施肥对小麦冠层温度的影响及其与生物学性状的关联

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摘要：利用红外测温仪等研究了不同施肥处理对小麦冠层温度的影响。结果表明：不同施肥处理可改变小麦基因型的冠层温度，对于同一基因型品种，养分胁迫越严重，冠层温度越高；籽粒灌浆期旗叶叶绿素含量、可溶性蛋白质含量、蒸腾速率、净光合速率及一些农艺性状与冠层温度呈显著负相关。这表明，优良的生物学性状和较低的冠层温度相联系，冠层温度的高低可能成为反映水、肥等栽培措施是否科学合理的便捷而较准确的指标。

关键词：小麦；冠层温度；不同施肥处理；生物学性状

Effect of fertilization on the canopy temperature of winter wheat and its relationship with biological characteristics

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Abstract: Remotely sensing infrared canopy temperature is an efficient way to rapidly and non-destructively monitor the whole-plant response to water stress. It has often been used as a screening tool to select genotypes with drought and heat tolerance. It is reported that the drought-stressed plants show higher canopy temperature than the well-watered plants at both the vegetative- and anthesis growth stages. However, there is little information available about the effects of nutrient stress on the canopy temperature of crops. The objective of our experiment was to study the effect of different fertilization treatments on the canopy temperature of winter wheat (*Triticum aestivum* L.) by using infra-red thermometry.

Field experiments were conducted from 2000 to 2003 at the Agricultural Experimental Station of Northwestern Sci-Tech University of Agriculture and Forestry, Yangling, Shaanxi Province, China. It is a sub-humid area susceptible to drought. We examined canopy temperature in five cultivars of winter wheat: Xiaoyan 6, Shaan 229, RB6, NR9405 and 9430. Previous studies indicated that the mean canopy temperature of these varieties after anthesis was different. Each variety received four fertilizer treatments: CK (no fertilizer), N fertilization (513.6kg/hm^2 urea), P fertilization (409.9kg/hm^2 triple super-phosphate) and NP fertilization (513.6kg/hm^2 urea plus 409.9kg/hm^2 triple super-phosphate). The treatments (variety × fertilizer) were factorially arranged in a 5×4 randomized complete block design. Each treatment was replicated three times. The area of each plot was 1.5m×1.2m (1.2m long, 6 rows at 25cm apart). The soil is classified as Eum-Orthic Anthrosol, equivalent to an Udic Haplustalf in the USDA system. The soil had the following characteristics: OM, 15.32g/kg; total-N, 0.73g/kg; NH_4^+-N, 6.28mg/kg; NO_3^--N, 26.43mg/kg; available P, 18.20mg/kg; and available K_2O, 201mg/kg. Beginning at ear emergence, the canopy temperature of the wheat was measured using a hand-held infra-red thermometer (BAU-I, China). Canopy temperature measurements were made at noon on clear days. A total of fifteen measurements were made on 2-3 day intervals. The chlorophyll and water-soluble protein content of the flag leaves were measured three times during the grain filling stage. The transpiration and net photosynthesis rate of the flag leaves were also determined using a portable

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photosynthesis system (LI-6400, USA LI-COR). Five measurements were made at seven day intervals from the start of anthesis. Each determination was measured between 9:00～11:00 in the morning.

The results showed that fertilization could change the canopy temperature of different wheat genotypes. Nutrient stressed plants (CK) had higher canopy temperatures compared to well-fertilized plants (NP). At the grain filling stage, the canopy temperature of winter wheat in the different fertilizer treatments had a negative relationship with the chlorophyll content, water soluble protein content, transpiration rate and net photosynthetic rate of the flag leaves. The corresponding coefficient of correlation was −0.818**, −0.716**, −0.8559** and −0.6547**, respectively. These results indicated that there was a good relationship between canopy temperature and the nutrition status of the wheat plants. The well-fertilized plants had lower canopy temperatures compared to nutrient-stressed plants. We also observed that plants with low canopy temperature grew better than plants with high canopy temperatures. The results from this experiment indicate that canopy temperature may be an efficient method for the rapid and non-destructive monitoring of whole-plant nutrient stress.

Key words: Winter wheat; canopy temperature; fertilization; biological characteristics

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近年来随着红外测温技术和仪器的快速发展,冠层温度已在判别作物水分状况[1~3]、抗旱基因型作物的筛选[4,5]、抗热胁迫基因型作物的筛选[6]等方面进行了较多研究,取得了有价值的进展。澳大利亚科学家们[7]还研发了一种能够在田间检测冠层温度的机器人来寻找高产作物。合理施肥是取得作物高产的一个非常重要的栽培措施,它一直是人们研究的热点,但对于不同施肥情况下冠层温度的变化,国内外尚未见有报道。研究不同施肥处理对冠层温度的影响,探讨冠层温度能否作为判断合理施肥的一个方便快捷的指标,对于小麦生物学理论的进一步研究和栽培实践均具有重要意义。

1　材料与方法

1.1　试验设计和材料

试验于 2000～2003 年在西北农林科技大学农作试验一站进行,该站为暖温带半湿润气候。供试土壤为塿土,0～20cm 土层土壤养分含量为:有机质 15.32g/kg、全氮 0.73 g/kg、NH_4^+-N 6.28 mg/kg、NO_3-N 26.43 mg/kg、速效磷 18.20 mg/kg 、速效钾 201 mg/kg。肥料试验设不施肥(CK)、单施磷肥(P)、单施氮肥(N)和氮磷全施(NP)4 个处理,肥料量按 513.6 kg/hm^2 尿素,409.9 kg/hm^2 三料磷肥的标准于播前按上述处理一次相应施入尿素、三料磷肥(按当地生产上大约 6000 kg/hm^2 产量确定氮肥和磷肥的施肥量)。供试小麦品种选用本课题组多年来研究发现的冠层温度差异比较明显的小偃 6 号、陕 229 、RB6、NR9405、9430 共 5 个品种,其中前三者常年温度偏低,后两者常年温度偏高。试验采用随机区组排列,重复 3 次,每小区 6 行,行长 1.2m,行距 0.25m,株距 0.03m,于 10 月上旬开沟带尺点播。其余管理措施同一般大田。

1.2　测定项目和方法

(1)冠层温度的测定　按农田小气候观测所要求的对称法进行,所用仪器为国产 BAU-I 型红外测温仪。

(2)叶绿素含量的测定　在灌浆初期、中期和末期分 3 次取旗叶样,用丙酮乙醇(1∶1)混合液浸提,国产 UV-754 型分光光度计比色测定。按 Arnon 公式计算叶绿素含量[8]。

(3)可溶性蛋白质含量的测定　同样,在灌浆初期、中期和末期前后 3 次取旗叶样,采用考马斯亮蓝 G-250 蛋白染色法测定[8],以牛血清蛋白做标准曲线。

(4)净光合速率和蒸腾速率的测定　用美国 LI-COR 公司生产的 LI-6400 便携式光合测定系统。自 5 月 2 日(开花期)开始,每隔 7d 定期测定 1 次旗叶的净光合速率和蒸腾速率,直至叶片干枯。时间为每天 9:00～11:00,往返取样,选取有代表性的旗叶进行测定,如遇阴天光强不足时,使用仪器的红蓝光源测定。每个品种的每个处理均重复取样 6 次。

(5)农艺性状　测定了株高、分蘖数、有效穗数、生物学产量,并于成熟后实测计产。

试验数据均采用 SAS 统计软件进行处理。

2　结果与分析

2.1　不同施肥处理下小麦冠层温度的变化

表 1 的冠层温度每隔 1～2d 测定 1 次,遇雨顺延,从抽穗期到成熟期共有 15 个观测日。表中每个品种氮磷全施处理的温度为实测值,其它处理的温度为与氮磷全施处理的温度差。

图 1 每个品种的数据为 15 个观测日的平均值,平均为 5 个供试品种的平均值。从表 1 和图 1 看出,供试的 5 个基因型小麦品种在不同施肥处理下的冠层温度存在差异,4 个施肥处理比较,氮磷全施的冠层温度最低,不施肥处理最高,其差异最大可达 2℃左右。单施氮、单施磷的冠层温度居中,其中两者的高低因品种不同而异,产生这种现象的原因可能与品种对氮磷敏感性的

不同有关。在测试的 5 个基因型小麦中，只有 NR9405 的温度为 NP＜P＜N＜CK，其余 4 个品种皆为 NP＜N＜P＜CK。说明营养胁迫越严重，其冠层温度越高，与 Carrity 和 O'Toole[9]等许多研究者在水分胁迫方面所得到的水分胁迫越严重，冠层温度越高结果类似。5 个基因型品种比较，在氮磷全施这种正常施肥情况下冠层温度高的品种如 9430 和 NR9405，在养分胁迫情况下其冠层温度也越高，但升高的幅度高低不一，与 Carrity 和 O'Toole 在水稻上所得的严重水分胁迫下冠层温度高的品种，在充分灌溉条件下其冠层温度也较高的结果亦甚相似。

表 1　灌浆成熟期间的冠层温度(℃)

Table 1　Canopy temperature of wheat during milk～filling

品种 Variety	处理 Treatment	日序 Order in the days 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	F
A	NP	28.5	29.8	28.3	26.6	26.2	23.4	21.9	23.4	25.0	23.9	27.0	29.1	32.1	32.8	37.2	27.7
	N	+0.2	+0.1	0.0	0.0	+0.2	+0.2	+0.2	+0.2	+0.2	+0.1	+0.3	+0.3	+0.4	+0.4	+0.6	+0.2
	P	+0.3	+0.3	+0.2	+0.2	+0.4	+0.3	+0.3	+0.5	+0.5	+0.4	+0.7	+1.2	+1.0	+1.0	+1.4	+0.6
	CK	+0.8	+0.9	+0.8	+0.9	+1.1	+0.9	+0.8	+1.0	+1.0	+1.0	+1.4	+1.5	+1.5	+1.4	+1.7	+1.1
B	NP	28.9	30.1	28.2	26.4	26.1	23.5	21.9	23.4	24.9	23.7	26.9	29.0	31.8	32.4	36.7	27.6
	N	+0.1	+0.2	+0.6	+0.7	+0.7	+0.4	+0.3	+0.3	+0.5	+0.5	+0.6	+0.8	+0.9	+0.9	+1.2	+0.6
	P	+0.2	+0.4	+0.6	+0.6	+0.7	+0.5	+0.4	+0.5	+0.6	+0.5	+0.7	+0.9	+1.0	+1.1	+1.3	+0.7
	CK	+0.2	+0.4	+0.7	+0.7	+0.7	+0.6	+0.7	+0.9	+0.9	+0.9	+1.1	+1.2	+1.2	+1.3	+1.6	+0.9
C	NP	28.3	29.4	27.6	25.8	25.6	23.1	21.5	23.0	24.6	23.3	26.3	28.2	30.9	31.4	35.5	27.0
	N	+0.6	+0.8	+0.8	+0.8	+0.6	+0.4	+0.2	+0.2	+0.1	+0.1	+0.3	+0.5	+0.6	+0.8	+0.9	+0.5
	P	+0.5	+0.7	+0.9	+0.9	+1.0	+0.7	+0.5	+0.5	+0.5	+0.5	+0.6	+1.0	+1.2	+1.4	+1.6	+0.8
	CK	+0.7	+1.0	+1.2	+1.3	+1.2	+1.0	+0.9	+1.0	+0.9	+0.9	+1.3	+1.4	+1.7	+1.9	+2.3	+1.2
D	NP	28.9	29.9	28.4	26.7	26.5	23.6	22.3	23.7	25.3	24.0	27.2	29.3	32.3	33.0	37.4	27.9
	N	+0.4	+0.5	+0.6	+0.7	+0.5	+0.5	+0.2	+0.5	+0.6	+0.6	+0.9	+1.0	+1.1	+1.1	+1.1	+0.7
	P	+0.4	+0.6	+0.5	+0.4	+0.4	+0.4	+0.2	+0.5	+0.4	+0.4	+0.7	+0.7	+0.6	+0.6	+0.7	+0.5
	CK	+0.8	+1.1	+0.9	+0.8	+0.6	+0.5	+0.4	+0.6	+0.6	+0.8	+1.0	+1.1	+1.2	+1.2	+1.5	+0.9
E	NP	29.2	30.2	28.6	26.9	26.5	23.6	22.1	23.8	25.3	24.2	27.5	29.9	33.1	33.9	38.5	28.2
	N	+0.1	+0.3	+0.1	+0.1	+0.2	+0.1	0.0	+0.1	+0.2	+0.2	+0.1	+0.2	+0.4	+0.4	+0.3	+0.2
	P	+0.6	+0.9	+0.8	+0.8	+0.9	+0.8	+0.7	+0.8	+0.9	+0.9	+1.4	+1.4	+1.2	+1.1	+1.4	+1.0
	CK	+1.1	+1.4	+1.4	+1.3	+1.3	+1.0	+0.8	+0.9	+1.1	+1.1	+1.5	+1.6	+1.6	+1.5	+1.8	+1.3

A　小偃 6 号 Xiaoyan6；B　陕 229 Shaan229；C　RB6；D　NR9405；E　9430；F　平均 Average；下同 the same below

2.2　不同施肥处理下冠层温度和一些重要生物学性状的关联

2.2.1　与叶绿素含量和可溶性蛋白质含量的关联　不同施肥处理对小麦旗叶叶绿素含量和可溶性蛋白质含量的影响见图 2 和图 3。图中每个品种的数据为灌浆初期、中期和末期 3 次测定结果的平均值，图中的平均为 5 个供试品种的平均值。从图 2 和图 3 看出，同一基因型品种在不同施肥处理下旗叶的叶绿素含量和可溶性蛋白质含量有差异，总体趋势为施肥处理大于对照，即在不施肥情况下旗叶叶绿素含量和可溶性蛋白质含量最低，氮磷全施含量最高，单施氮和单施磷居中，5 个品种表现趋势基本一致。与不同施肥处理下冠层温度的表现(图 1)呈负相关关系，其相关系数分别为 $r=-0.818^{**}$、-0.716^{**}，皆达极显著水平，说明冠层温度的高低在不同施肥情况下可一定程度上反映出植株的活力和代谢水平。

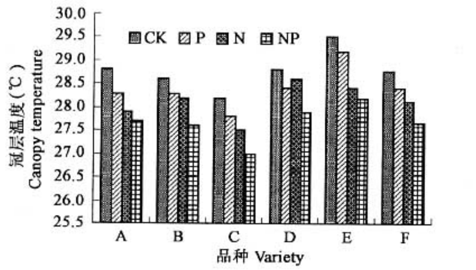

图 1　施肥对小麦冠层温度的影响

Fig. 1　Effect of fertilization on canopy temperature of wheat

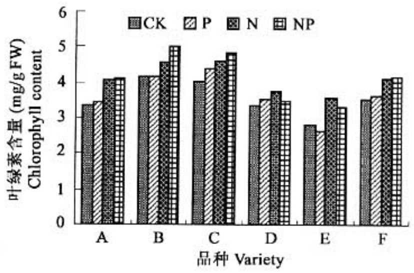

图 2　施肥对旗叶叶绿素含量的影响

Fig. 2　Effect of fertilization on chlorophyll content of wheat flag leaf

2.2.2　与蒸腾速率和净光合速率的关联　施肥处理对小麦旗叶蒸腾速率和净光合速率的影响见图 4 和图 5。图中每个品种的

数据为开花期、籽粒形成期、灌浆初期、中期和末期 5 次测定结果的平均值,图中的平均为 5 个供试品种的平均值。从图 4 和图 5 看出,同一基因型品种在不施肥情况下旗叶的蒸腾速率也为最低,氮磷全施时最高,单施氮和单施磷居中,5 个品种表现趋势一致。各施肥处理的净光合速率均大于不施肥处理,但施肥情况下的净光合速率不同品种表现不一,而总的趋势仍与前面叙述一致。与不同施肥情况下冠层温度的表现(图 1)比较,蒸腾速率和净光合速率皆呈负相关关系,其相关系数分别为 $r=-0.8559^{**}$、-0.6547^{**},皆达极显著水平,这说明,冠层温度在反映不同施肥处理下叶片蒸腾速率和净光合速率的水平上同样是较为灵敏的。

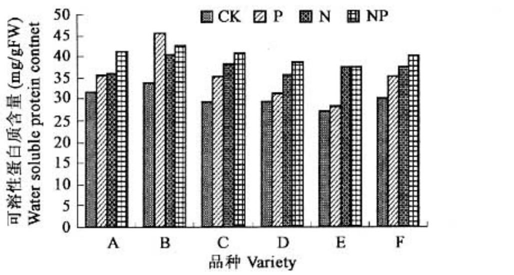

图 3　施肥对小麦旗叶可溶性蛋白质含量的影响

Fig. 3　Effect of fertilization on water soluble protein content of wheat flag leaf

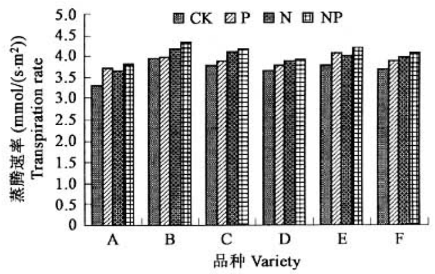

图 4　施肥对小麦旗叶蒸腾速率的影响

Fig. 4　Effect of fertilization on transpiration rate of wheat flag leaf

2.2.3　与重要农艺性状的关联　不同施肥处理下 5 个基因型小麦品种的农艺性状见图 6～图 8。从图中可以看出,5 个品种在不同施肥情况下,其有效穗数、生物学产量和籽粒产量皆有明显差异,4 个施肥处理比较,氮磷全施的有效穗数、生物学产量和籽粒产量最高,不施肥处理最低,达极显著差异。单施氮和单施磷居中,总体趋势为 NP＞N＞P＞CK。将农艺性状与冠层温度进行线性回归,所有指标均达极显著负相关,按相关系数从大到小排序依次为:有效穗数＞生物学产量＝籽粒产量＞分蘖数＞株高(见表 2)。说明农艺性状与冠层温度有着紧密联系并且均受植株的营养状况影响,营养状况越好,冠层温度越低,农艺性状越优。

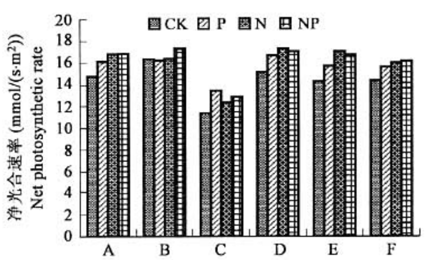

图 5　施肥对小麦旗叶净光合速率的影响

Fig. 5　Effect of fertilization on net photosynthetic rate of wheat flag leaf

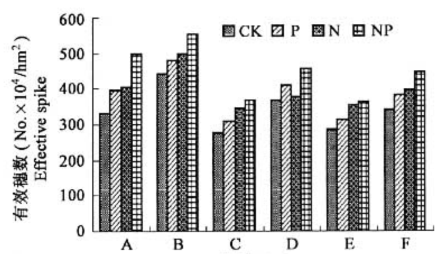

图 6　施肥对有效穗数的影响

Fig. 6　Effect of fertilization on effective spike

表 2　一些农艺性状与冠层温度的关系

Table 2　Relationship of canopy temperature and some agronomic characters

	株高(cm) Height	分蘖数(个) Tillering	有效穗数(×10⁴No./hm²) Effective spike	生物产量 Biomass(kg/hm²)	籽粒产量 Grain yield(kg/hm²)
线性方程 Formula of relationship	$Y=-8.028x+294.76$	$Y=-1.1103x+35.227$	$Y=-48.356x+1757.1$	$Y=-2625.5x+84491$	$Y=-1016.2x+33548$
r	-0.712	-0.851	-0.999	-0.981	-0.981

3　讨论

冠层温度的变化可以反映作物受水分胁迫的程度,这已为许多国内外研究者所证实,并已在抗旱、抗热基因型作物的筛选中得到应用。通过本研究可知,在籽粒灌浆期,不同施肥处理可改变小麦基因型的冠层温度,对于同一基因型品种,养分胁迫越

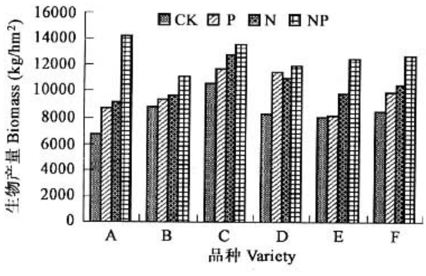

图 7 施肥对生物产量的影响

Fig. 7 Effect of fertilization on Biomass

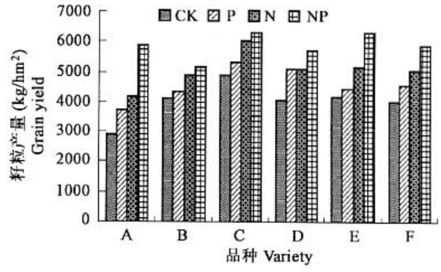

图 8 施肥对籽粒产量的影响

Fig. 8 Effect of fertilization on grain yield

严重，冠层温度越高；在正常施肥情况下冠层温度高的品种，在营养胁迫情况下冠层温度也较高，与冠层温度在水分胁迫处理时的表现趋势相一致。目前，冠层温度在灌溉方面具有一定的指导作用，由本试验可知，冠层温度的高低也有可能作为施肥情况是否良好的一个指标。较为合理的施肥处理具有较强的优势群体和较高的产量，这与其具有较强的生理代谢功能是密切相关的，籽粒灌浆期旗叶叶绿素含量和可溶性蛋白质含量及蒸腾速率和净光合速率在不同施肥处理下的表现就印证了这一点。根据冠层温度与一系列生物学性状呈显著负相关的分析表明，优良的生物学性状和较低的冠层温度相联系，因而，这就进一步说明较低的冠层温度必与较为合理的施肥措施相关联。但关于有机肥含量及与矿质肥料不同配比、不同土壤类型对冠层温度的影响还有待进一步研究。

目前，要实现小麦的超高产，除了培育优良的小麦品种外，合理的水肥管理等是进一步提高小麦产量的有力措施，根据冠层温度在水分管理上的应用和在施肥研究中的初步探讨可知，冠层温度的高低可能成为反映水、肥等栽培措施是否科学合理的便捷而较准确的指标，这对于推动群体冷性化栽培措施的运用将起到积极促进作用。

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