Study on Photosynthetic Characteristics of Yellow Green-revertible Line of *Brassica napus* L.

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Abstract In order to analyze the photosynthetic physiological characteristics of *Brassica napus* L., the changes of various photosynthetic characteristics were comparedand studied by using the stable and inheritable yellow-green revertible lines(Ygr) and near isogenic lines (Nil). The results showed that: with the development of leaves, the differences of chlorophyll content in the long-petiole leaf (LPL) and short-petiole leaf(SPL) ofthe Ygr and Nil reduced from 70.34%, 67.40% to 0.07%, 0.17%, respectively. The growth rates of chlorophyll content of the Ygr were 156.62%−727.03% and 118.72%−7 400.00% higher than those of the Nil, respectively. The contents of chlorophyll a, chlorophyll b, chlorophyll (a+b) and carotene in the main photosynthetic organs of the Ygr were significantly lower than those of the Nil. The light saturation point, light compensation point, light quantum efficiency, light respiration rate, CO_2 saturation point and dark respiration rate of leaf(LPL, SPL) and the light quantum efficiency, light respiration rate, light quantum efficiency of silique skin (SS) of the Ygr were significantly higher than those of the Nil. However, the carboxylation efficiency of the three types of photosynthetic organs in the Ygr was significantly lower than that in Nil. The initial fluorescence, quantum yield of PSⅡ regulatory energy dissipation, non-photochemical quenching coefficient in leaf(LPL, SPL) of the Ygr were significantly higher than those of the Nil, while the potential activity of PSⅡ, photochemical quenching coefficient, the effective quantum yield of photochemical energy conversion and the apparent electron transfer rate of PSⅡ in the leaves(LPL, SPL) of the Ygr were significantly lower than those of the Nil. The difference of the single leaf(LPL, SPL) and silique skin(SS) between the Ygr and Nil decreased by 25.85%, 24.23% and 14.15% from the early stage to late stage of no difference, respectively. The number of leaves, the pod number, the plant height and the biological yield of the Ygr were significantly lower than those of the Nil only at some stages. At the maturity stage, the branching site and the length of main inflorescence of the Ygr were significantly lower than those of the Nil, while the number of silique in the main inflorescence was significantly higher than that of the Nil. In conclusion, Ygr is a new leaf color mutant line of rapeseed with high value in research and application.

Key words *Brassica napus* L.; Yellow green-revertible line; Changes of photosynthetic characteristics; Comparison; Application value

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优化施肥对关中灌区冬小麦产量及氮肥利用的影响

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摘 要 为探索适合关中灌区冬小麦生产的施肥措施,实现陕西省粮食生产安全和土壤可持续利用,以冬小麦品种'小偃22'为对象,研究常规施用尿素(CK;N:270 kg/hm^2)、单施尿素(U;N:210 kg/hm^2)、尿素配施菌肥(UBF;N:210 kg/hm^2,菌肥:3 600 kg/hm^2)和尿素配施生物炭(UBC;N:210 kg/hm^2,生物炭:22 500 kg/hm^2)4种施肥措施对冬小麦生长发育、产量构成和氮肥利用的影响。结果表明,优化施肥处理UBF、UBC通过促进冬小麦中后期的生长,提高开花期叶面积指数和成熟期干物质积累量。开花期,优化施肥处理UBF、UBC冬小麦叶面积指数较常规施用尿素处理CK增加2.54%~5.00%;成熟期,尿素配施生物炭处理UBC冬小麦干物质积累量较其他3个处理增加8.41%~17.94%。优化施肥处理U、UBF、UBC冬小麦的成穗数和茎蘖成穗率较常规施用尿素处理CK分别增加1.79%~10.07%、13.70%~31.37%;产量和穗粒数规律均表现为U<CK<UBF<UBC,UBF、UBC较CK分别提高13.94%~21.22%、4.45%~8.21%。优化施肥处理UBF、UBC冬小麦地上部氮素积累量较常规施用尿素处理CK增加6.39%~6.88%,氮素吸收效率提高13.43%~36.79%,氮素利用效率提高6.59%~14.10%,氮肥偏生产力提高21.52%~55.86%。综上所述,尿素配施菌肥、生物炭均能促进冬小麦的生长发育和干物质积累,增加冬小麦氮肥利用和产量,其中播前配施120 kg/hm^{2}氮肥和22 500 kg/hm^{2}生物炭,拔节期追施90 kg/hm^{2}氮肥的处理表现最优,是关中灌区农业生产中较为适宜的优化施肥处理。

关键词 冬小麦;优化施肥;产量;氮肥利用;关中灌区

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肥料作为作物的粮食,对作物产量的贡献率达40%~50%,在粮食生产中有重要意义[1]。统计表明,中国每生产1.5 kg粮食需消耗0.5 kg化肥,约为国际公认安全线的2倍[2],化肥施用增长率达粮食产量增长率的8.7倍,产量与施肥量不再同步增长,化肥过量施用问题日益显著[3]。长期过量而单一地施用化肥,不仅会导致土壤理化性质恶化和肥料养分不平衡,造成土壤综合生产能力下降和资源浪费,还会影响生态环境[4]。因此,如何优化化肥使用量和调整施肥类型,对保障中国粮食生产安全和实现土壤可持续利用十分重要。

合理施用有机肥和生物炭是提高作物产量及实现土壤可持续利用的重要举措之一。生物菌肥是一类含有活体微生物的特定肥料,通过其生命活动为作物提供氮素营养,促进作物对养分的吸收[5],同时释放生长激素并抑制有害微生物的形成,改良土壤质量,提高作物产量,广泛应用于农业生产中[6-7]。Rose等[8]认为生物菌肥可以替代23%~52%的氮肥,达到减肥增效的目的;郝志萍等[9]研究发现,生物菌肥替代氮肥施入后,作物增产17.68%~30.81%;黄鹏等[10]研究表明,生物菌肥可以与氮肥配施促进作物生长、提高作物产量和资源利用效率,减氮配施生物菌肥处理的氮肥利用率较常规施氮处理增加4.21%~4.61%。生物炭是木材、农作物废弃物、植物组织或动物骨骼等生物质在低氧或缺氧(小于700 ℃)条件下不完全燃烧所产生的炭质[11],含有60%以上的碳元素,拥有较大的孔隙度和比表面积,较强的土壤理化性质改良作用,可提高土壤疏松性和保水保肥

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性,对作物生长和产量有促进作用[12-13]。Jeffery 等[14]通过 meta-analysis 系统分析施用生物炭与作物产量的关系后得出,施用生物炭后作物的产量平均增幅约为 10%。合理配施生物炭和氮肥,对植株的生长以及作物产量的提高都有较好的促进作用,还能显著增强植株肥料表观利用率和氮素利用率[15-16]。Chan 等[17]研究发现,生物炭配施氮肥后可使作物的干物质质量从 95%增至 266%;向伟等[18]研究表明,施入生物炭后作物产量提高 3.86%~10.98%,氮肥利用效率提高 7.7%~8.1%,特别是减氮配施生物炭处理的氮肥偏生产力较常规施氮处理提高 52.3%~57.1%。

关中灌区是陕西省粮食生产的主产区和高产区,冬小麦是该地区重要的粮食作物,实现该地区冬小麦的高效优质生产,对保障陕西省粮食生产有着重要意义。但是该地区冬小麦生产中由于过量施用氮肥和施肥类型单一,引发土壤肥力下降、氮肥利用率低和环境污染等一系列问题[19],化肥合理减施和施肥类型调整是该地区冬小麦生产亟待解决的问题。目前关于冬小麦施肥研究多集中在肥料施用量或者单一施肥类型方面,将生物菌肥、生物炭和尿素配合应用于小麦生产的研究还鲜有报道。基于此,本研究在尿素减施条件下,将生物菌肥、生物炭和尿素进行配施,研究不同施肥处理对关中灌区冬小麦生长发育、产量和氮肥利用的影响,筛选适宜该区冬小麦生产的施肥处理,为关中灌区冬小麦生产的化肥合理减施、增产增效提供理论依据。

1 材料与方法

1.1 试验地概况

试验地处于关中灌区,在陕西省泾阳县的西北农林科技大学斗口试验站内(东经 108°88′,北纬 34°61′),属暖温带半湿润性大陆性季风气候,年降雨量 517.7 mm,年平均气温 13.4 ℃。2017 年 10 月至 2018 年 5 月冬小麦生育期降雨量和日平均气温如图 1。供试土壤为塿土,播前土层基础养分含量状况:土壤体积质量为 1.61 g/cm^3,有机质含量为 19.37 g/kg,全氮含量为 1.22 g/kg,速效磷含量为 18.56 mg/kg,速效钾含量为 221.32 mg/kg,pH 为 8.51。

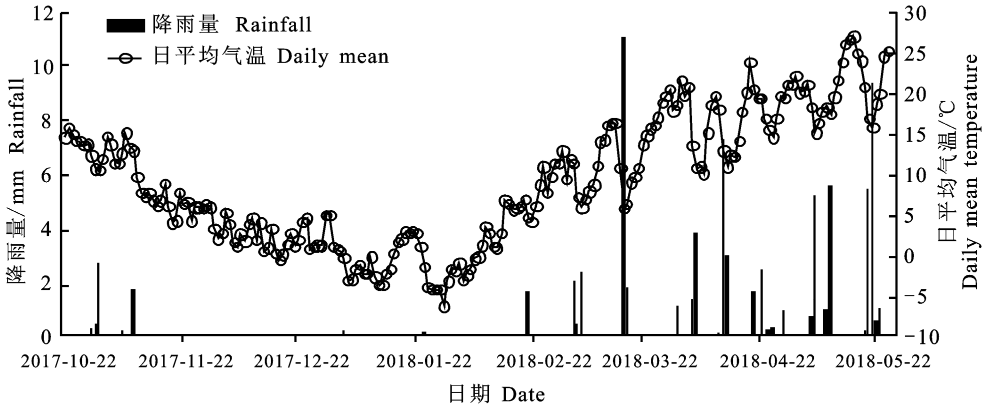


图 1　冬小麦生育季内降雨量和日平均气温

Fig. 1　Rainfall and daily mean temperature of winter wheat in growing seasons

1.2 试验设计

试验于 2017 年 10 月至 2018 年 5 月在西北农林科技大学斗口试验站内进行。供试冬小麦品种为'小偃 22',以常规施用尿素 CK(播前 210 kg/hm^2 氮肥+冬前 60 kg/hm^2 氮肥)为对照,设置 3 种优化施肥处理,单施尿素 U(播前 120 kg/hm^2 氮肥+拔节期 90 kg/hm^2 氮肥)、尿素配施菌肥 UBF(播前 120 kg/hm^2 氮肥和 3 600 kg/hm^2 菌肥+拔节期 90 kg/hm^2 氮肥)、尿素配施生物炭 UBC(播前 120 kg/hm^2 氮肥和 22 500 kg/hm^2 生物炭+拔节期 90 kg/hm^2 氮肥),共计 4 个处理,每个处理设 3 次重复,共 12 个小区,小区面积为 22.5 m^2。磷肥(P_2O_5)和钾肥(K_2O)施用量分别为 120 kg/hm^2、90 kg/hm^2,肥料撒入土壤表面后用旋耕机翻混入土壤,在越冬期和拔节期进行定量灌溉,灌水量均为 100 mm,其他田间管理方式一致。

1.3 测定项目与方法

1.3.1　群体质量指标　茎蘖动态:在冬小麦三叶期于各小区选取长势均匀的两个 1 m^2 进行标记

并统计基本苗，在越冬期、拔节期、成熟期调查标记区域内小麦的茎蘖数并计算茎蘖成穗率。

叶面积指数：在冬小麦越冬期、拔节期和开花期，于各小区选择健康且长势均匀的30片叶片制作小叶样，利用公式计算叶面积指数，叶面积指数＝小叶样面积(cm^2)×1 m^2 叶片干质量(g)÷小叶样干质量(g)÷10 000。

地上部干物质积累：在冬小麦越冬期、拔节期和成熟期，于各小区选取具有代表性的连续20 cm小麦植株进行分样，越冬期和拔节期分为叶片、茎鞘两个部分，成熟期分成茎鞘＋叶片、穗两部分，样品于105 ℃烘箱杀青30 min后于80 ℃烘干至恒质量，称量。

1.3.2 *产量及构成因素* 在冬小麦成熟期于每个小区收获长势均匀的1 m^2 植株，统计穗数和穗粒数，脱粒后测定千粒质量和含水量，计算14%水分含量下的产量。

1.3.3 *氮积累与利用* 将成熟期烘干称量后的各部分样品粉碎过筛，采用“$H_2SO_4-H_2O_2$ 消解－AA3型连续流动分析仪法”测定氮含量。氮含量以干质量表示，某一器官的氮积累量为该器官干物质量与氮含量的乘积，地上部氮积累量为各器官氮之和。氮积累与利用的相关计算公式：

氮素积累量(kg/hm^2)＝氮含量(g/kg)÷1 000×干物质量(kg/hm^2)；氮素吸收效率(kg/kg)＝成熟期植株地上部氮素积累量(kg/hm^2)÷施氮量(kg/hm^2)；氮素利用效率(kg/kg)＝籽粒产量(kg/hm^2)÷成熟期植株地上部氮素积累量(kg/hm^2)；氮肥偏生产力(kg/kg)＝籽粒产量(kg/hm^2)÷施氮量(kg/hm^2)。

1.4 数据处理与分析

采用Microsoft Excel 2016、SPSS 23.0软件进行数据整理、分析和作图。

2 结果与分析

2.1 优化施肥对冬小麦茎蘖动态的影响

如表1所示，随着冬小麦的生长发育，茎蘖数呈现先增加后降低的趋势，拔节期达到最高。在越冬期和拔节期，各处理冬小麦茎蘖数均表现为CK＞U＞UBF＞UBC，CK处理茎蘖数显著高于各优化施肥处理；成熟期，优化施肥处理U、UBF、UBC茎蘖数较CK分别增加1.79%、6.38%、10.07%，4个处理间差异不显著。优化施肥处理U、UBF、UBC茎蘖成穗率较CK处理分别增加13.70%、22.96%、31.37%，且差异显著，表现为UBC＞UBF＞U＞CK。

表1 不同施肥处理下冬小麦茎蘖动态和茎蘖成穗率

Table 1 Tiller dynamics and spike rate of winter wheat under different fertilization treatments

处理 Treatment	基本苗(×10^4)/hm^{-2} Basic seedling	越冬期(×10^4)/hm^{-2} Winter period	拔节期(×10^4)/hm^{-2} Jointing period	成熟期(×10^4)/hm^{-2} Maturity period	茎蘖成穗率/% Spike rate
CK	370.52 a	744.04 a	1 967.98 a	595.96 a	30.33 b
U	350.84 a	643.32 b	1 760.88 ab	606.64 a	34.49 ab
UBF	388.53 a	624.98 b	1 704.19 b	633.98 a	37.30 a
UBC	342.17 a	608.97 b	1 649.49 b	656.00 a	39.85 a

注：同列不同字母表示不同处理间差异显著(α= 0.05)，表2和表3同。

Note: Values followed by a different letters within the same columns indicate significant differences at 5% level among different treatments, the same as in table 2 and table 3.

2.2 优化施肥对冬小麦叶面积指数的影响

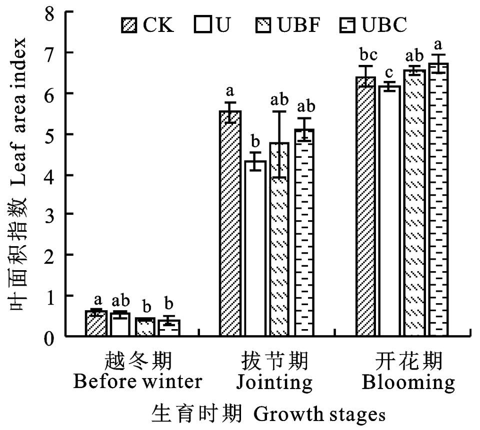
从越冬期到开花期，各处理叶面积指数不断增加(图2)。CK处理叶面积指数在越冬期和拔节期均最大，且与优化施肥处理呈现显著差异，越冬期较U、UBF、UBC处理分别增加9.49%、37.88%、44.54%，拔节期分别增加28.18%、17.12%、8.32%；开花期，各处理叶面积指数表现为UBC＞UBF＞CK＞U，优化施肥处理UBF、UBC叶面积指数较CK分别增加2.54%、5.00%，而U处理较CK降低3.33%。

2.3 优化施肥对冬小麦地上部干物质积累的影响

从越冬期到成熟期，冬小麦地上部干物质积累量呈现不断增加的趋势(图3)。越冬期，优化施肥处理各部位干物质积累量均低于CK；CK处理的干物质积累总量较优化施肥处理UBF、UBC分别显著增加47.87%、46.57%。拔节期，各部位干物质积累量均表现为CK＞UBC＞UBF＞U，CK处理与优化施肥处理呈现显著差异；CK处理干物质积累总量较优化施肥处理U、UBF、 UBC 分别增加 27.95%、21.21%、9.63%。成熟期,各处理茎叶积累量差异不显著,穗积累量和干物质积累总量均表现为 UBC＞CK＞UBF＞U,UBC 干物质积累总量较 CK、U、UBF 显著提高 8.41%～17.94%;与单施尿素处理 U 相比,CK、UBF、UBC 的穗积累量分别显著提高 10.22%、9.34%、29.99%,干物质积累总量分别显著提高 8.79%、7.60%、17.94%。

2.4　优化施肥对冬小麦产量的影响

如表 2 所示,4 个处理间穗数和千粒质量均无显著性差异,CK 穗数和千粒质量均低于优化施肥处理;UBC 处理穗数最多,较 CK、U、UBF 分别增加 10.07%、8.14%、3.47%;优化施肥处理 U、UBF、UBC 的千粒质量均为 35.15 g 以上,比 CK 增加 0.58～0.85 g。4 个处理的产量和穗粒数均表现为 U＜CK＜UBF＜UBC,UBF、UBC 的产量较 CK 分别显著提高 13.94%、21.22%;UBF、UBC 的穗粒数较 CK 分别显著提高 4.45%、8.21%,U 处理的穗粒数较 CK、UBF、UBC 处理分别降低 8.79%、12.68%、15.71%。



CK. 常规施用尿素;U. 单施尿素;UBF. 尿素配施菌肥;UBC. 尿素配施生物炭。不同小写字母表示不同处理间在 5%水平上差异显著,图 3、图 4、图 5 同

CK. Conventional application of urea; U. Single application of urea; UBF. Urea combined with bacterial fertilizer; UBC. Urea combined with biochar. Different lowercase letters indicate significant differences at 5% level among different treatments, the same as in Fig. 3, Fig. 4 and Fig. 5

图 2　不同施肥处理下冬小麦叶面积指数

Fig. 2　Leaf area index of winter wheat under different fertilization treatments

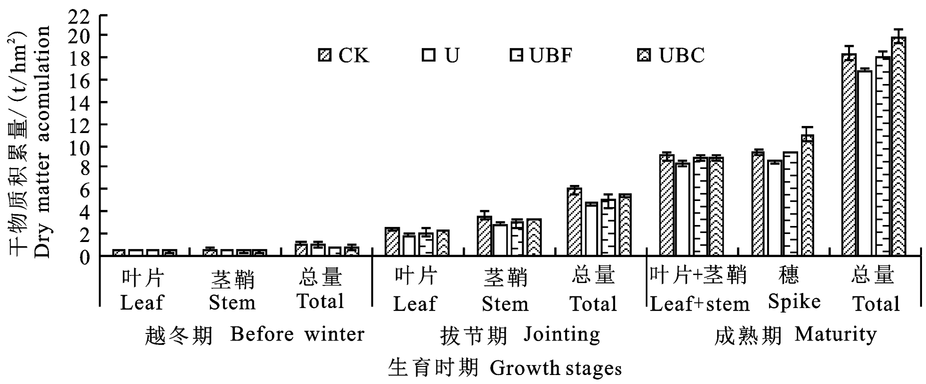


图 3　不同施肥处理下冬小麦地上部干物质积累

Fig. 3　Dry matter accumulation of winter wheat under different fertilization treatments

2.5　优化施肥对冬小麦地上部植株氮含量和氮素积累量的影响

由图 4 可知,小麦成熟期茎叶的氮含量低于穗的氮含量。各处理间茎叶氮含量呈现显著差异,表现为 UBF＞U＞UBC＞CK,优化施肥处理 U、UBF、UBC 茎叶氮含量较 CK 分别提高 16.34%、41.61%、9.22%;4 个处理间穗的氮含量差异不显著,CK 最高,较优化施肥处理 U、UBF、UBC 分别提高 10.73%、2.44%、11.19%。

由图 5 可知,小麦成熟期地上部植株的氮素主要积累在穗中。小麦地上部氮素积累总量表现为 UBF＞UBC＞CK＞U,优化施肥处理 UBF、UBC 较 CK 处理增加 6.39%～6.88%,单施尿素处理 U 较 CK、UBC、UBF 分别显著降低 11.77%、17.07%、17.45%。优化施肥处理 U、UBF、UBC 的茎叶氮含量较 CK 分别增加 8.23%、39.47%、7.28%,UBF 与其他处理呈显著差异;与 CK 处理相比,U、UBF 的穗氮素积累量分别降低 17.93%、3.15%,UBC 增加 6.11%,单施尿素处理 U 显著低于其他处理。

表 2　不同施肥处理下冬小麦产量及产量构成因素

Table 2　Grain yield and yield components of winter wheat under different treatments

处 理 Treatment	穗数(×10^4)/hm^{-2} Spikes	穗粒数 Kernels per spike	千粒质量/g 1 000 kernel mass	理论产量/(kg/hm^2) Grain yield
CK	595.96 a	28.43 ab	34.57 a	5 843.48 b
U	606.64 a	25.93 b	35.19 a	5 523.23 b
UBF	633.98 a	29.70 a	35.42 a	6 657.98 a
UBC	656.00 a	30.77 a	35.15 a	7 083.57 a

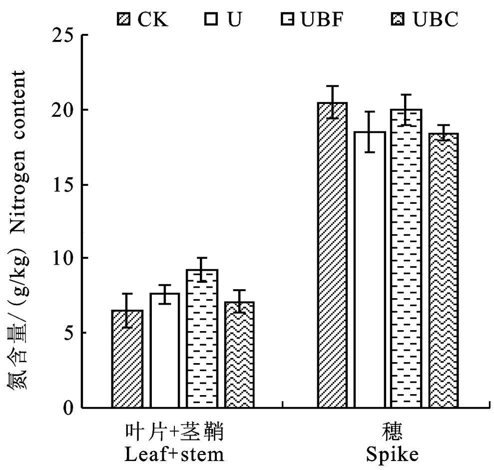


图 4　不同施肥处理下小麦成熟期植株各部位氮含量

Fig. 4　Nitrogen content during maturity period of winter wheat under different treatments

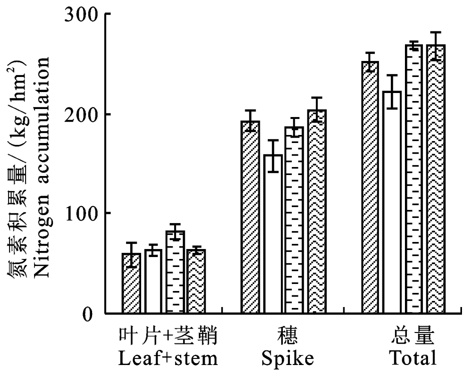


图 5　不同施肥处理下小麦成熟期植株氮素积累量

Fig. 5　Nitrogen accumulation during maturity period of winter wheat under different treatments

2.6　优化施肥对冬小麦氮素利用的影响

由表 3 可以看出，CK 处理的氮素吸收效率、氮素利用效率和氮肥偏生产力均表现为最低。优化施肥处理 U、UBF、UBC 的氮素吸收效率较 CK 分别增加 13.43%、37.42%、36.79%，UBF、UBC 的氮素吸收效率与 CK 呈显著差异；各处理氮素利用效率表现为 UBC＞U＞UBF＞CK，UBC 处理与 CK 差异显著，U、UBF、UBC 处理较 CK 分别增加 7.33%、6.59%、14.10%；优化施肥处理 U、UBF、UBC 的氮肥偏生产力显著高于 CK，增幅分别为 21.52%、46.49%、55.86%，U 处理显著低于优化施肥理 UBF、UBC。

表 3　不同施肥处理下冬小麦氮素吸收、利用效率和氮肥偏生产力

Table 3　Nitrogen uptake and use efficiency and nitrogen partial productivity of winter wheat under different fertilization treatments　　kg/kg

处 理 Treatment	氮素吸收效率 Nitrogen uptake efficiency	氮素利用效率 Nitrogen use efficiency	氮肥偏生产力 Nitrogen partial productivity
CK	0.93 c	23.27 b	21.64 c
U	1.06 bc	24.98 ab	26.30 b
UBF	1.28 a	24.81 ab	31.71 a
UBC	1.27 ab	26.55 a	33.73 a

3　讨 论

3.1　优化施肥对冬小麦生长和产量的影响

增施氮肥可以增加群体叶面积指数，提高冬小麦干物质积累量和产量[20-21]，但过量施用氮肥会改变冬小麦前中期的群体结构，导致无效分蘖增多，成穗数和茎蘖成穗率降低[22]。本研究中优化施肥处理的叶面积指数、干物质积累量和茎蘖数在越冬期和拔节期都低于常规施用尿素处理，但成穗数和茎蘖成穗率较常规施用尿素处理分别增加 1.79%～10.07%、13.70%～31.37%，其中尿素配施菌肥和生物炭处理冬小麦成穗数和茎蘖成穗率均显著高于常规施用尿素处理，这是因为菌肥和生物炭具有保肥供肥特性，可显著抑制养

分淋失、延缓肥料释放,促进作物中后期的生长,保证成穗数、提高成穗率[23-25]。本研究结果表明,尿素配施菌肥和生物炭均能显著提高冬小麦开花期的叶面积指数和成熟期干物质积累量,可能是菌肥中的活体微生物能够促进植株的新陈代谢,增加小麦的叶面积指数和光合速率,促进光合产物的积累及向穗部的分配,调控茎鞘物质的转运特性,有效提高小麦地上部干物质积累量和籽粒产量[26-27];生物炭施入后土壤中可利用养分增加,能够提高小麦叶面积指数,促进叶片光合产物转运到穗中,增加穗和植株的干物质积累量[28]。

研究表明,增施氮肥主要通过提高冬小麦穗数和穗粒数,特别是穗数来增加产量[29];氮肥过多则会降低小麦的穗数、千粒质量和产量[30];本研究结果表明,单施尿素处理与常规施用尿素处理相比,冬小麦产量和产量构成没有显著差异,可能与土壤本身氮素含量有关[31];尿素配施菌肥处理冬小麦的产量显著高于常规施用尿素和单施尿素处理,主要是因为菌肥配施增加冬小麦穗数、穗粒数和千粒质量,从而提高产量[32]。谢迎新等[33]发现生物炭配施后冬小麦千粒质量无明显差异,成穗数和穗粒数却存在显著差异,本研究中尿素配施生物炭处理提高冬小麦穗数和穗粒数,但是对千粒质量无影响,冬小麦产量较常规施用尿素和单施尿素显著增加 21.22%～28.25%,说明尿素配施生物炭也可促进冬小麦产量的增加。

3.2　优化施肥对冬小麦氮素积累和利用的影响

本研究结果显示,和常规施用尿素处理相比,优化施肥处理提高冬小麦植株的茎叶氮含量和氮积累量,可能是优化施肥各处理在拔节期进行追肥,更符合营养生长阶段小麦对养分的需求规律,有利于植株营养器官对氮素的吸收[34]。本研究还发现,尿素配施菌肥处理各部位氮含量和氮积累较单施尿素处理均有一定的增加,说明生物菌肥对小麦氮素吸收有一定的促进作用,与前人研究结果一致[35]。生物炭能够提高作物的氮吸收量[36],本研究中尿素配施生物炭处理穗的氮含量低于常规施用尿素处理,穗氮素积累量却高于其他处理,主要因为生物炭有利于小麦生长后期的生长和干物质的积累,促进穗部氮素的积累。

氮素吸收利用效率是作物吸收氮素并转化为籽粒的能力,氮肥偏生产力是施肥对产量影响的综合体现。适当降低施氮量不会影响作物产量和氮素利用效率,还会显著提高氮肥利用率和氮肥生理效率[37-38],本研究中优化施肥各处理冬小麦的氮素吸收、利用效率和氮肥偏生产力较常规施用尿素处理均有一定程度的增加,其中尿素配施菌肥和生物炭处理冬小麦的氮素吸收、利用效率和氮肥偏生产力显著高于常规施用尿素处理,说明氮肥减施条件下合理配施有机肥和生物炭可以显著增加作物的氮素吸收、利用效率和氮肥偏生产力,这是因为菌肥中的有益微生物可以繁殖氮素养分,有利于氮素的固定,促进植株对氮素的吸收和同化[39];生物炭表面有较多酸性官能团和负电荷,可以吸收固定更多土壤中的氨和离子,加上其孔隙度和表面积大,能够保持更多氮素在毛孔内部,促进植株对氮素的吸收、利用和积累[40-41]。

4　结 论

尿素配施菌肥、生物炭处理通过促进冬小麦中后期的生长,提高开花期叶面积指数和成熟期干物质积累量。与常规施用尿素处理相比,尿素配施菌肥、生物炭处理冬小麦的穗数、穗粒数、千粒质量均有不同程度的增加,产量显著提高 13.94%～21.22%。此外,尿素配施菌肥、生物炭处理冬小麦地上部氮素积累量较常规施用尿素处理增加 6.39%～6.88%,优化施肥各处理的氮素吸收效率、氮素利用效率、氮肥偏生产力较常规施用尿素处理均有提高。综上所述,尿素配施菌肥、生物炭均能促进冬小麦的生长发育和干物质积累,增加冬小麦氮肥利用率和产量,其中播前配施 120 kg/hm^2 氮肥和 22 500 kg/hm^2 生物炭,拔节期追施 90 kg/hm^2 氮肥的处理表现最优,是关中灌区农业生产中较为适宜的优化施肥处理。

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Effect of Optimized Fertilization on Yield and Nitrogen Utilization of Winter Wheat in Guanzhong Irrigation Area

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Abstract In order to explore suitable fertilization measures for winter wheat production in Guanzhong irrigation area, so as to realize food production safety and a sustainable soil utilization in Shaanxi province. The winter wheat variety 'Xiaoyan 22' was taken as object, the effects of four fertilization measures on the growth and development, yield composition and nitrogen utilization of winter wheat were studied, the four measures included conventional application of urea (CK; N:270 kg/hm^2), single application of urea (U; N:210 kg/hm^2), urea combined with bacterial fertilizer (UBF; N:210 kg/hm^2, bacterial fertilizer:3 600 kg/hm^2), urea combined with biochar (UBC; N:210 kg/hm^2, biochar:22.5 t/hm^2), the results showed that the UBF and UBC treatments could promote the growth of winter wheat at the middle and late stages, increased the leaf area index at the flowering stage and the dry matter accumulation at the mature stage. At the flowering stage, the leaf area index of winter wheat under UBF and UBC treatments increased by 2.54%-5.00% compared with CK; at maturity stage, the dry matter accumulation of winter wheat under UBC treatment increased by 8.41%-17.94% compared with the other three treatments. Compared with CK, the number of spike and the stem tiller rate of winter wheat under the optimized fertilization treatments of U, UBF, UBC increased by 1.79%-10.07%, 13.70%-31.37%, respectively; the law of yield and grain number per spike were both U<CK<UBF<UBC, the yield and grain number per spike of winter wheat under UBF and UBC treatments increased by 13.94%-21.22% and 4.45%-8.21% compared with CK. The nitrogen accumulation above ground of winter wheat under UBF and UBC treatments increased by 6.39%-6.88% compared with CK. Compared with the conventional urea treatment CK, the nitrogen uptake efficiency under optimized fertilization treatments of U, UBF, UBC increased by 13.43%-36.79%, the nitrogen utilization efficiency increased by 6.59%-14.10%, and the nitrogen partial productivity increased by 21.52%-55.86%. In summary, urea combined with bacterial fertilizer and urea combined with biochar could promote the growth and dry matter accumulation of winter wheat, and increase the nitrogen utilization and yield of winter wheat, among them, application of 120 kg/hm^2 nitrogen fertilizer and 22 500 kg/hm^2 biochar before sowing, and topdressing of 90 kg/hm^2 nitrogen fertilizer at jointing stage showed the best performance, and it was a more suitable optimized fertilization treatment in agricultural production in Guanzhong irrigation area.

Key words Winter wheat; Optimized fertilization; Yield; Nitrogen utilization; Guanzhong irrigation area

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