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# 遮阴对夏玉米干物质积累及养分吸收的影响*

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**摘 要** 以振杰2号(ZJ2)、登海605(DH605)和郑单958(ZD958)为试验材料,在大田条件下设置花粒期遮阴($S_1$)、穗期遮阴($S_2$)、全生育期遮阴($S_3$)3个遮阴处理,以自然光照条件为对照(CK),研究了遮阴对夏玉米干物质积累和氮、磷、钾吸收的影响.结果表明:遮阴后夏玉米籽粒产量和单株干物质积累量显著降低,降低程度与遮阴时期有关,表现为$S_3$>$S_1$>$S_2$,其中$S_1$、$S_2$和$S_3$籽粒产量平均降低61.6%、25.3%和92.8%,说明花粒期遮阴较花前遮阴对夏玉米干物质积累和籽粒产量影响更大,不同品种的变化趋势相同.夏玉米植株花前养分吸收量表现为钾>氮>磷,植株吸收总量表现为氮>钾>磷.遮阴后植株氮和磷积累量显著减少,由于遮阴后干物质较对照降低程度大于对氮、磷吸收的降低程度,各处理氮、磷相对含量有所升高;遮阴后各处理植株钾吸收量较对照显著降低,但$S_2$处理的钾吸收降低程度大于干物质积累降低程度,钾相对含量降低,即花前遮阴对玉米钾吸收的影响大于氮和磷.

**关键词** 遮阴 夏玉米 干物质积累 养分吸收 氮 磷 钾

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**Effects of shading on dry matter accumulation and nutrient absorption of summer maize.**

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**Abstract**: Taking summer maize cultivars Zhenjie 2 (ZJ2), Denghai 605 (DH605), and Zhengdan 958 (ZD958) as test materials, a field trial was conducted to study the effects of shading on the dry matter accumulation and nitrogen (N), phosphorus (P) and potassium (K) absorption of summer maize. Four treatments were installed, *i. e.*, shading from flowering stage to maturity stage ($S_1$), shading from six-leaf stage to flowering stage ($S_2$), shading all through the growth season ($S_3$), and no shading (CK). After shading, the grain yield and dry matter accumulation decreased significantly, and the decrement was related to shading period, showing $S_3$>$S_1$>$S_2$. The grain yield in treatments $S_1$, $S_2$, and $S_3$ was averagely 61.6%, 25.3%, and 92.8% lower than that of CK, respectively, indicating that the effects of shading after flowering were greater than those of shading before flowering. The responses of different cultivars to shading presented a similar trend. The nutrient absorption of summer maize before flowering stage showed K>N>P, and the nutrient absorption amount of whole plant showed N>K>P. After shading, the N and P absorption decreased significantly. The plant relative N and P absorption in different treatments had somewhat increase, because the decrement of dry matter accumulation after shading was larger than that of N and P absorption, as compared with the control. After shading, the plant K absorption decreased significantly, and the decrement in $S_2$ was larger than that of dry matter accumulation. Shading before flowering stage had larger effects on the plant K absorption than on the N and P absorption.

**Key words**: shading; summer maize; dry matter accumulation; nutrient absorption; nitrogen; phosphorus; potassium.

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玉米是喜光作物,光照对其光能利用效率和生产力起着决定性作用,良好的光照条件是其生长发育和高产的基础.黄淮海区域夏玉米生长期正处在一年中的主要降雨季节,近年来该区域阴雨寡照天气增多、太阳辐射不断减少[1],弱光已成为影响该区域夏玉米产量进一步提高的主要限制因素[2].

玉米产量由干物质的积累分配与转移特性所决定[3],且吐丝后的干物质积累与分配对籽粒产量影响最大[4].产量形成主要源于花后光合产物的积累.曾希柏等[5]指出,在一定的光强范围内,作物的光合速率和养分吸收量随光照的增强而增加.因此,光照对作物干物质积累、养分吸收和产量形成起着重要作用[6-8].前人围绕弱光(遮阴)对夏玉米生长发育的影响已做了大量研究,遮阴下叶片光合速率降低,植株发育变缓[9-10],光合产物积累减少[11-13],造成减产和品质降低[14-15].但是,有关遮阴对夏玉米干物质积累和养分吸收的影响鲜见报道.本研究旨在探讨夏玉米生育期内光照不足对干物质积累及氮、磷、钾吸收的影响,以期为应对气候变化条件下夏玉米生产提供理论和技术支持.

## 1 材料与方法

### 1.1 试验设计

试验于2010—2011年在山东农业大学试验农场进行.播种前0~20 cm土壤有机质9.34 g·kg$^{-1}$,全氮0.76 g·kg$^{-1}$,全磷0.88 g·kg$^{-1}$,碱解氮80.61 mg·kg$^{-1}$,速效磷37.19 mg·kg$^{-1}$,速效钾84.23 mg·kg$^{-1}$,pH值6.5.

共设置3个遮阴处理,分别为花粒期(吐丝-收获期,记作$S_1$)遮阴,穗期(拔节-吐丝期,记作$S_2$)遮阴和全生育期(出苗-收获期,记作$S_3$)遮阴,遮光度均为60%,以大田自然光照为对照(CK);实际遮阴小区面积27 m$^2$,3次重复,随机排列,等行距种植.利用脚手架和透光率为40%的黑色遮阴网搭建可拆卸式遮阴棚,使遮阴网与玉米冠层表面始终保持2 m的距离,从而保证遮阴棚内小气候与大田自然光照条件基本一致(表1).

使用CI-110型植物冠层数字图像分析仪于玉米冠层上部30 cm处测定光照强度;地温计(地表下5 cm)和普通温度计(穗位处)测定地温和群体温度;群体$CO_2$浓度和湿度采用GXH-305型便携式红外线$CO_2$仪于穗位处测定;AR816风速仪测定群体内风速.均在11:00测定,遮阴处理后10~15 d连续测定7 d,计算两年平均值.

2010年选用玉米品种为郑单958(ZD958)和振杰2号(ZJ2),6月14日播种,10月4日收获;2011年选用玉米品种为郑单958(ZD958)和登海605(DH605),6月19日播种,10月9日收获.行距60 cm,种植密度67500株·hm$^{-2}$.按12000 kg·hm$^{-2}$的产量水平施用N 300 kg·hm$^{-2}$,$P_2O_5$ 120 kg·hm$^{-2}$,$K_2O$ 240 kg·hm$^{-2}$;氮肥为尿素(652 kg·hm$^{-2}$,含N 46%),磷肥为过磷酸钙(706 kg·hm$^{-2}$,含$P_2O_5$ 17%),钾肥为氯化钾(400 kg·hm$^{-2}$,含$K_2O$ 60%);氮肥于拔节期施入40%,大喇叭口期施入60%,磷肥和钾肥于播种前一次性施入.距离玉米种植行10~15 cm开沟施肥.按高产田水平进行田间管理.

### 1.2 测定项目与方法

**1.2.1** 干物质积累和氮、磷、钾含量　分别于出苗期(V1)、拔节期(V6)、大喇叭口期(V12)、抽雄期(VT)、抽雄后20 d(VT+20)、抽雄后40 d(VT+40)和成熟期(R6)采样,每小区5株,整株保存,置烘箱内110 ℃杀青,然后80 ℃烘干至恒量,称量.样品烘干、粉碎,采用$H_2SO_4$-$H_2O_2$消煮,用AA3连续流动分析仪测定样品N和P的含量,用FPT 640火焰光度计测定样品K的含量[16].其他指标计算公式:花前干物质量(kg·hm$^{-2}$)=单位面积植株开花期干物质积累量;花后干物质量(kg·hm$^{-2}$)=单位面积植株成熟期干物质积累量−单位面积开花期干物质积累量;养分积累量(kg·hm$^{-2}$)=植株地上部干物质量×氮(磷、钾)含量;植株花前养分积累量(kg·hm$^{-2}$)=开花期养分积累量;植株花后养分积累量(kg·hm$^{-2}$)=植株最大养分积累量−开花期养分积累量.

**1.2.2** 测产与考种　每小区随机取30个果穗,分别

**表1 遮阴对田间小气候的影响**

**Table 1 Effects of shading on the microclimate in experimental field**

| 处理 Treatment | 气温 Air temperature (℃) | 地温 Ground temperature (5 cm, ℃) | 相对湿度 Relative humidity (%) | 风速 Air speed (m·s$^{-1}$) | 光照强度 Light intensity (μmol·m$^{-2}$·s$^{-1}$) | $CO_2$浓度 $CO_2$ concentration (μmol·mol$^{-1}$) |
|---|---|---|---|---|---|---|
| 遮阴 Shading | 28.1a | 23.8a | 51.3a | 0.8a | 671.4b | 334.3a |
| 对照 CK | 28.2a | 24.6a | 50.9a | 0.9a | 1628.2a | 329.0a |

同列不同小写字母表示处理间差异显著($P<0.05$) Different small letters in the same column meant significant difference among different treatments at 0.05 level. 下同 The same below.

装入尼龙网袋，晒干、脱粒，称量，以含水量 14% 时的质量计算产量. 同时进行考种，调查穗行数、行粒数和千粒重等指标.

### 1.3 数据处理

两年数据趋势一致，除产量数据外，品种 ZD958 数据均为 2010 和 2011 年的平均值. 采用 Microsoft Excel 2003 软件进行数据处理，DPS 7.05 软件进行数据统计与分析，采用 LSD 法进行差异显著性检验（$\alpha=0.05$）.

## 2 结果与分析

### 2.1 遮阴对夏玉米产量的影响

由表 2 可以看出，遮阴后玉米产量显著低于对照，不同时期遮阴的减产程度不同，表现为 $S_3>S_1>S_2$. DH605 和 ZD958（2011）的 $S_1$、$S_2$、$S_3$ 处理较 CK 分别减产 59.4%、14.9%、93.7% 和 48.7%、22.2%、89.2%，ZD958 和 ZJ2（2010）分别减产 72.6%、39.4%、96.9% 和 65.9%、44.8%、90.8%. $S_3$ 和 $S_2$ 的穗粒数较对照显著降低，但千粒重变化较少；$S_1$ 处理的穗粒数和千粒重都较对照降低；说明遮阴对穗粒数的影响大于千粒重，且开花后遮阴的影响大于开花前遮阴. 行粒数受遮阴的影响大于穗行数，处理间表现为 $S_3>S_2>S_1$.

### 2.2 遮阴对夏玉米干物质积累的影响

夏玉米干物质积累量随生育进程的推进呈不断增加，成熟期达到最大值. 遮阴使干物质积累量减少，收获期各处理干物质积累量表现为 $CK>S_2>S_1>S_3$，即 $S_3$ 和 $S_1$ 对干物质积累的影响大于 $S_2$，与产量变化趋势一致. $S_2$ 在拔节到开花期光照不足，花前干物质积累量较对照明显减少，解除遮阴后干物质积累量迅速增加，花后积累量占全生育期干物质积累量的 70% 左右；$S_1$ 花后干物质积累量仅占全生育期积累量的 40% 左右，这是籽粒产量降低的主要原因. 可见，遮阴不仅降低干物质积累总量，还影响开花前后干物质积累比例. 品种间总干物质量表现为 ZJ2>ZD958>DH605，总体变化趋势一致（表 3）.

### 2.3 遮阴对夏玉米养分吸收的影响

**2.3.1 氮素吸收** 由表 4 可以看出，各处理植株氮素积累量随生育进程推进逐渐增加，到成熟期积累量达到最大值，花前吸收比例略大于花后. V6 ~ VT 的氮素阶段吸收量最大，ZJ2、ZD958 和 DH605 此阶段氮素吸收比例分别达 58.2%、56.5% 和 41.2%，花后吸氮比例为 32.8% ~49.2%. $S_3$ 处理各时期氮素吸收量均小于对照，说明遮阴后植株吸氮能力降低，植株吸氮量减少. 开花后 $S_2$ 处理遮阴结束，氮素吸收量随植株干物质量的增加而迅速增加；$S_1$ 处理的花后氮素积累量显著减少. 遮阴使植株总吸氮量减少，不同时期遮阴处理花后氮素吸收比例为 $S_2>S_3>CK>S_1$，即 $S_2$ 处理花粒期氮素吸收比例增加，$S_1$ 处理减少. 不同玉米品种对遮阴的响应变化趋势一致.

**表 2 遮阴对夏玉米产量及其构成要素的影响**

**Table 2 Effects of shading on grains yield and its components of summer maize**

| 年份 Year | 品种 Cultivar | 处理 Treatment | 产量 Yield (kg·hm$^{-2}$) | 千粒重 1000-grain mass (g) | 穗粒数 Grains per ear | 穗行数 No. of rows per ear | 行粒数 No. of kernels per row |
|---|---|---|---|---|---|---|---|
| 2010 | ZJ2 | CK | 10511.7a | 367.2a | 506.8a | 14.6a | 34.8a |
| | | $S_1$ | 3585.6c | 255.3b | 329.4b | 13.8a | 23.8b |
| | | $S_2$ | 5803.7b | 356.3a | 336.2c | 13.6a | 24.9b |
| | | $S_3$ | 969.2d | 339.4a | 170.0d | 12.0b | 13.8c |
| | ZD958 | CK | 10727.7a | 332.0a | 555.2a | 15.0a | 37.1a |
| | | $S_1$ | 2938.8c | 251.5c | 304.5c | 13.9a | 21.3b |
| | | $S_2$ | 6497.7b | 295.2b | 436.9b | 14.3a | 30.5c |
| | | $S_3$ | 335.6d | 303.3b | 58.2d | 13.7a | 4.2d |
| 2011 | ZD958 | CK | 9978.9a | 334.5a | 488.1a | 14.9a | 32.8a |
| | | $S_1$ | 4831.1c | 289.2b | 300.7c | 14.7a | 20.5b |
| | | $S_2$ | 7762.8b | 324.1a | 415.1b | 14.5a | 32.0a |
| | | $S_3$ | 1020.4d | 343.2a | 95.6d | 13.2b | 7.3c |
| | DH605 | CK | 10106.9a | 320.5b | 518.9a | 16.1a | 32.2a |
| | | $S_1$ | 4104.2c | 306.8a | 226.6c | 15.5a | 14.6b |
| | | $S_2$ | 8601.7b | 328.9b | 435.8b | 15.4a | 28.3a |
| | | $S_3$ | 640.6d | 335.8b | 68.7d | 14.4b | 4.8c |

CK：无遮阴 No shading；$S_1$：花粒期（吐丝-收获期）遮阴 Shading from flowering stage to maturity stage；$S_2$：穗期（拔节-吐丝期）遮阴 Shading from six-leaf stage to flowering stage；$S_3$：全生育期（出苗-收获期）遮阴 Shading all through the growing season. 下同 The same below.

表 3 遮阴对夏玉米单株干物质积累的影响

**Table 3 Effects of shading on dry matter per plant of summer maize at different stages ($kg \cdot hm^{-2}$)**

| 品种 Cultivar | 处理 Treatment | V6 | V12 | VT | VT+20 | VT+40 | R6 | 花后积累比例 Proportion after VT (%) |
|---|---|---|---|---|---|---|---|---|
| ZJ2 | CK | 72.1a | 315.5a | 705.2a | 1107.0a | 1362.6a | 1637.6a | 57.0 |
| | $S_1$ | – | – | – | 774.0b | 953.6c | 1013.0c | 30.4 |
| | $S_2$ | – | 141.8b | 347.4b | 770.0b | 1129.5b | 1316.3b | 73.6 |
| | $S_3$ | 18.3b | 88.2c | 233.6c | 503.6c | 679.5d | 732.6d | 68.2 |
| ZD958 | CK | 43.8a | 284.0a | 557.6a | 891.5a | 1150.2a | 1454.0a | 61.7 |
| | $S_1$ | – | – | – | 623.3b | 854.6b | 934.7c | 40.4 |
| | $S_2$ | – | 138.2b | 291.2b | 608.4b | 884.7b | 1106.1b | 73.7 |
| | $S_3$ | 12.6b | 86.0c | 184.1c | 371.7c | 533.7c | 622.4d | 70.4 |
| DH605 | CK | 26.9a | 212.0a | 400.1a | 870.8a | 1013.4a | 1272.6a | 68.6 |
| | $S_1$ | – | – | – | 539.6b | 802.8b | 873.9b | 54.2 |
| | $S_2$ | – | 135.5b | 260.1b | 477.5b | 729.5b | 887.0b | 70.7 |
| | $S_3$ | 10.7b | 85.1c | 158.9c | 317.3c | 518.0c | 544.1c | 70.8 |

V6:拔节期 Jointing stage; V2:大喇叭口期 Male tetrad stage; VT:抽雄期 Tasseling stage; VT+20:抽雄后 20 d 20 days after tasseling stage; VT+40:抽雄后 40 d 40 days after tasseling stage; R6:成熟期 Maturity stage. ZD958 数据为 2010 和 2011 年的平均值 Values of ZD958 are mean of 2010 and 2011. 下同 The same below.

表 4 遮阴对夏玉米不同生育阶段氮素吸收的影响

**Table 4 Effects of shading on nitrogen uptake of summer maize at different growth stages**

| 品种 Cultivar | 处理 Treatment | V1 ~ V6 | | V6 ~ VT | | VT ~ VT+20 | | VT+20 ~ VT+40 | | VT+40 ~ R6 | | 花前/花后 Pre-anthesis/After-anthesis |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | SA | AP | SA | AP | SA | AP | SA | AP | SA | AP | |
| ZJ2 | CK | 24.7a | 9.1 | 158.0a | 58.2 | 43.5a | 16.0 | 22.6b | 8.3 | 22.9a | 8.4 | 67.2 : 32.8 |
| | $S_1$ | 24.7a | 10.6 | 158.0a | 67.9 | 30.4b | 13.1 | 11.5c | 5.0 | 8.1b | 3.5 | 78.5 : 21.5 |
| | $S_2$ | 24.7a | 9.6 | 130.7b | 50.6 | 37.6a | 14.6 | 37.5a | 14.5 | 27.7a | 10.7 | 60.2 : 39.8 |
| | $S_3$ | 5.9b | 3.4 | 103.0c | 58.6 | 40.4a | 23.0 | 18.8b | 10.7 | 7.8b | 4.4 | 61.9 : 38.1 |
| ZD958 | CK | 17.5a | 6.5 | 152.9a | 56.5 | 31.2a | 11.5 | 44.7a | 16.5 | 24.2a | 9.0 | 63.0 : 37.0 |
| | $S_1$ | 17.5a | 9.2 | 152.9a | 80.5 | 8.4c | 4.4 | 1.2c | 0.6 | 10.0b | 5.3 | 89.7 : 10.3 |
| | $S_2$ | 17.5a | 8.9 | 90. 9b | 46.1 | 30.8a | 15.6 | 37.8a | 19.2 | 20.1a | 10.2 | 55.0 : 45.0 |
| | $S_3$ | 3.8a | 2.9 | 86.9b | 66.3 | 20.9b | 15.9 | 21.6b | 16.5 | 2.4c | 1.8 | 65.8 : 34.2 |
| DH605 | CK | 21.5a | 9.6 | 92.4a | 50.1 | 47.9a | 21.4 | 41.6a | 18.5 | 20.8a | 9.3 | 59.7 : 40.3 |
| | $S_1$ | 21.5a | 13.6 | 92.4a | 58.2 | 12.1c | 7.6 | 21.4c | 13.5 | 11.4b | 7.1 | 71.7 : 28.3 |
| | $S_2$ | 21.5a | 13.5 | 58.6b | 36.7 | 43.9a | 27.5 | 20.1c | 12.6 | 15.8b | 9.9 | 50.1 : 49.9 |
| | $S_3$ | 6.8a | 6.0 | 56.1b | 49.9 | 21.4b | 19.1 | 26.7b | 23.8 | 1.3c | 1.2 | 56.0 : 44.0 |

SA:阶段积累量 Stage accumulation ($kg \cdot hm^{-2}$); AP:阶段积累量占总积累量的比例 Proportion of stage accumulation to total accumulation (%). 下同 The same below.

**2.3.2** 磷素吸收　自然光照下,夏玉米植株不同生育时期磷素吸收量与氮素吸收有所差异,阶段吸收量表现为 VT ~ R6>V6 ~ VT>V1 ~ V6,ZJ2、ZD958 和 DH605 等 3 个品种 V1 ~ V6 阶段的磷素吸收比例分别为 37.0%、37.0% 和 34.1%,花粒期吸收比例分别为 54.0%、56.1% 和 57.2%,即植株阶段磷素吸收量以抽雄到成熟期最多. $S_3$ 处理各阶段吸收量均小于对照;开花后,$S_1$ 处理的磷素吸收量占全生育期吸收比例的 26.5% ~36.6%,较对照减少 23.4%,其磷素吸收高峰主要在 V6 ~ VT 阶段,吸收比例约为 55.1%;$S_2$ 处理花后磷素吸收比例为 66.0% ~ 69.5%,较对照增加 12.5%. 说明遮阴使磷素吸收发生改变,穗期遮阴磷素吸收的主要时期在开花后,花粒期遮阴磷素吸收的主要时期在开花前(表 5).

**2.3.3** 钾素吸收　由表 6 可以看出,夏玉米植株钾素吸收主要在花后 40 d 之前完成,花后 40 d 出现钾素外渗现象,植株钾素吸收量出现负值,阶段钾素积累量表现为 V6 ~ VT>VT ~ R6>V1 ~ V6. ZJ2、ZD958 和 DH605 花前钾素吸收比例分别为 78.2%、71.2% 和 72.4%,说明夏玉米植株对钾素的吸收主要在开花前完成. 遮阴对钾素吸收的影响与氮、磷有所不同. 穗期和花粒期遮阴植株花前钾素吸收比例均较对照升高,这与钾素花后吸收较少有关.

**2.4** 遮阴对夏玉米干物质积累与 N、P、K 吸收关系的影响

全生育期内,夏玉米植株吸收氮最多,其次为

表 5　遮阴对夏玉米不同生育阶段磷素吸收的影响

**Table 5　Effects of shading on phosphorous uptake of summer maize at different growth stages**

| 品种 Cultivar | 处理 Treatment | V1 ~ V6 | | V6 ~ VT | | VT ~ VT+20 | | VT+20 ~ VT+40 | | VT+40 ~ R6 | | 花前/花后 Pre-anthesis/After-anthesis |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | SA | AP | SA | AP | SA | AP | SA | AP | SA | AP | |
| ZJ2 | CK | 9.5a | 9.0 | 38.9a | 37.0 | 26.5a | 25.2 | 16.2a | 15.3 | 14.2a | 13.4 | 46.0∶54.0 |
| | $S_1$ | 9.5a | 14.5 | 38.9a | 59.1 | 4.6c | 7.0 | 9.8b | 15.0 | 3.0b | 4.5 | 73.5∶26.5 |
| | $S_2$ | 9.5a | 11.2 | 16.4b | 19.3 | 26.2a | 30.9 | 15.1a | 17.9 | 17.5a | 20.6 | 30.5∶69.5 |
| | $S_3$ | 2.0b | 4.1 | 15.3b | 31.0 | 18.4b | 37.2 | 11.2b | 22.7 | 2.4b | 4.9 | 35.1∶64.9 |
| ZD958 | CK | 6.2a | 6.9 | 33.5a | 37.0 | 20.3a | 22.4 | 13.5b | 14.9 | 17.0a | 18.8 | 43.9∶56.1 |
| | $S_1$ | 6.2a | 10.3 | 33.5a | 55.7 | 2.9c | 4.8 | 13.6b | 22.5 | 4.0c | 6.7 | 66.0∶34.0 |
| | $S_2$ | 6.2a | 9.0 | 14.9b | 21.7 | 21.4a | 31.3 | 18.0a | 26.3 | 8.0b | 11.7 | 30.7∶69.3 |
| | $S_3$ | 0.9b | 2.2 | 14.8b | 36.1 | 12.2b | 29.8 | 10.5b | 25.7 | 4.2c | 10.2 | 34.3∶65.7 |
| DH605 | CK | 7.3a | 8.8 | 28.2a | 34.1 | 25.3a | 30.5 | 13.1b | 15.8 | 9.1a | 10.9 | 42.9∶57.2 |
| | $S_1$ | 7.3a | 13.0 | 28.2a | 50.4 | 10.2b | 18.2 | 7.9c | 14.0 | 2.4b | 4.3 | 63.4∶36.6 |
| | $S_2$ | 7.3a | 13.0 | 11.8b | 21.0 | 13.8b | 24.5 | 17.2a | 30.7 | 6.1a | 10.8 | 34.0∶66.0 |
| | $S_3$ | 1.1b | 3.0 | 11.3b | 30.0 | 10.6b | 28.4 | 12.9b | 34.4 | 1.6b | 4.2 | 33.0∶67.0 |

表 6　遮阴对夏玉米不同生育阶段钾素吸收的影响

**Table 6　Effects of shading on potassium uptake of summer maize at different growth stages**

| 品种 Cultivar | 处理 Treatment | V1 ~ V6 | | V6 ~ VT | | VT ~ VT+20 | | VT+20 ~ VT+40 | | VT+40 ~ R6 | | 花前/花后 Pre-anthesis/After-anthesis |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | SA | AP | SA | AP | SA | AP | SA | AP | SA | AP | |
| ZJ2 | CK | 21.5a | 10.5 | 139.1a | 67.6 | 35.12a | 17.1 | 10.0b | 4.8 | -13.8 | - | 78.2∶21.9 |
| | $S_1$ | 21.5a | 11.9 | 139.1a | 76.7 | 15.50c | 8.6 | 5.3c | 2.9 | -45.0 | - | 88.6∶11.4 |
| | $S_2$ | 21.5a | 15.7 | 99.5b | 72.7 | 15.95c | 11.6 | 13.0a | 9.6 | -19.5 | - | 88.4∶11.6 |
| | $S_3$ | 5.4b | 4.0 | 89.4b | 67.0 | 25.70b | 19.3 | 13.0a | 9.8 | -33.5 | - | 71.0∶29.0 |
| ZD958 | CK | 16.5a | 9.1 | 113.0a | 62.2 | 30.79a | 16.9 | 21.5a | 11.8 | -26.9 | - | 71.2∶28.8 |
| | $S_1$ | 16.5a | 11.4 | 113.0a | 77.9 | 10.39c | 7.2 | 5.2c | 3.6 | -19.7 | - | 89.3∶10.7 |
| | $S_2$ | 16.5a | 14.2 | 85.3b | 73.4 | 10.03c | 8.6 | 4.5c | 3.9 | -11.6 | - | 87.5∶12.5 |
| | $S_3$ | 4.3b | 4.4 | 67.7c | 68.9 | 18.25b | 18.6 | 11.6b | 11.8 | -30.6 | - | 69.6∶30.4 |
| DH605 | CK | 19.2a | 9.6 | 106.6a | 53.2 | 53.17a | 30.7 | 31.4a | 15.7 | -27.1 | - | 72.4∶27.6 |
| | $S_1$ | 19.2a | 13.5 | 106.6a | 75.0 | 14.16c | 11.4 | 12.1b | 8.5 | -17.7 | - | 94.3∶5.7 |
| | $S_2$ | 19.2a | 20.3 | 52.6b | 55.5 | 10.66c | 11.3 | 12.3b | 12.9 | -9.0 | - | 75.8∶24.2 |
| | $S_3$ | 5.1b | 5.7 | 53.2b | 58.8 | 22.86b | 25.3 | 9.3c | 10.3 | -12.6 | - | 64.5∶35.5 |

表 7　遮阴对夏玉米成熟期干物质积累及 N、P、K 吸收量的影响

**Table 7　Effects of shading on dry matter accumulation and uptake of N, P and K of summer maize at maturity stage**

| 品种 Cultivar | 处理 Treatment | 干物质 Dry matter (kg·hm$^{-2}$) | 降幅 Decrement (%) | N | | | P | | | K | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | 积累量 Accumulation (kg·hm$^{-2}$) | 降幅 Decrement (%) | AR (%) | 积累量 Accumulation (kg·hm$^{-2}$) | 降幅 Decrement (%) | AR (%) | 积累量 Accumulation (kg·hm$^{-2}$) | 降幅 Decrement (%) | AR (%) |
| ZJ2 | CK | 1637.6a | - | 271.6a | - | 1.35 | 105.2a | - | 0.428 | 191.9 | - | 0.781 |
| | $S_1$ | 1013.0c | 38.1 | 232.7c | 14.3 | 1.53 | 65.8c | 37.5 | 0.433 | 136.4 | 29.0 | 0.897 |
| | $S_2$ | 1316.3b | 19.6 | 258.0b | 5.0 | 1.41 | 84.7b | 19.5 | 0.429 | 117.5 | 38.8 | 0.595 |
| | $S_3$ | 732.6d | 55.3 | 175.9d | 35.2 | 1.60 | 49.3d | 53.2 | 0.448 | 100.0 | 47.9 | 0.910 |
| ZD958 | CK | 1454.0a | - | 270.5a | - | 1.24 | 90.3a | - | 0.415 | 154.9 | - | 0.711 |
| | $S_1$ | 934.7c | 35.7 | 190.0b | 29.8 | 1.35 | 60.1b | 33.5 | 0.429 | 125.3 | 19.1 | 0.673 |
| | $S_2$ | 1106.1b | 24.9 | 197.1b | 27.1 | 1.29 | 68.5b | 24.2 | 0.418 | 104.6 | 32.5 | 0.631 |
| | $S_3$ | 622.4d | 57.2 | 131.2c | 51.5 | 1.39 | 40.9c | 54.7 | 0.441 | 67.7 | 56.3 | 0.728 |
| DH605 | CK | 1272.6a | - | 224.1a | - | 1.07 | 82.9a | - | 0.435 | 173.2 | - | 0.908 |
| | $S_1$ | 873.9b | 31.3 | 158.8b | 29.2 | 1.29 | 50.0b | 29.7 | 0.458 | 124.3 | 28.2 | 0.949 |
| | $S_2$ | 887.0b | 30.3 | 159.8b | 28.7 | 1.15 | 56.1b | 22.3 | 0.442 | 85.7 | 50.5 | 0.569 |
| | $S_3$ | 544.1c | 57.2 | 112.3c | 49.9 | 1.38 | 37.5c | 54.8 | 0.459 | 77.8 | 55.1 | 0.953 |

AR：养分占干物质量的比例 Proportion of nutrient to dry matter accumulation.

钾,磷最少. $S_1$、$S_2$和$S_3$的植株氮、磷总积累量较对照显著减少,表现为 CK>$S_2$>$S_1$>$S_3$,与干物质变化趋势一致,说明遮阴影响干物质积累的同时也降低植株对氮素和磷素的吸收能力. 遮阴后植株干物质量较对照减少的程度大于对氮素和磷素吸收减少的程度,如 ZJ2 的 $S_1$、$S_2$、$S_3$干物质积累量分别较对照降低 38.1%、19.6%、55.3%,氮和磷吸收量分别较对照降低 14.3%、5.0%、35.2% 和 37.5%、19.5%、53.2%. 可见,遮阴后干物质量受到的影响要大于植株吸收氮素和磷素所受到的影响,使植株体内氮、磷含量略有上升(表 7). 遮阴对钾素吸收的影响与氮磷不同,遮阴后植株钾素积累量表现为 CK>$S_1$>$S_2$>$S_3$,且 $S_2$处理的钾素积累量较对照减少程度大于干物质降低程度,说明穗期遮阴对钾素吸收的影响大于对干物质的影响,导致植株钾素含量降低.

从品种差异来看,不同玉米品种对养分吸收能力不同,ZJ2 对氮、磷、钾的吸收量均明显高于 ZD958 和 DH605,ZD958 的氮、磷吸收量略高于 DH605,钾素吸收量较低.

## 3 讨 论

### 3.1 遮阴对夏玉米产量和干物质积累的影响

作为影响植物生长发育最重要的环境因子之一,光照对植物的直接贡献是光合作用即同化力形成的主要来源. 玉米产量形成的基础是干物质积累与分配,干物质积累与产量呈显著正相关[17]. Ottaviano 等[18]提出,干物质积累速率是玉米产量的主要限制因素之一,增加干物质积累是高产的基本途径[19]. 本研究表明,遮阴后玉米干物质积累量显著减少,产量降低. 籽粒产量的高低既受生物产量的影响,又受经济系数的制约,吐丝后干物质积累与分配对经济产量的影响最大[20]. 穗期遮阴处理的籽粒灌浆期光照充足,由于穗期遮阴导致的干物质积累量减少是造成籽粒产量下降的重要原因;花粒期遮阴主要影响了花后籽粒发育,使粒重降低,导致其干物质积累总量和产量均小于穗期遮阴处理. 可见遮阴对玉米干物质积累与分配均有影响.

### 3.2 遮阴对夏玉米植株养分积累的影响

生物产量的提高是作物高产的基础,而养分吸收与分配是调控生物产量及其组分动态转化的重要前提. 氮、磷、钾对夏玉米生长发育乃至产量的形成起重要作用,有关夏玉米对氮、磷、钾吸收的研究已有较多报道[21-23],但得出的结论不尽相同. 张福锁等[24]和胡昌浩等[22]研究认为,玉米对氮、磷、钾的吸收比例为钾>氮>磷,Belay 等[25]则认为氮>钾>磷. 在本试验条件下,3 个品种的对照和遮阴处理夏玉米植株氮、磷、钾吸收量均为氮>钾>磷. 胡昌浩等[22]指出,夏玉米抽雄后氮、磷、钾吸收约占总吸收量的 40% ~50%;李文娟等[26]则指出,钾素的吸收主要在吐丝期之前完成. 本研究表明,夏玉米植株花前养分吸收量为钾>氮>磷,钾的花前吸收量达 70%,磷的花前吸收量约为 50%;遮阴后氮、磷、钾积累总量显著减少,遮阴时期不同导致养分吸收高峰发生变化,说明遮阴影响干物质积累的同时也降低了植株对养分的吸收能力.

本研究表明,遮阴后夏玉米植株氮、磷养分吸收量减少,表现为 CK>$S_2$>$S_1$>$S_3$,与干物质量的变化趋势一致. 但夏玉米干物质积累受弱光的影响大于植株吸收氮、磷所受到的影响,植株体内氮、磷含量略有上升. 遮阴对钾素吸收的影响与氮、磷有所不同. 遮阴后钾的吸收总量显著降低,不同时期遮阴处理的植株钾吸收总量表现为 CK>$S_1$>$S_2$>$S_3$,且最终 $S_2$处理的钾素相对含量降低,主要是因为穗期遮阴干物质积累速度下降,植株吸钾量减少,但遮阴解除后,后期仍有较大的干物质积累量,而钾吸收量较少,导致钾素相对含量降低.

遮阴对夏玉米养分吸收的影响与遮阴时期和养分吸收特性密切相关. 穗期遮阴减少了拔节至开花期的氮、磷吸收总量,氮、磷的阶段吸收比例降低;随着干物质的迅速积累,花粒期植株对氮、磷仍有较高的吸收量,而钾素吸收较少,说明穗期遮阴对钾素吸收的影响大于氮素和磷素. 在穗期光照不足的条件下,适当减少穗期氮、磷的施入,增加花粒期施入量,可以起到相应的调控作用. 因此,在生产中既要考虑作物自身的养分积累与吸收规律,也要考虑气候变化对干物质积累和养分吸收的影响,通过适当调整播期和施肥方式来实现玉米的高产稳产.

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