城市污泥复合肥的肥效及其对小麦重金属吸收的影响

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摘要 通过盆栽和大田试验,初步探讨了污泥复合肥种植小麦的肥效及其对小麦重金属吸收的影响。试验结果表明,污泥复合肥对小麦的增产效果和土壤的培肥效果明显优于化肥,等同于市售复合肥。它能促进植株生长发育,提高小麦产量,对土壤速效养分的积累有明显的促进作用;污泥复合肥处理的小麦籽粒中重金属 Cu、Zn、Pb、Cd 的含量均在国家食品卫生标准范围内。

关键词 污泥复合肥; 肥效; 重金属

The Effects of Compound Fertilizer Made From Municipal Sewage Sludge Compost on N P K and Heavy Metals Uptake of Wheat

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Abstract: The amount of sewage sludge production is increasing with the raising of wastewater treatment in China, how to dispose it has been an urgent problem for government and wastewater treatment plants. Sewage sludge contains various kinds of pathogenic bacterium and heavy metals which may cause serious environmental pollution if without correctly disposed. However, sludge also contains various kinds of nutrients and organic matter, which are necessary for plant growth, and would be a resource if it were utilized for plant growth properly.

After harmlessly and steadily treated, the sewage sludge compost can be used as soil ameliorant or fertilizer for agricultural lands. There are lots of researches focused on the sewage sludge compost using for vegetable and crop. But it has derived of different viewpoints for sewage sludge compost application in agricultural land, since many pollutants are persistent and agricultural soils are irreplaceable. In this study, the sewage sludge compost was combined with the chemical fertilizers and made into compound fertilizer, in which the heavy metal contents should be lower and nutrient contents should be higher than sewage sludge compost. We studied the wheat growth, N P K and heavy metals uptake of wheat.

The experiments including pot and field experiments for wheat growth were carried out in 1998 and 1999. The sewage sludge collected from Fangzhuang wastewater treatment plant was composted and made into compound fertilizer in Institution of Geographical Sciences and Natural Resources Research. The pot experiment was conducted in green house with temperature of 15~25℃ and 10 hours of light per day. The relative humidity

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of the green house was kept between 50 ~ 60 percent. The field experiments were carried out in Beijing and Shijiazhuang province respectively. Four treatments were composed of the check(pot and plot experiment only), the sewage sludge compost (equal nutrient contents to chemical fertilizer, 1.13t/hm^2) and the marketable compound fertilizer(equal N content to the chemical fertilizer and sewage sludge compound fertilizer, higher P and K content than the two fertilizers, 1.13t/hm^2), the chemical fertilizer($Co(NH_2)_2$, $(NH_4)_2HPO_4$ and KCl), each one was replicated four times.

The results showed that the treatment of sewage sludge compound fertilizer did good effect on soil fertility and yield far higher wheat production than the chemical fertilizer, and equal to marketable compound fertilizer. In field experiments, the sewage sludge compound fertilizer improved the wheat yield by 10.7% ~ 17.0%, statistically greater ($\alpha = 0.05$) than chemical fertilizer. Wheat N uptake of all experiments was much higher in sewage sludge compound fertilizer treatments than which in chemical fertilizer and marketable compound fertilizer treatments. Compared with the other two fertilizer treatments, the nutrients utilization ratio of sewage sludge compound fertilizer treatment were enhanced 15.9% and 9.94% of N and 1.66% and 4.48% of P respectively. The soil nutrient contents were also improved after one year of sewage sludge compound fertilizer application. Increasing of heavy metal concentrations (Cu, Zn, Pb, Cd) in wheat seeds were observed with sewage sludge compound fertilizer application, but none exceeded the National Hygienic Standard for Foods.

Key words: sewage sludge; compound fertilizer; fertility efficiency; heavy metals

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城市污泥中含有植物生长所需要的营养元素及大量的有机质,经稳定化及卫生化处理后,杀灭了病原菌及杂草种子,可为植物提供养分、改良土壤[14],但是污泥中含有的重金属等有害成分成为限制其土地利用的因素。近年来随着各国环境立法的完善和环境管理水平的提高,城市污泥中的重金属含量均有一定幅度的降低,有的下降幅度甚至达到 95% 以上[5],我国的城市污泥中重金属的超标问题相对较轻[6]。因此,经过多年的争论之后,许多国家污泥的土地利用成为一种越来越重要的趋势[7]。

本研究目的是寻求一种安全、有效的污泥土地利用方式。根据污泥富含有机质、植物生长所需养分和具有粘结性的特点,利用稳定化处理后的生活污泥与化肥制成颗粒状有机-无机复合肥,一方面通过化肥补充污泥养分含量少的不足,另一方面充分利用了污泥中的有机质及养分,同时控制了重金属进入土壤和植物系统的总量。本试验通过盆栽、小区及大田试验,探讨了污泥复合肥对小麦的肥效及其对小麦吸收累积重金属的影响,为合理利用污泥、保护环境提供科学依据。

1 材料与方法

1.1 供试材料

供试污泥取自北京市方庄污水处理厂,属生活污泥。污泥采用 CTB 堆肥工艺进行工厂化快速堆肥处理,杀灭了病原菌、杂草种子,有机质达到稳定化之后,与化肥按一定比例混合制成污泥复合肥。污泥堆肥的基本性质见表 1,其重金属含量均低于我国农用污泥污染物控制标准[8]。供试污泥复合肥由中国科学院地理科学与资源研究所环境修复室研制,其养分含量 $N\text{-}P_2O_5\text{-}K_2O = 8\text{-}8\text{-}6$,市售复合肥养分含量为 $N\text{-}P_2O_5\text{-}K_2O = 8\text{-}8\text{-}9$,化肥为尿素、磷酸氢二铵及氯化钾。

盆栽试验的土壤采自北京市朝阳区洼里南口农田,风干、粉碎后过 2mm 筛。小区试验设在中国科学院栾城农业生态系统试验站,大田试验分别设在中国科学院栾城农业生态系统试验站及中国科学院遗传所农场。土壤均属于壤质褐土,其基本性质见表 1。

供试作物为小麦:盆栽试验小麦品种为掖单 22,小区及大田试验小麦品种为冀麦 38。

1.2 试验方法

1.2.1 盆栽试验 盆栽试验在温室中进行,室温控制在 15~25℃ 之间,光照时间 10h,相对湿度 50%~60%,每盆装土 1.25kg。试验设 4 个处理,分别为:①空白对照(不施肥);②污泥复合肥 5g/盆(与化肥处理等养

分);③化肥对照:尿素 0.54g/盆、磷酸氢二铵 0.83g/盆、氯化钾 0.5g/盆;④市售复合肥 5g/盆(与污泥复合肥处理等氮量),每个处理重复 4 次。

表 1　供试材料的基本性质

Table 1　The properties of experimental soil and sewage sludge compost

试验材料 Experiment materials	有机质 Organic matter (g/kg)	pH	全氮 Total-N (g/kg)	全磷 Total-P (g/kg)	速效养分(mg/kg) Available nutrients 碱解氮 Available N	速效磷 Available P	速效钾 Available K	重金属(mg/kg) Heavy metals Cu	Zn	Pb	Cd
盆栽土壤①	21.3	7.82	1.03	0.87	78.9	15.1	105	37.9	94.1	41.9	0.06
栾城土壤②	12.9	7.80	1.01	0.74	97.6	20.3	85.2	34.6	96.7	39.0	0.05
北京土壤③	14.3	7.86	1.07	0.82	72.17	19.0	85.2	23.6	71.2	34.0	0.07
污泥堆肥④	319	6.84	16.1	1.80				121	658	61.9	0.48
中国农用污泥污染物控制标准(土壤 pH≥6.5)[8]⑤								500	1000	1000	20

①Pot soil,②Soil of Luancheng,③Soil of Beijing,④Sewage sludge compost,⑤The national criterion of pollutants in sewage sludge application to agricultural land (soil pH≥6.5)

1.2.2　小区试验　小区试验面积为 1m²,设 4 个处理,分别为:①空白对照(不施肥);②污泥复合肥 113g/m²(与化肥处理等养分);③化肥对照:尿素 12.3g/m²、磷酸氢二铵 18.8 g/m²、氯化钾 11.3 g/m²;④市售复合肥 113g/m²(与污泥复合肥处理等氮量),每个处理重复 4 次。小麦收获后进行考种,并测定小麦籽粒中重金属含量及土壤中速效氮、磷的含量。

1.2.3　大田试验　大田试验面积分别为 10m²,共设 3 个处理:① 污泥复合肥 1.13kg/小区(与化肥处理等养分);② 化肥对照:尿素 123g/小区、磷酸氢二铵 188 g/小区、氯化钾 113 g/小区;③ 市售复合肥 1.13kg/小区(与污泥复合肥处理等氮量)。每处理重复 3 次。

2　分析测定方法

土壤和植物养分的测定参考《土壤农业化学常规分析方法》[9]。土壤和污泥堆肥中重金属用王水-高氯酸消煮,植物中的重金属用硝酸-高氯酸消煮,Cu、Zn 含量采用火焰原子吸收分光光度计测定;Pb、Cd 含量采用石墨炉原子吸收分光光度计测定[10]。

3　结果分析与讨论

3.1　污泥复合肥对小麦产量的影响

小麦成熟后的考种结果表明(表 2),施用污泥复合肥与空白和化肥对照相比,小麦株高分别增加 4.0 cm 和 1.7cm,有效分蘖增加 0.8 个和 0.2 个,每穗粒数增加 4.4 个和 1.2 个,盆栽试验中(表 3),污泥复合肥处理小麦生物量比不施肥处理增产 103%,差异达显著水平,而 3 个肥料处理之间没有明显差异。小区试验结果表明,所有处理中污泥复合肥处理小麦产量最高,比不施肥增产 64.4%,且差异显著,比施用化肥和市售复合肥分别增产 11.04%和 6.08%,但差异不显著。大田试验中,污泥复合肥及市售复合肥比化肥处理产量高 10%17%,且达显著性差异,但是两种复合肥之间差异不显著。

表 2　小区试验的小麦产量构成要素

Table 2　The yield basics of wheat in plot experiment

处理 Treatments	株高(cm) Height	有效分蘖(个/株) Effective tiller	穗粒数(个) Seeds/spike	千粒重(g) Weight of thousand seeds
空白对照①	70.9	1.6	30.7	40.2
化肥对照②	73.2	2.2	31.2	41.0
市售复合肥③	74.6	2.4	31.9	41.4
污泥复合肥④	74.9	2.4	32.4	41.5

① The control, ② Chemical fertilizer, ③ Commercial compound fertilizer, ④Sewage sludge compound fertilizer

由此可见,虽然污泥中 91% 以上的 N 和 95% 以上的 P 是以有机态存在[11],其速效养分含量低,但是由于污泥复合肥是有机肥与化肥的结合,其中有机肥稳定而持续的供肥特性和无机化肥养分供应速效性的特点互补,相互协调,无疑对作物生长发育有良好促进作用,其增产效果优于等养分的化肥。

3.2 小麦的养分吸收

判断肥料肥效的高低,作物对养分吸收量是一项重要指标。由图 1 看出,在各组试验中,污泥复合肥处理小麦籽粒吸收的 N、P 总量均显著高于空白处理和化肥处理,而与市售复合肥相比差异不显著。小区试验污泥复合肥处理的小麦籽粒,N 吸收总量比不施肥和化肥处理分别提高 139.4%和 12.5%,P 吸收总量分别提高 89.6%和 15.5%;栾城大田试验小麦籽粒吸收 N、P 总量,污泥复合肥处理比化肥处理分别提高 31.8%和 13.5%;北京大田试验中小麦籽粒吸收 N、P 总量,污泥复合肥处理比化肥处理分别提高 22.8%和 17.9%。因此,污泥复合肥的肥效优于化肥,与市售复合肥等同。

通过计算小区试验小麦籽粒对肥料中 N、P 的利用率得出,污泥复合肥处理的小麦籽粒对氮磷的利用率最高,其中氮的利用率分别比化肥和市售复合肥提高 15.9%和 9.94%;磷的利用率分别比化肥和市售复合肥处理提高 1.66%和 4.48%。可能是因为污泥复合肥中含有一定量的有机质,可以进行生物降解,而且可提高土壤 CEC,提供养分交换和吸附的活性点,从而提高对肥料的利用率。

表 3 不同施肥对小麦产量的影响

Table 3 The effect of different fertilizer on wheat yield

	处理① Treatments	产量* Yield	增产(%) Rate of increase production
盆栽试验,生物量(g/盆) Pot experiment, Biomass (g/pot)	空白对照	2.89b	
	化肥对照	5.78a	100
	市售复合肥	6.08a	110
	污泥复合肥	5.86a	103
栾城小区试验 Luancheng plot experiment (kg/hm²)	空白对照	5188b	
	化肥对照	7680a	48.0
	市售复合肥	8035a	54.9
	污泥复合肥	8524a	64.3
栾城大田试验 Luancheng field experiment (kg/hm²)	化肥对照	3932b	
	市售复合肥	4539a	15.4
	污泥复合肥	4359a	10.7
北京大田试验 Beijing field experiment (kg/hm²)	化肥对照	3442b	
	市售复合肥	3826a	11.1
	污泥复合肥	4025a	17.0

①同表 2 The same as table 2;* 同一列数据后标注不同字母,表示处理间 5%显著性差异水平($P<0.05$),下同 Values with different letter are significantly different in the same line

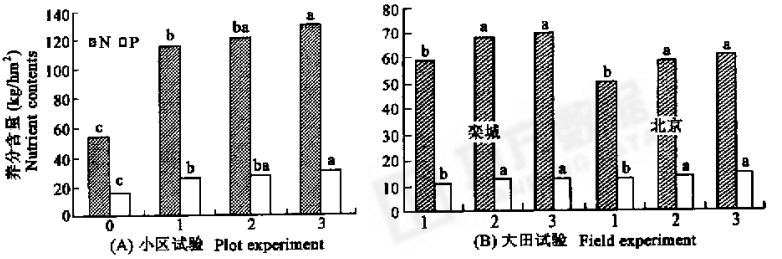

图 1 小麦吸收 N、P 养分含量

Fig. 1 The wheat N and P absorption with different treatments

0 空白 The control,1 化肥 Chemical fertilizer,2 市售复合肥 Commercial compound fertilizer,3 污泥复合肥 Sewage sludge compound fertilizer

3.3 污泥复合肥对土壤养分状况的影响

从土壤养分含量分析的结果可以看出(表 4),在盆栽试验小麦收获后,污泥复合肥处理的土壤速效 N、P 含量,比不施肥处理的分别提高 10.3mg/kg 和 37.1mg/kg;比化肥处理的分别提高 2.70mg/kg 和 10.7mg/kg,且差异均达显著水平;与市售复合肥相比没有明显差异。小区试验与盆栽试验的基本趋势一致,污泥复合肥处理的土壤速效 N、P 含量比不施肥处理提高 6.1mg/kg 和 9.0mg/kg,比化肥处理的提高 3.5mg/kg 和 8.1mg/kg,且差异均达显著水平,但与市售复合肥相比,土壤速效 N、P 含量没有明显差异。说明,污泥中的有机质和营养成分,对培肥土壤有积极的促进作用。因此污泥复合肥对土壤肥力的培肥效果明显高于化肥,与选用的市售复合肥相等。

Keefer[7]研究表明,施用 3740t/hm²干污泥,土壤 NH_3-N 由 4.8mg/kg 提高到 6.06.5mg/kg,速效磷由

13mg/kg 提高到 2750mg/kg。周立祥等人[13]的研究也表明,污泥施用量与土壤氮磷残留率呈显著的正相关。但是,随着污泥施用量的增大,造成重金属污染的危险性也就越大,而施用污泥制成的复合肥,纯污泥的使用量可降低到 1/1000 或者更多,带入的重金属大幅减少,因此土壤和作物受重金属污染的风险大大地降低 ;同时将复合肥制备成颗粒状,在贮存、运输和施用上均比直接施用污泥及其堆肥要方便。

3.4　污泥复合肥对小麦重金属吸收的影响

重金属是限制污泥农用的主要因素之一。李国学研究表明[14],随着污泥堆肥施用量的增加,青菜中 Cu、Zn、Pb、Cd 含量呈累积趋势。在污泥施用量≥5%时,青菜地上部 Cu、Zn 浓度分别超过国家允许标准(10mg/kg 和 20mg/kg),当施用量≥10%时,青菜组织中 Cd 含量超过国家允许标准 0.05 mg/kg。许多研究还表明,DTPA 提取的 Cu、Zn、Pb、Cd 随着污泥施用量的增大而增加[15,16]。

小区试验中,不同肥料处理小麦籽粒重金属含量的分析测定结果列于表 5。不施肥处理的籽粒中 Cu、Zn 含量分别为 4.06mg/kg、26.9mg/kg,施肥处理小麦籽粒中 Cu、Zn 的含量分别为 4.865.01mg/kg 和 29.030.7mg/kg,比不施肥处理有显著增加,而施肥处理之间 Cu、Zn 含量没有明显差异 ;小麦籽粒中 Pb、Cd 含量施肥处理与不施肥处理极为近似,含量在 0.110.13mg/kg 和 0.0080.010mg/kg 之间,没有显著差异。以上所有处理的重金属含量均在我国小麦籽粒含量的背景值范围[17],且低于国家食品卫生标准[18]。以上结果说明,施用污泥复合肥没有使小麦籽粒受到重金属污染,其对小麦籽粒累积重金属的影响程度,与施用等养分化肥和等氮量的市售复合肥的影响完全相当。

表 4　小麦收获后土壤养分含量

Table 4　The soil nutrient contents after wheat harvested

项目 Item	处理* Treatments	养分含量(mg/kg) Nutrient contents 速效氮 Available N	速效磷 Available P
盆栽试验 Pot experiment	空白对照	84.4 c	16.2 c
	化肥对照	92.0 b	42.6 b
	市售复合肥	95.1 a	51.1 a
	污泥复合肥	94.7 a	53.3 a
小区试验 Plot experiment	空白对照	83.6 c	5.20 b
	化肥对照	86.2 b	6.10 b
	市售复合肥	89.9 a	13.3 a
	污泥复合肥	89.7 a	14.2 a

* 同表 2 The same as table 2

表 5　不同肥料处理小麦籽粒重金属含量 (mg/kg)

Table 5　The heavy metals contents in wheat seeds with different treatments

项目 Item	Cu	Zn	Pb	Cd
空白对照 The control	4.06 b	26.9 b	0.11 a	0.008 a
化肥对照 Chemical fertilizer	4.91 a	29.0 a	0.12 a	0.010 a
市售复合肥 Commercial compound fertilizer	4.86 a	30.1 a	0.13 a	0.008 a
污泥复合肥 Sewage sludge compound fertilizer	5.01 a	30.7 a	0.11 a	0.009 a
中国小麦籽粒中重金属背景值[17] The background value of heavy metals in Chinese wheat seed	6.08.0	16.676.3	0.050.13	0.0130.107
国家食品卫生标准[18] The National Hygienic Standard for Foods	≤10	≤50	≤0.4	≤0.1

决定重金属是否被植物吸收的另一重要因素,是重金属元素在土壤中的存在形态,因为土壤中重金属的生物有效性主要决定于其有效态含量[19]。研究表明[20],植物从污泥堆肥中吸收的 Cd、Zn 通常比从含等量重金属的无机盐中吸收的少,这说明重金属在污泥中多以稳定的化学形态存在。Chang[21]等对比了含等量重金属的污泥堆肥与液态污泥对大麦吸收重金属的影响,发现液态污泥处理的大麦籽粒中 Cd 含量高于污泥堆肥处理,说明污泥经堆肥后重金属形态发生了变化。

由此可见,尽管一部分人担心农田施入污泥存在重金属污染的危险性,但如果合理使用就不会对食物链产生危害。本试验结果表明,污泥复合肥在增产和提高土壤养分含量方面等同于市售复合肥和化肥,而在这 3 个肥料处理中,作物对吸收累积重金属没有明显差异。

4　结论

(1) 施用污泥复合肥对小麦有增产效果,与等养分化肥相比最大增产达 17% ;(2) 施用污泥复合肥明

显促进小麦对养分的吸收和利用,氮素的利用率较化肥和市售复合肥提高 9.94%15.9%,磷素的利用率较化肥和市售复合肥提高 1.66%4.48% ;(3) 施用污泥复合肥可提高土壤速效养分水平,其效果与市售复合肥效果相当,明显优于等养分的化肥 ;(4) 施用污泥复合肥的小麦籽粒中,Cu、Zn、Pb、Cd 的含量均在国家食品卫生标准范围内,与施用化肥和市售复合肥相比,重金属含量没有显著性增加。

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