The Ecological Effects of Young Elm Trees Belt-Pumpkin Strip Intercropping System at the Agro-Pastoral Ecotone in Northern China

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Abstract

Young elm trees belt-pumpkin strip intercropping was studied to solve the actual problem of resource losses in the large barren area resulted from reconverting cultivated land into forest in the agro-pastoral ecotone in northern China. The final objective was to realize effective utilization of the barren land with both ecological improvement and economic development. Field experiments were conducted together with laboratory analysis. The results indicated that the soil moisture level was remarkably increased in young elm trees belt-pumpkin strip intercropping because the pumpkin vines covered the gap between pumpkin planting-furrow and elm trees belt. The water use efficiency of the intercropping system was increased by 23.7-163.3% as compared with the single cropping. Elm trees belt-pumpkin strip intercropping changed the sequential succession trend of the grasses growing in the gap of the pumpkin planting-furrow. The annual grasses become the dominant vegetation. The nutritive value as fodder and yield of the annual grasses were also increased remarkably. The biomass of pumpkin, elm trees and grasses under intercropping increased by 24.4, 28.4 and 144.4%, respectively, as compared with those under single cropping. The land use efficiency was increased by 132%. It was also indicated that the soil erosion from the intercropping land was not increased due to pumpkin plantation. The differences in the soil erosion among intercropped area, elm trees belt and pumpkin strip with single cropping were not remarkable. Therefore, it was concluded that young elm trees belt-pumpkin strip intercropping is an effective way to utilize the barren land between the young elm trees belt and realize synergistic enhancement of ecological benefit and economic profit.

Key words: ecotone, young elm trees belt-pumpkin strip intercropping, water use efficiency, land use efficiency, ecological benefit, economic profit

INTRODUCTION

The high altitude and cold-arid climate are the limiting factors for vegetation and habitat succession at the agro-pastoral ecotone in northern China (Zhang 2001). The imbalance in the ecological environment in that area has caused one of the nearest sandstorms headstreams to Beijing, the capital of China. The imbalance in the natural environment has directly threatened the ecological and economic security of Beijing and other areas of northern China. In addition, with social and economic development, the people also demand a better ecological environment. Thus, the project of returning farmland to forest/grassland (Green Project) is under way as a state policy of China for the ecologi-

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cally fragile areas, which began in the year 2000. This is the first instance in Chinese history which seeks to convert productive farm land back to natural forest and grasslands (Wu and Wang 2002; Wang et al. 2004; Ma and Fan 2005; He et al. 2006). The objective of the Green Project is to restore and rebuild the ecological environment and to regenerate and increase the existing resource capacity. However, recent studies have shown that the large-scale artificial forestation may result in the problems such as severe shortage of water resource, less vegetation coverage and reduction in plant diversity in this type of ecotone (Cao et al. 2007). The artificial planted forest suffers a reduction in biomass output, and vegetation coverage thereby causing large track of the land to remain greatly underdeveloped, thus waste. This wasted land rapidly loses both of its ecological function and economic benefit. This is very prominent case nowadays found in Hebei Province of northern China. This phenomenon has created the perception in the local farmers that Green Project changes the farmlands into wastelands. The vegetation biomass output decreased by 38.4-72.3% in this system (Du and Zhang 2007). It has created a conflict between the government which wants to protect the natural environment and the farmers who want to use the land as an income and food security source. Hence, the 88% of the farmers did not agree to plant trees or grass with the de-farming subsidy from government (Cao et al. 2007). Further, once the state government has stopped providing the financial compensation to the farmers, their economic income could sharply decrease. It un-avoidably forces the farmers to reclaim the de-farming farmlands resulting in a large economic loss to the government due to huge farmland reclamation (Du and Zhang 2007). It remains a primary problem as to how to protect the good ecological environment and, at the same time, satisfy the basic needs of the farmers for living and food production. Both of these issues also speak to the welfare of the nation, both today and tomorrow.

The extensive studies have been carried out in the agro-pastoral ecotone of northern China with ecological imbalance such as different types of farmlands (Liu and Zhang 2004), feasible forestation pattern and its potential productivity (Wu and Wang 2002; Wang et al. 2004; Ma and Fan 2005; He et al. 2006), establishment of scientific economic compensation mechanism after de-farming (Huang et al. 2002; Zhi et al. 2004; Lai and Liu 2006), and mechanism of the succession and enhancement of the productivity in de-farming eco-system (Liu and Zhang 2004), etc. Other studies on the agro-forestry systems were conducted in the farming area and mainly focused on the economic effects (Jiang et al. 2006), microclimate change (Wang et al. 2001; Yuan et al. 2002) and plant root growth of the complex eco-system (Singh et al. 1989; Lehmann et al. 1998). The key interest of these studies in the ecological fragile area of northern China is focused on balancing the distribution of traditional crops in order to decrease soil and wind erosion, which is one of the biggest problems. The experiments were conducted using oat-potato strip intercropping (Zhao et al. 2005) and ryegrass-oat-potato intercropping to increase the coverage ratio in winter (Chen et al. 2007). But, in the de-farming agro-pastoral ecotone of northern China, the information regarding rebuilding the vegetation community structure to provide both increased economic profit and ecological benefit is lacking. To address this problem on reclaimed forest from farm land, the pumpkins were planted between the rows of young elm trees belt, the so-called wasteland. The wasteland was tilled using conservation methods. The elm trees were selected to provide a long-term soil cover and the pumpkins as one kind of sparse-planted cash crop. This method is contrary to the local tradition of planting grain crops instead of sparse-planted cash crops. This method is contrary to the local tradition of planting grain crops instead of sparse-planted cash crops. The objective of the study was to reveal the economic and ecological effects of the intercropping pattern and then provide an idea and technology for restoring vegetation coverage, increasing farmers’ income and eventually gaining a persistent ecological restoration and economic development in this ecotone of northern China.

MATERIALS AND METHODS

Experimental site

The field experiments were conducted at the Key Field Research Station, Zhangbei Agricultural Resource and Ecological Environment, Hebei Province of northern China under the guidance of Ministry of Agriculture, China. The experimental site was located at 41°11.35’N
and 114°51.20´E (at 1 419 m above sea level). The ecological and economic conditions around the station are representative for the whole region. The region has a cold and dry climate with annual average temperature of 2.6°C and annual precipitation of 393.2 mm. There is an average frost-free period of 103 d. The tested field was with 0-20 cm layer sandy chestnut soil. The organic matter content in the soil was 12.1 g kg⁻¹. The contents of total nitrogen and phosphorus were 0.89 and 0.18 g kg⁻¹, respectively and the content of available nitrogen, phosphorus and potassium were 71.7, 2.5 and 60 mg kg⁻¹, respectively. The bulk density of the soil was 1.54 g cm⁻³, and pH value was 7.2.

**Experimental design**

The tested trees belt consisted of a young elm (*Ulmus pumila*) planted in 2001, when the Green Project of returning farmland to forest was implemented at Zhangbei, Hebei Province, China. A trees belt consisted of four rows of young elms. The trees were planted 1 m apart in the row with 1.5 m spacing between rows. The distance between the trees belt was 9 m. In 2005, six belts of young elm with relatively uniform growth size (average height 70 cm, basal diameter 1.23 cm) were selected in a preliminary test. From 2005 to 2007, three rows of pumpkin (*Cucurbita moschata*) were planted at 2, 4.5 and 9 m apart from the trees belt. The organic manure was applied in the planting furrows of 1 m width. Subsequently, chemical fertilizer [(NH₄)₂HPO₄ + CO(NH₂)$_₂$ containing 60 kg ha⁻¹ of N and 45 kg ha⁻¹ of P₂O₅] was applied and the furrows were mulched with white plastic-film 90 cm width by ridger-mulcher simultaneously. These operations made pumpkin furrows a water-holding and fertilizer-enriching strip. The 2 m-wide row between the pumpkin planting furrows without tillage was covered by weed (grass). The 70 m-long young elm trees belt-pumpkin strip intercropping was regarded as the treatment. Three adjacent single-cropping trees belts, individual trees and an adjacent single-cropped pumpkin field were regarded as the controls for the intercropping. The amount of fertilizers and planting pattern of the single-cropped pumpkin was the same as that of intercropping, but the single cropped trees belt didn’t receive any fertilizer as that of intercropping. Thus, three groups of comparisons were formed as the young elm trees belt in the intercropping - the young elm trees with single-cropping, the grass in the gap between pumpkin planting furrows - the grass in the gap between young elm trees belts with single-cropping, and the pumpkin in the intercrop - the pumpkin with single-cropping. Each treatment of the experiment included three replications. The young elm trees belt-pumpkin strip intercropping is illustrated in Fig.1.

![Fig. 1 Diagrammatic presentation of young elm trees belt-pumpkin strip intercropping.](image)

On May 15 of each year, pumpkin seedlings with Redsun variety from South Korea were grown in the greenhouse of research station from 2005 to 2007. The seedlings were transplanted to experimental field with water supplement at two leaf stage. Except the water supplement when transplanting from greenhouse to experimental field, the pumpkin seedlings were rain-fed without irrigation during the whole growth period. The pumpkin seedlings were planted at the spacing of 40 cm apart in the row with the plant population of 9 000 plants ha⁻¹.

**Determination of soil moisture**

The soil samples were collected from the time when the elm trees were sprouted (i.e., before the pumpkin seedlings were transplanted) to the time when pump-
kins were harvested. The soil samples were collected at each growth stage of the pumpkin within the depth of 0-80 cm from both treatment and controls. The soil moisture content was measured with oven dry method. The precipitation in the whole growth period of each year was monitored.

Soil moisture (mm) = Soil layer thickness (cm) × Bulk density (g cm⁻³) × 10 × Fresh weight of the soil layer / Dry weight of soil layer. The field water consumption of each treatment at each growth period of the pumpkin (mm) = The soil moisture content at the initial growth stage + Precipitation - The soil moisture content at the final growth stage

Determination of biomass from each treatment

The whole pumpkin samples were collected at each growth stage in each plot. The dry matter weight per ha and dry biomass ratio were calculated after drying the samples. The ground diameter and plant height of ten elms trees randomly chosen were determined before sprouting, at the mid stage of elm trees growth and after the defoliation of trees. The above-ground part of these 30 elms trees were removed, then dried and weighed. The dry matter weight of elms per ha was calculated. According to the data from the three sample day, the correlation among dry matter weight (Y) and ground diameter (D), plant height (H) was expressed with the equation of \[ Y = 45.4386 + 0.321D + 0.21H \] (R² = 0.9237***). On the day when pumpkin samples were collected, the ground diameter and plant height of elms trees were also determined. According to the correlation equation, the cumulative biomass of the elms trees was calculated for the same period. The grass samples growing in the gap between pumpkin furrows and elm trees belts were also collected, dried and weighed with the sampling area of 1 m × 2 m for biomass weight.

Determination nutrients in grass samples

The grass samples were collected finally, dried and analyzed for total N and crude protein (N × 6.25) content by micro-kjeldahl method. The crude fat, crude fiber and crude ash content were determined with residue weight, acid-base treatment and burning method, respectively (Yang 1993; Han 1998).

Determination of soil wind erosion mass in the intercropping and single-cropping fields

The soil wind erosion mass was measured with the BSNE sand sample collector in the open intercropping and single-cropping fields between 10:00 and 17:00 on windy days. Three groups of sand sample collectors were arranged vertically to the wind direction in each kind of field. The soil wind erosion was measured at 20, 50, 100, 150, and 200 cm above the ground level. The tested field area met the requirements of the sand sample collector, which is a large open field. At the same time, the wind velocity and direction of wind were also determined.

Data processing

Experimental data was collected from 2006 and 2007. The data presented in this article are the means of these two years. The figures were plotted using Excel 2003 and analysis of variance was carried out using SAS 8.12.

RESULTS

The comparisons of vegetation biomass yield between intercropping and single-cropping plots

Taking the apparent coverage area of each vegetation and the growing stage of pumpkin as the reference, the cumulative biomass difference among pumpkin, grass and elm trees per ha was compared at the same growth stage as pumpkin. The average results of this 2 yr study are shown in Table 1.

The significant differences were observed for the cumulative biomass of grass between intercropping and single-cropping at each growth period. After blooming of the pumpkin, the intercropping was started to show advantages, and there were significant differences in biomass accumulation of pumpkin between intercropping and single-cropping at each growth stage. After spreading of the pumpkin vine, the differences of elm trees biomass accumulation were also significant between intercropping with pumpkin and single-cropping at each growth stage. In view of the whole growth...
period, there were significant differences between the intercropping and single-cropping for all these three vegetations. Because of intercropping, the biomass yield per unit area of the pumpkin increased by 24.0%, elm trees biomass increased by 23.1% and grass biomass increased by 144.5%. Under intercropping, the pumpkins in marginal rows spread their vines to the elm trees belt, and those in the mid rows spread the vines to the both sides. The light interception area of pumpkin leaves was enlarged to a great extent. Under single-cropping, the pumpkin vines were overlapped by each other, the photosynthesis was restricted and the biomass yield decreased. The increase in the yield by intercropping, increased the economic output of pumpkin by 23.2%. The tillage operation for the pumpkin were effectively buried the grass seeds. The annual grass became the dominant grass, and the biomass yield of grass in the gap between pumpkin rows was significantly increased compared with that in single-cropping. This was one of the important causes that promoted the grass biomass yield to increase greatly. Land equivalent ratio (LER) is the total land area of single cropping required to achieve the same yield as of the intercropping. LER was used to express the comprehensive resource utilization of young elm trees belt-pumpkin strip intercropping. According to the concept of LER, the occupied field area of elm trees belt-pumpkin strip intercropping system was estimated to be 2.32. It showed that the land utilization was increased by 132% compared with single cropping.

Table 1 The biomass yield (kg ha⁻¹) and economic value of pumpkin, grass and elm trees under intercropping and single cropping

<table>
<thead>
<tr>
<th>Growth stage</th>
<th>Pumpkin Intercropping</th>
<th>Pumpkin Single-cropping</th>
<th>Grass Intercropping</th>
<th>Grass Single-cropping</th>
<th>Elm trees Intercropping</th>
<th>Elm trees Single-cropping</th>
</tr>
</thead>
<tbody>
<tr>
<td>Before vine spreading May 15-Jul. 4</td>
<td>42.9 a</td>
<td>43.4 a</td>
<td>423.7 a</td>
<td>175.8 b</td>
<td>86.4 a</td>
<td>84.3 a</td>
</tr>
<tr>
<td>Vine spreading-flowering Jul. 5-Jul. 22</td>
<td>653.2 a</td>
<td>581.3 a</td>
<td>634.5 a</td>
<td>252.4 b</td>
<td>172.5 a</td>
<td>130.1 b</td>
</tr>
<tr>
<td>Flowering-fruit development Jul. 23-Aug. 14</td>
<td>1979.4 a</td>
<td>1547.9 b</td>
<td>696.6 a</td>
<td>288.6 b</td>
<td>184.1 a</td>
<td>138.5 b</td>
</tr>
<tr>
<td>Fruit development-maturity Aug. 15-Sep. 1</td>
<td>786.5 a</td>
<td>621.3 b</td>
<td>-34.4 b</td>
<td>-13.1 a</td>
<td>91.5 a</td>
<td>81.2 b</td>
</tr>
<tr>
<td>Whole growth period May 15-Sep. 1</td>
<td>3465.0 a</td>
<td>2793.9 b</td>
<td>1720.4 a</td>
<td>703.7 b</td>
<td>534.4 a</td>
<td>434.1 b</td>
</tr>
<tr>
<td>Economic output value (Yuan ha⁻¹)</td>
<td>10350 a</td>
<td>8400 b</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

The values denoted by different letters are significantly different from each other at $P < 0.05$ level. -, no data. The same as below.

Comparison of soil moisture changes in each vegetation between intercropping and single-cropping

The soil moisture content of each vegetation in field with intercropping and single cropping at 0-80 cm soil layer is shown in Table 2. The soil moisture content of pumpkin rows with intercropping and single cropping were both higher than that in grassland and elm-trees belt, before transplanting the pumpkin due to water conservation by plastic-film mulching. The differences ranged from 6.0 to 10.1 mm. The effect of soil water conservation was continued until vine spreading of the pumpkin. From the transplanting of the pumpkin to vine spreading, the differences in soil moisture content in grassland and elm-trees belt was not significant between intercropping and single-cropping. It showed that the young elm trees belt-pumpkin strip intercropping did not affect the soil moisture content in grassland between the pumpkin row and elm trees belt during this period. After vine spreading of the pumpkin, its leaf area and biomass were increased rapidly. Similarly, the water-consumption for transpiration increased greatly. At the flowering of pumpkin (July 22), the soil

Table 2 The soil moisture level (mm) in pumpkin, grass and elm trees belt field at 0-80 cm soil layer under intercropping and single-cropping

<table>
<thead>
<tr>
<th>Time</th>
<th>Pumpkin Intercropping</th>
<th>Pumpkin Single-cropping</th>
<th>Grass Intercropping</th>
<th>Grass Single-cropping</th>
<th>Elm trees Intercropping</th>
<th>Elm trees Single-cropping</th>
</tr>
</thead>
<tbody>
<tr>
<td>Before transplanting May 15</td>
<td>50.2 a</td>
<td>52.8 a</td>
<td>44.2 a</td>
<td>43.8 a</td>
<td>42.7 a</td>
<td>44.1 a</td>
</tr>
<tr>
<td>Transplanting Jun. 7</td>
<td>54.6 a</td>
<td>55.4 a</td>
<td>45.4 a</td>
<td>48.4 a</td>
<td>47.2 a</td>
<td>45.4 a</td>
</tr>
<tr>
<td>Vine spreading Jul. 5</td>
<td>81.8 a</td>
<td>78.8 a</td>
<td>64.3 a</td>
<td>65.6 a</td>
<td>71.2 a</td>
<td>67.6 a</td>
</tr>
<tr>
<td>Flowering Jul. 22</td>
<td>56.4 a</td>
<td>58.5 a</td>
<td>75.7 a</td>
<td>56.4 b</td>
<td>66.4 a</td>
<td>55.5 b</td>
</tr>
<tr>
<td>Fruit development Aug. 14</td>
<td>31.2 a</td>
<td>34.7 a</td>
<td>50.7 a</td>
<td>31.9 b</td>
<td>43.1 a</td>
<td>31.2 b</td>
</tr>
<tr>
<td>Maturity Sep. 1</td>
<td>34.4 a</td>
<td>35.8 a</td>
<td>55.4 a</td>
<td>36.7 b</td>
<td>45.7 a</td>
<td>34.3 b</td>
</tr>
</tbody>
</table>

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moisture content in pumpkin planting row was 10.0-19.3 mm lower than that in grassland and elm-trees belt. The differences in soil moisture content were not significant in pumpkin planting-row between intercropping and single-cropping. From flowering to maturity of pumpkin, the vines were spread entirely in the gaps between pumpkin planting rows and most parts of elm trees belt. The land surface was effectively covered by the pumpkin vines and water evaporation was significantly reduced. Hence, the soil moisture content in these areas with intercropping was significantly increased. In this period, the differences between intercropping and single-cropping ranged from 18.7 to 19.7 mm in grassland and from 10.9 to 11.9 mm in elm trees belt. The arid climate is the limiting factor for vegetation growth in the agro-pastoral ecotone of northern China. The intercropping of sparsely-planted pumpkin with vines covering land surface and young elm trees belt could reduce evaporation of soil moisture and increase the soil moisture content in the grassland between pumpkin planting rows and elm trees belt effectively. This is another important reason that made the biomass of grass and elm trees significantly higher with intercropping than that with single-cropping.

The effects of soil moisture utilization in each vegetation under intercropping and single-cropping

The growth stage of the pumpkin was regarded as the standard period. The soil water utilization of each vegetation under intercropping and single-cropping is compared at the same period in Table 3. The field water consumption was calculated from transplanting (June 7) to harvesting (Sep. 1). Before vine spreading of the pumpkin, the differences at each vegetation were not significant between intercropping and single-cropping and cumulative biomass of the same vegetation between intercropping and single-cropping was equivalent. It indicated that there was no significant difference in the water utilization efficiency of the same vegetation between intercropping and single-cropping. The water consumption of each vegetation was less than the precipitation, thus the soil moisture content increased to a certain degrees. The pumpkin was grown rapidly from vine spreading of to flowering. The vines were covered with the full grassland between pumpkin planting rows, and the soil moisture in the grassland with intercropping was increased by 11.4 mm, while the soil moisture content with single-cropping was decreased by 9.2 mm. The vines covering could reduce the soil water evaporation, due to the reason the water utilization efficiency of the grass with intercropping was increased by 2.23 times compared with that with single-cropping. As the part of elm trees belt was covered by the pumpkin vines, the water consumption of elm trees with intercropping was 7.3 mm less than that with single-cropping, and the water utilization was increased by 54.4%. There was no significant difference at each comparison of pumpkin between intercropping and single-cropping. After flowering to fruit development of pumpkin each vegetation was continued to grow.

Table 3 The water consumption of pumpkin, grass, and elm trees under intercropping and single cropping

<table>
<thead>
<tr>
<th>Growth stage</th>
<th>Precipitation (mm)</th>
<th>Item</th>
<th>Pumpkin Inter-</th>
<th>Single-</th>
<th>Grass Inter-</th>
<th>Single-</th>
<th>Elm trees Inter-</th>
<th>Single-</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Water consumption (mm)</td>
<td>53.0 a</td>
<td>56.8 a</td>
<td>78.7 a</td>
<td>77.0 a</td>
<td>70.3 a</td>
<td>73.9 a</td>
</tr>
<tr>
<td>May 15-Jul. 4</td>
<td></td>
<td>Soil moisture level (mm)</td>
<td>27.2 a</td>
<td>23.4 a</td>
<td>20.1 a</td>
<td>21.8 a</td>
<td>28.5 a</td>
<td>23.9 a</td>
</tr>
<tr>
<td>Vine spreading-</td>
<td></td>
<td>Water use efficiency (kg mm⁻¹ ha⁻¹)</td>
<td>0.81 a</td>
<td>0.76 a</td>
<td>5.38 a</td>
<td>2.28 b</td>
<td>1.23 a</td>
<td>1.12 a</td>
</tr>
<tr>
<td>flowering</td>
<td>84.5</td>
<td>Water consumption (mm)</td>
<td>109.9 a</td>
<td>104.8 a</td>
<td>73.1 b</td>
<td>93.7 a</td>
<td>89.3 a</td>
<td>96.6 a</td>
</tr>
<tr>
<td>Jul. 5-Jul. 22</td>
<td></td>
<td>Soil moisture level (mm)</td>
<td>-25.4 a</td>
<td>-20.3 a</td>
<td>11.4 a</td>
<td>-9.2 b</td>
<td>-4.8 a</td>
<td>-12.1 b</td>
</tr>
<tr>
<td>Flowering-fruit</td>
<td>46.9</td>
<td>Water use efficiency (kg mm⁻¹ ha⁻¹)</td>
<td>5.94 a</td>
<td>5.55 a</td>
<td>8.68 a</td>
<td>2.69 b</td>
<td>1.93 a</td>
<td>1.35 b</td>
</tr>
<tr>
<td>development</td>
<td></td>
<td>Water consumption (mm)</td>
<td>72.1 a</td>
<td>70.7 a</td>
<td>71.9 a</td>
<td>71.4 a</td>
<td>70.2 a</td>
<td>71.2 a</td>
</tr>
<tr>
<td>Jul. 23-Aug. 14</td>
<td></td>
<td>Soil moisture level (mm)</td>
<td>-25.2 a</td>
<td>-23.8 a</td>
<td>-25 a</td>
<td>-24.5 a</td>
<td>-23.3 a</td>
<td>-24.3 a</td>
</tr>
<tr>
<td>Fruit developmen-</td>
<td></td>
<td>Water use efficiency (kg mm⁻¹ ha⁻¹)</td>
<td>27.45 a</td>
<td>21.89 b</td>
<td>9.69 a</td>
<td>4.04 b</td>
<td>2.62 a</td>
<td>1.94 b</td>
</tr>
<tr>
<td>maturity</td>
<td>13.5</td>
<td>Water consumption (mm)</td>
<td>10.3 a</td>
<td>12.4 a</td>
<td>8.8 a</td>
<td>8.7 a</td>
<td>10.9 a</td>
<td>10.4 a</td>
</tr>
<tr>
<td>Aug. 15-Sep. 1</td>
<td></td>
<td>Soil moisture level (mm)</td>
<td>3.2 a</td>
<td>1.1 a</td>
<td>4.7 a</td>
<td>4.8 a</td>
<td>2.6 a</td>
<td>3.1 a</td>
</tr>
<tr>
<td>Total growth</td>
<td>243.7</td>
<td>Water use efficiency (kg mm⁻¹ ha⁻¹)</td>
<td>76.36 a</td>
<td>50.11 b</td>
<td>-</td>
<td>-</td>
<td>8.39 a</td>
<td>7.81 a</td>
</tr>
<tr>
<td>period</td>
<td></td>
<td>Water consumption (mm)</td>
<td>245.3 a</td>
<td>244.7 a</td>
<td>232.5 b</td>
<td>250.8 a</td>
<td>240.7 b</td>
<td>253.5 a</td>
</tr>
<tr>
<td>May 15-Sep. 1</td>
<td></td>
<td>Soil moisture level (mm)</td>
<td>-20.2 a</td>
<td>-19.6 a</td>
<td>11.2 a</td>
<td>-7.1 b</td>
<td>3.0 a</td>
<td>-9.8 b</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Water use efficiency (kg mm⁻¹ ha⁻¹)</td>
<td>14.13 a</td>
<td>11.42 b</td>
<td>7.40 a</td>
<td>2.81 b</td>
<td>2.22 a</td>
<td>1.71 b</td>
</tr>
</tbody>
</table>

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rapidly. Since precipitation was less than water consumption of the three vegetations in this period, there was a net reduction in the soil moisture content. The higher water utilization efficiency in intercropping than that of single-cropping was fully demonstrated because of the precipitation shortage. The water utilization was increased by 25.6% in pumpkin strip, 139.9% in grassland and 35.1% in elm trees belt. From pumpkin fruits development to maturity, as compared with single-cropping the water utilization efficiency was increased in intercropping by 52.4% in pumpkin strip, and 6.6% in elm trees belt. In view of the total growth period, the water consumption with intercropping was 18.3 mm less than that with single-cropping in grass strip, 12.7 mm less in elm trees belt. The soil moisture level under intercropping system was higher in grassland and elm trees belt due to conservation of water than the single-cropping system. The water utilization efficiency in intercropping system was increased by 23.7% in pumpkin strip, by 163.3% in grass strip and by 35.3% in elm trees belt as compared to single-cropping. The annual grass become dominant species under elm trees belt-pumpkin strip intercropping system. The growth period of the annual grass and pumpkin coincided well with the period of precipitation. This was the basic reason behind the significant increase in the water utilization efficiency.

Comparisons of grass communities and nutritive value of grass as fodder in young elm trees belt-pumpkin strip intercropping and single-cropping system

Under intercropping system, the major grass species in the rows between pumpkins included green bristlegrass [Setaria viridis (L.) Beauv], salsola (Salsola collina Pall.), Oakleaf Goosefoot (Chenopodium glaucum L.), melilot (Melilotus suaveolens Ledeb.), bindweed (Convolvulus arvensis L.), denticulata ixeris [Iseris denticulate (Houtt.) Stebb.], etc. On the other hand, scabrous cleistogenes [Cleistogenes squarrosa (Trin.) Keng], Artemisia dalai-lamae Krasch., Common Cephalanoplos Herb (Cirsium segetum Bunge), barbate needlegrass (Stipa capillata Linn.), and siberian cocklebur (Xanthium sibiricum Patr.) were the dominant grass species in the single cropping system. The palatability and nutritive value of these grasses as fodder was not fit for the animal husbandry. The tillage practices during the intercropping system enhanced the annual weeds to become the dominant grass species. The comparison of nutritive values of these grasses as forage crop (Fig.2) showed that there was significant difference in crude protein (CP), ether extract (EE) and crude ash (CA) contents between intercropping and single-cropping. Under the intercropping system the CP, EE and CA contents were increased by 2.25, 1.10 and 1.15%, respectively, while the crude fiber (CF) contents were decreased by 4.7%. All of these showed that intercropping had increased the nutritive value of the grass as forage for animal husbandry. In view of the nutritive value of grasses as forage under intercropping and single-cropping system, the intercropping system significantly increased the yield of crude protein by 78%, ether extract by 83%, crude fiber by 101%, and crude ash by 187% (Fig.3). It indicated that young elm trees belt-pumpkin intercropping system changed the pattern of natural succession of the plant communities in the rows between the elm trees belts, and made the annual grass to become the dominant species. The annual grass with higher biomass yield could not only prevent wind erosion effectively but also had higher economic value.

Comparison of the soil wind erosion between intercropping and single-cropping

The comparison of soil wind erosion is shown in Table 4 and Fig. 2. The nutritional contents of the grass in intercropping and single-cropping system. CP, crude protein; EE, ether extract; CF, crude fiber; CA, crude ash. The same as below.
Table 4 Comparison of the soil erosion mass (mg) in pumpkin, grass and elm trees under intercropping and single-cropping system

<table>
<thead>
<tr>
<th>Repeat</th>
<th>Elm trees belt-pumpkin strip intercropping</th>
<th>Pumpkin as single cropping</th>
<th>Elm trees belt as single cropping</th>
<th>Elm trees belt-pumpkin strip intercropping</th>
<th>Pumpkin as single cropping</th>
<th>Elm trees belt as single cropping</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2010</td>
<td>2134</td>
<td>1928</td>
<td>50</td>
<td>53</td>
<td>53</td>
</tr>
<tr>
<td>2</td>
<td>1820</td>
<td>2125</td>
<td>2124</td>
<td>45</td>
<td>50</td>
<td>44</td>
</tr>
<tr>
<td>3</td>
<td>2140</td>
<td>1785</td>
<td>2096</td>
<td>50</td>
<td>47</td>
<td>49</td>
</tr>
<tr>
<td>4</td>
<td>2095</td>
<td>1978</td>
<td>2113</td>
<td>55</td>
<td>46</td>
<td>45</td>
</tr>
<tr>
<td>5</td>
<td>1630</td>
<td>2145</td>
<td>1907</td>
<td>45</td>
<td>50</td>
<td>50</td>
</tr>
<tr>
<td>6</td>
<td>2040</td>
<td>2228</td>
<td>2117</td>
<td>45</td>
<td>45</td>
<td>42</td>
</tr>
<tr>
<td>Average</td>
<td>1956 a</td>
<td>2066 a</td>
<td>2048 a</td>
<td>48 a</td>
<td>49 a</td>
<td>47 a</td>
</tr>
</tbody>
</table>

The data are the sum of the amount of collected sand at five height levels (20, 50, 100, 150, and 200 cm) in each day of observation.

restoration.

DISCUSSION

In the agro-forestry ecosystem, the competition for natural resource between trees and crops has always been matter of concern reported by many researchers (McIntyre et al. 1997; Smith and Jarvis 1998; Zhao et al. 2006). The occurrence of competition was related to natural environment, crop types and trees specific properties. The earlier studies on the effect of intercropping system of Chinese white poplar with soybean, peanut and wheat showed that tree-crops intercropping improved the soil water and nutrient contents of the planting area resulting in vigorous growth of the trees. It was directly related to timely irrigation, covering the field surface by crops and improving the field microclimate (Yang et al. 2005). However, the height of the 6-7 yr compared with single-cropping system of pumpkin and elm trees, but there was no significant difference between intercropping zone and single-cropping zone. Under the condition of soft wind (wind velocity \( \leq 5.0 \text{ m s}^{-1} \)), the soil wind-erosion in the single-cropping system of pumpkin was higher than that of intercropping zone and less than single-cropping system in elm trees, but there was no difference between these three kinds of cropping. This indicated that the planting of pumpkin with plastic-film mulching between the young elm trees belts did not aggravate the soil wind-erosion either with heavy wind or with light wind. The elm trees belt-pumpkin strip intercropping system ensured the ecological and economic benefit. As to the comparison of the soil wind erosion under single-cropping of pumpkin and elm trees belts, there was no significant difference for heavy and light wind. It can be concluded that elm trees belt-pumpkin strip intercropping is a new planting system which leads to both ecological and economic benefit. This system has not only efficiently utilized the waste land between the elm trees belts but also increased the biomass yield to promote vegetation

Fig. 3 The yield of grass in intercropping and single-cropping system.
elm trees in the de-farming land was less than 2 m and the crown diameter was less than 40 cm, which was not exuberant. Thus, the elm trees belt-pumpkin strip intercropping system did not incur water/fertilizer competition, and crown shading of trees did not affect the natural growth of pumpkin. In the waste grassland between the elm trees belts, the low grass coverage and soil hardening resulted in rapid evaporation of soil water. It was a large loss for rain-fed vegetations. But, in the elm trees belt-pumpkin strip intercropping system, the pumpkin vines spread to the elm trees belt and covered the soil surface. This had reduced the soil water evaporation effectively and maintained higher soil water content to promotes elm trees growth, especially during dry seasons. Young elm trees belt-pumpkin strip intercropping could alleviate the water-stress for plant growth. Moreover, the intercropping had increased the biomass yield of the grass between elm trees belts. In the arid agro-pastoral ecotone, one of the deep causes for the increasing serious desertification was too low biomass productivity of vegetation (Luo 2001). In this sense, young elm trees belt-pumpkin strip intercropping could accelerate the vegetation restoration and prevent soil desertification.

Rainwater storage and efficient utilization is an effective way to develop crop resources in the arid or semi-arid agro-pastoral ecotone. The sparsely planting of cash crops is an optimum choice to utilize the rainwater efficiently. Pumpkin was sparsely planted with plastic-film mulching in the planting-furrows with enriched water and fertilizer. The rainwater was pooled to the root zone of the pumpkin and efficiently utilized. The pumpkin vines covered the ground surface in the strip and elm trees belt to fully access sunlight. The limited resource of rainwater, heat and sunlight was also efficiently utilized through the microhabitat differentiation coupling with pumpkin production in one field. The experiments were also showed another advantageous effect of this system. After raining in spring, the residual plastic-film was collected through manpower. Subsequently, the planting-furrow of pumpkin was ploughed, fertilizers were applied and mulched with plastic-film. The mulching had not only avoided soil wind erosion but also conserved the soil moisture in the furrows. As pumpkin is a typical cold-season crop, it could be grown during the relative cool climate in the ecotone and sold to the tropical regions such as Central China and Southern China during summer and autumn. Thus, unseasonable production of pumpkin could gain the obvious advantage of the market monopolization. In the de-farming waste grassland, the output value and net benefit of pumpkin per unit area were 8.35 and 13.35 times as many as those of oat that was the most important grain crop. This has started the development of an open marketable agriculture. The young elm trees belt-pumpkin strip intercropping system established a new type of farming system, with the moderate utilization of waste-grassland between young elm trees belts and promoted the enhancement of the ecological and economic benefits in the agro-pastoral ecotone in northern China.

To develop sustainable agricultural productivity in the agro-pastoral ecotone, agronomists put forward that the farming system with the minimum tillage and no-tillage should be adopted to reduce the soil wind erosion (Zhou and Lu 2004; He et al. 2005; Hu and Zhang 2005; Yang et al. 2005; Qin et al. 2007) in northern China. But it was inevitable that the soil surface would be exposed while planting during spring when hard wind are very common in northern China. Therefore, the efforts of reducing wind erosion were weakened. Moreover, in the ecological transitional region, developing unstable and traditional agriculture would easily cause low agricultural productivity and economic efficiency. While many forest experts put forward that returning farmland to forest and building shelterbelt should be carried out for ecology protection. Indeed, the function of returning farmland to forest and restoring vegetation for improving ecological environment was indoubtable, but precipitation in the arid region cannot meet the water demand for forest growth (Cheng 1999, 2002). As the land surface is not covered by bush and grass, the ecological effect of pure forest for wind-break and sand fixation is not obvious (Zhao et al. 2003). Considering the economic value, forestry is a long-term industry and its medium-term or short-term effects are inferior as compared with agriculture. It is difficult to resolve the conflict between the long-term interests that are the society’s demands to improve ecological environment, and the current benefits that are the farmer’s demand to increase economic income. Comparatively, based on returning farmland to forest, rationally exploiting the waste grassland between the
young elm trees belts and sparsely planting pumpkin as a cash crop with necessary protective tillage not only effectively restrained the natural degeneration and increased the biomass yield of the grass between the forest belts, but also promoted the young elm trees growth. Taking the pumpkin as an exchange medium with market chain, the market exchange makes different systems to greatly increase the comprehensive utilization efficiency of agricultural resources. Meanwhile, due to market exchange functions, the prolonged industry chain could resolve the conflict between short-term profits and long-term interests and promote the harmonious development of the ecology, economy and society in the agro-pastoral ecotone in northern China.

CONCLUSION

Young elm trees belt-pumpkin strip intercropping system increased the biomass yield of pumpkin by 24.4% and its economic output value by 23.2%. The biomass accumulation of young elm trees was increased by 28.4% and grass by 144.4% compared with single-cropping. The land utilization efficiency was increased by 132%. The soil disturbance from field management for pumpkin promoted the annual grass to become the prominent vegetation in the gaps between pumpkin planting furrows. The biomass yield of the annual grass was significantly higher than that in waste grassland between young elm trees belts. The content and yield of some forage nutrients, such as CP, EE and CP in the annual grass was significantly increased compared with the grass from the waste grassland. It is of great significance to develop animal husbandry in the agro-pastoral ecotone in northern China. As pumpkin vines effectively covered soil surface gaps between the pumpkin planting furrows and the elm trees belt, intercropping effectively restrained soil water evaporation and promoted the grass and young elm trees growth under a relatively sufficient water condition. Therefore, the water utilization efficiency of the vegetation with intercropping and that with single-cropping showed that there was no significant difference in soil wind erosion among intercropping, single cropping of pumpkin and the young elm trees belt because the ground surface of planting furrows and the gaps was covered with the plastic-film as a mulch, pumpkin vines and grass. The soil wind erosion was not increased due to soil disturbance in pumpkin field. So it was concluded that the young elm trees belt-pumpkin strip intercropping system is an applicable way to efficiently utilize the secondary resource in the de-farming land with planting forest and to realize synergistic enhancement of ecological benefit and economic profit.

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References


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