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Application of Crop Residues in Protected Cultivation in China

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ABSTRACT

China is a country with abundant crop residue resources and largest area of protected cultivation in the world. The resources of crop residues and their application status are briefly introduced in this paper. Aimed at the reuse of agricultural waste resources and the sustainable development of protected cultivation, the utilization and effects of crop residues under protected cultivation in China are presented. The future prospects and current problems of crop residue application have also been discussed.

Keywords: agricultural wastes, crop straw, growing media, organic fertilizer, soil amendment

CONTENTS

INTRODUCTION

Crop residues are the main by-products from an agricultural production system; at the same time, they are extremely valuable biological resources, in which the content of carbon, oxygen and hydrogen accounts for more than 95%, and that of potassium, nitrogen, phosphorus, silica, calcium, magnesium, sulfur and other mineral elements shares only about 5%. The reasonable exploitation and utilization of crop residues is beneficial for the protection of the ecological environment and for the development of resource-saving and sustainable agriculture, and has been the subject of worldwide attention (Coxworth *et al*. 1981; Dev and Bhardwaj 1991; Zhang *et al*. 2006).

There are many ways to make use of crop residues, for example, returning crop residues to the field (both direct returns and indirect returns), developing straw forage, as fuel or raw materials of chemical and industrial products, and so on (Gao *et al*. 2002; Han *et al*. 2002; Liu *et al*. 2006a). Roughly speaking, 23% of crop residues are currently used as forage in China; 67% of livestock are fed by crop residues-related materials (Liu *et al*. 2007). As fuel, crop residues provide about 30-35% of domestic energy consumption in rural China (Liu *et al.* 2006a).

RESOURCES OF CROP RESIDUES IN CHINA

Being an important agricultural country, China has abundant resources of crop residues. The annual total amount of crop residues in the world is approximately 20×10^8 ton, of which China produces about 30% (Zhang *et al*. 2006). Based on a detailed investigation, Liu *et al*. (2007) concluded that the average production of crop residues in China was estimated at 6.3×10^8 tons in the last decade, that the average increase rate was about 1.2% in the last two decades, and that the production of crop residues would reach 7×10^8 tons in the next decade.

Rice straw, wheat straw and corn stalks are the predominant kinds of crop residues in China, occupying 76.1% of the total. Rice straw ranks first, at about 31.6%, followed by corn stalks and wheat straw, at 23.9% and 21.6%, respectively. The proportions of residues from grain crops, rape crops and legumes are just 4.1%, 3.8% and 2.7%, respectively (Gao *et al*. 2002). Along with the structural readjustment of crop cultivation, the percentage of economic crop residues is rising.

Geographically speaking, rice straw is mainly located in the central south, east China and some provinces in southwest regions; corn stalks are mainly distributed in the northeast, north China and some provinces in the east and central south regions; wheat straw comes mainly from the east, central south and north China (Han *et al*. 2002).

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Invited Mini-Review

CURRENT SITUATION OF CROP RESIDUE APPLICATION

China has the tradition of utilizing crop residues, most of which were directly applied as fertilizer, fuel or forages when agriculture was more traditional. Nowadays, direct returning of crop residues to fields is still practiced for its ease of application. At the same time, indirectly returning to the fields is becoming more and more popular, including decomposed organic fertilizer, manure digested by livestock and ashes.

The current leading utilization of crop residues is still organic fertilizer (including direct returns), which accounts for 36.6% of the total, followed by fuel and forages, 23.7% and 22.6%, respectively, with only 4.4% serving as raw materials. Above 40% of both wheat and rice straws are used as fertilizer by direct or indirect returns. Besides, 12.7% of crop residues is burned or discarded, which causes severe resource waste and environmental pollution (Gao *et al*. 2002).

Some new technologies have been developed in recent years and have shown prospective potential, by which crop straws are recycled as biomass energy resources or Industrial raw materials (Han *et al*. 2002; Zhang *et al*. 2006).

DEVELOPMENT OF PROTECTED CULTIVATION IN CHINA

There is a long history of protected cultivation in China, but which had not developed rapidly until the late 1980s. Currently, China has become the country with the largest area of protected cultivation in the world. The area of vegetable protected cultivation reached 2.50 million hectares at the end of 2003 (Zhang 2006), while only 28,770 ha and 50,000 ha for flowers and fruits in 2006 (Shen *et al*. 2007). Considering the types of protected facilities, greenhouses in China are characterized by solar-heated greenhouses whose area went beyond 0.60 million hectares in 2003, approximately 50% of the total area of greenhouses and high tunnels (Li 2005). Large multi-span greenhouses developed slowly in China due to the high construction investment and operating cost, with only 700 ha at the end of 2003 (Li 2005).

Soilless culture was introduced to vegetable commercial production in the late 1970s in China, and has developed rapidly since the end of the last century. The total area of soilless culture exceeded 1,070 ha by 2004 on mainland China, most of which was media cultivation, predominating in eco-organic type (Jiang and Yu 2005).

PROBLEMS IN SUSTAINABLE DEVELOPMENT OF PROTECTED CULTIVATION

Owing to the special environmental conditions and cultivation manners, the soil under protected cultivation often engenders continuous cropping obstacles, appearing as the deterioration of soil physical, chemical and biological properties, the increase of soil-borne pests and diseases, and the decline of crop yield and quality (Yu and Du 2000). Previous studies showed that continuous cropping of cucumber (*Cucumis sativus* L.) in greenhouse could result in alteration in structure and number of soil microorganisms, and activities of soil enzymes, pathogenic fungi, such as *Fusarium oxysporum*, accumulated obviously and became the dominant physiological group, while the activity of saccharase decreased (Wu *et al*. 2002a; Ma *et al*. 2004). The changes of soil biological properties will influence the transformation and absorption of nutrients, occurrence of diseases and insect pests, degradation of pollutants, as well as restoration of soil quality (Insam *et al*. 1991; Wang and Zhou 2002).

Secondary salinization of successively cropped soil is another limiting factor for crop growth, together with soil acidification and hardening, and nutrient unbalance, which are caused primarily by excessive and unbalanced fertilization (Tong and Chen 1991). Li *et al*. (2002a) pointed out that continuous cropping and excessive and unbalanced fertilization had become visible problems in protected cultivation. In recent years, continuous cropping obstacles in protected cultivation increasingly occur, and more and more attention has been paid to the improvement of successively cropped soil.

Many measures, for example, appropriate rotation, soil sterilization, application of organic manure, grafting and soilless culture, etc., have been put into practice to alleviate growth disorders of vegetables in successively cropped soil (Yu and Du 2000). Many studies have showed that the application of crop residues could improve the characteristics of continuous cropped soil and promote the yield under protected cultivation (Song 1997; Zhu *et al*. 2001b; Yu and Song 2003; Yuan *et al*. 2004).

APPLICATION AND EFFECTS OF CROP RESIDUES IN PROTECTED CULTIVATION

ORGANIC FERTILIZER

Manure application to fields has been common practice for many centuries in China. Crop residues are rich in organic matter and mineral nutrients, and the application of crop residues could increase soil humus and organic matter, promote nutrient transformation, improve nutrient availability and use efficiency (Dev and Bhardwaj 1991; Wu *et al*. 2002b; Bu *et al*. 2006). The effects of applying crop residues on improvement of nitrogen, phosphorus and potassium in protected cultivated soil have been confirmed, despite the various results from different straw types, soil conditions and application methods (Song 1997; Zhu *et al*. 2001a; Wu *et al*. 2006). In field experiments, the contents of available Zn, Mn, Fe and Cu increased respectively by 0.70-2.05, 4.77-5.94, 3.24-5.28 and 0·19-0·63 $mg \cdot kg^{-1}$ in soil applied with corn stalks at 3% of soil weight (Chen and Jiang 2000). Moreover, the application of corn stalks could improve the sulfur level in soil, and non-composed stalks were better than composed ones (Yan *et al*. 1994). Qi *et al*. (2003) found that the flowering and harvesting date of tomato (*Lycopersin esculentum* Mill., var. 'Zhongza No. 9') was 2-3 days earlier when cultivated in mixtures of soil with decomposed wheat straw, corn stalks and dung, the early yield increased by 14.43%, and fruit quality also showed obvious improvement.

There are two ways to apply crop residues: one is direct application, chopped or unprocessed, turned over into the soil or mulched on the ground; another is indirect application, including composting, animal digestion and burning. Generally, the reasonable amount of crop residues for direct application is around 0.5%-2.0% of soil weight, depending on the soil conditions, nitrogen fertilizer at 2%-5% of straw weight should be concurrently applied to adjust the C/N ratio and to prevent nitrogen competition among plants and microorganisms (Song 1997; Zhu *et al*. 2001a; Yu and Song 2003; Qi *et al*. 2007).

Besides traditional high temperature fermentation, specific microbial strains and agents, such as EM, cellulose and semi cellulose decomposing bacteria, have been developed and applied to fermentation of crop residues, in order to shorten the composting period and improve composting effects. Several specialized organic fertilizer factories have been set up in recent years, where crop residues are transformed into high-quality organic fertilizers by a process of machinery turning over, high-temperature composting and biological fermenting. It will undoubtedly promote the utilization of crop residues as organic fertilizer.

GROWING MEDIA

Rock wool and peat moss are ideal media for soilless culture. However, owing to the continuous increase in cost and the limited availability of peat moss, from the point of view of environmental protection and sustainable utilization of natural resources, many countries in the world have been trying to search for alternative resources since the end of last century (Bragg 1998; Carlile and Papadopoulos 1999). The development of other growing media becomes increasingly imperative, more and more attention has been paid to the reuse of organic and agricultural wastes (Lamanna *et al.* 1991; Tian and Wang 2000; Li *et al.* 2002b).

Following the rapid development of soilless culture in China, crop residues, such as corn and sunflower stalks, corn cob, wheat and rape straws, rice and cotton seed hulls, coconut husk, sugarcane trash and so on, have been exploited as growing media to reduce production cost (Li *et al.* 2002b; Liu *et al.* 2006b). Crop residues are usually the components of complex media due to their lower bulk density and higher porosity (Gao 2006). Sand: coconut coir (5:5), peat moss: corn stalks: cinder (2:6:2), both are ideal media for eco-organic soilless culture of most vegetables and flowers (Liu *et al.* 2006b). Jespersen (1993) found that composted organic wastes (mink manure, cow dung, wheat straw and wood chips) mixed with peat moss at 20%-40% had similar or better effects than peat moss. In our studies, compared with those grown in media of peat moss and vermiculate at 3:1 (v/v), the earlier first harvesting date and higher yield of both tomato and cucumber were observed, the fruit quality was also improved when grown in decomposed corn stalks and chicken manure or wheat straw and chicken manure at 1:1.5 (Dw/Dw) (Zhu 2002).

SOIL AMENDMENT

Crop residues contain cellulose, hemicelluloses as well as other substances, can increase the C/N ratio of soil and provide sufficient carbon and nitrogen for propagation and activities of microorganisms, which leads to great changes in microbial flora and quantity, and activities of soil enzymes (Zhu *et al.* 2001b; Song *et al.* 2002; Cai *et al.* 2004). Microbial activities affect physical, chemical and biological properties of soil, and play important roles in nutrient supply, disease control and soil conservation. It was found that the application of rice straw could boost the amount of actinomycetes and fungi in soil, while the number of nitrite, nitrate and denitrifying bacteria decreased as the rate of rice straw increased (Yin *et al.* 1996). In another experiment, at 14 days after rice straw application at 3% of soil weight, the amounts of bacteria, actinomyces and fungi increased by 4.8, 8.4 and 11 times, respectively, *Trichoderma* sp. and *Penicillium* sp. dominated in fungi, both of them are saprophytic fungi and with an idiosyncratic antagonism to *Fusarium oxysporum* and *Rhizoctonia solani* (Yuan *et al.* 2004).

All biological and chemical processes in soil must be catalyzed by enzymes, which positively influence soil fertility. The remaining maize stubble in fields could remarkably raise the activities of urease, phosphatase, cellulose and invertase (Song *et al.* 2002). In our greenhouse experiments with potted cucumber, the activities of saccharase, urease and catalase increased positively with the application rates of corn stalks or wheat straw after two months' supply, and there was no significant difference among the rates beyond 1.2% of soil in weight; After four months, the soil receiving 1.2% corn stalks demonstrated the highest enzyme activity, however, the enzyme activity increased proportionnally with the amount of wheat straw applied; The activity of saccharase in soil activated by corn stalks or wheat straw at the rate of 1.2% or above were always significantly higher than that in the soil fertilized with chicken manure (Qi 2006).

The application of crop residues could significantly increase organic matter and porosity, reduce bulk density and electrical conductivity, improve physical and chemical properties of successively cropped soil. The EC of soil continuously cropped by cucumber reduced by 26.5% when rice straw was independently applied, and the disease index and death rate of blight decreased by 10.8% and 7%, respectively; However, a 64.8% reduction in EC could be achieved when rice straw was applied with EM (Yu and Song 2003).

Aiming to improve successively cropped soil and control soil-borne diseases, chopped crop straws mixed with lime nitrogen ($CaCN_2$) are applied to soil in hot summer when greenhouses are vacant, followed by deep tillage, ridging, film mulching and overall irrigation, then sealing the greenhouses and keeping the soil at high temperature for at least 15 days. This measure doubles the effects on both soil sterilization and fertilization (Yu 2006).

IMPROVING ECOLOGICAL ENVIRONMENT

The environment inside greenhouses in winter is characterrized by low temperatures, high humidity, and CO_2 deficiency, which could be improved to a certain extent by the application of crop residues. Guo and Li (2003) reported that application of rice straw at 12 $kg{\cdot}m^{-2}$ with puffed chicken manure at 10 $kg{\cdot}m^{-2}$ could keep higher CO_2 concentration in solar greenhouse for more than 5 months and meet the CO_2 demand of long-season cultivated tomato. Nevertheless, greenhouse CO_2 varied with the application method, and deep underground was superior to uniform broadcasting and surface mulching (Wu *et al.* 2006).

Soil surface mulching with 5 cm-long wheat straw in a solar greenhouse could not only shorten the period of fruit development and increase the yield of cucumber, but also keep a stable soil temperature by lowering the maximum soil temperature and raising the minimum soil temperature (Zhai *et al.* 2005a). The daily average temperature was increased by 1.1-2.3°C in soil applied with corn stalks at 0.4%-1.2% (w/w), which could alleviate the damage of low soil temperature, and promote the growth of greenhouse grown cucumber in winter (Song 1997). On the other hand, straw mulching contributed to the preservation of soil moisture and the reduction of air humidity (Wu *et al.* 2006); Soil surface mulching with wheat straw or wheat straw and plastic film in a solar greenhouse cold increased the water utilization efficiency of cucumber by 74.2% and 102.3%, respectively (Zhai *et al.* 2005b).

"Straw bio-reactor technology" has been developed in some areas of China where crop residues, inoculated with special microbial strains, are placed into the soil by concentrated application, followed by irrigation and aeration. Fermentation of crop residues increases CO_2 concentration and soil temperature in greenhouse; at the same time, it provides plants with nutrients necessary for growth. It was reported that "Straw reactor technology" increased the yield of cucumber, tomato, pumpkin, and pepper by 30%-40%, and reduced the application of chemical fertilizers by 33% (Cao *et al.* 2005).

One ecological pattern of crop residues' comprehensive utilization integrates livestock breeding, vegetable cultivation and biogas generation in a solar greenhouse. Crop residues are used as forages of livestock breeding, fertilizer of vegetable growing and raw material of biogas; at the same time, biogas can be used for greenhouse heating and CO_2 enrichment.

PROSPECTS AND PROBLEMS OF CROP RESIDUE APPLICATION IN PROTECTED CULTIVATION

There are abundant crop residue resources in China, which has become the country with the largest protected cultivation area in the world, providing broader spaces for the application of crop residues. However, the application of crop residues under protected cultivation is still limited. Factors limiting utilization of crop residues may be attributed to the following:

(1) Currently, the collection, processing and application of crop residues are relatively inconvenient, labor-intensive and time-consuming, having few attractions for growers;

(2) The uneven distribution of crop residues in China and the diversity in types and sources as well as soil conditions lead to different characteristics and application effects;

(3) For direct returns, many technological problems, such as decomposing speed, nitrogen competition, disease

dissemination, quantitative application, etc., have not basically been resolved;

(4) Processing technologies and equipments for crop residues utilization have not fully developed, and few advanced technologies and equipments have been adopted;

(5) Industries, both organic fertilizers and growing media from crop residues, are initial starting and less developed in industralization and specialization. Scientific, unified product standards and regulations have not been established.

Comprehensive utilization of crop residues in protected cultivation profits the development of high efficient, environmentally-friendly, resource-saving and sustainable agriculture. However, the scale and technological level of crop residue utilization nowadays are still low, and both fundamental and applied research must be strengthened. At the same time, introduction and absorption of advanced technologies and equipments from developed countries should also be emphasized. More attention should be paid to the research and exploration of technology-dependent, market-oriented products from crop residues, as well as the standardized application techniques in protected cultivation.

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REFERENCES

* In Chinese with English abstract

Bragg NC (1998) The commercial development of a sustainable peat alternative substrate from locally derived industrial by-products. *Acta Horticulturae* **469**, 61-70

Bu YS, Miao GY, Zhou NJ, Shao HL, Wang JC (2006) Analysis and comparison of the effects of plastic film mulching and straw mulching on soil fertility. *Scientia Agriculturae Sinica* **39 (5)**, 1069-1075*

Cai XB, Qian C, Zhang Y, Pu Q (2004) Microbial characteristics of straw-amended degraded soil in central Tibet and its effect on soil fertility. *Chinese Journal of Applied Ecology* **15 (3)**, 463-468*

Cao CY, Pang SP, Xiao JZ, Yu FY, Zhou Z, Hou LF, Chen PJ (2005) Application of straw bio-reactor in solar greenhouses. *Chinese Agricultural Science Bulletin* **11**, 170-171*

Carlile WR, Papadopoulos AP (1999) The effects of environment lobby on the selection and use of growing media. *Acta Horticulturae* **481**, 587-596

Chen LR, Jiang Y (2000) Effects of corn stalks and stubble at different decomposition stage on available microelements in soil. *Journal of Jilin Agricultural Sciences* **25 (6)**, 23-25*

Coxworth E, Kernan J, Knipfel J, Thorlacius O, Crowle L (1981) Review: Crop residues and forages in western Canada; Potential for feed use either with or without chemical or physical processing. *Agriculture and Environment* **6 (2-3)**, 245-256

Dev SP, Bhardwaj KKR (1991) Recycling of crop wastes for improving crop yields and nitrogen-use efficiency in a wheat-maize system. *Bioresource Technology* **37 (2)**, 135-139

Gao XH (2006) Study on utilizing methods of agricultural straw and fertilizer and water management under tomato long-season cultivation in greenhouse. *Nanjing Agricultural University*, pp 6-21*

Gao XZ, Ma WQ, Ma CB, Zhang FS, Wang YH (2002) Analysis on the utilization current status of crop straw in China. *Journal of Huazhong Agricultural University* **21 (3)**, 242-247*

Guo WH, Li TL (2003) Effects of mixed application of organic materials on CO_2 concentration in greenhouse and tomato physiology. *Acta Horticulturae Sinica* **30 (5)**, 592-594*

Han LJ, Yan QJ, Liu XY, Hu JY (2002) Straw resources and their utilization in China. *Transactions of the Chinese Society of Agricultural Engineering* **18 (3)**, 87-91*

Insam H, Mitchell CC, Donnaar JF (1991) Relationship of soil microbial biomass and activity with fertilization practice and crop yield of three ultisols. *Soil Biology and Biochemistry* **23**, 459-464

Jespersen LM (1993) Production of compost in a heat composting plant and test of compost mixtures as growing media for greenhouse culture. *Acta Horticulturae* **342**, 127-142

Jiang WJ, Yu HJ (2005) Status, problems and prospect of soilless culture in China. *Greenhouse Horticulture* **6**, 14-16*

Lamanna D, Castelnuovo M, D'Angelo G (1991) Compost-based media as alternative to peat on ten pot ornamentals. *Acta Horticulturae* **294**, 125-130

Li JL, Cui DJ, Meng XX (2002a) Fertilization status and problems in vegetable cultivation under the controlled environments in Shouguang, Shandong. *Chinese Journal of Soil Science* **33 (2)**, 126-128*

Li SQ, Guo SR, Li SJ (2002b) Utilization of organic wastes for manufacturing soilless media. *Journal of Natural Resources* **17 (4)**, 515-519*

Li TL (2005) Current situation and prospect of greenhouse industry development in China. *Journal of Shenyang Agricultural University* **36 (2)**, 131-138*

Liu H, Jiang GM, Zhuang HY, Wang KJ (2007) Distribution, utilization structure and potential of biomass resources in rural China: With special references of crop residues. *Renewable and Sustainable Energy Reviews*, in press

Liu LX, Wu CZ, Hong W, Li J, Cai BL, Lin SW (2006a) Advances in comprehensive utilization of crop straw. *Subtropical Agriculture Research* **2 (1)**, 75-80*

Liu W, Yu HJ, Jiang WJ (2006b) Review on research progress and application of growing media for vegetable production in China. *Chinese Journal of Eco-Agriculture* **l4 (3)**, 4-7*

Ma YH, Wei M, Wang XF (2004) Variation of micro flora and enzyme activity in continuous cropping cucumber soil in solar greenhouses. *Journal of Applied Ecology* **15 (6)**, 1005-1008*

Qi WQ, He CX, Zhang ZB, Zou ZR (2003) Effects of straw and organic manure on the growth and development of tomato in greenhouse. *Shaanxi Journal Agricultural Sciences* **6**, 3-5*

Qi YF (2006) Effects of crop straw application on characteristics of continuously cropped soil and growth of cucumber in solar greenhouse. *Shandong Agricultural University*, pp 8-38*

Qi YF, Wei M, Wang XF, Su H (2007) Effects of straw on growth of continuous cropping cucumber in solar greenhouse and the suitable amount of application. *Journal of Shandong Agricultural University* **38 (2)**, 178-182*

Shen HL, Wen JH, Zou LR, Dong B (2007) Research progress in protected cultivated fruit trees in China. *Journal of Jilin Agricultural Sciences* **32 (2)**, 50-54*

Song SY (1997) Improvement effects of corn stalks on soil continuously cropped with vegetables in plastic greenhouse. *Transactions of the Chinese Society of Agricultural Engineering* **13 (1)**, 135-139*

Song R, Wu CS, Mou JM, Jiang Y, Guo JX(2002) Effects of maize stubble remaining in field on dynamics of soil microbial biomass C and soil enzyme activities. *Chinese Journal of Applied Ecology* **13 (3)**, 303-306*

Tian JL, Wang YH (2000) Current situations and research prospects on soilless culture substrates. *Acta Agriculturae Shanghai* **16 (4)**, 87-92*

Tong YW, Chen DF (1991) Study on the cause and control of soil secondary salinization in greenhouses. *Acta Horticulturae Sinica* **18 (2)**, 159-162*

Wang H, Zhou DM (2002) The improvement of soil enzyme activities as symboling in soil fertility. *Journal of Hebei Agricultural University* **25 (Suppl.)**, 60-62*

Wu CC, Cao X, QI MF, Li TL, Wang JF (2006) Effect of rice straw application on main environmental factors of soil in greenhouse. *Journal of Shenyang Agricultural University* **37 (3)**, 528-530*

Wu FZ, Zhao FY, Gu SY (2002a) The effects of continuous cultivating cucumber on the bio-chemical properties of soil in the plastic greenhouse. *System Sciences and Comprehensive Studies in Agriculture* **18 (1)**, 20-22*

Wu ZJ, Zhang HJ, Xu GS, Zhang YH, Liu CP (2002b) Effect of returning corn straw into soil on soil fertility. *Chinese Journal of Applied Ecology* **13 (5)**, 539-542*

Yan L, Guan LZ, Zhu FC (1994) The regulating effects of maize stalks combined with chemical fertilizers on potassium and sulfur in soil. *Chinese Journal of Soil Science* **25 (7)**, 61-63*

Yin YX, Zhang CL, Yao HL (1996) The effects of crop straw on microorganism in soil for protected vegetable cultivation. *Chinese Journal of Soil Science* **27 (5)**, 239-240*

Yu FL (2006) Methods for controlling continuously cropped obstacles of vegetables under protected cultivation. *China Vegetables* **(11)**, 51-52*

Yu JQ, Du YS (2000) Soil sickness problem in the sustainable development for the protected production of vegetables. *Journal of Shenyang Agricultural University* **31(1)**, 124-126*

Yu ZD, Song SY (2003) Effects of rice straw mixed with microbial inoculums on improvement of continuously cropped soil in greenhouse. *Transactions of the Chinese Society of Agricultural Engineering* **19 (1)**, 177-179*

Yuan F, Peng Y, Zhang CL, Shen QR (2004) Microbial effect of organic materials on controlling cucumber seedling diseases. *Chinese Journal of Applied Ecology* **15 (5)**, 867-870*

Zhai S, Liang YL, Wang JY (2005a) Effects of soil surface mulching on solar greenhouse grafted and own-rooted cucumber growth and soil environment. *Chinese Journal of Applied Ecology* **16 (12)**, 2344-2348*

Zhai S, Wang JY, Liang YL (2005b) Effects of soil surface mulching on cucumber production and water use efficiency in solar greenhouse. *Transactions of the Chinese Society of Agricultural Engineering* **21 (10)**, 129-133*

Zhang FM (2006) Stressing technological innovation and promoting modernization level of protected horticulture in China. *Journal of Shenyang Agricultural University* **37(3)**, 261-264*

Zhang XW, Zhao GB, Yang RQ, Wang Y (2006) Comprehensive utilization of agricultural straws in recycle economy. *Transactions of the Chinese Society of Agricultural Engineering* **22 (Suppl. 1)**, 107-109*

Zhu L, Peng Y, Yuan F, Zhang CL (2001a) Effects of application of rice straw and other organic material on available nutrients in soil. *Chinese Agricultural Science Bulletin* **17 (2)**, 30-36*

Zhu L, Zhang CL, Shen QR (2001b) The influence of organic materials application on pH, EC and microbe in continuously cropped soil. *Journal of Anhui Agricultural University* **28 (4)**, 350-353*

Zhu ZY (2002) The fermentation of crop straws and chicken manure and the effects on soilless culture of tomato and cucumber. *Shandong Agricultural University*, pp 38-43*