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秸秆还田和施肥对砂姜黑土理化性质及小麦-玉米产量的影响

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摘要:通过安徽省蒙城县砂姜黑土上连续 4a 的冬小麦-夏玉米连作长期定位试验,研究了秸秆还田配合施用不同量氮肥对土壤理化性质及作物产量的影响。结果表明,秸秆还田可降低土壤容重 2.5%—9.2%,提高含水量 8. 2%—28. 5%和表层土壤贮水量 4.1%—19.9%;增加土壤总孔隙度 1.1%—8.9%、毛管孔隙度 18.9%—41.0%,非毛管孔隙度降低 6.4%—38.8%,土壤毛管孔隙度占土壤总孔隙度的比例增加。秸秆还田所有处理耕层的土壤硝态氮含量高于秸秆移除处理,施氮 540、630、720 kg N hm^{-2} a^{-1} 时,秸秆还田处理的硝态氮含量显著高于秸秆移除,而铵态氮含量无明显变化规律。无论秸秆还田还是秸秆移除,耕层土壤的硝态氮含量随氮肥用量的增加呈指数趋势增加,硝态氮含量与施氮量的相关性秸秆移除处理高于秸秆还田处理;秸秆还田处理的铵态氮含量随施氮量增加成指数趋势增加,而秸秆移除处理呈指数趋势减小,相关性均不显著。秸秆还田条件下,小麦和玉米获得高产的年氮肥用量分别为 630、696 kg N hm^{-2} a^{-1},秸秆移除为 579、627 kg N hm^{-2} a^{-1}。经作用力分析,秸秆还田是影响土壤物理性质的最重要因素,作物产量受秸秆还田和施氮量的影响,但氮肥水平大于秸秆还田。

关键词: 秸秆还田;砂姜黑土;氮肥水平;理化性质;作物产量

Effects of combined straw and N application on the physicochemical properties of lime concretion black soil and crop yields

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Abstract: The effects of a combination of returned straw and different N fertilizer application rates on the physical and chemical properties of lime concretion black soil and crop yields were systematically studied, based on data from a four year experiment using a winter wheat-summer maize rotation system in Mengcheng City, Anhui Province, China. The results showed that the bulk density of surface soil under areas where straw was either incorporated or removed were 1.14—1.20 g/cm^3 and 1.24—1.31 g/cm^3, respectively. Straw incorporation decreased soil density by 2.5%—9.2%, while soil water content and water storage increased over the four years by 8.2%—28.5% and 4.1%—19.9%, respectively, after the return of the straw. The total soil porosity and capillary soil porosity in the areas of returned straw treatments ranged from 3.0%—57.1% and 33.9%—41.0%, respectively, whilst the same parameters ranged from 50.7%—54.6% and 27.3%—29.5%, respectively, under the areas where straw was removed. In contrast, non-capillary porosity decreased by 6.4%—38.8%, showing a significant difference between areas where straw was incorporated or removed. The nitrate nitrogen content of top

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soil under the returned straw treatment areas was significantly increased by 9.80%—86.71% greater than that of the areas where straw was removed, especially with N application rates of 540, 630, and 720 kg N hm^{-2} a^{-1}. Nitrogen accumulation in surface soil for N application rates of 360, 450, 540, 630 and 720 kg N hm^{-2} a^{-1} were 1.42, 1.53, 2.22, 2.51 and 2.12 times that of areas where no fertilizer was added, respectively, for the returned straw areas and 1.24, 1.38, 1.53, 1.59, 1.72 times the no added fertilizer accumulation for the area where straw was removed. For both straw incorporated areas or not, there were exponential relationships between the nitrate nitrogen content and N application amount, although the correlation coefficient was higher under the straw incorporation treatments than for those where straw was removed. Compared to nitrate, the ammonia nitrogen content showed no obvious differences between areas of straw incorporation and removal. Ammonia accumulation under different N application rates was affected by straw addition. Under straw return treatments, it increased exponentially with the increase of N application rates, and decreased exponentially under areas where straw was removed, but there was no significant correlation. The effects of straw incorporation and N application rates on maize and wheat yields were different. For maize, the yield gradually increased from 360 kg N hm^{-2} a^{-1} to 720 kg N hm^{-2} a^{-1} of N application levels under both straw added areas and straw removed areas. However, the wheat yield gradually increased from 360 kg N hm^{-2} a^{-1} to 450 kg N hm^{-2} a^{-1} and from 360 kg N hm^{-2} a^{-1} to 630 kg N hm^{-2} a^{-1}, and decreased when N exceeded 450 kg N hm^{-2} a^{-1} and 630 kg N hm^{-2} a^{-1} under areas of straw removal and straw incorporation. The high yields of maize and winter-wheat with straw incorporation treatments would be obtained under the N application rates of 696, 630 kg N hm^{-2} a^{-1}, respectively. N application rates of 579, 627 kg N hm^{-2} a^{-1} in straw removal areas would obtain high yields, but they were lower than that from areas of returned straw treatments. The force analysis showed that returning straw was the most important influencing factor of soil physical properties, and both straw incorporation and N application rates can compact crop yields, but the force of N level to yield is stronger than that for returning straw.

Key Words: returning straw; lime concretion black soil; N application rate; physicochemical properties; crop yield

植物残体能有效增加土壤有机质含量、改良土壤、培肥地力,特别对缓解我国氮、磷、钾肥比例失调的矛盾,弥补磷钾肥不足等具有十分重要的意义。目前,秸秆覆盖在发达国家已相当完善,得到了较大普及,并且取得了较好的效果[1-5]。虽然国内关于秸秆还田的研究起步较晚,但涉及作物产量[6-7]、土壤理化性状[8]、微生物群落[9-10]等方面的研究文献报道目前也比较多。国内外已有的研究表明,秸秆覆盖可以显著改善土壤物理性状[11],缓和土壤温度的季、日变化[12-13],减少土壤水分蒸发[14],提高土壤含水率[15-17]以及不同程度的增加土壤有机质、全磷和全氮的含量[18-21]。

安徽省黄淮海南部砂姜黑土区是全省主要的粮食产区,但该区土壤质地粘重、结构性差,加之有机质含量低,养分贫乏,严重影响作物的正常生长,导致土壤生产率较低。该区农业生产长期以来偏向于施用化学氮肥,盲目施肥不仅导致肥料的浪费,长此以往也将限制作物产量和品质的提高,而且更严重的是土壤结构以及土壤肥力持续性受到破坏,土壤质量下降[22-24]。近年来,该区也推广应用秸秆还田技术,但关于秸秆还田条件下土壤理化性质与作物产量的理论性探讨,尚未见试验性研究报道。因此,本文基于连续4a的小麦-玉米秸秆还田长期定位试验,探讨了长期秸秆还田同时配施不同量的化学氮肥对砂姜黑土理化性质及作物产量的影响,旨在为该区科学的进行秸秆还田和施肥提供理论依据和技术支持。

1　材料与方法

1.1　试验区概况

试验于2008—2012年度在安徽省蒙城县农业示范场进行,试验地土质为砂姜黑土,0—20 cm土层养分含量为:土壤有机质14.24 g/kg, 全氮含量0.99 g/kg, 碱解氮57.84 mg/kg,全磷含量0.67 g/kg,有效磷21.57 mg/kg,速效钾197.46 mg/kg。供试小麦品种为济麦22,玉米品种为郑单958。

1.2　田间试验设计

试验采用裂区设计,设秸秆还田和施氮量两因

素。其中秸秆处理为主区,设小麦-玉米秸秆全量粉碎还田(S)和移除(R)两种方式,秸秆全量还田年还田量为 21000 kg/hm^2,其中小麦 9000 kg/hm^2,玉米 12000 kg/hm^2;氮肥施用为副区,设置 6 个处理,施氮量为 0、360、450、540、630、720 kg N hm^{-2} a^{-1},分别用 N0、N1、N2、N3、N4、N5 表示;磷、钾肥施用量分别为 180 kg P_2O_5 hm^{-2} a^{-1}、180 kg K_2O hm^{-2} a^{-1},除 N0(对照)之外,其余氮肥处理均施用磷钾肥,且施用量一致。各处理氮、磷、钾肥小麦季施用量占年施用总量的 45%,玉米季 55%。小麦季氮肥基追比为 55∶45,追肥时期为拔节期,磷钾肥在小麦播种时一次性基施;玉米季氮肥基追比为 45∶55,追肥时期为大喇叭口期,磷钾肥在玉米播种时一次性基施。小麦 10 月中旬播种,玉米 6 月中旬播种。小区面积 21.6 m^2,随机排列,3 次重复。

1.3 样品采集

土样采集:土壤样品于 2012 年 10 月采集,取 0—20 cm 的土样,每个样品均为多点采集混合而成,然后用四分法取出足够的样品,保存于 4℃冰箱中,4 d 之内测完。

1.4 指标测定

无机氮 土样采集后测定土壤水分以及硝态氮和铵态氮含量。分析硝态氮和铵态氮时先将土壤解冻,称取 10 g 鲜土于震荡瓶(150 mL)中,加入 2 mol/L KCl 溶液 50 mL,震荡 1 h 后过滤,浸提液硝态氮采用双波长(220 nm,275 nm)法测定,铵态氮采用靛酚蓝比色法(625 nm)测定,同时测定土壤含水量以矫正水分系数[25]。

土壤容重 采集 0—20 cm 原状土壤样品,环刀法测定。

土壤孔隙度 通过土壤容重和密度计算得到,公式如下:

$$Pt = (1 - Bd / Ds) \times 100$$

式中,Pt 表示土壤总孔隙度,%;Bd 表示土壤容重,g/cm^3;Ds 表示土壤密度,通常采用的密度值为 2.65 g/cm^3。

土壤毛管孔隙度用下式计算:

$$Pc = Wc \times Bd / V \times 100$$

式中,Pc 表示土壤毛管孔隙度,%;Wc 表示土壤毛管含水量,%;V 表示土壤体积,为 100 cm^3。

作物产量 小麦和玉米成熟后实收每小区产量。

1.5 数据分析

试验数据采用 SPSS 16.0 和 Excel 2003 软件进行处理和作图。分析试验中秸秆还田、氮肥水平及秸秆还田×氮肥水平交互效应对试验结果的作用力,用变异度表示。分析过程中按照导致试验结果产生差异的来源,将作用力分为区组、秸秆还田、氮肥水平、秸秆还田×氮肥水平、误差共 5 种。

2 结果与分析

2.1 对土壤容重和含水量的影响

土壤容重可以概括地反映土壤质地、结构状况以及腐殖质含量的高低,是土壤重要的物理特性之一,而土壤含水量则决定了土壤的宜耕性,并与作物的正常生长发育紧密相关。砂姜黑土土壤物理性状差、土壤粘重、容重大、通气透水性能差,进行秸秆还田处理 4a 后,于 2012 年玉米收获期对 0—20 cm 土层的土壤容重和含水量进行了测定,其不同处理间存在显著差异(表 1)。秸秆移除(R)各处理在 1.24—1.31 g/cm^{3}之间,而秸秆还田(S)各处理在 1.14—1.20 g/cm^{3}范围内,秸秆还田处理均较秸秆移除处理土壤容重降低,下降幅度为 2.5%—9.2%。所有秸秆还田和秸秆移除处理施用氮肥后土壤容重均较不施氮肥降低,但过量增施氮肥后土壤容重又有所增加,其中高量氮肥处理(N5)秸秆移除较秸秆还田容重增加幅度可达到 9.2%。秸秆还田提高了土壤含水量,秸秆还田较秸秆移除处理土壤含水量提高了 8.2%—28.5%,表层土壤贮水量提高了 4.1%—19.9%。

2.2 对耕层土壤孔隙度的影响

如表 2 所示,土壤总孔隙度、土壤毛管孔隙度及毛管孔隙度/总孔隙度各处理变化趋势一致,所有秸秆还田处理高于秸秆移除处理。土壤总孔隙度各处理在 50.7%—57.1% 之间,秸秆还田较秸秆移除处理增加 1.1%—8.9%;其中秸秆移除(R)的土壤总孔隙度变化范围在 50.7%—54.6%之间,秸秆还田为 53.0%—57.1%,秸秆还田显著高于秸秆移除。土壤毛管孔隙度秸秆移除各处理在 27.3%—29.5%范围变化,而秸秆还田在 33.9%—41.0%之间,秸秆还田较秸秆移除增加 18.9%—41.0%,二者之间差异达显著水平。土壤非毛管孔隙度与土壤总孔隙度、土壤

毛管孔隙度的变化趋势相反,秸秆还田比秸秆移除处理降低 6.4%—38.8%,二者之间差异显著;土壤毛管孔隙度占总孔隙度比例秸秆还田显著高于秸秆移除处理,变化幅度分别为秸秆还田 61.7%—75.4%、秸秆移除 50.1%—56.9%。

表 1 秸秆还田对耕层土壤容重和含水量的影响

Table 1 Effects of straw incorporating on soil buck density and soil water content

处理 Treatments	容重 Soil buck density /(g/cm^3)	比秸秆移除降低 Decrease/%	含水量 Soil water content /(g/cm^3)	比秸秆移除降低 Decrease/%	土壤贮水量 Soil water storage /(g/cm^3)	比秸秆移除降低 Decrease/%
R+N0	1.29 bc	—	19.0 ab	—	48.9 ab	—
S+N0	1.20 bc	7.0	24.5 g	28.5	58.7 c	19.9
R+N1	1.24 bc	—	19.5 abcd	—	48.2 ab	—
S+N1	1.19 abc	4.0	21.4 cdef	9.9	50.5 ab	4.9
R+N2	1.27 bc	—	19.7 abcd	—	50.1 ab	—
S+N2	1.19 bc	6.3	21.3 bcdef	8.2	54.0 bc	7.8
R+N3	1.20 bc	—	19.1 abc	—	45.9 a	—
S+N3	1.17 ab	2.5	22.7 efg	19.1	53.2 bc	16.1
R+N4	1.21 bc	—	20.4 abcde	—	49.2 ab	—
S+N4	1.14 a	5.8	23.2 fg	13.5	52.6 abc	6.9
R+N5	1.31 c	—	18.9 a	—	49.5 ab	—
S+N5	1.19 bc	9.2	21.7 def	14.9	51.5 ab	4.1

表中数据为 3 次重复平均值;同一列数据后不同字母表示不同处理间差异显著(P< 0.05)(LSR 法检验);S 表示秸秆还田,R 表示秸秆移除;N0、N1、N2、N3、N4、N5 表示施氮量分别为 0、360、450、540、630、720 kg N hm^{-2} a^{-1};Each value in the table is mean of 3 replicates. Values followed by a different letter within a column are significantly different at P < 0.05 according to LSR test. In the 1st column, S denotes straw mulching, R indicates straw removed. N0, N1, N2, N3, N4, N5 indicate N application rates of 0、360、450、540、630、720 kg N hm^{-2} a^{-1}, respectively. The below is same

表 2 秸秆还田对耕层土壤孔隙度的影响

Table 2 Effects of straw incorporation on soil porosity in tilth layer of soil

处理 Treatments	土壤总孔隙度 Total soil porosity	比秸秆移除提高 Increase/%	土壤毛管孔隙度 Soil capillary porosity	比秸秆移除提高 Increase/%	土壤非毛管孔隙度 Soil aeration porosity	比秸秆移除提高 Increase/%	毛管孔隙度/总孔隙度 Soil capillary porosity/ Total soil porosity	比秸秆移除提高 Increase/%
R+N0	51.5 ab	—	29.1 a	—	22.4 bcd	—	56.6 abc	—
S+N0	54.7 abc	1.1	41.0 c	41.0	13.7 a	38.8	75.4 e	33.2
R+N1	53.3 abc	—	28.5 a	—	24.8 cd	—	53.6 abc	—
S+N1	55.3 abc	3.7	33.9 b	18.9	21.4 abcd	13.7	61.7 bcd	15.1
R+N2	53.0 ab	—	27.6 a	—	24.4 cd	—	53.1 ab	—
S+N2	54.3 ab	2.5	36.3 b	31.5	15.9 ab	34.8	69.6 de	31.1
R+N3	54.6 abc	—	27.3 a	—	27.3 d	—	50.0 a	—
S+N3	55.8 bc	2.2	36.3 b	33.0	19.5 abc	28.6	65.1 cde	30.2
R+N4	54.4 abc	—	29.5 a	—	25.0 cd	—	54.1 abc	—
S+N4	57.1 c	5.0	36.5 b	23.7	21.7 bcd	13.2	62.1 bcd	16.3
R+N5	50.7 a	—	28.7 a	—	22.0 bcd	—	56.9 abc	—
S+N5	55.2 abc	8.9	34.6 b	20.6	20.6 abcd	6.4	63.2 bcd	11.6

2.3 对土壤耕层速效氮的影响

秸秆还田和氮肥施用对土壤中硝态氮、铵态氮含量的影响如图 1 所示。土壤耕层硝态氮、铵态氮含量的变化范围分别为秸秆还田(S)处理 26.90—67.54、15.43—26.87 kg/hm^2,秸秆移除(R)处理 24.49—42.33、15.44—20.87 kg/hm^2;S 和 R 处理土

壤中硝态氮、铵态氮含量随氮肥用量呈增加—下降的趋势,各处理土壤硝态氮含量高于铵态氮,施用氮肥比不施氮肥处理显著增加了土壤中的硝态氮含量,S+N4 处理的硝态氮和铵态氮含量最高,而 R+N5 处理其硝态氮含量最高。方差分析表明(表 3),氮肥用量相同时,土壤硝态氮含量 S 处理均显著高于 R 处理,提高幅度达 9.80%—86.71%,其中 N4 水平的提高幅度最大,比 R 处理增加 31.37 kg/hm^{2}的硝态氮含量,即使不施肥,S 比 R 的土壤硝态氮也要高出 2.40 kg/hm^2。与土壤硝态氮含量比较,铵态氮含量表现规律各处理不一致。图 2 显示,夏玉米收获后表层土壤的硝态氮含量随着氮肥用量的增加呈指数趋势增加,硝态氮含量与施氮量的相关性 R 处理高于 S 处理;氮肥施用分别为 N1、N2、N3、N4 和 N5 处理时,秸秆还田条件下耕层土壤硝态氮累积量分别为 N0 处理的 1.42、1.53、2.22、2.51 和 2.12 倍,秸秆移除条件下分别为 1.24、1.38、1.53、1.59 和 1.72,显然,随着施氮量的增加硝态氮的累积越明显。铵态氮含量在秸秆还田时随施氮量增加呈指数趋势增加,而秸秆移除条件下呈指数趋势减小,相关系数分别为 0.0487、0.3173。

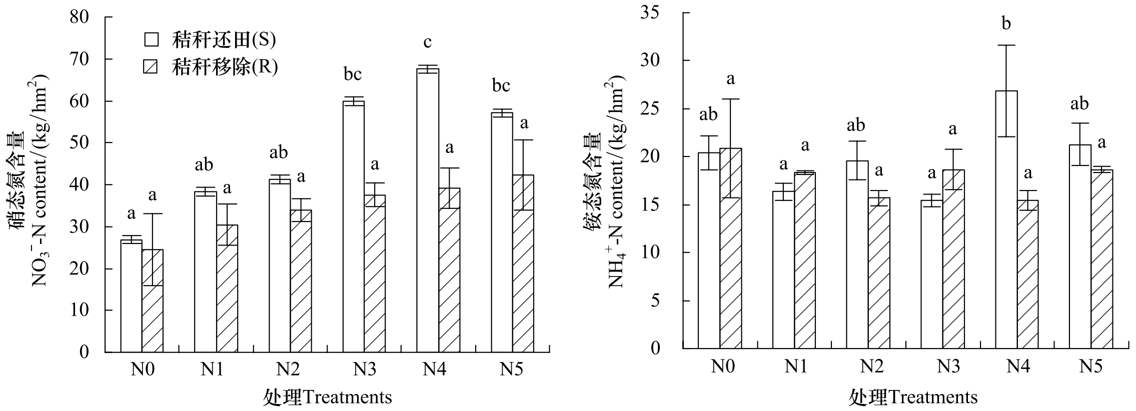

图 1 秸秆还田配施不同量氮肥条件下耕层土壤无机氮变化

Fig.1 Change in soil inorganic nitrogen in soil tilth layer under the combination of straw mulching and nitrogen fertilizer application

图中字母表示秸秆相同还田条件下氮肥水平处理之间的差异显著性,不同字母表示差异达显著水平(P<0.05)

表 3 秸秆还田条件下耕层土壤无机氮方差分析

Table 3 Variance analysis of soil inorganic nitrogen in soil tilth layer under the straw incorporation

处理 Treatments	硝态氮 Nitrate nitrogen/(kg/hm^2)						铵态氮 Ammonium nitrogen/ (kg/hm^2)					
	N0	N1	N2	N3	N4	N5	N0	N1	N2	N3	N4	N5
S	26.90 a	38.27 a	41.28 a	59.92 a	67.55 a	57.10 a	20.40 a	16.34 a	19.60 a	15.43 a	26.87 a	21.28 a
R	24.49 b	30.38 b	33.87 b	37.52 b	39.17 b	42.33 b	20.87 a	18.33 b	15.68 b	18.67 b	15.44 b	18.65 b

2.4 长期秸秆还田对小麦、玉米产量的影响

由图 3 可以看出,对单施氮肥的处理来说,在一定范围内,施用氮肥可以增加玉米籽粒产量, 施氮量从 360 kg N hm^{-2} a^{-1}上升到 720 kg N hm^{-2} a^{-1},玉米籽粒产量逐渐增加,增加率为 0.2%—2.9% 。但对于小麦产量,施氮量从 360 kg N hm^{-2} a^{-1}增加到 450 kg N hm^{-2} a^{-1}时,产量随施氮量增加呈递增趋势,增加幅度为 1.5%—6.7%;但施氮量从 540 kg N hm^{-2} a^{-1}上升到 720 kg N hm^{-2} a^{-1}时,产量不再增加反而下降了 2.4%。说明过量施用氮肥并不能有效提高小麦产量,但能提高玉米产量。对秸秆还田加施氮处理来说,玉米产量随施氮量的增加呈递增趋势;对于小麦产量,施氮量从 360 kg N hm^{-2} a^{-1}上升到 630 kg N hm^{-2} a^{-1},产量逐渐增加,增加率为 1.3%—6.2%,随着施氮量的增大增加率降低,但施氮量从 630 kg N hm^{-2} a^{-1}达到 720 kg N hm^{-2} a^{-1}时,产量不再增加反而下降了 0.4%。说明秸秆还田条件下过量施用氮肥并不能有效提高小麦产量,而显著提高了玉米产量。小麦和玉米的年产量变化趋势与玉米一致,随施氮量增加呈递增趋势变化。

相同施氮量条件下,秸秆还田与秸秆移除的产量比较,各氮肥处理玉米季 4a 平均产量秸秆还田高

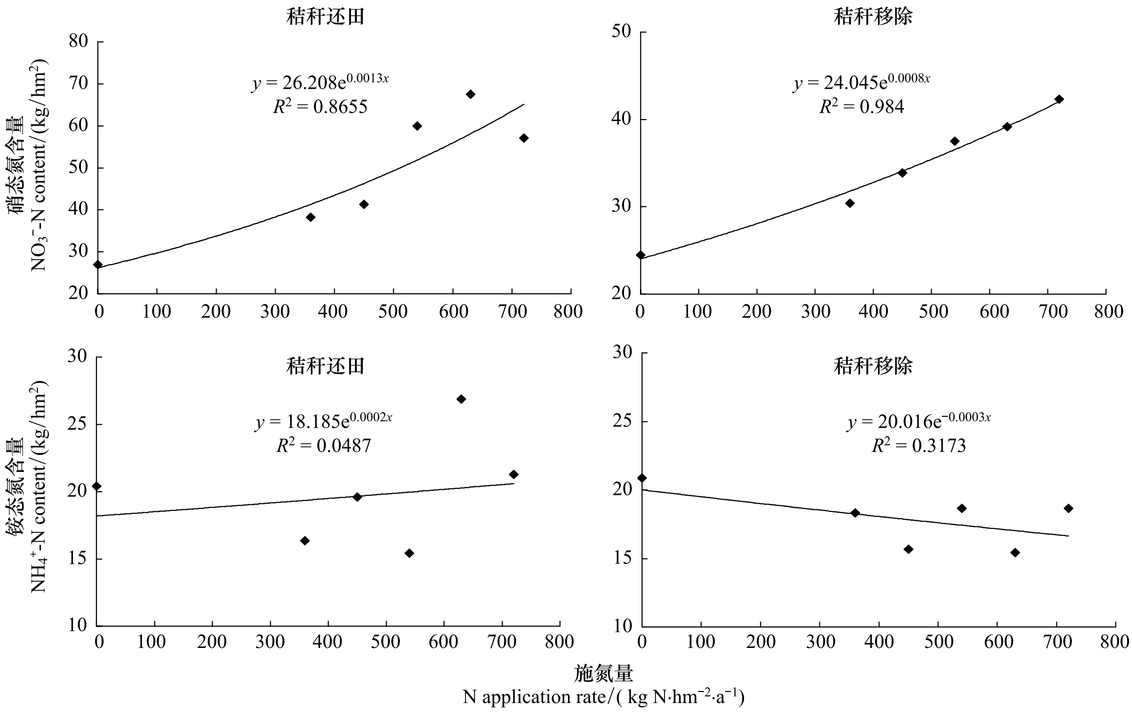

图 2　2012 年玉米收获后耕层土壤无机氮与施氮量的关系

Fig.2　Correlation of soil inorganic nitrogen content and nitrogen application rates after maize harvesting in 2012

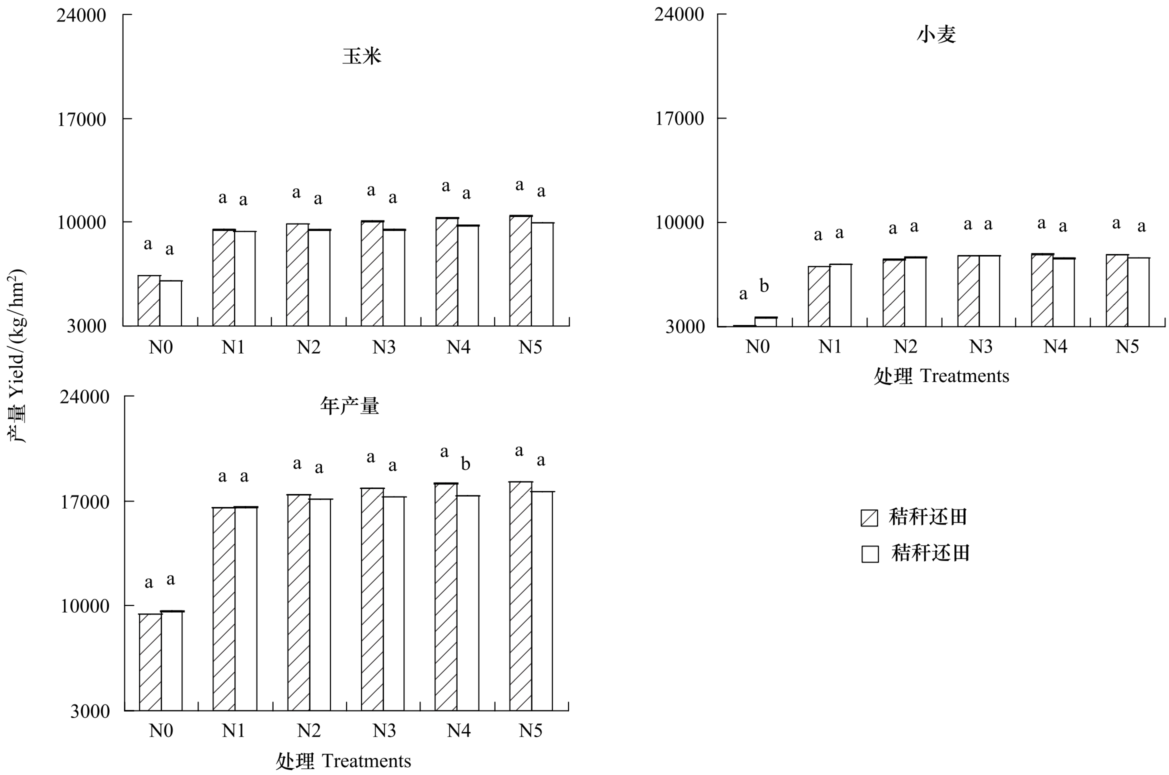

图 3　4 年连续秸秆还田条件下不同施氮量小麦和玉米的平均产量

Fig.3　Yields of crops under the straw incorporation continuously for four years

于秸秆移除 109.5—562.5 kg/hm^2,N3 处理的增幅最高;小麦季在施氮量降低时,秸秆还田有降低产量的趋势,但施氮量增加至 630 kg N hm^{-2} a^{-1}时,其产量超过秸秆移除处理最高,为 286.5 kg/hm^2。从施氮

量与作物产量的关系看(图 4),无论秸秆还田还是秸秆移除,小麦和玉米产量均与施氮量呈二次曲线关系,但是秸秆还田条件下,产量与施氮量的相关性高于秸秆移除。玉米季,秸秆还田施氮量为 696 kg N hm^{-2} a^{-1}时获得最高产量,达 10360.5 kg/hm^2,而秸秆移除在施氮量为 627 kg N hm^{-2} a^{-1}时达到高产 9861.5 kg/hm^2,相对秸秆移除,秸秆还田条件下获得高产的施氮量增加了 69 kg N hm^{-2} a^{-1};小麦季,秸秆还田氮肥用量为 630 kg N hm^{-2} a^{-1}时产量最高,达 7900.5 kg/hm^2,而秸秆移除在施氮量为 580.5 kg N hm^{-2} a^{-1}时达到高产 7782.0 kg/hm^2,相对秸秆移除,秸秆还田获得高产的施氮量增加了 51 kg N hm^{-2} a^{-1}。可见,秸秆还田条件下要取得高产,必须要多施一定量氮肥。

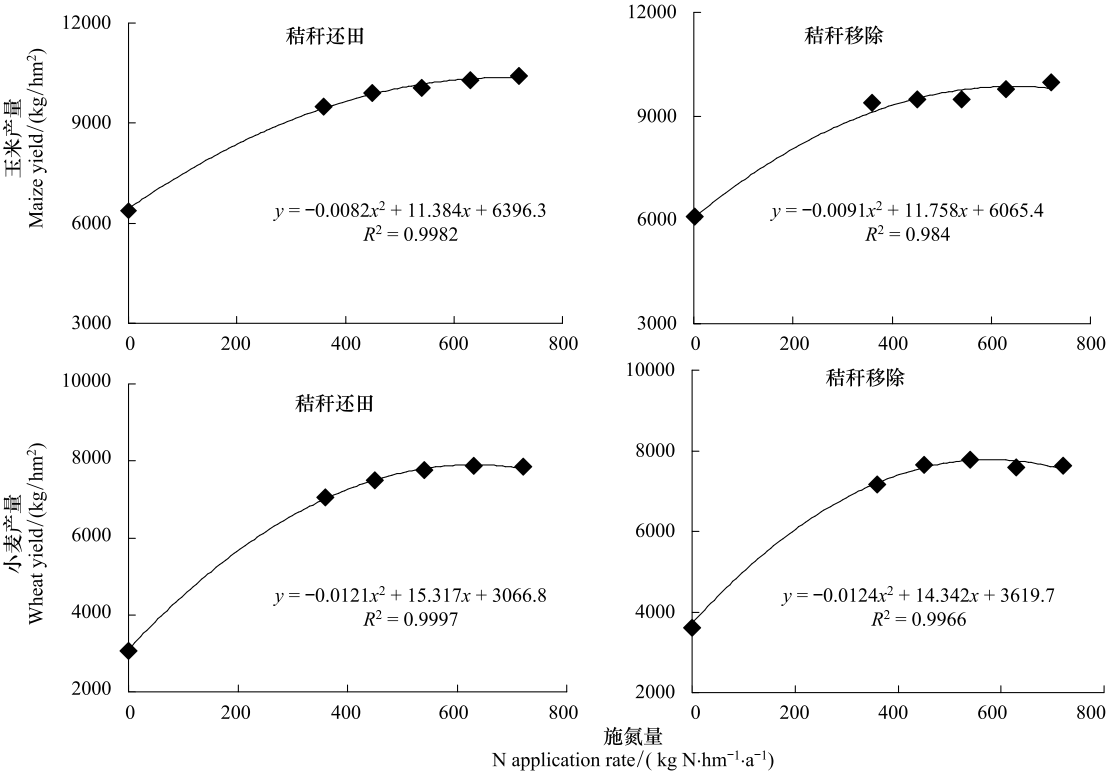

图 4 连续秸秆还田条件下施氮量和作物产量的关系

Fig.4 Correlation of nitrogen application rates and crop yields under the straw incorporation

2.5 单项技术对土壤理化性质的作用力及交互效应分析

由分析可知,在各因素独立效应中,秸秆还田措施对土壤容重、土壤毛管持水量、土壤总孔隙度和作物产量的影响达显著水平,对土壤含水量、土壤贮水量、土壤毛管孔隙度、土壤非毛管孔隙度、土壤毛管孔隙度/土壤总孔隙度、土壤耕层硝态氮含量的影响均达到极显著,而对铵态氮含量没有显著影响。氮肥水平仅对土壤耕层硝态氮含量和作物产量有极显著影响,各测定指标均不受秸秆还田×氮肥水平的交互效应(表 4)。

3 结论与讨论

土壤容重、孔隙度反映了土壤的紧实状况,关系到土壤水、气、热状况和养分的调节,以及作物根系的伸展和生长发育。国内外研究认为,连续秸秆还田结合土壤浅耕,能够降低耕层土壤容重[26];在施氮、磷化肥的基础上秸秆还田可降低土壤容重 1.2%—7.1%,提高土壤含水量 4.7%—13.5%[19]。北方干旱地区 18 年的长期秸秆还田田间定位试验表明,长期秸秆覆盖玉米生育期耗水量减少,土壤贮水量增加,水分利用效率明显增加[27]。本研究结果表明,秸秆还田能降低土壤容重和非毛管孔隙度,提高耕层贮水量,增加土壤总孔隙度和毛管孔隙度。可见,逐年连续全量秸秆还田,能起到疏松土壤、降低土壤容重、增强土壤蓄水能力、增加孔隙度的作用;与之相反,氮肥施用对土壤物理性状没有显著的改善作用。这与秸秆还田使秸秆纤维腐解残体与土

表 4　单项技术措施对土壤物理性质和作物产量的作用力及交互效应分析

Table 4　Force analysis of single and interactive measure on soil physical properties and crop yields

差异源 Source of variance	变异度 The level of variation%										
	土壤含水量	土壤贮水量	土壤容重	土壤毛管持水量	土壤总孔隙度	土壤毛管孔隙度	土壤非毛管孔隙度	毛管孔隙度/总孔隙度	耕层硝态氮	耕层铵态氮	年产量
区组	2.91	5.93	3.96	2.98	4.97	7.78	8.64	1.77	1.61	2.44	4.38
秸秆还田(S)	72.74**	68.35**	61.25*	72.38*	85.22*	79.43**	82.50**	65.43**	45.82**	28.98	22.54*
氮肥水平(N)	0.63	0.88	10.78	0.13	0.57	1.46	3.80	2.29	25.76**	26.30	53.42**
S×N	13.25	16.49	21.26	17.28	4.09	8.86	2.22	21.63	13.37	35.26	1.091
误差	10.48	8.35	2.75	7.23	5.15	2.46	2.84	8.88	13.44	7.02	8.75

* 表示显著水平, ** 表示极显著水平;土壤含水量 Soil water content;土壤贮水量 Soil water storage;土壤容重 Soil bulk density;土壤毛管持水量 Soil capillary water capacity;土壤总孔隙度 Total soil porosity;土壤毛管孔隙度 Soil capillary porosity;土壤非毛管孔隙度 Soil non-capillay porosity;毛管孔隙度/总孔隙度 Soil capillary porosity/ total soil porosity;耕层硝态氮 Soil nitrate nitrogen;耕层铵态氮 Soil ammonium nitrogen;年产量 Annual yield

壤团粒结合改善了土壤结构,增加土壤入渗、减少土面蒸发有关。降雨过程中,土壤表层的秸秆覆盖物对雨滴起到缓冲和吸附水分的作用,使土壤免受雨水的直接冲击,利于水分入渗土壤;另外,有利于雨水快速下渗,也增强了土壤的保水性能。秸秆覆盖使土面蒸发受到明显的抑制,并且表层水分含量明显高于秸秆移除,土壤贮水量增加。

据慕平等[28]研究,全量秸秆连续还田能增加耕层 0—30 cm 土层有机质、全氮、全磷含量,速效氮、速效钾显著增加。本研究中秸秆还田处理耕层的土壤硝态氮含量高于秸秆移除处理,施氮 540、630、720 kg N hm^{-2} a^{-1}时,硝态氮含量秸秆还田处理显著高于秸秆移除处理,表明长期秸秆还田能提高土壤的速效养分,主要是因为秸秆还田与秸秆移除对土壤有机氮的矿化程度不同,秸秆还田可明显增强土壤有机养分的矿化,秸秆自身腐解也会释放出丰富的碳、氮、磷、钾等速效养分,但是秸秆的分解程度与氮肥的施用量有密切联系[29]。

有文献报道秸秆还田对小麦、玉米有增产作用[30-31],但也有减产的报道[32]。本研究结果表明,秸秆还田配施适量化学氮肥可以提高作物产量。秸秆还田配施纯氮 630 kg N hm^{-2} a^{-1}时冬小麦产量最高,增产幅度最大,比秸秆移除增产 3.8%;配施纯氮 720 kg N hm^{-2} a^{-1}的夏玉米产量最高,增产幅度最大,同样比秸秆移除增产 4.5%。关于秸秆还田增产的原因,研究结果不尽一致。刘义国等[33]认为,秸秆还田提高了小麦叶绿素含量,促进了旗叶的光合作用与蒸腾作用,进而促进了物质的合成和转化;赵鹏等[34]认为,秸秆还田配施适量氮肥可以解决土壤微生物与作物竞争土壤中氮源的问题,提高了冬小麦的氮效率。还有研究者认为,秸秆还田向土壤微生物提供了碳源,可刺激微生物生长和酶的活性,促进土壤的供养能力,提高作物产量[35]。

作用力分析结果证明,秸秆还田是土壤理化性质最重要的变异源,其作用力大于氮肥水平及秸秆还田×氮肥水平的交互效应;对于土壤耕作层硝态氮含量和作物产量,氮肥水平因素的独立效应均大于秸秆还田及秸秆还田×氮肥水平的交互效应,各测定指标均不受秸秆还田×氮肥水平交互效应的影响。

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