应用生态学报 2013年8月 第24卷 第8期
Chinese Journal of Applied Ecology, Aug. 2013,24(8): 2205-2210

喷灌对冬小麦植株氮素积累运转及籽粒蛋白质含量的影响*

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摘 要 以百农矮抗58为试验材料,以地面灌溉为对照,采用大田试验的方法,研究了喷灌对冬小麦植株氮素积累运转及蛋白质含量的影响.结果表明:拔节期喷灌条件下冬小麦植株氮素积累量与地面灌溉条件下相比没有显著差异;孕穗期至成熟期,喷灌条件下冬小麦植株氮素积累量显著高于地面灌溉条件.喷灌条件下叶片、茎鞘、颖壳开花前贮藏氮素的运转量和对籽粒氮素的贡献率均大于地面灌溉条件;而开花后同化氮素对籽粒的贡献率较地面灌溉条件降低.喷灌条件下冬小麦籽粒的蛋白质含量和蛋白质产量较地面灌溉条件显著提高.表明喷灌可明显调节冬小麦氮素物质运转和籽粒蛋白质积累.

关键词 喷灌 冬小麦 氮素 积累 运转
文章编号 1001-9332(2013)08-2205-06 **中图分类号** S275.5, S512.1 **文献标识码** A

Effects of sprinkler irrigation on the plant nitrogen accumulation and translocation and kernel protein content of winter wheat.
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Abstract: Taking wheat cultivar Bainong AK58 as test material, a field experiment was conducted to study the plant nitrogen accumulation and translocation and kernel protein content of winter wheat under sprinkler irrigation and surface irrigation, aimed to understand the differences in the nitrogen metabolism characteristics of winter wheat under different irrigation regimes. At booting stage, no significant difference was observed in the total amount of plant nitrogen accumulation between sprinkler irrigation and surface irrigation; while from booting stage to maturing stage, the total amount of plant nitrogen accumulation under sprinkler irrigation was significantly higher. Under sprinkler irrigation, the translocation amount and contribution rate of the nitrogen stored in leaf, glume, stem and sheath at pre-anthesis to the kernel increased, while the contribution rate of the assimilated nitrogen after anthesis to the kernel nitrogen declined. Both the relative protein content and the total protein yield in the kernel increased significantly under sprinkler irrigation. In conclusion, sprinkler irrigation could significantly regulate the nitrogen translocation and kernel protein accumulation of winter wheat.

Key words: sprinkler irrigation; winter wheat; nitrogen; accumulation; translocation.

水资源不足已经成为制约华北地区粮食生产及经济发展的关键因素,发展和应用农业节水技术是该地区水资源可持续利用的必然选择.喷灌作为一种现代的节水灌溉技术,是调节作物生长环境的重要手段之一,在农业生产上得到了越来越广泛的应用.喷灌以类似于降雨的方式湿润土壤,补充作物所需要的水分,喷灌条件下土壤水分空间分布特征与传统的地面灌溉相比具有明显差异[1-3].喷灌的水

* 国家自然科学基金项目(50909043)、农业部作物需水与调控重点开放实验室开放基金项目(CWRR200905)和河南科技学院青年骨干教师计划项目(060101)资助.
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2012-11-20 收稿,2013-06-02 接受.

滴蒸发和冠层截留水蒸发使一部分灌溉水以水汽的形式进入到冠层内外的大气中去,影响到冠层附近的温度、湿度及周围的水汽状况,从而使作物生长的农田环境因子发生变化[4-8]. 喷灌条件下土壤水分的空间变异和农田环境因子的改变已被大量研究和实践所证明,生长环境的改变使小麦籽粒灌浆、生长等过程受到了明显影响[9-12],同时小麦生长发育过程中,叶鞘、茎秆等器官各个时期氮素的消长、贮存及运转动态直接影响后期籽粒中蛋白质的积累. 但喷灌条件下因生长环境改变而导致的对小麦各器官氮素积累、运转及籽粒蛋白质含量的影响研究甚少. 本研究以冬小麦为对象,通过设置喷灌和地面灌溉对比试验,研究喷灌对冬小麦氮素积累和运转过程的影响,进而探讨喷灌对冬小麦品质形成的影响机制,以期为小麦节水高产优质栽培提供理论依据.

1 材料与方法

1.1 试验设计

试验于2007—2009 年两个冬小麦生长季在河南省新乡市洪门镇的河南科技学院试验场进行,该试验场地处豫北平原,属大陆性季风气候,年均降水量约600 mm,无霜期210 d,年均气温14.4 ℃,年均日照时数 2398 h. 试验地土壤为壤质潮土,耕层(0~20 cm)土壤有机质 13.7 g·kg^{-1},全氮 1.03 g·kg^{-1},碱解氮 92.49 mg·kg^{-1},速效磷 6.73 mg·kg^{-1},速效钾125.62 mg·kg^{-1},pH 8.4. 供试的小麦品种为当前河南省重点推广、增产潜力较大的百农矮抗58.

采用大田试验,设置喷灌处理和地面灌溉处理(对照). 喷灌试验区的面积为130 m×104 m,采用管道式喷灌,喷头选择13 m×13 m 的正方形布置. 地面灌溉试验区的面积为130 m×104 m,采用低压管道输水小畦灌,畦宽4 m,畦长65 m. 在喷灌和地面灌溉大区试验区内各设置3 个取样重复小区,每个小区的面积为4 m×65 m. 喷灌灌溉时间由土壤水分来确定,当表层60 cm 内土壤体积含水量低于田间持水量的55% ~60%时进行灌溉,喷灌每次的灌水量约50 mm. 地面灌溉灌水时间根据当地传统灌溉模式参考周围冬小麦农田的灌水进行,灌水量通过水表读数计算得到. 2 年试验期间,喷灌和地面灌溉条件下灌溉时间和灌水量见表1. 2007—2008 年冬小麦生长季喷灌试验田灌水3 次,总灌溉水量为149.6 mm,地面灌溉试验田灌水2 次,总灌溉水量为161.9 mm. 2008—2009年冬小麦生长季喷灌试验田灌水3 次,总灌溉水量为148.5 mm,地面灌溉试验田灌水2 次,总灌溉水量为158.7 mm. 除灌水处理外,喷灌和地面灌溉试验区的施肥等其他田间管理措施保持一致.

表1 喷灌和地面灌溉条件下灌水时间和灌水量

Table 1 Irrigation date and amount under sprinkler irrigation and surface irrigation

年份 Year	喷灌 Sprinkler irrigation		地面灌溉 Surface irrigation	
	灌溉时间 Irrigation date	灌水量 Irrigation amount (mm)	灌溉时间 Irrigation date	灌水量 Irrigation amount (mm)
2007—2008	2008-03-15	48.0	2008-03-15	81.3
	2008-04-07	51.1	2008-05-09	80.6
	2008-05-09	50.5	-	-
2008—2009	2009-03-09	50.0	2009-03-09	85.3
	2009-04-16	48.5	2009-05-07	73.4
	2009-05-07	50.0	-	-

1.2 测定项目与方法

1.2.1 植株全氮含量　于开花后每间隔7 d 取样1 次,每小区采集植株样品20 株,用剪刀贴近地表沿根茎结合处剪下植株,取地上部分作为混合样品. 在每个小区内,不同生育阶段取样时避开前期调查样段. 样品采集后于105 ℃杀青,80 ℃烘至恒量,采用半微量凯氏定氮法测定植株全氮含量[13]. 并计算开花后营养器官贮存的氮素向籽粒的转移量,开花前贮藏氮素运转量或花后同化氮素量对籽粒的贡献率. 相关计算公式为:开花前贮藏氮素运转量=开花期营养器官全氮量-成熟期营养器官全氮量;花后氮素积累量=成熟期籽粒全氮量-开花前营养器官贮藏氮素运转量;对籽粒氮贡献率=开花前贮藏氮素运转量(或花后同化氮素量)/成熟期籽粒全氮量.

1.2.2 土壤体积含水量　定期采用土钻对不同层次土壤进行取样,取样的土壤层次分别为0~10 cm、10~20 cm、20~30 cm、30~40 cm 和40~60 cm. 将每层土样分别装入铝盒,称其鲜质量,然后在110 ℃烘至恒量,称其干质量,计算土壤质量含水量. 根据0~60 cm 土层平均土壤含水量计算土壤质量含水量,土壤体积含水量由土壤质量含水量乘以土壤容重计算得到. 相关计算公式为:土壤质量含水量=(土壤鲜质量-土壤干质量)/土壤干质量×100%;土壤体积含水量=土壤质量含水量×土壤容重.

1.2.3 产量　冬小麦成熟时每处理取20 株,按常规法进行室内考种,分析产量构成因素,每处理试验区机割实收计产,折算成单位面积籽粒产量(kg·hm^{-2}).

1.3 数据处理

数据处理采用 SAS 统计软件包，方差分析采用 ANOVA 过程，采用 LSD 法进行差异显著性检验（$\alpha=0.05$）.

2 结果与分析

2.1 喷灌与地面灌溉条件下冬小麦植株的氮素积累

从表 2 可以看出，喷灌与地面灌溉条件下冬小麦植株的氮素积累量随生育进程逐渐增加，但不同处理间冬小麦植株氮素积累特征存在明显差异：在拔节期，喷灌条件下的冬小麦植株氮素积累量与地面灌溉条件下相比没有显著差异，随着冬小麦生育进程的推移，孕穗期至成熟期，喷灌条件下冬小麦植株氮素积累量显著高于地面灌溉条件，在 2007—2008 和 2008—2009 试验年份分别较地面灌溉提高了 14.6% ~24.6% 和 10.3% ~28.6%，说明与地面灌溉条件相比，喷灌促进了冬小麦植株对氮素的吸收.

2.2 喷灌与地面灌溉条件下冬小麦植株的氮素运转

从表 3 可以看出，在氮素运转方面，喷灌条件下叶片、茎鞘、颖壳等营养器官开花前贮藏氮素的运转量和对籽粒氮素的贡献率均显著大于地面灌溉条件下. 表明喷灌促进了小麦营养器官开花前贮存氮素的运转，提高了开花前贮存氮素对小麦籽粒氮素的贡献率.

进一步将开花前贮藏氮素和开花后同化氮素对籽粒氮素的贡献率作比较，从表 4 可以看出，与地面灌溉条件相比，喷灌条件下冬小麦植株花前贮存氮素的转运量和对籽粒氮素的贡献率显著增加，在 2007—2008 和 2008—2009 年，分别比地面灌溉条件下提高了 9.4% 和 7.2%. 喷灌条件下开花后同化氮素对籽粒的贡献率较地面灌溉条件降低. 可见喷灌有利于促进营养器官开花前储藏氮素向籽粒的运转，从而提高了其对籽粒氮素的贡献率.

表 2 喷灌和地面灌溉条件下冬小麦植株氮素积累

Table 2 Nitrogen accumulation of winter wheat under sprinkler irrigation and surface irrigation

年份 Year	灌溉方式 Irrigation method	植株氮素积累量 Nitrogen accumulation ($kg \cdot hm^{-2}$)				
		拔节期 Jointing	孕穗期 Booting	开花期 Anthesis	乳熟期 Milking	成熟期 Maturing
2007—2008	喷灌 Sprinkler irrigation	75.69a	176.79a	197.90a	213.33a	231.55a
	地面灌溉 Surface irrigation	78.22a	147.30b	158.86b	183.30b	202.03b
2008—2009	喷灌 Sprinkler irrigation	77.59a	160.62a	207.27a	228.56a	248.75a
	地面灌溉 Surface irrigation	75.49a	145.65b	161.24b	196.34b	208.94b

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 treatments at 0.05 level. 下同 The same below.

表 3 喷灌和地面灌溉条件下冬小麦各器官氮素输出量和贡献率

Table 3 Exportation amount and contribution rate of nitrogen in various organs under sprinkler irrigation and surface irrigation

年份 Year	器官 Organ	灌溉方式 Irrigation method	开花期氮积累量 Nitrogen accumulation at anthesis stage ($kg \cdot hm^{-2}$)	成熟期氮积累量 Nitrogen accumulation at maturing stage ($kg \cdot hm^{-2}$)	输出量 Exportation amount ($kg \cdot hm^{-2}$)	贡献率 Contribution rate (%)
2007—2008	叶片	喷灌 Sprinkler irrigation	78.74	20.35	58.39	32.4
	Leaf	地面灌溉 Surface irrigation	63.21	18.10	45.10	29.3
	茎鞘	喷灌 Sprinkler irrigation	94.23	25.32	68.91	38.3
	Stem and sheath	地面灌溉 Surface irrigation	76.87	24.87	52.00	33.8
	颖壳	喷灌 Sprinkler irrigation	24.93	5.79	19.14	10.6
	Glume	地面灌溉 Surface irrigation	18.78	5.11	13.70	8.9
2008—2009	叶片	喷灌 Sprinkler irrigation	71.67	18.21	53.46	27.4
	Leaf	地面灌溉 Surface irrigation	54.73	13.94	40.79	24.3
	茎鞘	喷灌 Sprinkler irrigation	104.69	27.51	77.18	39.5
	Stem and sheath	地面灌溉 Surface irrigation	81.95	21.06	60.89	36.3
	颖壳	喷灌 Sprinkler irrigation	30.91	7.79	23.12	11.8
	Glume	地面灌溉 Surface irrigation	24.56	6.10	18.46	11.0

表 4 喷灌和地面灌溉条件下冬小麦开花前储藏氮素和开花后同化氮素对籽粒的贡献率

Table 4 Contribution rates of pre-anthesis stored nitrogen and post-anthesis assimilated nitrogen to nitrogen amount of grain under sprinkler irrigation and surface irrigation

年份 Year	灌溉方式 Irrigation method	开花前储藏氮素运转量 Translocation amount of pre-anthesis stored nitrogen (kg·hm^{-2})	对籽粒氮素的贡献率 Contribution rate (%)	开花后同化氮素运转量 Translocation amount of post-anthesis assimilated nitrogen (kg·hm^{-2})	对籽粒氮素的贡献率 Contribution rate (%)
2007—2008	喷灌 Sprinkler irrigation	146.44	81.3a	33.64	18.7b
	地面灌溉 Surface irrigation	110.78	72.0b	43.17	28.0a
2008—2009	喷灌 Sprinkler irrigation	153.75	78.8a	41.49	21.3b
	地面灌溉 Surface irrigation	120.14	71.6b	47.70	28.4a

表 5 喷灌和地面灌溉条件下冬小麦成熟期籽粒蛋白质含量和蛋白质产量

Table 5 Grain protein contents and protein yields of winter wheat at maturity stage under sprinkler irrigation and surface irrigation

年份 Year	灌溉方式 Irrigation method	籽粒产量 Grain yield (kg·hm^{-2})	蛋白质含量 Protein content (%)	蛋白质产量 Protein yield (kg·hm^{-2})	籽粒氮素积累量 Nitrogen accumulation in grain (kg·hm^{-2})
2007—2008	喷灌 Sprinkler irrigation	7411a	13.9a	1030a	180a
	地面灌溉 Surface irrigation	6980b	12.8b	893b	156b
2008—2009	喷灌 Sprinkler irrigation	7837a	14.2a	1112a	195a
	地面灌溉 Surface irrigation	7177b	13.3b	954b	167b

小麦籽粒氮素的来源包括两部分,一是花后直接吸收同化的氮素;二是开花前植株贮藏氮素的再运转.在2007—2008和2008—2009年,地面灌溉处理花前贮存氮素转运量对籽粒氮素的贡献率分别为72.0%和71.6%,喷灌处理则分别为81.3%和78.8%,表明与对照相比,喷灌条件下冬小麦籽粒氮素积累对开花前储藏氮素再运转的依赖程度增大.

2.3 喷灌与地面灌溉条件下小麦籽粒蛋白质含量和蛋白质产量

与地面灌溉相比,喷灌处理显著提高了小麦籽粒产量、蛋白质含量、蛋白质产量和籽粒氮素积累量(表5),在2007—2008和2008—2009年,蛋白质含量的提高幅度分别为8.6%和6.8%,蛋白质产量的提高幅度分别为15.3%和16.5%.喷灌与地面灌溉对小麦氮同化和氮运转的影响是导致两种灌溉方式下籽粒蛋白质含量、蛋白质产量及籽粒氮素积累量产生差异的主要原因.与地面灌溉相比,喷灌可以促进营养器官开花前氮素的积累和贮藏氮素的运转,促进籽粒氮素的积累,从而有利于籽粒蛋白质的合成与积累,使蛋白质含量和产量提高.

3 讨 论

水分不仅影响土壤中氮素的有效性,而且影响作物氮素积累[14].合理减少灌水有利于提高小麦氮素积累量[15-16].与地面灌溉相比,喷灌灌水量较小,灌水周期短,灌水量分布均匀,协调了水分在不同生育阶段的分布,调节了植株的水分状态.本研究表明,喷灌条件下冬小麦植株氮素积累量在拔节期与地面灌溉条件下相比没有显著差异,从孕穗期至成熟期显著高于地面灌溉,与前人合理减少灌水有利于提高小麦氮素积累量的研究结论相同.喷灌和地面灌溉条件下冬小麦干物质积累的差异是造成这种影响的主要原因.本研究中,与地面灌溉相比,在冬小麦生长的中前期(分蘖期-拔节期),喷灌条件下冬小麦地上部干物质总量较小,但其单位干物质含氮量高于地面灌溉;在冬小麦生长的中后期(孕穗期-成熟期),喷灌有利于植株对干物质的积累,其干物质总量明显高于地面灌溉条件[17],而且喷灌条件下单位干物质含氮量也高于地面灌溉,从而使氮的积累量较高.

小麦从开花至成熟,其叶片、茎鞘等器官中的氮素不断进行再分配,主要是自营养器官向穗部籽粒输出[18].小麦籽粒氮素的来源包括两个部分,一是花后直接吸收同化的氮素;二是开花前植株贮藏氮素的再运转.许多研究表明,小麦籽粒蛋白质中的氮素来自开花后同化的氮素约占20%,而来自开花前营养器官储存再运转的氮素约占80%,也就是说籽粒中的氮素绝大部分来源于开花前植株储存氮素的再运转,只有少部分是开花后吸收的[19-22].对于多数品种而言,开花前营养体氮的调运是籽粒氮的主

要来源[23-24]. 诸多研究证实,冬小麦灌浆期各器官的氮素分布及其重新调运过程对于增加产量、提高品质有重要意义[18,23],小麦生长后期植株得到较多的氮素能提高籽粒的蛋白质含量,从而改善品质[25-26]. 本研究表明,与地面灌溉相比,喷灌条件下冬小麦叶片、茎鞘、颖壳开花前贮藏氮素的运转量及对籽粒氮素的贡献率均有提高;喷灌条件下开花后同化氮素对籽粒的贡献率较地面灌溉降低. 小麦籽粒蛋白质含量的提高在很大程度上依赖于开花前植株氮素的积累与运转[21,26-27]. 与地面灌溉相比,喷灌可以促进营养器官开花前植株氮素的积累和贮藏氮素的运转,促进了籽粒氮素的积累,从而有利于籽粒蛋白质的合成与积累,使蛋白质含量和蛋白质产量提高. 这与诸多研究关于小麦籽粒蛋白质含量的提高在很大程度上依赖于开花前植株氮素的积累与运转的研究结论相同.

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