夏闲期耕作对旱地小麦土壤水分及植株氮素吸收、运转特性的影响*

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摘 要 采用大田试验,研究了夏闲期耕作对旱地小麦播种前和各生育期0~300 cm土壤水分、植株氮素吸收和运转特性的影响.结果表明:夏闲期耕作可提高播种前和各生育期0~300 cm土壤蓄水量,且枯水年效果较好.夏闲期耕作可显著提高各生育期植株氮素积累量、开花期叶片和茎秆+茎鞘氮素积累量、成熟期籽粒氮素积累量,显著提高茎秆+茎鞘氮素运转量及其对籽粒的贡献率、叶片氮素运转量、花前氮素运转量、花后氮素积累量,最终提高氮素吸收效率,以前茬小麦收获后45 d深翻效果较好.夏闲期耕作条件下,土壤水分与花前氮素运转量及籽粒氮素积累量显著相关,且枯水年关系更密切;播种至开花期土壤水分与花后氮素积累量在丰水年显著相关,而枯水年无显著相关关系.夏闲期耕作,尤其是雨后深翻有利于蓄水保墒及植株氮素吸收和转运.

关键词 旱地小麦 夏闲期 耕作 氮素吸收运转 氮效率
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Effects of tillage in fallow period on soil water and nitrogen absorption and translocation by wheat plant. REN Ai-xia, SUN Min, ZHAO Wei-feng, DENG Lian-feng, DENG Yan, GAO Zhi-qiang (*College of Agronomy, Shanxi Agricultural University, Taigu* 030801, *Shanxi, China*). -*Chin. J. Appl. Ecol.*, 2013, **24**(12): 3471-3478.

Abstract: Field test was carried out to study the effect of tillage in fallow period on soil water before sowing and growth stages, and nitrogen (N) absorption, translocation by wheat plant. The current data showed that tillage in fallow period improved the soil water at the depth of 0-300 cm before sowing and growth stages, especially in dry years. Such tillage significantly improved N accumulation in leaf, stem and sheath (SS) at anthesis, grain N accumulation at maturity, N mobilization in SS and the contribution of mobilized N to grain N, amount of mobilized N in leaf, level of N accumulation before anthesis, N transportation from vegetative organs to grains after anthesis, and nitrogen accumulation after anthesis, which in turn enhanced the efficiency of N uptake. Deep tillage at 45 days after harvest had the best effect. Significant correlations were detected between soil water and N accumulation before anthesis as well as N translation from vegetative organs to grains after anthesis, particularly in dry years, while the correlation between soil water from sowing to anthesis and nitrogen accumulation amount after anthesis was significant in wet years, but not in dry years. Tillage in fallow period especially deep tillage after raining could benefit soil water preservation, as well as N absorption and translocation by plant.

Key words: wheat in upland; summer fallow period; tillage; nitrogen absorption and translocation; nitrogen efficiency.

氮素是作物生长发育的必需营养元素.小麦对氮素吸收、运转与土壤水分有密切关系,干旱胁迫和过量灌溉均不利于植株氮素的吸收和运转,适量灌溉是促进植株氮素吸收,提高氮肥利用效率的基础.大量研究认为,干旱胁迫减少了小麦吸氮量,同时也降低了开花前贮存在植株各营养器官中氮素的再运

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转量和再运转率,从而减少了籽粒氮素积累量和籽粒产量[1-4]. 还有研究认为,氮素在籽粒中的分配量随灌水量的增加先升高后降低,分配比例随灌水量的增加而降低[5-6],适量灌水可增加植株氮素积累量、开花后营养器官氮素向籽粒的转移量和籽粒氮素积累量,最终提高氮肥利用率[7-8]. 目前,植株对氮素吸收运转方面的研究多集中在有灌溉条件下,在旱地条件下的报道较少.

旱地小麦唯一的水分来源是自然降水,60% 的降雨集中在夏闲期(7—9 月)[9-10],由于夏季温度高,地表水分蒸发损失多,达不到伏雨春用的目的,因此,蓄保夏闲期降雨逐渐被旱地小麦栽培工作者重视. 廖允成等[11]研究认为,夏闲期采用高留茬、深松耕可把夏闲期占小麦全生产年 50% 的降水最大限度地蓄积并保存在土壤中,改善旱地小麦的水分条件,达到增产增收的效果. 侯贤清等[12-13]研究认为,夏闲期深松和翻耕可以增加土壤蓄水量,提高降水利用效率. 土壤水分是影响植株氮素吸收运转的重要因素,尤其制约着旱地小麦的高产与高效. 因此,本文立足蓄保夏闲期降雨,研究夏闲期耕作的蓄水保墒效果及其对植株氮素吸收利用的影响,探索旱地小麦夏闲期蓄水保墒技术的新途径.

1 研究区域与研究方法

1.1 试验地概况

本试验于 2009—2011 年在山西农业大学闻喜试验基地进行. 试验地为夏闲地,2009 年 7 月 1 日测定 0 ~ 20 cm 土层土壤肥力:全氮 0.74 g · kg^{-1}、碱解氮 32.93 mg · kg^{-1}、速效磷 20.08 mg · kg^{-1}、有机质 8.65 g · kg^{-1}. 试验区十年九旱,降水 60% ~ 70% 集中于夏秋季(7—9 月). 两年度降雨量差异较大(表 1),2009—2010 年较干旱,全年降雨量比常年低 20.8%,为枯水年;2010—2011 年雨水较充沛,全年降雨量较常年高 26.4%,为丰水年.

1.2 试验设计

供试小麦品种为运旱 20410,由闻喜县农业局提供. 试验采用二因素裂区设计,以夏闲期耕作时间为主区,设麦收后 15 d(7 月 1 日)和麦收后 45 d(8 月 1 日)两个水平(2009—2010 年两次耕作的降雨量相差 50 mm,2010—2011 年相差 132.3 mm);以耕作方式为副区,设深翻(深度为 25 ~ 30 cm,DT)、深松(深度为 30 ~ 40 cm,SS)、对照(不进行耕作,CK)3 个水平,共 6 个处理,重复 3 次,小区面积 30 m×3 m. 前茬小麦收获时留高茬,夏闲期施有机肥 1500 kg · hm^{-2},而后进行耕作处理,8 月 25 日耙耱收墒. 10 月 1 日播种,基施氮、磷、钾肥,施纯 N 150 kg · hm^{-2}, P_2O_5 150 kg · hm^{-2}, K_2O 150 kg · hm^{-2},基本苗 225×10^4 株 · hm^{-2},行距 20 cm,机械条播.

1.3 田间取样与测定方法

土壤水分的测定:分别于播种前、越冬期、拔节期、孕穗期、开花期、成熟期,用土钻取 0 ~ 300 cm 土样,每 20 cm 为一层,采用烘干法测定土壤水分. 土壤蓄水量(mm)= [(湿土质量-烘干土质量)/烘干土质量×100%]×土层厚度(mm)×土层容重.

植株干物质量及含氮率的测定:于越冬期、拔节期、孕穗期、开花期、成熟期取样 20 株,将越冬期整株,拔节期和孕穗期分为叶片、茎秆+茎鞘两部分,开花期分为叶片、茎秆+茎鞘、穗子 3 部分,成熟期分为叶片、茎秆+茎鞘、颖壳+穗轴、籽粒 4 部分,于 105 ℃杀青 30 min,75 ℃烘至恒量,称量. 然后磨碎,用 H_2SO_4-H_2O_2-靛酚蓝比色法测定植株全氮含量,经与半微量凯氏定氮法测定结果进行比较,两方法测定结果一致.

表 1 闻喜试验点降水量
Table 1 Precipitation in the Wenxi experimental site (mm)

年份 Year	夏闲期 Summer fallow period 7 月 July	8 月 August	9 月 September	播种前-越冬期 Before sowing-wintering stage	越冬期-拔节期 Wintering stage-elongation stage	拔节期-开花期 Elongation stage-anthesis stage	开花期-成熟期 Anthesis stage-maturity stage	总计 Total
2005—2009(mean)	89.90	81.80	69.50	42.50±15.05	41.23±8.43	34.10±10.80	64.08±20.75	423.11±17.82
2009—2010	50.00	71.70	51.40	64.50	12.60	33.90	50.90	335.00
2010—2011	132.30	219.50	49.70	27.10	19.10	22.20	64.80	534.70

数据来源于山西省闻喜县气象站 The data were from meteorological observation station of Wenxi County, Shanxi Province, China. 夏闲期为 7 月上旬至 9 月下旬,播种前-越冬期为 10 月上旬至 11 月下旬,越冬期-拔节期为 12 月上旬至 3 月下旬,拔节期-开花期为 4 月上旬至 4 月下旬,开花期-成熟期为 5 月上旬至 6 月中旬 Fallow period was from the first 10 d of July to the last 10 d of September, before sowing-wintering stage was from the first 10 d of October to the last 10 d of November, wintering stage-elongation stage was from the first 10 d of December to the last 10 d of March in the following year, elongation stage-anthesis stage was from the first 10 d of April to the last 10 d of April, anthesis stage-maturity stage was from the last 10 d of May to the middle 10 d of June. 下同 The same below.

1.4　数据处理

植株氮素积累、运转量及效率的计算公式：花前氮素运转量=开花期营养器官氮素积累量-成熟期营养器官氮素积累量；花前运转氮素贡献率=花前氮素运转量/籽粒氮素积累量×100%；花后氮素积累量=成熟期植株氮素积累量-开花期植株氮素积累量；花后积累氮素贡献率=花后氮素积累量/籽粒氮素积累量×100%；氮素吸收效率=植株氮素积累量/施氮量；氮素收获指数=籽粒氮素积累量/植株氮素积累量；氮素利用效率=籽粒产量/植株氮素积累量；氮肥生产效率=籽粒产量/施氮量.

采用 Microsoft Excel 2003 软件处理数据和作图，用 DPS 和 SAS 9.0 软件进行统计分析，差异显著性检验用 LSD 法，显著性水平设定为 $\alpha=0.05$.

2　结果与分析

2.1　夏闲期耕作对小麦播种前和各生育期 0～300 cm 土壤蓄水量的影响

夏闲期耕作可显著提高播种前 0～300 cm 土壤蓄水量，前茬小麦收获后 45 d 耕作效果显著. 2009—2010 年，与对照相比，深翻可使 0～300 cm 土壤蓄水量增加 75.79～91.31 mm，深松可增加 36.58～62.53 mm；2010—2011 年，深翻和深松可分别增加 67.33～69.85 mm 和 36.52～41.44 mm. 可见，夏闲期雨后深翻具有较好的蓄水保墒效果，且枯水年效果更好，可为旱地小麦适期播种创造有利条件.

随生育进程的推移，各生育期 0～300 cm 土壤蓄水量呈降低趋势，越冬期最高（表 2）. 夏闲期耕作可提高各生育期 0～300 cm 土壤蓄水量，以麦收后 45 d 耕作效果较好. 不同降雨年型耕作方式对各生育期 0～300 cm 土壤蓄水量的影响存在差异：2009—2010 年，与对照相比，深翻可使各生育期 0～300 cm 土壤蓄水量分别提高 17.2%～22.0%（越冬期）、28.0%～46.0%（拔节期）、28.9%～43.0%（孕穗期）、26.7%～43.3%（开花期）、18.6%～25.9%（成熟期），深松可分别提高 5.2%～13.1%、13.3%～35.2%、12.4%～31.4%、8.3%～34.0%、4.1%～15.7%. 2010—2011 年，深翻可分别提高 9.7%～12.8%、5.5%～10.8%、3.5%～9.8%、4.2%～6.3%、3.8%～6.1%，深松可分别提高 4.8%～5.5%、3.3%～5.0%、1.7%～5.1%、1.5%～3.2%、0.9%～2.3%. 可见，夏闲期深翻较深松提高了各生育期 0～300 cm 土壤蓄水量，且枯水年可显著延续到成熟期，丰水年可显著延续到孕穗期.

2.2　夏闲期耕作对小麦植株氮素吸收的影响

2.2.1 对各生育期植株氮素积累的影响　随生育进程的推移，植株氮素积累量呈增加趋势，成熟期最大（表 3）. 夏闲期耕作可显著提高各生育期植株氮素积累量，前茬小麦收获后 45 d 耕作氮素积累量显著高于 15 d. 麦收后 15 d 耕作，深翻较深松可提高各生育期植株氮素积累量，且越冬期、孕穗期、开花期和成熟期处理间差异显著；麦收后 45 d 耕作，深翻较深松可显著提高各生育期植株氮素积累量. 可见，

表 2　夏闲期耕作对小麦播种前和各生育期 0～300 cm 土壤蓄水量的影响

Table 2　Effects of tillage in summer fallow period on soil water storage at depth of 0-300 cm at before sowing and growth stages of wheat (mm)

年份 Year	处理时间 Treatment Time (d)	耕作 Tillage	播种前 BSS	越冬期 WS	拔节期 ES	孕穗期 BS	开花期 AS	成熟期 MS
2009—2010	15	DT	413.59b	371.71b	337.59c	286.59c	262.59c	222.09b
		SS	374.39d	333.72d	298.89d	249.89d	224.56d	194.89d
		CK	337.80e	317.22e	263.80e	222.30e	207.30e	187.30e
	45	DT	429.79a	387.84a	385.29a	321.79a	297.79a	237.29a
		SS	401.01c	359.72c	357.01b	295.51b	278.51b	218.01c
		CK	338.48e	317.95e	263.98e	224.98e	207.82e	188.48e
2010—2011	15	DT	473.76b	433.80b	390.30c	340.29c	303.02cd	263.07c
		SS	442.96c	402.85c	370.12d	325.71d	294.11de	253.73d
		CK	406.44d	384.52d	352.39d	309.93e	284.99e	247.98d
	45	DT	515.65a	456.92a	422.65a	364.48a	322.22a	287.74a
		SS	487.25b	439.43b	414.07ab	358.18ab	313.80ab	279.77b
		CK	445.80c	416.43c	400.82bc	352.30b	309.24bc	277.27b

DT：深翻 Deep tillage；SS：深松 Deep loose；CK：对照 Control. BSS：Before sowing stage；WS：Wintering stage；ES：Elongation stage；BS：Booting stage；AS：Anthesis stage；MS：Maturity stage. 下同 The same below. 同一年份同列不同字母表示差异显著（$P<0.05$）Different letters in the same column indicated significant difference among treatments at the same growth stage at 0.05 level.

夏闲期耕作有利于植株氮素积累,且雨后深翻效果更好.

2.2.2 对开花期植株各器官氮素积累的影响 夏闲期耕作显著提高了开花期叶片、茎秆+茎鞘氮素积累量,前茬小麦收获后45 d耕作氮素积累量高于15 d耕作,而夏闲期耕作降低了开花期穗的氮素积累量,且夏闲期深翻较深松可显著提高叶片、茎秆+茎鞘的氮素积累量(表4).说明夏闲期雨后深翻促进了花前叶片、茎秆+茎鞘的氮素积累.

2.2.3 对成熟期植株各器官氮素积累的影响 直至成熟期,植株体内73.1% ~87.1%的氮素转移到籽粒中(表4).夏闲期耕作可显著提高籽粒氮素积累量及其所占整株比率,且以前茬小麦收获后45 d耕作显著高于15 d;而夏闲期耕作降低了茎秆+茎鞘的氮素积累量,且以麦收后45 d耕作较低.夏闲期深翻较深松显著提高了籽粒、叶片、颖壳+穗轴的氮素积累量,显著降低了茎秆+茎鞘的氮素积累量.可见,夏闲期雨后深翻有利于减少茎秆+茎鞘中氮素的残留,促进成熟期籽粒氮素积累.

2.3 夏闲期耕作对小麦植株氮素运转的影响

2.3.1 对开花前植株各营养器官氮素运转量及其籽粒贡献率的影响 开花期各营养器官氮素对籽粒的贡献率以茎秆+茎鞘最高,穗部最低,叶片居中(表5).夏闲期耕作可显著提高茎秆+茎鞘氮素运转量

表3 夏闲期耕作对小麦各生育期植株氮素积累量的影响

Table 3 Effects of tillage in summer fallow period on N accumulation amount in wheat plant at different growth stages ($kg \cdot hm^{-2}$)

处理时间 Treatment Time (d)	耕作 Tillage	越冬期 WS	拔节期 ES	孕穗期 BS	开花期 AS	成熟期 MS
15	DT	8.98c	31.82c	69.19c	102.93b	129.76b
	SS	7.74d	30.98c	67.22d	98.33c	123.77c
	CK	5.43e	28.16d	61.26e	92.64d	114.10e
45	DT	10.81a	37.21a	78.01a	110.35a	140.93a
	SS	10.31b	35.49b	74.81b	103.50b	131.45b
	CK	5.62e	28.69d	62.92e	97.52c	120.71d

同一时期同列不同字母表示差异显著($P<0.05$) Different letters in the same column indicated significant difference among treatments at the same growth stage at 0.05 level. 下同 The same below.

表4 夏闲期耕作对小麦开花期和成熟期植株各器官氮素积累量的影响

Table 4 Effects of tillage in summer fallow period on N accumulation amount in various organs of wheat at anthesis and maturity stages ($kg \cdot hm^{-2}$)

处理时间 Treatment time (d)	耕作 Tillage	开花期 Anthesis stage			成熟期 Maturity stage				
		叶片 Leaf	茎秆+茎鞘 Stem+sheath	穗子 Spike	叶片 Leaf	茎秆+茎鞘 Stem+sheath	颖壳+穗轴 Glume+spike	籽粒 Grain	
								Ⅰ	Ⅱ
15	DT	23.69b	59.32b	19.92ab	5.19a	14.78c	6.20a	103.59c	79.8c
	SS	22.02c	57.42c	18.89b	2.05d	15.76c	4.45b	101.51d	82.0b
	CK	19.23e	52.84e	20.57a	2.50c	20.69b	3.49b	87.43e	76.6d
45	DT	29.65a	65.52a	15.18c	3.91b	8.24e	6.08a	122.70a	87.1a
	SS	24.01b	60.58b	18.92b	2.44c	11.01d	4.13b	113.87b	86.6a
	CK	20.97d	55.09d	21.45a	2.79c	25.36a	4.33b	88.24e	73.1e

Ⅰ:积累量 Accumulation amount; Ⅱ:积累率 Accumulation rate (%).

表5 夏闲期耕作对小麦开花前植株各营养器官氮素运转量及其对籽粒贡献率的影响

Table 5 Effects of tillage in summer fallow period on N moblization in various organs of wheat and their contributions to grain before anthesis

处理时间 Treatment Time (d)	耕作 Tillage	叶片 Leaf		茎秆+茎鞘 Stem+sheath		穗子 Spike	
		Ⅰ	Ⅱ	Ⅰ	Ⅱ	Ⅰ	Ⅱ
15	DT	18.50d	17.9d	44.54c	43.0b	13.72b	13.3b
	SS	19.97c	19.7b	41.66d	41.0c	14.44b	14.2b
	CK	16.74e	19.1bc	32.15e	36.8d	17.08a	19.5a
45	DT	25.74a	21.0a	57.29a	46.7a	9.10c	7.4c
	SS	21.57b	18.9c	49.57b	43.5b	14.79b	13.0b
	CK	18.19d	20.6a	29.73f	33.7e	17.12a	19.4a

Ⅰ:运转量 Amount of N mobilized ($kg \cdot hm^{-2}$); Ⅱ:贡献率 The contribution of mobilized N to grain N (%).

及其对籽粒的贡献率和叶片氮素运转量，以前茬小麦收获后 45 d 耕作显著高于 15 d，且深翻显著高于深松. 夏闲期耕作显著降低了穗部氮素运转量及其对籽粒的贡献率，且深翻低于深松. 可见，夏闲期雨后耕作有利于开花前植株氮素向籽粒的运转，增加了运转量和贡献率，尤其是茎秆+茎鞘，且以深翻效果更好.

2.3.2 对花前氮素运转和花后氮素积累的影响　夏闲期耕作可显著提高花前氮素运转量和花后氮素积累量，前茬小麦收获后 45 d 深翻高于 15 d（表 6）. 不同时间耕作对籽粒的贡献率表现不同，麦收后 15 d 耕作可提高花后氮素积累量对籽粒的贡献率，其中深翻高于深松；麦收后 45 d 耕作可提高花前氮素运转量对籽粒的贡献率，以深松高于深翻. 可见，夏闲期等雨耕作有利于促进花前植株氮素向籽粒的运转，为籽粒氮素积累奠定了基础.

2.4　夏闲期耕作对小麦氮效率的影响

夏闲期耕作可显著提高氮素吸收效率和氮素生产效率，前茬小麦收获后 45 d 深翻高于 15 d（表 7）. 不同降雨年型耕作对氮素收获指数和氮素利用效率的影响存在差异：2009—2010 年，麦收后 15 d 耕作降低了氮素利用效率，麦收后 45 d 深翻显著降低了氮素收获指数和氮素利用效率；2010—2011 年，夏闲期耕作显著提高了氮素收获指数和氮素利用效率. 说明夏闲期耕作更有利于丰水年小麦植株氮素向籽粒运转及产量形成.

2.5　小麦播种前和各生育期 0～300 cm 土壤蓄水量与氮素吸收、运转的相关性

夏闲期耕作条件下，2009—2010 年，播种前和各生育期 0～300 cm 土壤蓄水量与花前氮素运转量、籽粒氮素积累量呈显著或极显著正相关；而 2010—2011 年，仅播种前、越冬期 0～300 cm 土壤蓄水量与花前氮素运转量、籽粒氮素积累量呈显著或极显著正相关（表 8）. 说明土壤水分与花前氮素运转量及籽粒氮素积累量相关，且枯水年关系更密切. 不同降雨年型播种前和各生育期 0～300 cm 土壤蓄水量与花后氮素积累量的相关性存在差异：2009—2010 年表现为负相关，但均不显著；2010—2011 年，表现为正相关，且播种前至开花期达到显著或极显著水平. 可见丰水年土壤水分与花后氮素积累关系较密切，即土壤水分保持一定水平可提高花后氮素积累，从而有利于籽粒的氮素积累.

表 6　夏闲期耕作对小麦花前氮素运转和花后氮素积累的影响

Table 6　Effects of tillage in summer fallow period on N mobilization before anthesis and N accumulated amount after anthesis of wheat

处理时间 Treatment time (d)	耕作 Tillage	花前运转量 NABA ($kg \cdot hm^{-2}$)	花前运转量对籽粒的贡献率 Contribution of NABA to N in grains (%)	花后积累量 NAAA ($kg \cdot hm^{-2}$)	花后积累量对籽粒的贡献率 Contribution of NAAA to N in grains (%)
15	DT	76.76c	74.1a	26.83bc	25.9a
	SS	76.07c	74.9a	25.44c	25.1a
	CK	65.96d	75.5a	21.46d	24.6a
45	DT	92.12a	75.1a	30.58a	24.9a
	SS	85.93b	75.5a	27.94b	24.5a
	CK	65.04d	73.7a	23.20d	26.3a

NABA: Translation amount of N before anthesis from vegetative organs to grains after anthesis; NAAA: N accumulation amount after anthesis. 下同 The same below.

表 7　不同降雨年型夏闲期耕作对小麦氮素利用效率的影响

Table 7　Effects of tillage in summer fallow period on nitrogen use efficiency of wheat at different rainfall years

处理时间 Treatment Time (d)	耕作 Tillage	氮素吸收效率 N uptake efficiency ($kg \cdot kg^{-1}$)		氮素收获指数 N harvest index		氮素利用效率 N use efficiency ($kg \cdot kg^{-1}$)		氮素生产效率 N productive efficiency ($kg \cdot kg^{-1}$)	
		2009—2010	2010—2011	2009—2010	2010—2011	2009—2010	2010—2011	2009—2010	2010—2011
15	DT	0.73a	0.87b	0.71b	0.80c	20.35d	36.34a	14.94b	31.44ab
	SS	0.63b	0.83c	0.69b	0.82b	22.03c	36.05a	13.91c	29.75c
	CK	0.56c	0.76e	0.69b	0.77d	22.54c	32.33c	12.69d	24.59d
45	DT	0.77a	0.94a	0.69b	0.87a	21.73c	34.02b	16.80a	31.96a
	SS	0.62b	0.88b	0.80a	0.87a	24.94a	34.91ab	15.52b	30.59bc
	CK	0.56c	0.80d	0.78a	0.73e	23.74b	30.70d	13.37c	24.70d

表 8 小麦播种前和各生育期 0~300 cm 土壤蓄水量与氮素吸收、运转的相关性

Table 8 Correlation between soil water storage at depth of 0-300 cm and N absorption and mobilization of wheat at before sowing and different growth stages

时期 Stage	花前氮素运转量 NABA		花后氮素积累量 NAAA		籽粒氮素积累量 NAG	
	2009—2010	2010—2011	2009—2010	2010—2011	2009—2010	2010—2011
BSS	0.9014**	0.9037**	-0.1739	0.9702**	0.9362**	0.9248**
WS	0.9169**	0.8359*	-0.1649	0.9240**	0.9541**	0.8617*
ES	0.8639*	0.7090	-0.0756	0.7955*	0.9111**	0.7337
BS	0.8871**	0.6546	-0.1062	0.7547*	0.9313**	0.6822
AS	0.8764**	0.7174	-0.1096	0.8052*	0.9193**	0.7425
MS	0.9128**	0.6253	-0.1433	0.7025	0.9531**	0.6473

NAG: Nitrogen accumulation in grain.

3 讨 论

水分是旱地小麦产量、品质提升的重要限制因子,如何“蓄住天上水、保住地上墒”一直以来受到旱地小麦生产工作者的重视. 目前,前人在耕作蓄水方面已取得了较大进展. 毛红玲等[14]研究表明,夏闲期深松可增加 0~300 cm 土层平均土壤含水率. 侯贤清等[15]研究认为,夏闲期深松和翻耕均能有效蓄雨保墒,翻耕可提高旱地小麦播前 0~200 cm 土壤贮水量,深松可提高播前及整个生长阶段 0~200 cm 土壤贮水量. 本课题组从 2009 年起在山西农业大学闻喜试验基地进行旱地小麦蓄水保墒技术的研究,结果表明,夏闲期深翻或深松可提高旱地小麦播前 0~300 cm(尤其是 80~160 cm 土层)土壤蓄水量,实现伏雨春夏用的目标[16-18]. 这与前人研究结果一致. 但前人的研究仅围绕耕作的蓄水保墒效果,并未深入研究耕作的具体时间及不同降雨年型的蓄水保墒效果. 本文选择 7 月 1 日或 8 月 1 日进行深翻或深松,研究其蓄水效果. 两次处理相隔一个月,降雨量的差异是导致处理间差异的主要原因:2009—2010 年降雨量相差 50 mm,2010—2011 年相差 132.30 mm. 结果表明,8 月 1 日耕作,即雨后耕作更有利于蓄水保墒. 此外,本文两试验年度降雨量差异较大,夏闲期耕作对“枯”水年播前土壤蓄水量有较大的调控效应. 夏闲期耕作对各生育期土壤蓄水量的提高幅度呈先升高后降低的趋势,且蓄水效应在“枯”水年可延续至成熟期,丰水年延续至孕穗期,以深翻的蓄水效果较好. 因此,夏闲期耕作可为干旱年份旱地小麦稳产提供保障. 王红光等[19]研究认为,耕作有利于提高冬小麦整个生育时期 0~200 cm 土层土壤贮水量. 这与本研究中耕作对各生育期的蓄水效果一致. 总之,夏闲期雨后耕作有利于蓄积夏闲期降雨,蓄水保水效果可延续至孕穗期.

秦红灵等[20]研究表明,深松能提高土壤氮的矿化率,增加土壤矿质氮含量,同时深松打破了犁底层,促进了作物根系生长,从而有利于土壤氮素的吸收和利用. 郑成岩等[21]在济南小孟镇的研究认为,深松+条旋耕和深松+旋耕较单独条旋耕和旋耕可促进拔节后氮素的吸收,增加氮素积累量. 本研究认为,植株对氮素的吸收运转与土壤水分状况密切相关,8 月 1 日(雨后)耕作改善了生育中后期土壤水分状况,有利于开花期叶片和茎秆+茎鞘中氮素的吸收,并减少了成熟期茎秆+茎鞘中氮素的残留,促进氮素向籽粒中运转,从而提高了籽粒氮素积累量.

改善土壤水分状况不仅可促进植株氮素的吸收,而且影响了氮素自营养器官向籽粒的转移,增加总氮素产量[22-23]. 有研究认为,深松+条旋耕和深松+旋耕较单独条旋耕和旋耕提高了 0~200 cm 土层土壤贮水量,增加了开花期营养器官中贮存的氮素向籽粒中的转移量和转移率[21,24]. 还有研究表明,对籽粒氮素积累量而言,花前氮素运转量对籽粒的贡献率起主导作用[25]. 本研究认为,夏闲期耕作主要通过花前茎秆+茎鞘中氮素对籽粒的贡献,实现籽粒氮素积累量的提高,这与前人研究结果基本一致. 总之,夏闲期雨后耕作有利于植株氮素吸收,并促进花前茎秆+茎鞘中氮素向籽粒运转.

土壤水分状况影响氮素的吸收和运转,而氮效率反映了植物矿质养分吸收和运转能力. 氮素吸收效率反映了植株对氮肥吸收能力的高低,氮素收获指数反映氮素从源到籽粒库的分配比例,氮素利用效率反映植株氮素经济系数的高低,氮肥生产效率反映氮肥的生产能力. 前人关于氮效率的研究主要集中在灌溉条件下,而对旱地小麦来说,氮效率的研究也同样重要. 本研究认为,夏闲期耕作可提高氮素吸收效率和氮素生产效率,而对氮素收获指数和氮素利用效率的影响不同降雨年型间存在差异. “枯”水年,夏闲期深翻降低了氮素利用效率;丰水年,夏闲期耕作显著提高了氮素收获指数和氮素利用效率.

相关分析可知,土壤水分与花前氮素运转量和籽粒氮素积累量显著相关,播种至开花期土壤水分与花后氮素积累量在丰水年显著相关,而在“枯”水年无显著相关关系. 说明水分不足主要促进花前氮素向籽粒运转,水分充足同时可促进花后氮素积累,更有利于籽粒中氮素的积累. 总之,夏闲期耕作尤其是雨后耕作有利于提高氮素吸收效率和氮素生产效率.

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