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# 耕作方式对农田土壤理化因子和生物学特性的影响*

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**摘 要** 不同耕作方式对土壤水热、养分及生物特性产生的影响不同,实施合理的农田土壤管理措施不仅可以改善土壤理化性状,也可改变农田土壤生态过程.保护性耕作方式不同程度地改善了土壤质量,免耕能有效提高土壤酶活性,免耕和深松耕等能为土壤微生物的生长繁殖提供丰富的可利用资源,免耕、少耕等能减少对土壤动物的扰动,进而影响到土壤动物的数量、多样性及种群结构.本文综述了不同耕作方式下农田土壤理化性质和生物学特性的研究进展,重点分析了不同耕作方式对土壤理化因子、酶活性、微生物多样性和土壤动物的影响,指出了适宜的耕作方式对土壤质量修复的可能性及研究方向.

**关键词** 耕作方式; 土壤理化因子; 生物学特性; 保护性耕作
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**Effects of tillage methods on soil physicochemical properties and biological characteristics in farmland: A review.** LI Yu-jie, WANG Hui, ZHAO Jian-ning, HUANGFU Chao-he, YANG Dian-lin (*Agro-Environmental Protection Institute, Ministry of Agriculture, Tianjin* 300191, *China*). -*Chin. J. Appl. Ecol.*, 2015, **26**(3): 939-948.

**Abstract**: Tillage methods affect soil heat, water, nutrients and soil biology in different ways. Reasonable soil management system can not only improve physical and chemical properties of the soil, but also change the ecological process of farmland soil. Conservation tillage can improve the quality of the soil to different degrees. For example, no-tillage system can effectively improve soil enzyme activity. No tillage and subsoiling tillage can provide abundant resources for soil microbe's growth and reproduction. No tillage, minimum tillage and other conservation tillage methods exert little disturbance to soil animals, and in turn affect the quantity and diversity of the soil animals as well as their population structure. Effects of different tillage methods on soil physical and chemical properties as well as biological characteristics were reviewed in this article, with the soil physical and chemical indices, enzyme activities, soil microbe diversity and soil animals under different tillage patterns analyzed. The possibility of soil quality restoration with appropriate tillage methods and the future research direction were pointed out.

**Key words**: tillage method; soil physicochemical properties; biological characteristics; conservation tillage.

农业可持续发展的前提是拥有健康、高质量的农田土壤,耕作方式影响土壤质量演化及农业可持续利用.合理的耕作方式不仅可以改善土壤特性,还可以提高田间水分利用效率,达到保水增产的目的,并有效促进农田生态系统的良性循环,提高资源利用率[1].目前,我国农田耕作方式主要有传统耕作(翻耕、深松耕)、少耕(浅耕、旋耕)和免耕(留茬、留茬覆盖)等.其中,免耕是目前生产上广泛应用的一种耕作方式[2].土壤耕作作为农业生产过程中的重要技术措施,是改善土壤耕层质量、培肥地力的重要途径,对土壤生态环境有极为重要的影响.土壤的理化性质、生物学性质与土壤质量密切相关[3],不同的耕作方式不仅可以直接影响土壤的物理性质[4],还可以间接影响农田耕层土壤的养分含量[5]和土壤酶活性[6],并改变土壤微生物区系[7].土壤生物学特性作为衡量土壤质量的重要指标,可以表征土壤质量演变趋势.近年来,我国土地频繁翻耕、肥料施用不当、作物残茬清除或焚烧等低水平的农作管理

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导致土壤侵蚀和严重退化,传统耕作方式在不施有机肥或补充不足的条件下,易加剧有机质矿化,不利于土壤肥力的维持[8].保护性耕作是相对于传统翻耕的新型耕作技术,以秸秆覆盖、免耕播种、以松代翻、化学除草为特点,具有蓄水保墒、培肥地力、节本增效、防治农田扬尘、减少水土流失、促进农业可持续发展等作用[9].实施合理的耕作方式既有利于培肥农田土壤、减轻农田水土流失和土壤侵蚀,又能有效提高土地生产力,还能在一定程度上减少大气污染,有利于生态环境的改善.因此,研究不同耕作方式下农田土壤理化因子和生物学特性具有重要意义.目前,关于不同耕作方式对土壤理化性状与生物学特性方面的研究已经开展了大量的工作,并取得一定的进展.本文综述了不同耕作方式下农田土壤理化因子和生物学特性的研究进展,为探索提高土壤生物学质量的技术与机理提供理论依据,为农业生产提供决策分析和技术支持,为农业的可持续利用与发展提供可行的参考依据.

## 1 不同耕作方式对土壤理化因子的影响

### 1.1 土壤水分

不同耕作方式直接影响土壤水分、容重、硬度和孔隙度等性质.常规的传统耕作方式过度扰动土壤,破坏土壤结构,一定程度上加剧了农田土壤的水分胁迫.多年的常规耕作会造成玉米田犁底层上移、土壤耕层变浅(10~15 cm)、土壤结构紧实、物理性状变劣[10].研究发现,免耕秸秆覆盖对土壤物理质量的改善效果最为明显,免耕秸秆覆盖将有助于形成良好的土壤结构,减少土壤侵蚀[11].

长期不合理的耕作导致土壤水分含量下降,不能为作物生长提供良好的水分条件.传统垄播耕作大豆破坏土壤结构,造成土壤水分损失,随地面蒸发不断增强,导致土壤含水率降低较快,不利于降水入渗,致使含水率降低[12].有研究认为,与传统耕作相比,免耕可保持更多的土壤水分,能显著提高水分利用率[13].浅层耕作也可以提高土壤水分及水分利用率[14].从作物生长的整个生育期来看,免耕地较翻耕地具有更好的贮水能力,免耕或少耕可提高土壤含水量[15].免耕条件下土壤孔隙连通性较好,其储水和抗水蚀能力高于常规耕作,利于蓄水和保水.免耕剖面土壤储水量高于传统耕作.然而有研究发现,与免耕相比,传统耕作和少耕的水分利用效率分别增加了 36%和 15%,这主要受气象条件和耕作方式的影响[16].长期免耕留茬也可以提高土壤含水量,有利于改善土壤结构[17].免耕秸秆覆盖能蓄水保墒、提高水分利用效率,覆盖对表层土壤有较为显著的保水效果[18],深旋松耕处理较旋耕和间隔深松耕作可以储蓄更多的水分;在降雨量较少时期,相比旋耕和深松,深旋松耕能很好地保存水分,为作物高产稳产提供良好的土壤水分条件[19].

### 1.2 土壤容重

不同耕作方式对土壤容重影响的研究结果目前还没有一致的结论.有研究认为,免耕和少耕会降低土壤的入渗量,使土壤表层容重增大[20].在西北高原干旱区,免耕使耕作层土壤容重增加,团聚体稳定性提高,土壤抗蚀力增强[21];在亚热带地区,免耕处理土壤容重增大[22].青海省互助县南门峡镇采用不同耕作方式(留茬免耕、带状免耕旋播、秸秆还田免耕、常规耕作)的春种油菜地土壤容重则减小[23];辽宁省昌图县东嘎镇坤都村玉米耕作试验中,与旋耕相比,深旋松可使土壤容重降低 4.1%~10.2%;与深松耕相比,深旋松可使土壤容重降低 2.7%~7.5%[24].间隔深松耕能够在一定程度上打破犁底层,降低土壤容重,增加土壤通透性[25-26].河北吴桥地区实施耕作两年内,深旋松耕处理的土壤容重一直显著低于深松和旋耕[19].与播种期相比,收获期免耕及松耕农田耕层土壤容重呈下降趋势,翻耕则无明显变化[27].也有研究表明,免耕与传统耕作的土壤容重无明显差异[28].

### 1.3 土壤硬度

土壤硬度对土壤水分入渗、保持和供应以及土壤通气性有影响,并间接影响土壤养分转化、运输和土壤热特性等指标.有研究表明,保护性耕作会增加土壤硬度[29].在吉林省德惠市中层黑土上进行的 8 年玉米-大豆轮作和玉米连作试验表明,在 2.5~17.5 cm 土层,免耕土壤硬度都明显高于秋翻处理,分析土壤硬度值发生变化的原因为免耕对土壤不进行扰动,土壤自身下沉而引起土壤颗粒之间排列比较紧实;而秋翻处理每年对土壤进行翻耕,使上层土壤比较疏松,故土壤硬度较小.免耕减少了机械作业的次数,同时也减少了对土壤的翻耕扰动,使其横断面土壤硬度曲线起伏较小[30].

### 1.4 土壤空隙

耕作方式对土壤孔隙的影响是目前耕作研究的重点内容之一.孔隙作为土壤结构的重要组成部分,对土壤中水和空气的传导、运动及植物根的穿扎和吸水具有重要作用.免耕可提高表层土壤的孔隙度,在封丘进行的 3 年试验结果表明,秸秆覆盖促使土

壤总孔隙度增加[31]；在内蒙古赤峰市农牧交错区的试验表明，长期免耕留茬可提高非毛管孔隙度，有利于改善土壤结构[17]．然而有研究发现，在亚热带地区，免耕处理表层土壤孔隙度会有所降低[32]；陕西渭北旱塬冬小麦-春玉米轮作区在免耕/深松轮耕措施下，0~60 cm 土层平均土壤孔隙度较连续翻耕处理提高 4.4%[33]．

### 1.5　土壤养分

耕作方式对土壤养分的影响比较显著，不同耕作方式对土壤有效养分和全量养分含量的影响也有所不同．免耕增加了土壤表面植物残体量，并改善了土壤的层化现象，而翻耕使有机质与土壤混合，改变了土壤有机质的分布状况[34]．相同耕作层内，碱解氮含量在免耕、机械旋耕及生物耕作（接种释放蚯蚓）中呈现下降趋势；土壤全氮、全磷、全钾、有效磷、速效钾等均表现出相同的变化趋势[35]．豫西旱区坡耕地深松覆盖和免耕覆盖耕层全氮较传统耕作有所增加，土壤全氮含量为免耕最高（0.797 $g \cdot kg^{-1}$），比传统耕作增加了 10.4%[36]．对江西红壤区 4 种不同耕作方式花生地土壤养分的研究发现，全量养分受耕作方式的影响不明显，但有效养分明显受到影响[37]．

耕作方式对土壤有机碳的影响也有所不同．长期且频繁地犁翻土壤，会导致表层土壤有机碳和结构稳定性下降，从而加剧农田表层土壤流失和养分损失[38]．非传统耕作有助于增加土壤养分，有利于提高土壤中碱解氮、全氮和有机碳含量，从而提高土壤质量．与传统耕作方式相比，免耕有利于土壤储存更多的碳[39]，促进土壤有机碳的增加与积累[23]，从而使农业土壤成为 $CO_2$ 的“汇”．在亚热带地区，免耕可提高土壤总有机碳含量[40]，采用免耕能不同程度地提高土壤有机碳、易氧化有机碳的含量．在华北夏玉米不同生育期，土壤总有机碳含量表现为免耕最高，翻耕和旋耕次之；玉米成熟期，免耕、旋耕、翻耕条件下的土壤碳库管理指数与撂荒相比分别提高了 47.4%、30.4%、27.0%[41]．豫西旱区坡耕地深松覆盖条件下土壤有机碳含量最高，为 6.79 $g \cdot kg^{-1}$，与传统耕作相比增加了 13.8%[36]．但也有研究认为，免耕条件下土壤有机碳储量与传统耕作相比差异并不明显[42]；在质地黏重、排水不良以及侵蚀微弱的土壤上实施免耕并不能明显增加土壤有机碳的含量[43]；旋耕比免耕更利于有机碳质量分数的提高[44]．免耕使土壤有机碳在土壤表层富集[45]，免耕在玉米-大豆轮作和玉米连作下 0~5 cm 土壤有机碳含量分别比秋翻增加了 15.2% 和 11.5%（$P<0.05$）[46]．分析原因可能是免耕耕作使地表覆盖度增加，减少了地表裸露，有效抑制了土壤的过度通气，减少了有机碳的氧化降解，使土壤有机碳水平表现出提高的趋势．免耕表层残茬的积累使土壤有机碳含量高于翻耕，下层较高的土壤有机碳分解率使免耕的土壤有机碳含量低于翻耕[47]．

## 2　不同耕作方式对土壤酶活性的影响

土壤酶对土壤肥力有直接影响[48]．土壤酶对作物轮作、残留物管理和土壤压实、翻耕等不同土壤管理措施的响应比较敏感．耕作方式是影响土壤酶活性的重要因素之一，采用合理的耕作方式能够有效提高土壤酶活性．

不同耕作方式对土壤酶活性的影响不同，相对于传统耕作，深松覆盖和免耕覆盖可以避免土壤生物退化，维持土壤质量．山东农业大学大田试验表明，深松耕还田显著提高了土壤脲酶、蔗糖酶活性[6]．与传统耕作相比，黄土高原西部旱农区免耕处理土壤脲酶、碱性磷酸酶、蔗糖酶活性分别增加了 11.6%、12.4% 和 20.9%[49]．中国科学院封丘农业生态实验站保护性耕作定位试验发现，在小麦整个生育期内，与传统耕作相比，免耕使土壤脲酶、转化酶、碱性磷酸酶活性增加，全翻耕使这 3 种酶的活性降低，免耕结合秸秆还田能较好地提升土壤酶活性[50]．Madejón 等[51] 认为，免耕覆盖土壤的过氧化氢酶、蛋白酶、葡萄糖酶和碱性磷酸酶活性均高于传统翻耕．实施深松覆盖和免耕覆盖的豫西旱区坡耕地上，0~10 cm 土层土壤脲酶、转化酶和过氧化氢酶活性明显提高，其中脲酶活性增加最多[52]．免耕和深松使作物残余物累积在表层，改善土壤特性，有利于微生物的生长，从而提高土壤表层微生物活性和生物量及土壤碳、氮和磷的含量，并增加土壤水分、容重及团粒稳定性，进而提高土壤酶活性[6]．也有研究发现，旱地玉米连续 4 年实施免耕覆盖，其土壤酶活性基本趋于稳定[53]．在大豆田整个生育期内，免耕留高茬的土壤蔗糖酶活性先升后降，普通耕作方式只呈现单峰曲线[54]．水稻大田试验研究发现[55]，免耕处理土壤酶活性在上、下土层的差异更大，在空间分布上表现出典型的表层富集特性．免耕和免耕+秸秆处理上层土壤的脲酶、酸性磷酸酶、蛋白酶和纤维素酶活性大于常耕（传统耕作）处理，而下层土壤 4 种酶活性以常耕+秸秆处理最高，免耕+秸秆处理次之，免耕和常耕处理较低．

不同的耕作方式结合秸秆覆盖有利于提高土壤酶活性.水稻大田试验表明[55],不论哪种耕作方式,4 种酶活性均表现为有秸秆还田处理高于无秸秆还田处理,其原因可能是秸秆还田增加了土壤有机质,使表土疏松、通气性好,提高了土壤微生物数量和微生物生物量碳、氮含量,进一步提高了包括土壤酶在内的分泌物数量,使土壤酶活性相应提高.

## 3 不同耕作方式对土壤微生物多样性的影响

耕作方式的差异对农业生态环境、农田土壤微生物的影响很大[56-57].合理的耕作措施可以通过有效地增加土壤有机质含量,调节土壤 C/N 及土壤温度和水分的变化,为土壤微生物的生长与繁殖提供丰富的可利用资源[58].

耕作方式可影响土壤呼吸,与常规旋耕相比,免耕能降低土壤呼吸作用,减少 $CO_2$ 的释放[59].对常规耕作、旋耕、耙耕和免耕的麦田土壤研究发现,在 0~10 cm 土层,免耕土壤的呼吸速率最高,常规耕作和耙耕居中,旋耕最低;在 10~20 cm 土层,常规耕作的土壤呼吸速率最高,其次为耙耕,免耕最低,免耕比常规耕作和耙耕分别低 6.1% 和 5.5%[60].与常规耕作无秸秆还田相比,保护性耕作和秸秆还田在耕作初期能提高土壤呼吸,而在后期尤其是旋耕还田能显著降低土壤呼吸,减少土壤碳素的亏损,但其时间效应有待进一步研究[6].分析原因可能是免耕没有对土壤进行机械扰动的过程,土表集中了较丰富的基质,表层土壤结构、通气状况和持水特性等均得到改善,从而有效地促进了微生物的发育[35];耕作层水热条件和通气状况好,也有利于微生物的生长和繁殖[61].

不同耕作方式对土壤微生物生物量的影响不同.微生物生物量越大,土壤保肥作用越强.豫西旱区坡耕地免耕、深松处理显著增加了土壤微生物生物量碳、氮含量,免耕和深松条件下 0~20 cm 土层土壤微生物生物量碳、氮含量较传统耕作分别增加 79.3%、19.9% 和 17.9%、8.1%[36].小麦田 0~10 cm 土层中,土壤微生物生物量碳含量则表现为旋耕和免耕最低,其次为耙耕,常规耕作最高;10~20 cm 土层的土壤微生物生物量碳含量免耕比常规耕作低 12.8%[60].山东农业大学多年连续秸秆覆盖免耕大田试验研究发现,免耕能提高表层土壤微生物生物量,深松耕还田可显著提高土壤活跃微生物量[6].麦田 0~20 cm 土层中,旋耕处理土壤活跃微生物量较高[60];影响土壤活跃微生物量的主要因素可能是土壤通透性或营养因素[62].豫西旱区长期耕作导致坡耕地土壤微生物生物量碳、氮具有不同程度的坡下富集现象,而免耕和深松使作物残余物在表层累积,导致土壤表层微生物活性和生物量增加[36].

耕作方式会对土壤微生物的数量与分布产生影响.土壤微生物的数量分布对土壤环境质量的变化反应敏感.黄土高原半干旱区麦药轮作小麦农田,免耕处理深层土壤细菌、真菌和微生物总数升高,放线菌数量逐渐升高,与传统耕作相比,细菌、真菌、放线菌数量和微生物总数分别增加 62.9%、92.9%、14.3% 和 66.7%[63].在长期免耕条件下,土壤微生物数量明显高于传统耕作[64],镰孢菌种类和数量明显增加[65].在玉米全生育期,与传统耕作相比,免耕处理的土壤细菌、放线菌、真菌和纤维素分解菌数量分别提高 41.9%、470.1%、67.9% 和 65.7%[48].徐阳春等[66]研究表明,保护性耕作下表层土(0~7.5 cm)的微生物量增加.连续 3 年实施免耕显著提高了玉米-小麦轮作系统土壤微生物量[67];而 Adl 等[68]研究发现,短期免耕(4 年)不影响土壤微生物丰度.这可能是因为短期耕作对不同类型的微生物群落影响不同,不同微生物群落间丰度增减相互抵消.李景等[69]研究表明,两茬耕作、深松覆盖和免耕可以提高土壤细菌、古菌和真菌的多样性、丰富度和均匀度指数,尤其对古菌和真菌的影响较大.这是由于免耕、深松结合小麦秸秆覆盖和小麦-花生轮作等措施均可改善土壤团聚体状况,提高土壤微生物多样性.另有研究发现,接种蚯蚓能够显著增加土壤耕层内氨化细菌的数量,接种(释放)蚯蚓以及免耕处理可有效提高无机磷分解菌的数量[70].这可能是因为蚯蚓活动增加整个土壤微生物量,还可能与它们活动形成蚓穴和蚓粪中生理菌群微生物量的增加有关.Robert 等[71]研究指出,在 0~2 cm 土层中,免耕加黑麦草覆盖处理的土壤含有较多的异氧细菌和真菌;在 2~10 cm 土层,其数量会显著下降,在单独免耕处理的土壤中也发现了这种趋势.耕作对土壤真菌表现为中度或轻度抑制,对于免耕与常规耕作作物相同的系统,在多数情况下耕作对细菌为轻度抑制,而长年免耕常常会对细菌产生抑制,一般情况下耕作会减少土壤中的微生物总量[59].Helgason 等[72]研究指出,40 年免耕处理土壤具有更高的真菌丰度.2011 年在湖北省均川镇为期两年的试验结果表明,与翻耕相比,长期免耕显著降低了真菌(44.3%~100%)和革兰氏阴性菌(46.3%~47.1%)的生物量[73].15 年的小麦-玉米轮作农田试验表明,免耕能

增加土壤微生物群落，其中真菌占主导地位[74]．关于耕作方式对微生物群落多样性方面的研究较多．一般认为，传统耕作方式具有降低土壤微生物多样性的作用，免耕、少耕和秸秆还田等有利于提高土壤微生物多样性．长期免耕（4～25 年）可以增加棉田土壤微生物多样性[68]．Gouaerts 等[74]发现，15 年免耕还田增加了小麦-玉米轮作系统的土壤微生物群落多样性．长期（超过 10 年）小麦-玉米轮作下，细菌群落在免耕秸秆还田条件下有更高的多样性[75]．Mathew 等[76]报道，真菌在长期免耕系统中未占主导地位，土壤微生物多样性与土壤的通气状况和营养状况密切相关，短期耕作增加了土壤扰动和通气性[77]，从而影响微生物群落结构．在中国科学院海伦长期定位试验的研究结果表明，免耕和少耕对土壤细菌多样性的影响不明显，但可以显著提高真菌多样性[78]，免耕和传统耕作土壤细菌种群分布无明显差异，免耕和传统耕作提高了真菌种群多样性[79]．

不同耕作方式对土壤微生物群落代谢和功能多样性产生较显著影响．对天津市武清区撂荒、翻耕、免耕和旋耕 4 种不同耕作方式土壤微生物群落代谢功能多样性进行分析，结果发现，免耕条件下微生物功能多样性指数、优势度指数和丰富度指数与撂荒条件相似，翻耕和旋耕后 3 个指标均显著下降．免耕条件下，土壤微生物具有接近于撂荒处理的碳源代谢模式和代谢能力，翻耕和旋耕与免耕差异较大[80]．

## 4　不同耕作方式对土壤动物的影响

土壤动物是生态系统中物质与能量交换的枢纽，主要包括线虫、线蚓、蛆阁、软体动物、昆虫及其幼虫、甲壳类、多足类、螨类、蜘蛛的某些类群．土壤动物能够改善土壤的通透性和土壤肥力，可以作为一种相对稳定的指示因子反映土壤环境状况．耕作方式的改变会引起农田生态系统中土壤动物生存环境的改变，进而影响土壤动物的群落结构、多样性及空间分布．

不同的耕作方式对土壤动物数量有显著影响．免耕保护了对扰动敏感的土壤动物，少耕则促进了土壤动物的繁殖，有利于提高大多数土壤动物类群的数量[81]．与传统耕作相比，免耕有利于土壤动物幼虫的生长和数量的增加，通常有更高的土壤动物数量、生物多样性和种群结构稳定性，更有利于农业生态系统的环境保护[82]．这主要是由于免耕为土壤动物的生存提供了较好的栖息场所，免耕秸秆还田处理给土壤动物提供了充足的饲料来源和有利的滋生场所[83]．黄淮海平原玉米拔节期土壤动物类群和数量为免耕处理高于翻耕处理．在免耕和秸秆覆盖条件下，土壤小节肢动物群体数量一般会增加[84]，免耕条件下土壤动物类群数免耕高于翻耕，覆盖量越大，个体数量越多[85]．免耕能增加甲螨的数量和多样性[68]，少耕和免耕较其他耕作方式更有利于土壤螨类群落结构的稳定性及多样性的保持[86]．采用不同耕作方式的花生田中，以免耕秸秆还田处理花生蛴螬数量最多（12.8 头 · $m^{-2}$），其次为免耕清理秸秆处理（11.4 头 · $m^{-2}$），休耕田处理蛴螬数量最少（8.6 头 · $m^{-2}$）[87]．也有研究表明，农业耕作活动增加了土壤大孔隙数量，更有利于土壤小节肢动物数量的增长[88]．

与传统耕作相比，保护性耕作增加了农田土壤动物群落的丰富度[89]，免耕在一定程度上增强了土壤动物群落结构的丰富性与多样性．小麦-玉米试验地连续 5 年秸秆全量还田后，免耕、耙耕和深松等耕作措施导致田间地下害虫群落的物种丰富度及均匀度均较高[90]．在黄淮海平原小麦-玉米一年两熟地区，耕作方式通过对土壤动物的时间动态和垂直分布产生影响而间接影响土壤动物数量及其组成．土壤动物 Shannon 多样性指数在整体上表现为翻耕高于免耕处理，玉米季翻耕条件下的均匀度指数更高，但小麦季均匀度指数差异不显著[91]．耕作方式的改变能够引起一些土壤动物类群在土壤层次分布上发生显著变化，免耕使多数土壤动物趋于表层分布[85]，翻耕处理下层（10～20 cm）土壤中也有较大分布．免耕条件下土壤动物主要聚集在土壤表层的主要原因是免耕播种减少了机械操作对土壤的压实作用，导致下层土壤大中型孔隙减少，不利于土壤动物的移动和取食，土壤动物受到来自外界的干扰也相应减少，这在一定程度上促进了土壤动物的发展．然而，免耕使土壤容重增大、土壤动物表聚化，随时间延长，可能导致土壤动物的空间容量缩小，这有待于进一步研究[92]．

## 5　研究结论与展望

与传统耕作相比，适宜的耕作方式为作物高产、稳产提供了良好的水分、养分条件，通过对土壤容重、硬度、孔隙及有机碳的影响来改善土壤质量．绝大多数研究表明，免耕能有效提高土壤酶活性，免耕结合秸秆覆盖对土壤微生物的影响比较明显．采用

合理的耕作方式能使作物残余物积累在表层,改善土壤特性,为土壤微生物的生长与繁殖提供丰富的可利用资源,从而有效提高土壤酶活性.耕作方式的改变会引起农田生态系统中土壤动物生存环境的变化,免耕、少耕保护了对扰动敏感的土壤动物,进而影响土壤动物的数量、多样性及种群结构.在不同的土地利用方式下,土壤动物群落结构、多样性及空间分布与土壤理化性质的表现不同,将土壤动物与土壤环境相结合,作为评价土壤质量的一项参考指标具有积极意义.

今后应对以下几个方面开展研究:

1)长期实施单一免耕和深松等保护性耕作措施导致土壤结构紧实,土壤表层富营养化,土传病虫害发生几率提高,影响幼苗生长,不利于作物生长发育.因此,建立合理的土壤轮耕制度,在不同的土壤类型上采用适宜的耕作方法,形成与种植制度相适应的土壤轮耕技术体系是未来研究的重点之一.

2)免耕取得成功的关键在于对农田杂草的有效控制[93].免耕会增加农田杂草数量,多年生杂草有增加趋势,杂草种类也发生显著变化,增加除草难度,恶性杂草发生趋于严重.在进行保护性耕作的同时如何更高效地防除杂草需要进一步的研究.

3)土壤动物表聚化现象也是未来研究的重点.适当减少农业生产中的耕作措施、降低耕作强度,有利于农田生态系统中土壤动物种群结构的稳定.未来应强化对农业生态系统土壤动物功能和作用的研究;将土壤动物、土壤微生物、作物地下部分以及土壤环境进行整合研究更具现实意义.

4)耕作方式的改良依赖于农业机械的进步.农业机械作为农业生产中常用的生产工具,在农业发展中发挥了至关重要的作用.农业机械正逐渐走向大型化、高效化、数字化及绿色化的发展道路,我国传统农业机械与发达国家相比有很大差距,已不能适应农业的发展,应加强对该领域的研究及资金投入.

## 参考文献


[1] Pei X-X (裴雪霞), Dang J-Y (党建友), Zhang D-Y (张定一), *et al*. Effects of different tillage methods on phospholipid fatty acids and enzyme activities in calcareous cinnamon soil. *Chinese Journal of Applied Ecology* (应用生态学报), 2014, **25**(8): 2275-2280 (in Chinese)

[2] Chen Q-H (陈庆华), Zhou X-G (周小刚), Zheng S-J (郑仕军), *et al*. Effects of tillage methods on weed emergence and wheat yield. *Weed Science* (杂草科学), 2013, **31**(2): 50-52 (in Chinese)

[3] Liu E-K (刘恩科), Zhao B-Q (赵秉强), Li X-Y (李秀英), *et al*. Biological properties and enzymatic activity of arable soils affected by long-term different fertilization systems. *Chinese Journal of Plant Ecology* (植物生态学报), 2008, **32**(1): 176-182 (in Chinese)

[4] Chen X-W (陈学文), Zhan X-P (张晓平), Liang A-Z (梁爱珍), *et al*. Effects of tillage mode on black soils penetration resistance and bulk density. *Chinese Journal of Applied Ecology* (应用生态学报), 2012, **23**(2): 439-444 (in Chinese)

[5] Xu S-Q (徐尚起), Cui S-Y (崔思远), Chen F (陈阜), *et al*. Effect of tillage on content of density fractions of paddy soil organic carbon and its spatial distribution. *Journal of Agro-Environment Science* (农业环境科学学报), 2011, **30**(1): 127-132 (in Chinese)

[6] Wang Y (王 芸), Han B (韩 宾), Shi Z-Q (史忠强), *et al*. Effects of conservation tillage on soil microbial characters and soil enzyme activities. *Journal of Soil and Water Conservation* (水土保持学报), 2006, **20**(4): 120-122, 142 (in Chinese)

[7] Wu H-Y (吴海燕), Fan Z-W (范作伟), Liu C-G (刘春光), *et al*. Analysis on the regularity and influence factors of change of soil microflora under maize planting technology of conservation tillage. *Journal of Maize Sciences* (玉米科学), 2008, **16**(4): 135-139 (in Chinese)

[8] Zhang J-J (张建军), Wang Y (王 勇), Fan T-L (樊廷录), *et al*. Effects of different tillage and fertilization modes on the soil physical and chemical properties and crop yield under winter wheat/spring corn rotation on dryland of East Gansu, Northwest China. *Chinese Journal of Applied Ecology* (应用生态学报), 2013, **24**(4): 1001-1008 (in Chinese)

[9] Yu H-Y (余海英), Peng W-Y (彭文英), Ma X (马秀). Effects of no-tillage on soil water content and physical properties of spring corn fields in semiarid region of northern China. *Chinese Journal of Applied Ecology* (应用生态学报), 2011, **22**(1): 99-104 (in Chinese)

[10] Jing G-C (景国臣), Wang Y-J (王亚娟), Wang Z-X (王占喜). The causes of the formation of the middle-low-yielding fields and the improvement countermeasures enriching the fields. *Technology of Soil and Water Conservation* (水土保持应用技术), 2009(4): 34-36 (in Chinese)

[11] Zhang R-Z (张仁陟), Luo Z-Z (罗珠珠), Cai L-Q (蔡立群), *et al*. Effects of long-term conservation tillage on soil physical quality of rainfed areas of the Loess Plateau. *Acta Prataculturae Sinica* (草业学报), 2011, **20**(4): 1-10 (in Chinese)

[12] Wang L-X (王丽学), Gao Y-Y (高园园). Research on the influence of conservation tillage on soil moisture content, soybean growth and yield. *China Rural Water and Hydropower* (中国农村水利水电), 2013(9): 37-40 (in Chinese)

[13] Zhang SL, Zhang XY, Huffman T, *et al*. Influence of topography and land management on soil nutrients varia-

bility in Northeast China. *Nutrient Cycling in Agroecosystems*, 2011, **89**: 427-438
[14] Sarkar S, Singh SR. Interactive effect of tillage depth and mulch on soil temperature, productivity and water use pattern of rainfed barley (*Hordium vulgare* L.). *Soil and Tillage Research*, 2007, **92**: 79-86
[15] Naudin K, Gozé E, Balarabe O, *et al*. Impact of no tillage and mulching practices on cotton production in North Cameroon: A multi-locational on-farm assessment. *Soil and Tillage Research*, 2010, **108**: 68-76
[16] Liu S (刘　爽). Modeling on Crop Yield and Soil Water, Heat and Nutrient Dynamics for Different Tillage Managements and Fertilizations. PhD Thesis. Beijing: University of Chinese Academy of Sciences, 2013 (in Chinese)
[17] Chang X-H (常旭虹), Zhao G-C (赵广才), Yang Y-S (杨玉双), *et al*. Effect of tillage practice on nitrogen use efficiency of wheat in the farming-pasture zone. *Journal of Nuclear Agricultural Sciences* (核农学报), 2013, **27**(8): 1209-1215 (in Chinese)
[18] Huang G-B (黄高宝), Li L-L (李玲玲), Zhang R-Z (张仁陟), *et al*. Effects of no-tillage with stubble retention on soil temperature of rainfed spring wheat field. *Agricultural Research in the Arid Areas* (干旱地区农业研究), 2006, **24**(5): 1-4 (in Chinese)
[19] Yang X (杨　雪), Pang H-C (逄焕成), Li Y-B (李轶冰), *et al*. Effects of deep rotary sub-soiling tillage on the physical properties and crop growth of the sticky loamy soil in north China. *Scientia Agricultura Sinica* (中国农业科学), 2013, **46**(16): 3401-3412 (in Chinese)
[20] Glab T, Kulig B. Effect of mulch and tillage system on soil porosity under wheat (*Triticum Aestivum*). *Soil and Tillage Research*, 2008, **99**: 169-178
[21] Gong W-F (巩文峰), Li L-L (李玲玲), Zhang X-P (张晓萍), *et al*. Influence of conservation tillage on top soil physical and chemical quality in rain-fed areas of the Loess Plateau. *Chinese Agricultural Science Bulletin* (中国农学通报), 2013, **29**(32): 280-285 (in Chinese)
[22] Wyngaard N, Echeverría HE, Sainz Rozas HR, *et al*. Fertilization and tillage effects on soil properties and maize yield in a Southern Pampas Argiudoll. *Soil and Tillage Research*, 2012, **119**: 22-30
[23] Li Q-Y (李全宇), Li Y-M (李月梅). Effects of conservation tillage on soil nutrients and some physical properties. *Qinghai Agro-Technology Extension* (青海农技推广), 2013(3): 58-64 (in Chinese)
[24] Li H (李　华), Pang H-C (逄焕成), Ren T-Z (任天志), *et al*. Effects of deep rotary-subsoiling tillage method on brown physical properties and maize growth in northeast of China. *Scientia Agricultura Sinica* (中国农业科学), 2013, **46**(3): 647-656 (in Chinese)
[25] Abu-Hamdeh NH. Compaction and sub-soiling effects on corn growth and soil bulk density. *Soil Science Society of America Journal*, 2003, **4**: 1212-1218
[26] Lipiec J, Hatano R. Quantification of compaction effects on soil physical properties and crop growth. *Geoderma*, 2003, **116**: 107-136
[27] Wang Y (王　岩), Zhang J (张　静), Liu Y-H (刘玉华). Long-term effects of conservation tillage on soil bulk density in cropping zone of cold plateau in north China. *Chinese Agricultural Science Bulletin* (中国农学通报), 2013, **29**(6): 131-136 (in Chinese)
[28] Zhang F-W (张福武), Cai L-Q (蔡立群), Chen Y (陈　英). Effect of no-tillage on the soil physical characteristics. *Gansu Agricultural Science and Technology* (甘肃农业科技), 2008(8): 9-11 (in Chinese)
[29] Lapen DR, Topp GC, Edwards ME, *et al*. Combination cone penetration resistance/water content instrumentation to evaluate cone penetration-water content relationships in tillage research. *Soil and Tillage Research*, 2004, **79**: 51-62
[30] Chen X-W (陈学文), Zhang X-P (张晓平), Liang A-Z (梁爱珍). Effects of tillage mode on black soil's penetration resistance and bulk density. *Chinese Journal of Applied Ecology* (应用生态学报), 2012, **23**(2): 439-444 (in Chinese)
[31] Zhou L-Y (周凌云). Effects of straw mulch on soil physical conditions in field. *Research of Agricultural Modernization* (农业现代化研究), 1997, **18**(5): 311-314 (in Chinese)
[32] Sasal MC, Andriulo AE, Taboada MA. Soil porosity characteristics and water movement under zero tillage in silty soils in Argentinian Pampas. *Soil and Tillage Research*, 2006, **87**: 9-18
[33] Bai W-X (柏炜霞), Li J (李　军), Wang Y-L (王玉玲), *et al*. Effects of different tillage methods on soil water and crop yield of winter wheat-spring maize rotation region in Weibei highland. *Scientia Agricultura Sinica* (中国农业科学), 2014, **47**(5): 880-894 (in Chinese)
[34] Wander MM, Bidart MG, Aref S. Tillage impacts on depth distribution of total and particulate organic matter in three Illinois soils. *Soil Science Society of America Journal*, 1998, **62**: 1704-1711
[35] Li S-X (李双喜), Zheng X-Q (郑宪清), Yuan D-W (袁大伟), *et al*. Effects of biological tillage on soil microbiota and bacterial physiologies colony. *Acta Agriculturae Boreali-Sinica* (华北农学报), 2012, **27** (suppl.): 339-344 (in Chinese)
[36] Zhang J (张　洁), Yao Y-Q (姚宇卿), Jin K (金轲), *et al*. Change of SMBC and SMBN under conservation tillage on sloping dryland. *Journal of Soil and Water Conservation* (水土保持学报), 2007, **1**(4): 126-129 (in Chinese)
[37] Li L-N (李丽娜), Xiong Y-J (熊英杰), Liu Y-C (刘衍琛), *et al*. Effect of soil nutrients and enzyme activity on peanut planting by different cropping patterns. *Journal of Wuyi University* (Natural Science) (五邑大学学报: 自然科学版), 2013, **27**(1): 75-78 (in Chinese)
[38] Luo Z-Z (罗珠珠), Huang G-B (黄高宝), Zhang R-Z (张仁陟), *et al*. Effect of long-term conservation tillage on soil fertility in rain-fed areas of the Loess Plateau.

*Chinese Journal of Eco-Agriculture* (中国生态农业学报), 2010, **18**(3): 458-464 (in Chinese)

[39] Varvel GE, Wilhelm WW. No-tillage increases soil profile carbon and nitrogen under long-term rainfed cropping systems. *Soil and Tillage Research*, 2011, **114**: 28-36

[40] Li CF, Yue LX, Kou ZK, *et al*. Short-term effects of conservation management practices on soil labile organic carbon fractions under a rape-rice rotation in central China. *Soil and Tillage Research*, 2012, **119**: 31-37

[41] Liu H-M (刘红梅), Ji Y-Y (姬艳艳), Zhang G-L (张贵龙), *et al*. Effects of different tillage methods on soil organic carbon content in a summer maize field. *Ecology and Environmental Sciences* (生态环境学报), 2013, **22**(3): 406-410 (in Chinese)

[42] Divito GA, Sainz Rozas HR, Echeverría HE, *et al*. Long term nitrogen fertilization: Soil property changes in an Argentinean Pampas soil under no tillage. *Soil and Tillage Research*, 2011, **114**: 117-126

[43] Alvarez R, Russo ME, Prystupa P, *et al*. Soil carbon pools under conventional and no-tillage systems in the Argentine rolling Pampa. *Agronomy Journal*, 1998, **90**: 138-143

[44] Chen S-H (陈尚洪), Zhu Z-L (朱钟麟), Liu D-H (刘定辉), *et al*. Influence of straw mulching with no till on soil nutrients and carbon pool management index. *Plant Nutrition and Fertilizer Science* (植物营养与肥料学报), 2008, **14**(4): 806-809 (in Chinese)

[45] Quan G-M (全国明), Zhang J-E (章家恩), Yan H-C (严会超), *et al*. Review on influence of no-tillage on soil fertility of paddy field. *Chinese Agricultural Science Bulletin* (中国农学通报), 2005, **21**(9): 266-269 (in Chinese)

[46] Chen X-W (陈学文), Wang N (王 农), Shi X-H (时秀焕), *et al*. Evaluating tillage practices impacts on soil organic carbon based on least limiting water range. *Acta Ecologica Sinica* (生态学报), 2013, **33**(9): 2676-2683 (in Chinese)

[47] Franzluebbers AJ. Soil organic matter stratification ratio as an indicator of soil quality. *Soil and Tillage Research*, 2002, **66**: 95-106

[48] Zhang X-J (张星杰), Liu J-H (刘景辉), Li L-J (李立军), *et al*. Effects of different conservation tillage on soil microbes quantities and enzyme activities in dry cultivation. *Journal of Maize Sciences* (玉米科学), 2008, **16**(1): 91-95, 100 (in Chinese)

[49] Miao L (苗 琳), Wang L (王 立), Huang G-B (黄高宝), *et al*. Effects of cotton continuous cropping on the amount of soil microbes and enzyme activities in Xinjiang. *Agricultural Research in the Arid Areas* (干旱地区农业研究), 2009, **27**(1): 6-11 (in Chinese)

[50] Lu Y-Q (路怡青), Zhu A-N (朱安宁), Zhang J-B (张佳宝), *et al*. Effects of no-tillage and straw incorporation on soil enzyme activity during wheat growth. *Journal of Ecology and Rural Environment* (生态与农村环境学报), 2013, **29**(3): 329-334 (in Chinese)

[51] Madejón E, Murillo JM, Moreno F, *et al*. Effect of long-term conservation tillage on soil biochemical properties in Mediterranean Spanish areas. *Soil and Tillage Research*, 2009, **105**: 55-62

[52] Zhang J (张 洁), Yao Y-Q (姚宇卿), Lyu J-J (吕军杰), *et al*. Effect of green manure on soil fertility properties in summer fallow period in Weibei Dryland. *Agricultural Research in the Arid Areas* (干旱地区农业研究), 2011, **29**(2): 142-146 (in Chinese)

[53] Zhang L-H (张丽华), Huang G-B (黄高宝), Zhang R-Z (张仁陟). Effects of different cover and rotation on soil microbial biomass phosphorus in rain-fed agriculture. *Journal of Gansu Agricultural University* (甘肃农业大学学报), 2006, **41**(6): 98-101 (in Chinese)

[54] Shao L-H (邵立红), Ma Z-Y (马振勇), Ma X-L (马晓岚). Effects of conservation tillage on soil enzyme activity in dry farmland. *Farm Machinery Using & Maintenance* (农机使用与维修), 2013(7): 96-97 (in Chinese)

[55] Ren W-J (任万军), Huang Y (黄 云), Wu J-X (吴锦秀). Effects of no-tillage and stubble-remaining on soil enzyme activities in broadcasting rice seedlings paddy field. *Chinese Journal of Applied Ecology* (应用生态学报), 2011, **22**(11): 2913-2918 (in Chinese)

[56] Gao M (高 明), Zhou B-T (周保同), Wei C-F (魏朝富), *et al*. Effect of tillage system on soil animal, microorganism and enzyme activity in paddy field. *Chinese Journal of Applied Ecology* (应用生态学报), 2004, **15**(7): 1177-1181 (in Chinese)

[57] Zhen C-Y (郑成岩), Cui S-M (崔世明), Wang D (王 东), *et al*. Effects of soil tillage practice on dry matter production and water use efficiency in wheat. *Acta Agronomica Sinica* (作物学报), 2011, **37**(8): 1432-1440 (in Chinese)

[58] Pang L (逄 蕾), Huang G-B (黄高宝). Impact of different tillage method on changing of soil organic carbon in semi arid area. *Journal of Soil and Water Conservation* (水土保持学报), 2006, **20**(3): 110-113 (in Chinese)

[59] Jiang Y (姜 勇), Liang W-J (梁文举), Wen D-Z (闻大中). Effects of no-tillage on soil biological properties in farmlands: A review. *Chinese Journal of Soil Science* (土壤通报), 2004, **35**(3): 347-351 (in Chinese)

[60] Li H-J (李洪杰). Effects of Tillage Methods and Nitrogen Levels on Soil Microbial Properties and Yield of Wheat. Master Thesis. Tai'an: Shandong Agricultural University, 2009 (in Chinese)

[61] Chen B (陈 蓓), Zhang R-Z (张仁陟). Effects of no-tillage and mulch on soil microbial quantity and composition. *Journal of Gansu Agricultural University* (甘肃农业大学学报), 2004, **39**(6): 634-638 (in Chinese)

[62] Gao Y-C (高云超), Zhu W-S (朱文珊), Chen W-X (陈文新). Bacterial and fungal biomass and activities in straw mulch no-tillage soils. *Chinese Journal of Ecology* (生态学杂志), 2001, **20**(2): 30-36 (in Chinese)

[63] Yang J-S (杨江山), Zhang E-H (张恩和), Huang G-

B（黄高宝）. Effects of conservation tillage on soil microbes quantities and enzyme activities in wheat-herb rotation system. *Acta Ecologica Sinica*（生态学报）, 2010, **30**(3): 824-829 (in Chinese)

[64] Fan X-G（樊晓刚）, Jin K（金　轲）, Li Z-J（李兆君）, *et al*. Soil microbial diversity under different fertilization and tillage practices: A review. *Plant Nutrition and Fertilizer Science*（植物营养与肥料学报）, 2010, **16**(3): 744-751 (in Chinese)

[65] Siegrid S, Ingrid L. Impact of tillage on the incidence of *Fusarium* spp. in soil. *Plant and Soil*, 2004, **267**: 13-22

[66] Xu Y-C（徐阳春）, Shen Q-R（沈其荣）, Ran W（冉炜）. Effects of zero tillage and application of manure on soil microbial biomass C, N and P after sixteen years of cropping. *Acta Pedologica Sinica*（土壤学报）, 2002, **39**(1): 89-96 (in Chinese)

[67] Wang JJ, Li XY, Zhu AN, *et al*. Effects of tillage and residue management on soil microbial communities in north China. *Plant and Soil Environment*, 2012, **1**: 28-33

[68] Adl SM, Coleman DC, Read F. Slow recovery of soil biodiversity in sandy loam soils of Georgia after 25 years of no tillage management. *Agriculture. Ecosystems & Environment*, 2006, **2-4**: 323-334

[69] Li J（李　景）, Wu H-J（吴会军）, Wu X-P（武雪萍）, *et al*. Effects of long term tillage measurements on soil aggregate characteristic and microbial diversity. *Chinese Journal of Applied Ecology*（应用生态学报）, 2014, **25**(8): 2341-2348 (in Chinese)

[70] Tao J（陶　军）, Zhang S-J（张树杰）, Jiao J-G（焦加国）, *et al*. Effects of earth worm on number of soil bacterial physiological groups and enzyme activity in a maize residue amended wheat agro-ecosystem. *Acta Ecologica Sinica*（生态学报）, 2010, **30**(5): 1306-1311 (in Chinese)

[71] Robert A, Carmine C, Antonio G, *et al*. Functional and molecular responses of microbial communities under differing soil management practices. *Soil Biology & Biochemistry*, 2004, **36**: 1873-1883

[72] Helgason BL, Walley FL, Germida JJ. Fungal and bacterial abundance in long-term no-till and intensive-till soils of the northern Great Plains. *Soil Science Society of America Journal*, 2009, **1**: 120-127

[73] Guo L-J（郭梨锦）, Cao C-G（曹凑贵）, Zhang Z-S（张枝盛）, *et al*. Short-term effects of tillage practices and wheat-straw returned to rice fields on topsoil microbial community structure and microbial diversity in central China. *Journal of Agro-Environment Science*（农业环境科学学报）, 2013, **32**(8): 1577-1584 (in Chinese)

[74] Gouaerts B, Mezzalama M, Unno Y, *et al*. Influence of tillage, residue management, and crop rotation on soil microbial biomass and catabolic diversity. *Applied Soil Ecology*, 2007, **37**: 18-30

[75] Ceja-Navarro JA, Rivera-Orduna FN, Patino-Zuniga L, *et al*. Phylo genetic and multivariate analyses to determine the effects of different tillage and residue management practices on soil bacterial communities. *Applied and Environmental Microbiology*, 2010, **11**: 3685-3691

[76] Mathew RP, Feng Y, Githinji L, *et al*. Impact of no-tillage and conventional tillage systems on soil microbial communities. *Applied and Environmental Soil Science*, 2012, doi: 10. 1155/2012/548620

[77] Azooz RH, Arshad MA, Franzluebbers AJ. Pore size distribution and hydraulic conductivity affected by tillage in Northwestern Canada. *Soil Science Society of America Journal*, 1996, **4**: 1197-1201

[78] Xiang X-H（向新华）, Wei W（魏　巍）, Zhang X-Y（张兴义）, *et al*. Effect of conservation tillage systems on soybean growth and soil microbial diversity. *Soybean Science*（大豆科学）, 2013, **32**(3): 321-332 (in Chinese)

[79] Helgason BL, Walley FL, Germida JJ. Long-term no-till management affects microbial biomass but not community composition in Canadian Prairie agroecosystems. *Soil Biology & Biochemistry*, 2010, **42**: 2192-2202

[80] Ji Y-Y（姬艳艳）, Zhang G-L（张贵龙）, Zhang R（张　瑞）, *et al*. Effects of different tillage modes on metabolic functional diversity of soil microbial community. *Chinese Agricultural Science Bulletin*（中国农学通报）, 2013, **29**(6): 117-123 (in Chinese)

[81] Zhan L-L（战丽莉）. Diversity and Influencing Factor of Meso-Soil Animal under Farm Land of Black Soil. PhD Thesis. Beijing: University of Chinese Academy of Sciences, 2013 (in Chinese)

[82] Faiek E, Sihem BM, Moncef BH, *et al*. Soil invertebrates in durum wheat (*Triticum durum* L.) cropping system under Mediterranean semi arid conditions: A comparison between conventional and no-tillage management. *Soil & Tillage Research*, 2011, **112**: 122-132

[83] Wu J-X（吴菊香）, Wang B-L（王宝亮）, Wang H-L（王海兰）, *et al*. Effects of different tillage managements on white grubs occurrence and yield of peanut in peanut field. *Hubei Agricultural Sciences*（湖北农业科学）, 2013, **52**(7): 1565-1570 (in Chinese)

[84] Miura F, Nakamotoa T, Kanedab S, *et al*. Dynamics of soil biota at different depths under two contrasting tillage practices. *Soil Biology & Biochemistry*, 2008, **2**: 406-414

[85] Zhu Q-G（朱强根）, Zhu A-N（朱安宁）, Zhang J-B（张佳宝）, *et al*. Effect of conservation tillage on soil fauna in wheat field of Huang-Huai-Hai Plain. *Journal of Agro-Environment Science*（农业环境科学学报）, 2009, **28**(8): 1766-1772 (in Chinese)

[86] Zhan L-L（战丽莉）, Xu Y-L（许艳丽）, Zhang X-Y（张兴义）, *et al*. Effect of tillage systems on community structure of soil mites. *Chinese Journal of Eco-Agriculture*（中国生态农业学报）, 2013, **21**(5): 598-605 (in Chinese)

[87] Wang L-X（王利霞）, Liu S-T（刘顺通）, Wang S-Z（王淑枝）. Comprehensive prevention and control technology of grubs under the condition of less no-till. *Modern Agricultural Sciences and Technology*（现代农业

科技), 2011(7): 187 (in Chinese)
[88] Wardle DA. Impacts of disturbance on detritus food webs in agroecosystems of contrasting tillage and weed management practices. *Advances in Ecological Research*, 1995, **26**: 105-185
[89] Zhu Q-G (朱强根), Zhu A-N (朱安宁), Zhang J-B (张佳宝), *et al*. Relation of agricultural soil fauna and soil fertility under conservation tillage systems. *Transactions of the Chinese Society of Agricultural Engineering* (农业工程学报), 2010, **26**(2): 70-76 (in Chinese)
[90] Han H-F (韩惠芳), Ning T-Y (宁堂原), Tian S-Z (田慎重), *et al*. Primary study on species and distribution of underground pests under conservation tillage in autumn-sown period. *Shandong Agricultural Sciences* (山东农业科学), 2009(6): 58-60 (in Chinese)
[91] Zhu Q-G (朱强根), Zhu A-N (朱安宁), Zhang J-B (张佳宝), *et al*. Abundance and diversity of soil fauna under different tillage systems in fluvor aquic soil in north China. *Soils* (土壤), 2010, **42**(2): 236-242 (in Chinese)
[92] Zhu Q-G (朱强根), Zhu A-N (朱安宁), Zhang J-B (张佳宝), *et al*. Diversity of soil fauna in corn fields in Huang-huai-hai Plain of China under effects of conservation tillage. *Chinese Journal of Applied Ecology* (应用生态学报), 2009, **20**(10): 2417-2423 (in Chinese)
[93] Tubbs RS, Gallaher RN. Conservation tillage and herbicide management for two peanut cultivars. *Agronomy Journal*, 2005, **97**: 500-504

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