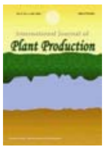

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Using SNPs for transplanting of cotton seedlings to increase plant growth and yield

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Abstract

Straw nursery pots (SNPs), which utilize agricultural residues such as wheat straw and corn stalks as raw materials, can be widely used in the transplanting of seedlings of crops, vegetables, flowers and trees. Plastic nursery pots (PNPs) and direct sowing (DS) were used as controls in evaluating the effects of SNPs on plant growth, dry matter partitioning, yields and economic benefits of transplanted cotton. SNPs significantly increased the rate of emergence, shortened the convalescent period by about 7 d and increased the transplant survival rate by 8.8% compared to PNPs. This led to significantly increased dry matter accumulation: that of reproductive parts for SNP seedlings were 1.5- and 1.8-fold of that for PNPs and DS, respectively. The lint yield using SNPs was 11.5 and 17.5% greater than for PNPs and DS, respectively. Boll number per plant with SNPs was 7.5 and 23.3% greater than for PNPs and DS, respectively; lint weight was not significantly different than with PNPs and was 5.8% greater than for DS. There were no significant differences in lint percentage among the three systems. Further benefit analysis showed that net revenue per hectare from using SNPs in cotton production was US$108 and US$279 greater than for PNP and DS, respectively. This was mainly due to significantly increased output, a reduced number of seedlings needed, nursery pot costs accounting for a relatively small proportion of total investment, and the relatively low labor costs in China.

Keywords: Straw nursery pot; Cotton; Seedling transplanting; Yield; Revenue.

Introduction

Cotton is one of the most important economic crops in China (Dong et al., 2009). Cotton is an indeterminate species (Bange and Milroy, 2004), and cotton yield per unit ground area is limited by heat accumulation in many cotton growing areas of the world. This is because the duration of plant growth and development, particularly the period of flowering and boll development, is restricted by low temperatures late in the season (Dong et al., 2007; Shu et al., 2009). Like other dicots, cotton seeds require high soil moisture and good soil preparation before sowing for successful emergence. When the soil is very dry, an inadequate number of seedlings become established, even when the number of cotton seeds sown is increased. Therefore, producers are continually searching for new techniques and methods to counteract the climatic and soil limitations.

Seedling transplanting can significantly increase yield, reduce seeding rates and improve crop establishment by eliminating harmful environmental effects before transplanting. For cotton, the duration of growth and development was extended in comparison with normal planting methods in northern Shandong, China (Dong et al., 2005). Such advantages for cotton transplanting have also been demonstrated in other countries (Sherif et al., 1995; El-Sahrigi et al., 2001; Greer et al., 2003; Karve, 2003; Sales et al., 2006). In recent years, many experts and producers have tested a variety of seedling transplanting methods, such as naked-root transplanting, soil-less seedlings, floating nursery seedlings in water-beds and micro-bowl seedlings. Nursery pots are still the main cultivation method in China's cotton-producing regions (Yu et al., 2000), with pots mostly made of soil or plastic. However, soil nursery pots easily deteriorate when they absorb water, and plastic nursery pots have poor ventilation and can easily damage plant roots during shelling and transplanting, and can even lead to environmental pollution.

To overcome these problems, we recently developed a straw nursery pot (SNP; Figure 1a). The SNP is composed of agricultural waste straw (e.g. wheat straw, corn stalks and other crop residues as raw material) and can be widely used in transplanting seedlings of some small trees and all crops, vegetables and flowers. Compared with soil and plastic nursery pots (PNPs), SNPs have at least three advantages. Firstly, they have better water holding capacity [the pot wall can maintain good strength even when saturated with water, helping maintain the rhizosphere soil moisture], promote seed germination, and effectively improve the drought resistance and survival rate of transplanted seedlings. Secondly, SNP is a single-use pot and requires no shelling before transplanting, which ensures ease of transport and greatly reduces the possibility of root damage (Figure 1b). Thirdly, SNPs are completely decomposed by soil organisms, thus reducing pollution of the soil and improving soil structure and fertility by increasing soil organic matter.

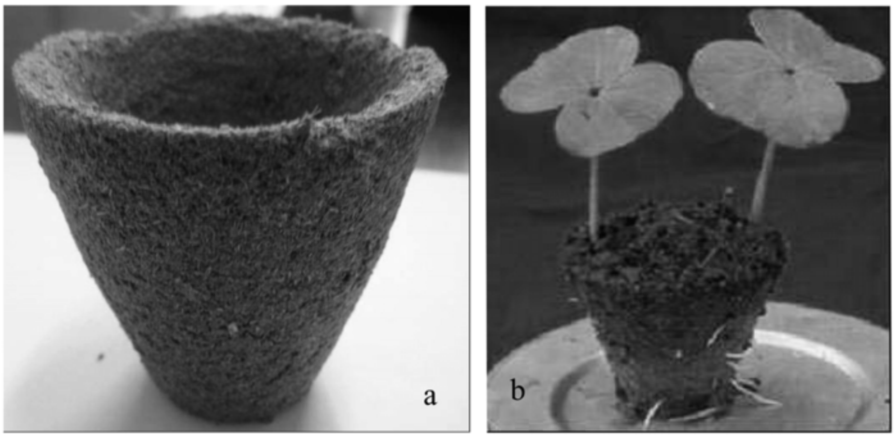

Figure 1. Straw nursery pot (SNP) (a) and cotton seedling raised using a SNP (b).

Annual straw fiber production is about 40×10^8 tons worldwide. Annual production in China amounts to several million tons, so straw fiber is a huge natural and renewable resource of biological polymers (Deng et al., 2009; Pan et al., 2010). Reports on crop straw modification and application have flourished in the literature (Wang and Sun, 2002; Sain and Panthapulakkal, 2006; Silverstein et al., 2007; Binod et al., 2010; Kaparaju and Felby, 2010; Talebnia et al., 2010; Tamaki and Mazza, 2010; Xu et al., 2010; Zhou et al., 2010). Bustamante et al. (2008) reported use of composts from distillery wastes as peat substitutes for transplant production. Gruda and Schnitzler (2004a) and Gruda and Schnitzler (2004b) reported the suitability of wood fiber substrate for production of vegetable transplants, but there have been few studies on seedling transplanting using nursery pots composed of crop straw.

The main objective of this paper is to investigate the effect of seedling transplanting using SNPs on cotton plant growth, fiber yield and yield components, and also to analyze the output value and cost composition of SNPs in cotton production to provide a reference for producers.

Materials and Methods

Site characterization and materials

Field experiments were conducted in Linyi County (34° 58′ N and 40° 17′ E), Shanxi Province, China, in 2008. The climate of this region belongs to the warm temperate zone. The mean annual rainfall is 508 mm and is confined to 3 months: July, August and September. The sunshine duration is 2272 h and the average air temperature 13.5 °C over the year, and the crop growing period is 208 d. The soil of the experimental area was a sandy loam with 30.1 g/kg organic matter, 1.24 g/kg total N, 76.1 mg/kg available P and 21.4 mg/kg available K.

SNPs (6 cm in diameter and 6 cm high) were made by machine-molding from modified corn stalks. Black PNPs of the same size, and plastic film (12 µm in thickness) to mulch the field were bought from the local market.

The cotton (*Gossypium hirsutum*) cultivar used was 'Jinmian 48', kindly provided by the Institute of Cotton, Shanxi Academy of Agricultural Sciences, Yuncheng, Shanxi.

Experiment design and cultural practice

With SNP and PNP treatments, cotton seeds were planted in a plastic house on 23 March 2009 and transplanted to mulched field plots on 22 April. Seeds for the DS treatment were directly sown into the mulched field plots on 22 April. The three treatments in the experiment were arranged in a completely randomized plot design with three replications. Each plot was five rows with row lengths of 20 m and row spaces of 80 cm.

To raise seedlings, prepared SNPs and PNPs were placed on a soil bed that was 10 cm deep and 2 m wide, each nursery pot was sown with one cotton seed and then filled with a mixture of soil and organic fertilizer. After watering, the seedling bed was covered with plastic film supported by bamboo sticks to form a 50-cm-high arched hut. The seedlings were grown in the hut until most reached the 2-3 true leaf stage when they were suitable for transplanting.

The seedlings from the SNPs and from the PNPs (with the plastic shell removed manually), were transplanted with a hand transplanter to the mulched field plots. Soon after transplanting, each field plot was watered to allow seedlings to recover normal growth quickly. Management practices in all the plots were conducted according to local practices.

Measurements and analysis

The data collected included the emergence rate, percentage of transplanted seedling survival, convalescent period, dry weight of seedlings, yield components and lint yield. For dry matter measurement, five plants were randomly selected from the center two rows in each plot on 15 August. Yield components consisted of plant density, boll number per plant, boll weight and lint percentage. Plots were harvested three times and lint percentage determined using a laboratory gin.

Data were statistically analyzed with Microsoft Excel 2003 and means were determined using Duncan's Multiple Range Test at $P<0.05$ or $P<0.01$.

Results

The emergence rate of seedlings

The effects of three different seedling transplanting systems (i.e. SNPs, PNPs and DS) were evaluated on the emergence rate of cotton seedlings (Figure 2). The emergence rate of SNP seedlings reached 97.3%, which was 12.2 and 28% more than in PNPs and DS in the field, respectively. The differences among the three systems were significant.

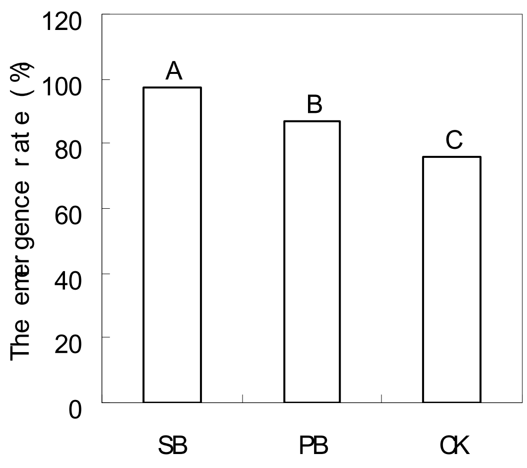

Figure 2. Effect of seedling systems on the emergence rate of cotton seedlings.

Transplanted seedling survival percentage and convalescent period

There were significant effects of seedling transplanting with SNP or PNP on seedling survival percentage and convalescent period (Table 1). Compared with PNP, the average seedling survival percentage was 8.8% higher and the convalescent period of SNP was about 7 d shorter. The sowing date for seedlings in SNP and PNP was about 20 d earlier than for DS, which had no need for transplanting and a convalescent period.

Table 1. Effect of seedling system on the convalescent period and survival seedling percentage of cotton.

Seedling system	Sowing date	Transplanting date	Convalescent period (days)	The survival seedling percentage (%)
SNP	23 March	22 April	2.5	96.9
PNP	23 March	22 April	9.4	89.1
DS	22 April	-	-	-

Dry matter partitioning

Plant biomass was increased significantly by transplanting seedlings (Table 2). SNPs and PNPs increased total dry matter weight by 49.7 and 20.7%, respectively, compared to DS. For SNPs, dry matter weights of leaves, stems and roots were 23.4, 21.0 and 18.1% greater than for PNPs, respectively, and 39.1, 45.0 and 21.0% greater than for DS. The dry matter weights of reproductive parts for SNP seedlings were 1.5- and 1.8-fold of that for PNP and DS seedlings, respectively.

Table 2. Effect of seedling system on the dry matter partitioning of cotton.

Seedling system	Leaf (g)	Stem (g)	Root (g)	Reproductive parts (g)	Total (g)
SNP	35.9[a]	38.0[a]	9.8[a]	41.9[a]	125.6[a]
PNP	29.1[b]	31.4[b]	8.3[b]	32.5[b]	101.3[b]
DS (CK)	25.8[c]	26.2[c]	8.1[b]	23.8[c]	83.9[c]

[a] Values in each column followed by the same letter are not significantly different (P=0.05) according to Duncan's multiple range test.

Yield and yield components

Seed cotton yield, lint yield, boll number and boll weight were significantly affected by the seedling transplanting systems; however, lint percentage was not (Table 3). Compared with DS, lint yield was 13.5 and 9.3% higher for SNP and PNP, respectively. Cotton seed yield of the different systems showed a similar trend to lint yield. The boll number per plant with SNPs was 7.5 and 23.3% greater than for PNPs and DS, respectively; and the boll weight using SNPs was 5.8% greater than for DS but not significantly different to PNPs.

Table 3. Effect of seedling system on yield and yield component of cotton.

Seedling system	Plant density (plants hm^{-2})	Boll no. (no. $plant^{-1}$)	Boll weight (g)	Lint percentage (%)	Seed cotton yield (kg ha^{-1})	Lint yield (kg ha^{-1})
SNP	51.225	20.1[a]	4.53[a]	38.7[a]	4663.5[a]	1804.5[a]
PNP	51.225	18.7[b]	4.45[a]	38.1[a]	4491.0[b]	1618.5[b]
DS (CK)	58.905	16.3[c]	4.28[b]	37.4[a]	4108.5[c]	1536.0[c]

[a] Values in each column followed by the same letter are not significantly different (P=0.05) according to Duncan's multiple range test.

Input, output and revenue

Output, input and net revenue of the SNP, PNP and DS systems in cotton production were calculated (Table 4). The output value of seedling transplanting, based on cotton seed yield, was considerably higher than that of DS; US$488 and US$336 per hectare higher for SNPs and PNPs, respectively, than for DS. For inputs, both SNPs and PNPs required only one-third of the seed cost of DS, but required additional nursery pot and labor days to nurture and transplant the seedlings. The material cost of SNPs was higher than of PNPs, but PNP treatment required extra labor to remove the plastic shell before transplanting, whereas seedlings in SNPs could be directly transplanted. Therefore, the total input value of SNPs was still US$44 higher than for PNPs; and SNPs and PNPs were US$209 and US$165 higher than for DS, respectively. However, the net revenue from SNPs was still US$108 and US$279 per hectare higher than from PNPs and DS methods, respectively.

Table 4. Input, output and net revenue in cotton production with SNP, PNP and DS system.

Seedling system	Seed cotton yield (kg ha^{-1})	Output value[a] ($ ha^{-1})	Input value ($ ha^{-1})				Net revenue ($ ha^{-1})
			Seed[b]	Material[c]	Labor[d]	Total	
SNP	4664	4103	44	1001	718	1763	2340
PNP	4491	3951	44	924	751	1719	2232
DS (CK)	4109	3615	132	770	652	1554	2061

[a] All values in this figure were converted from Chinese Yuan ¥ to US $ according the official foreign exchange rate (1$=6.82 ¥ in 2009). Seed cotton price was 6 ¥ /kg in 2009.
[b] Cotton seed price was 30 ¥ /kg in 2009.
[c] Material input includes transplanting block, fertilizer and other fees without the seed and labor. It costs 0.03 ¥ per straw nursery pot and 0.02 ¥ per plastic nursery pot, respectively.
[d] One labor per day costs 30 ¥ in 2009.

Discussion

Seedling growth in the field is retarded by stresses such as excesses or deficits in soil water, temperature extremes and soil-borne diseases (Vos, 1995; Leskovar and Vavrina, 1999; Dong et al., 2010; Eslami et al., 2010). One method to combat this problem is to manage the crop using a seedling transplanting system, in which seedlings are raised in a plastic house early in the season and transplanted to open fields after the temperature rises (Dong et al., 2004; Dong et al., 2005; Dong et al., 2006). In the present study, the emergence rates of SNP and PNP treatments were significantly higher than that of DS. Raising seedlings in nursery beds simplifies soil temperature and humidity control, and is more effective in preventing pest damage during the seedling period and therefore enhances individual seedling quality.

In general, there is a convalescent period in adapting to a new environment when cotton seedlings are transplanted into the field, due to water loss of seedlings and some root death (Xu et al., 2007). The greater the water loss and root death, the longer the convalescent period. Factors affecting convalescence time include age and seedling quality, transplanting technology and environmental conditions when transplanting (Xu et al., 2007). In this study, the convalescence period of cotton seedlings using SNPs was 7 d shorter than for PNPs and the survival rate was also significantly higher, due to the following reasons. Firstly, seedling roots in SNP can pass through the pot wall and form a more developed root system (Figure 1b). This is conducive to greater absorption of nutrients and water within the rhizosphere, ensuring better seedling quality, whereas the root system with PNPs is restricted to the pot before transplanting. Secondly, when seedlings are transplanted, the shelling process for PNPs can easily scatter the rhizosphere soil and make roots vulnerable. However, the SNPs can be transplanted together with the seedling and does not need shelling, thus causing relatively little damage to roots. Thirdly, better water holding capacity and permeability of SNPs maintains the transplanted seedling in a relatively stable micro-environment in the field, helping to shorten the convalescent period, enhance plant growth and improve survival.

As cotton is an indeterminate species, cultivation practices may have a significant impact on dry weight accumulation of roots, and vegetative and reproductive production (Bange and Milroy, 2000; Bange and Milroy, 2004; Read et al., 2006; Akram-Ghaderi and Soltani, 2007; Liu et al., 2010). Seedling transplanting techniques integrated with plastic-film mulching effectively alleviated the limitation of low temperatures after sowing on emergence and growth of cotton. Transplanting also allowed earlier sowing and extended the period of flowering and bolling, thus helping to resolve the conflicts between vegetative and reproductive growth, and individual development and group development (Dong et al., 2007). In the present study, the total dry matter of SNP seedlings was 24.0 and 49.7% greater than for PNPs and DS, respectively. The dry matter of SNP reproductive production was 1.5- and 1.8-fold that of PNPs and DS, respectively; the dry matter of leaves, stems and roots were also increased to some degree. This may be due to the better seedling quality before transplanting with SNP; in addition, the straw material may provide better water and ventilation conditions for cotton root production and shoot growth.

Transplanting cotton seedlings significantly increased the number of flowers and bolls per unit area early in the season, and increased cotton yield by > 11% (Dong et al., 2007). In the present study, with SNP transplanting, lint yield was 11.5 and 17.5% higher than for PNPs and DS, respectively; and boll number per plant was 7.5 and 23.3% higher, respectively. SNP boll weight was not significantly different to that of PNPs and was 5.8% higher than of DS, while lint percentage did not significantly differ among the three systems. Therefore, the yield increase with use of SNPs was mainly due to increased boll number and boll weight per plant, and the increased boll number may be important in producing the higher yield than for PNP.

Compared to corn, wheat and other field crops, the cultivation of cotton is labor-intensive, with higher inputs as well as higher outputs. The use of SNPs produced US$108 and US$279 more net revenue per hectare compared with PNPs and DS, respectively. Output per unit area was significantly higher for SNPs than for PNPs and DS, but required accordingly higher total input. Further analysis of the composition of input costs showed that one reduced cost with SNP and PNP treatments was due to less seed being required due to use of precision sowing technology; however, there was a need to increase other costs such as nutrients, pot and related materials, transplanting nursery management and labor. It is noteworthy that higher net income for the SNP system was mainly due to significantly increased yields and effective reduction of the amount of sown seed. Other important factors are that pot costs accounted for a relatively small proportion of investment and labor costs are relatively low in China.

Although the experiment with SNPs applied to cotton production was only conducted for one year in the field, the results were similar to those found for other plants for which the technique had been applied successfully, such as maize, watermelon, *Caragana intermedia* etc. It seems to have provided a new alternative to conventional clay for seedling transplanting. In conclusion, the growth of cotton seedlings and transplanting with SNPs had significant benefits on emergence, survival percentage and convalescent period of seedlings, dry matter partitioning, and yield and its components, compared with the PNP and DS systems in the present study. The net revenue unit area for SNP was also significantly higher than for PNP and DS, with accordingly higher total input. Therefore, the SNP system has the potential to further enhance cotton production in southern Shanxi and other cotton-growing areas with similar ecological conditions.

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