Zhejiang Province of the P. R. of China at present is usually around 150～450 kg/hm^2(pure nitrogen). This makes the caloric value increase within the range 258～774 J/g for Jiayu 948 and 186～558 J/g for Jiayu 93390, which accounts for the 1.5%～4.5% in early crop rice and 1.1%～3.3% in late crop rice when compared to the basic caloric value. This study showed that when using

caloric values to calculate energy input and output in rice production system, nitrogen effect on the caloric value should be considered and a regression model for accurate calculation be established.

Key words: caloric values; rice; nitrogen; paddy soil

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稻田系统是农业生态系统的重要组成部分,作物生产实际上是物质能量的生产过程,它给人类及第二性生产提供了能量基础。热值是研究特定生态系统的能流变化的重要指标,作物的热值是衡量有机体生命活动及组成成分的指标之一,通常用每克(g)干物质所含的焦耳(J)数来表示。在作物生产系统中,研究热值的变化对于提高产量与改进系统能流输入、输出变化,提高作物生产系统的效率是非常重要的[1]。

自 Long 于 20 世纪 30 年代首先较系统地进行植物热值研究以来,借助热值(能值)指标对生态系统的发展、变化机制的研究日趋广泛[2]。目前在农田生态系统水平上的能流、物流分析已经有过不少的研究报道[3]。在研究中,准确地得知物质的热值是实现能流分析的第一步。在我国有关作物的热值研究在 20 世纪 80 年代初才见端倪[3~5]。王方桃测定了几种主要作物的颗粒、苞叶、根茬中的热值,孙国夫对早稻的 3 个品种进行了动态分析[1],谢甫绨在北方对大豆耐旱性与能量(热值)的关系研究表明,耐旱性强的品种开花后热量积累速率高[6]。但将热值指标同作物生长环境、田间管理措施相联系,在农业生态学、农学上的应用方面进行的研究仍不多。孙良夫对早稻的初步研究表明热值因品种、组织结构而异,也随着生育期的进展而有差异,实测的热值远高于常用的热值标准,这是否同当时的稻田生态环境与生产管理手段(如耕作施肥)、作物本身的生态特性有关,需进一步深入研究。

国外的热值研究主要集中于 20 世纪 70 年代中期以前,已有不少学者对不同生态环境下的作物热值状况进行分析。如 Bliss 、Gorham 发现植物组织热值与光合作用、呼吸作用等生理活动有关[7,8]。Ovington 的研究表明同自然生态系统相比,玉米系统具有高的叶绿素含量与高的热值表现,其原因归结为 N 肥的施用与密度适宜[9]。Bliss 发现常绿灌木的热值高于落叶灌木,Hadley 和 Tinkle 等人指出多年生植物的冬季热值高于春夏季,高寒地区植物的热值比热带高,高海拔地区植物高于低海拔地区,所有这些结果表明热值绝非一个固定不变值,它随着植物本身的生理生态特性,所处的地形与生态环境条件而变化[10]。Girardin 和 Hedin 等研究了玉米和棉花的能值后,认为通过能值可以为增加经济产量提供新的方法[11~13]。选择和开发能将其大部分的能量分配到子粒的玉米将是可行的方式。在生态系统中,关于热值和能量的分配中,Golley 测定了世界上从热带雨林到极地主要植物群落中优势植物种类的平均能量值[14]。但国外的研究未对造成热值不同的原因进行更深入系统的分析,特别是对于水稻这一广泛种植的作物,热值的动态研究资料非常少。如果能弄清各种作物特性与所处生态环境对热值影响的具体关系,研究环境因子特别是氮素对作物生长、热值变化影响的动态耦合关系,就可以利用热值指标对稻田系统进行更准确的分析,拓宽热值的研究与应用领域,探索热值指标与作物生理指标相结合在生态学、作物栽培技术及生产实践上的应用,并且提供重要理论依据。

1 材料与方法

试验于 1999 年在原浙江农业大学实验农场进行。试验区的土壤为粉沙壤土,早稻供试品种为嘉育 948(籼稻),晚稻供试品种为嘉育 93390(粳稻)。实验小区面积为 8m×4m(32m^2),4 次重复,完全随机区组设计。栽种密度为 20cm×15cm,每穴种植 5~6 株。氮肥处理为 0 (T0)、80 (T1)、120 (T2)、160 (T3)、200 (T4) kg/hm^2 N 水平,氮肥肥料为尿素,分 3 次使用,55%的氮(N)在移栽前使用,35%在分蘖期使用,15%在小花分化期使用。其他各项栽培管理措施同高产大田栽培要求一致。

试验过程中,在水稻营养生长期定期 10d,生殖生长期定期 7d 取样观测生育进程及测定干物质累积动态。每次取样 10 丛,分成根、茎、叶、穗、子粒、稻壳分别测定干物质积累,热值测定取磨碎的组织样品 1~2g,在烘箱中烘 2~3h 至衡重,样品放入氧弹中,密封后充入纯氧(99.5%)至 30 个大气压左右,采用长沙仪器公司出产的 GR-3500 型热值仪进行燃烧测定,测定方法步骤参照有关说明书。以两次测定的平行误差不超过 80J/g 的热值,作为最后水稻各器官热值指标,并取平均值,否则,重新称样测定。水稻各组织器官

中的氮素提取采用凯氏消煮法(H_2SO_4-H_2O_2)，用紫外分光光度计在 490nm 处比色测定氮素的含量(奈氏比色法)。

2　结果与分析

2.1　不同氮素处理下的水稻热值变化

水稻组织的热值变化在不同的氮素处理下，随着发育阶段与氮肥使用量的不同而发生变化，具有一定的变化规律。从表 1 可见，随着施氮量的增加，在不同取样时期的早稻的平均热值都增加。无肥区处理的热值变动在 16 420～17 263 J/g，T1 为 16 685～17 486 J/g，T2 为 16 609～17 548 J/g，T3 为 16 854～17 584 J/g，T4 为 16 805～17 591 J/g。热值最低值出现在移栽后 42d(相当于小花分化期)，最大值出现在移栽后 25d(相当于分蘖盛期)。随着水稻开花(移栽后 60d)进入生殖生长期，水稻的热值就开始逐渐下降，直到成熟。

虽然晚稻大田生长时所处气候环境同早稻完全不同，但不同氮素处理下晚稻的热值变化同早稻基本一致。随着施氮量的增加，水稻植株的平均热值也增长。不同氮素处理下的最低热值出现在晚稻移栽后 40d(小花分化期为移栽后 43d)，热值最高值在低氮(0，$<80kg/hm^2$)处理时出现在移栽后 26d(分蘖高峰后期)；$>120kg/hm^2$ N 时则出现在移栽后 82d(在水稻抽穗开花期)，见表 2。由上述早、晚水稻的热值变化结果说明，热值不仅同外界施肥因素有关，即随着施氮量的增加而增加，而且同水稻本身所处的生育时期有很大关系，在水稻的分蘖高峰期(早稻)和开花灌浆初期(晚稻)，热值出现最大值，而在小花分化期则出现最低值。

表 1　不同氮素处理对早稻植株热值的动态影响

Table 1　The dynamic of early rice's caloric value under different nitrogen application levels (J/g, 1999)

移栽后天数(d) Day after transplanting	N 素肥(纯 N)(kg/hm²) Nitrogen application amount				
	0(T0)	80(T1)	120(T2)	160(T3)	200(T4)
14	17058	17087	17160	17282	17383
25	17263	17486	17548	17584	17591
42	16420	16685	16609	16854	16805
56	16940	16969	17150	17185	17353
63	16670	16746	16883	16949	17036
70	16992	17041	17117	17210	17288
77	16941	16955	17026	17102	17235
81	16768	16795	16970	17095	17074
平均 Mean	16881	16970	17058	17157	17221

表 2　不同氮素处理下晚稻植株的热值变化

Table 2　The dynamic of late rice's caloric value under different nitrogen application levels (J/g, 1999)

移栽后天数(d) Days after transplanting	N 素肥(纯 N)(kg/hm²) Nitrcgen application amount				
	0(T0)	80(T1)	120(T2)	160(T3)	200(T4)
12	16599	16864	16853	16926	16969
26	17059	17130	17140	17256	17236
40	16511	16513	16590	16611	16668
54	16673	16680	16737	16678	16767
68	16914	17051	17104	17142	17252
82	16971	17049	17210	17251	17287
89	17050	17060	17203	17257	17276
91	16991	17053	17119	17162	17279
平均 Mean	16846	16925	16995	17036	17092

2.2　不同氮素处理对水稻植株各器官的热值影响

由于水稻各组织器官在生长发育中的发育进程与功能的不同，所以定期取样测定了不同组织器官热值。表 3 给出了在不同氮素处理下，两种水稻组织各器官的热值变化的平均值。由表可见，水稻的根系在两种水稻类型中热值最低，其次为茎、稻壳、叶片、子粒和稻穗。对于早稻来说根系热值变化在 15 807～16 191 J/g；储藏器官(小穗)最大的热值变化在 18 194～18 519 J/g 干物质，晚稻根系热值变化在 15 641～16 003 J/g，储藏器官(子粒)热值最大，变化在 17 986～18 771 J/g 干物质，由此可见，氮素对根系的热值影响较小，而对储藏器官的热值影响较大。从表 3 还可以看出，随着施氮量的增加，根、茎、叶、穗等器官的热值也增加。尤其是对储藏器官(籽粒、稻穗)的作用明显。对早稻的作用效果要大于晚稻。

2.3　不同施氮处理下水稻叶片氮含量同叶片热值的关系分析

不同氮素处理下，氮素对水稻的热值有较大的影响，随着氮肥增加，水稻植株热值增加，同时，叶片中的氮素含量也增加，但叶片氮素同水稻叶片热值之间则没有任何显著相关性。仅早稻嘉育 948 在开花期后(移栽后 62d)，叶片氮含量同叶片热值存在相关性，即随着叶片氮含量的下降，叶片热值也随之降低。但在

晚稻嘉育 93390 中则没有这种较为明显的趋势(表 4)。这表明,叶氮含量对热值没有直接的相关性,但叶氮含量高低在适宜范围内对光合作用有较大影响[15],因此不同氮素处理对叶片热值的影响可能通过叶片氮对光合作用与碳水化合物的形成与贮存作用而致。

表 3 不同氮素处理对早、晚稻各组织器官热值的影响(J/g)

Table 3 The effects of different N levels on the caloric values of organs in two rices

氮素处理* Nitrogent treatment	根系 Root	茎 Stem	叶 Leaf	小穗 Panicle	籽粒 Grain	稻壳 Husk	平均 Mean
			早 稻 Early rice				
T0	15807	16388	17620	18194	17963	16486	17076
T1	15884	16499	17672	18337	18359	16813	17261
T2	15971	16592	17763	18386	18427	17808	17491
T3	16042	16746	17898	18366	18454	17941	17574
T4	16191	16789	17856	18519	18560	17852	17628
平均 Mean	15979	16603	17762	18360	18353	17380	17406
			晚 稻 Late rice				
T0	15641	16408	17665	18238	18088	16211	17042
T1	15740	16451	17793	18251	17986	16993	17202
T2	15776	16508	17891	18370	18771	17294	17435
T3	15847	16508	17924	18422	18467	17661	17472
T4	16003	16506	17982	18426	18520	17984	17570
平均 Mean	15802	16476	17851	18341	18366	17228	17344

* Nitragen application amount(kg/hm^2):T0=0,T1=80,T2=120,T3=160,T4=200

表 4 叶片氮含量动态变化同水稻植株热值变化的关系

Table 4 Relationship between leaf N content (%) and caloric energy (kJ/g) of cultivar Jia you 948.

		移栽后天数 Day after Transplanting(d)							
		14	25	42	56	63	70	77	81
早稻 嘉育 948	Early rice 948								
T0	叶片热值(CVL)	17.89	17.95	17.35	17.75	17.67	17.81	17.46	17.06
	叶 N 含量(NCL)	2.398	2.931	0.773	0.608	0.724	0.861	0.544	0.465
T1	叶片热值 CLV	18.03	18.07	17.56	17.85	17.71	17.75	17.52	16.92
	叶 N 含量 NCL	2.693	2.749	0.785	0.822	0.872	0.844	0.622	0.58
T2	叶片热值 CLV	17.95	18.11	17.41	17.96	17.80	17.86	17.64	17.34
	叶 N 含量 NCL	2.646	2.968	0.839	0.816	0.803	0.849	0.769	0.612
T3	叶片热值 CLV	17.94	18.17	17.75	18.07	18.06	17.95	17.66	17.56
	叶 N 含量 NCL	2.773	3.035	0.811	0.939	0.986	0.96	0.736	0.752
T4	叶片热值 CLV	18.05	18.14	17.58	18.10	17.89	17.94	17.74	17.39
	叶 N 含量 NCL	2.867	3.089	0.923	1.016	0.988	0.98	0.773	0.705
		移栽后天数 Day after transplanting(d)							
		13	27	41	55	69	83	89	92
晚稻嘉育 93390	Late rice 93390								
T0	叶片热值 CLV	16.96	18.13	17.96	17.96	17.52	17.59	17.72	17.46
	叶 N 含量 NCL	1.856	1.738	1.494	1.569	1.552	1.309	1.162	1.072
T1	叶片热值 CLV	17.46	18.07	17.96	17.86	17.85	17.71	17.66	17.75
	叶 N 含量 NCL	1.825	1.725	1.587	1.592	1.625	1.906	1.354	1.381
T2	叶片热值 CLV	17.47	18.17	18.17	17.95	17.89	17.81	17.88	17.77
	叶 N 含量 NCL	2.27	1.967	1.861	1.689	1.873	1.9	1.387	1.447
T3	叶片热值 CLV	17.48	18.25	18.19	17.76	17.94	18.06	17.90	17.78
	叶 N 含量 NCL	2.171	1.969	1.815	1.7	1.872	1.9	1.421	1.617
T4	叶片热值 CLV	17.59	18.20	18.20	17.97	18.06	17.88	17.86	18.06
	叶 N 含量 NCL	2.098	1.92	2.1	1.845	1.753	1.849	1.419	1.581

T0~T4 见表 3 The same as table 3,CVL:Caloric value of leaf, NCL:Nitrogen content of leaf

2.3 不同施氮水平下对两种水稻类型热值数量特征的统计分析

借助方差分析与 Duncan's 多重比较表明,早、

表 5 水稻不同器官的热值多重比较分析 (J/g)

Table 5 Mean caloric energy of different plant organs

晚稻根、茎、叶、小穗和籽粒间热值分别有显著差异。而且两个品种的差异性完全一致,见表 5。

在不同氮素处理下的两种水稻热值的差异性统计分析见表 6,结果表明,200kg/hm² N 氮素处理下的水稻热值同无氮素使用处理的水稻热值存在显著性差异,而其余氮素处理的水稻热值之间无显著性差异。但不同氮素处理对水稻稻穗的热值有较大影响,高氮处理的水稻(>80 kg/hm²)小穗同无氮和低氮(≤80kg/hm²)处理水稻小穗有显著的差异,表明水稻在不同氮素水平下对储藏器官的热值影响较大,这可能同氮素对最终产量形成,蛋白质、脂肪、碳水化合物的积累有很大关系。

不同氮素处理下,水稻根、茎、叶热值与氮素水平相互作用的差异性结果说明(表 7),在高氮素条件下(>160kg/hm² N),在水稻植株中,叶片具有最高的热值,同茎、根系有显著的差异。在相同的器官组织中,也以高氮素水平下的组织热值最大,但不同氮素处理间,热值没有显著差异。但在早稻嘉育 948 品种中,高氮处理下,根系的热值同低氮条件下的茎热值没有显著性差异。而晚稻则没有此现象,这说明氮素对提高早稻各器官的热值影响具有较大的变动性,而晚稻相对较稳定,茎、叶、根之间的热值差异性不能通过提高氮素水平来加以减少。无论如何,在所有处理组合中,水稻根系在无氮肥处理条件下,表现出最低的热值。所有组织器官都随着氮素增加,其热值相应增加。

3　讨论

3.1　水稻植株热值指标的变化特征

利用水稻植株中的各种物质的含量来计算水稻单位干物重的热值是普遍采用的方法,特别是在水稻的能量转化与分析中,以及将水稻的茎、叶、穗等器官作为饲料时,需要计算有关的热值。本试验的结果表明,水稻植株的热值不仅因品种、器官而异,存在着显著的差异,而且随着水稻生长发育的进程不同有显著差异。在本试验中,所有氮肥处理下的早稻嘉育 948 和晚稻嘉育 93390 品种的全生育期内平均热值分别为 17 406 J/g 和 17 344 J/g,没有显著差异。如果以最后一次收获时,取样分析得出的水稻各组织器官的热值计算平均热值,则早稻为 17 455 J/g,晚稻为 17 225 J/g。由此可见,在能量生态学的研究中,不可能采用唯一的作物热值标准来计算相关的热值,否则误差是相当大的。热值的这种差异与在生育期中的变化幅度同水稻的特性、构成物质(蛋白

水稻组织器官 Rice organs	早稻嘉育 948 Early rice948	晚稻嘉育 93390 Late rice 93390
根 Root	15979 a	15801 a
茎 Stem	16603 b	16476 b
叶 Leaf	17762 c	17851 c
穗 Panicle	18360 d	18342 d
子粒 Grain	18354 d	18366 d
稻壳 Husk	17380 e	17228 e
平均 Mean	17406	17344

表 6　不同氮素处理下水稻植株平均热值的差异性统计分析比较

Table 6　Statistic comparison of mean caloric value of rice cultivars Jia yu 948 and Jia yu 93390 under different nitrogen fertilizer treatments (J/g)

氮素处理 Nitrogen treatment	嘉育 948 Early rice 948		嘉育 93390 Late rice 93390	
	根茎叶 Stem,root and leaf	稻穗 Grain	根茎叶 Setm,root and leaf	稻穗 Grain
T4	16945 a	18519 a	16830 a	18426 a
T3	16895 ab	18386 b	16760 ab	18422 a
T2	16775 ab	18366 bc	16725 ab	18369 ab
T1	16685 ab	18273 cd	16660 ab	18251 bc
T0	16604 b	18194 d	16571 b	18238 c

每例中相同字母项之间在 $p=0.05$ 检验水平下相关不显著　Means within a column followed by a common letter are not significantly different at $p=0.05$ according to Duncan's Multiple Range Test

表 7　不同氮素处理与水稻组织结合对水稻热值影响的差异性分析

Table 7　Effect of nitrogen fertilizer treatment on caloric energy of rice plant organs of cultivars, Jia yu 948 and Jia yu 93390 (J/g)

早稻 嘉育 948 Early rice 948			晚稻 嘉育 93390 Late rice 93390		
处理×器官 Treatments ×Organs	能值 Caloric Values	$p=0.05$	处理×器官 Treatments ×Organs	能值 Caloric Values	$p=0.05$
T3 leaf	17898	a	T4 leaf	17982	a
T4 leaf	17856	a	T3 leaf	17924	a
T2 leaf	17763	a	T2 leaf	17891	a
T1 leaf	17672	a	T1 leaf	17793	a
T0 leaf	17620	a	T0 leaf	17665	a
T4 stem	16789	b	T3 stem	16508	b
T3 stem	16746	b	T2 stem	16508	b
T2 stem	16592	bc	T4 stem	16506	b
T1 stem	16499	bcd	T1 stem	16451	b
T0 stem	16388	bcde	T0 stem	16408	b
T4 root	16191	cdef	T4 root	16003	c
T3 root	16042	def	T3 root	15847	c
T2 root	15971	ef	T2 root	15776	c
T1 root	15884	ef	T1 root	15736	c
T0 root	15803	f	T0 root	15641	c

Means within a column followed by a common letter are not significantly different at $p=0.05$ according to Duncan's Multiple Range Test

质、脂肪、碳水化合物、类脂化合物等)及与环境存在密切的关系[15]。

3.2 氮素使用对水稻热值的影响

本试验的结果表明,氮素对水稻的热值有着显著的影响,一般地随着氮素使用的增加,各组织器官的热值增加,这种效应对早稻的影响相对比晚稻大些。高施氮下水稻小穗热值显著大于低施氮下的水稻小穗的热值,表明氮素在水稻生产后期对产量与能量的转化与积累起着重要作用,Long 与孙国夫通过试验就发现氮肥对水稻植株热值存在着正效应[1,2]。本研究更进一步证实了这一点,而且通过回归分析发现氮素同水稻植株热值之间存在着极高相关性,可以用如下方程表示:

早稻嘉育 948 $Y=16980.7+1.721N$ (r=0.9856***)

晚稻嘉育 93390 $Y=16979.1+1.238N$ (r=0.9921***)

这里 Y 代表水稻热值 J/g, N 代表使用的氮素肥料量(纯 N)kg/hm^2。

从上述线性方程可见,两种水稻不施氮肥下的基础热值为 16 979 J/g。此值同 Sinclair 和 de Wit 利用水稻植株中各有机物质(蛋白质 8%、脂肪 2%、碳水化合物 88%、类脂与灰分 2%等)的比例及标准的有机物热值计算出的水稻热值 16 970 J/g,极为接近[16]。但显然,如果仅此用于水稻生产中的能量输出分析,则会产生较大误差。在本试验氮素显然对水稻热值存在显著效应,通过方程可以看到每增加 1kg/hm^{2}纯氮将使早稻的热值增加 1.721J/g ,而晚稻的热值增加 1.238 J/g,这表明氮肥使用对早稻的热值增加效应要高于晚稻。而目前水稻生产上的氮素使用(纯 N)在浙江省普遍在 150~450kg/hm^2,因此将使早稻和晚稻的热值分别提高 258~774 J/g 和 186~558 J/g,约占水稻基础热值(16979 J/g)的 1.5%~4.5%和 1.1%~3.3%。因此在应用水稻热值进行能量的输入输出分析时,有必要建立相关的氮素水平同水稻热值变化的关系,并合理地加以应用。

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