Front. Agric. China 2009, 3(4): 388–396
DOI 10.1007/s11703-009-0053-7

RESEARCH ARTICLE

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Root distributions in tillage layers and yields of pumpkin and oil sunflower in an intercropping system

Abstract Studies on the distribution of roots of pumpkin and oil sunflower in tillage layers and their relations with their above-ground biomass in an intercropping system were conducted by digging roots by layers, combined with DT-Scan and the WinRHIZO root analysis system, during harvest in the plateau of the northwest part of Hebei Province, China. The results of analyzing roots and ratio of root to shoot showed that oil sunflower had an advantage over pumpkin in the intercropping system. Root dry weight of oil sunflower in treatments of pumpkin intercropped with one row (J1) and two rows of oil sunflower (J2) was, respectively, 2.5 and 1.83 times that of sole oil sunflower cropping (YD); the root length was 1.25 and 1.27 times, the root surface area was 1.20 and 1.14 times, and the root volume was 1.53 and 1.44 times that of sole oil sunflower cropping, respectively. As oil sunflower was dominant in absorbing nutrition and water in the intercropping system, the growth and development of pumpkin were restricted. Root dry weight of pumpkin in sole cropping (ND) was 1.5 and 1.9 times as much as that in treatments of J1 and J2 in a 0- to 40-cm soil layer, with the root length, surface area, and volume being 1.02 and 1.13, 1.04 and 1.26, 1.22 and 1.22 times that of treatments of J1 and J2, respectively. The root and the above-ground biomass of intercropped pumpkin with oil sunflower were lower than those in sole pumpkin cropping, while those of oil sunflower were the opposite. Root density of pumpkin decreased in power function with the soil layers, while it decreased by exponential function in oil sunflower. It was concluded that sole pumpkin cropping rather than pumpkin-oil sunflower intercropping is the suitable planting regimen in this area.

Keywords pumpkin, oil sunflower, intercropping, root system

Received August 3, 2008; accepted October 25, 2008

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1 Introduction

Pumpkin (*Cucurbita moschata*) is a kind of vegetable with rich nutrients, and it possesses functions in both nutrition and health care for human beings. It can be used as both vegetable and food crop. As it has the characteristics of drought tolerance and suitability for larger-spacing planting, it is usually taken as the first candidate crop for increasing economic benefit in arid areas.

In recent years, with the ever-increasing demand for pumpkin, many studies have been done on pumpkin nutrient analysis (Zhang et al., 2002), variety selection (Zhang et al., 2001), rules of growth and development (Li et al., 2006; Yang et al., 2008), and water-fertilizer application (Wen et al., 2006; Huang et al., 2007; Gao et al., 2008), but few studies on the root system of pumpkin have been reported. Resources could be used with high efficiency in the intercropping system, and the distribution of root systems could be used to explain the reasons for the intercropping system of food crop with food crop (Liu et al., 2007b), but study on the distribution of roots of pumpkin and oil sunflower (*Helianthus* sp.) in an intercropping system has barely started.

Root is a very important organ for absorption, transition, and storage of nutrients, and it plays an important role in shoot growth and development. Its distribution characteristics can reflect the utilization conditions of underground resources by plant (Cheng et al., 2008). At the same time, the input of photosynthetic products is much needed to back up the root biomass and its physiological activity (Pregitzer, 2003), which means that the root mass may also be affected by the shoot biomass. The spatial distribution of roots in the soil determines the ability of a crop to uptake soil nutrients and water necessary to sustain plant growth. Although information on root distribution is fundamental for understanding a wide range of vegetation and especially crop processes, such as water and nutrient uptake and root competition, the methodological difficulties associated with data sampling are responsible for the lack of knowledge on root distribution (Liedgens and Richner, 2001).

Many studies show that the main difference in roots space distribution is due to the heterogeneity of the soil space, and the area with rich nutrition and water contributes to root activity. In the northwest part of Hebei Province, the soil layer is shallow (about 20 cm), and the soil is coarse, drought, and sterile. Hence, our study mainly investigated the relationships between roots and shoots in the intercropping system of pumpkin and oil sunflower and offers a theoretical foundation for reasonable planting and using pumpkin with a high efficiency in this area.

2 Materials and methods

2.1 Trial background

A field experiment was conducted in 2006–2007 at Zhangbei Agricultural Resource and Ecological Environment Key Field Research Station, Ministry of Agriculture of China (41°11.35′N, 114°51.20′E, and at 1416 m above sea level), in Hebei Province, China. This area has a cold and dry climate with an annual mean temperature of 2.6ºC and an annual average precipitation of about 350–400 mm. The non-frost period averaged 103 days (Liu and Zhang, 2004). The tested soil was sand chestnut soil with the physical characteristics shown in Table 1.

2.2 Experimental design

Oil sunflower and pumpkin were selected as testing crops. 0–2 rows of oil sunflower were interplanted with every 2 rows of pumpkin. The spacing of sole-cropped pumpkin (ND) was 200 cm × 45 cm, and that of sole-cropped oil sunflower (YD) was 50 cm × 25 cm. When pumpkin intercropped with one row of oil sunflower (J1), the distance between the 2 kinds of plants was 1 m; when pumpkin intercropped with two rows of oil sunflower (J2), the distance was 0.75 m. Four treatments were set, and the planting patterns are given in Table 2. Each treatment was randomly arranged with 3 replicates at a plot size of 24 m^2 (6 m × 4 m).

A seedling transplant method was used for both pumpkin (Sun from Korea) and oil sunflower (France A15). Seeds were planted in a small arch shed nursery on May 13. The seedlings were transplanted when 2 leaves spread (on June 3). Before transplantation, 2 kg diammonium hydrogen phosphate was applied to each plot. Pumpkin and oil sunflower needed 1 kg of water each; pumpkin was planted at the ridge base in a ridged plot, with a ridge 7–8 cm high and with the ridge top and ridge base being 60 cm and 25 cm wide, respectively. Plastic film mulching (wide 80 cm) was used on the ridge. A flat plot was used in YD, and the oil sunflower was planted on the ridge base in intercropping. Field management was conducted in the same way as a high-yield field was managed, and the crops were harvested on August 22.

2.3 Measurement and methods

2.3.1 Root measurement

During harvesting, all the roots of pumpkin and oil sunflower in the soil up to 40 cm deep were dug out by layers, with 10 cm of soil thickness considered as a layer.

Table 1 Physical characteristics of the tested soil

depth of soil/cm	bulk density/($g\cdot cm^{-3}$)	total porosity/%	field capacity/%	wilting moisture/%	soil available water/mm
0–20	1.54	41.89	19.72	4.07	31.30
20–40	1.57	40.75	10.27	3.11	14.32
40–60	1.78	32.83	9.65	3.52	12.26
60–80	1.65	37.74	13.16	3.27	20.78
80–100	1.62	38.87	20.61	3.21	34.80

Table 2 Planting patterns of treatments

treatment	spacing of oil sunflower/cm	spacing of pumpkin/cm
oil sunflower sole cropping (YD)	50 × 25	–
pumpkin intercropped with one row oil sunflower (J1)	200 × 25	200 × 45
pumpkin intercropped with two rows oil sunflower (J2)	150 × 25	200 × 45
	50 × 25	
pumpkin sole cropping (ND)	–	200 × 45

The primary experiment showed that a 40-cm soil bulk almost held all the roots of pumpkin and oil sunflower under the tested soil conditions.

Pumpkin roots were dug out by centering the plant and cutting a soil bulk of 45 cm × 45 cm × 40 cm, which nearly covered the pumpkin root range. As for oil sunflower, a soil bulk at 25 cm row width, about 25–50 cm length, and 40 cm depth was cut according to different intercropping patterns. All the soil between the 2 kinds of plants was dug out to ensure all the roots were collected. The soil volume per layer was recorded.

The roots were picked out from every layer of soil sample by screening the soil through a sieve with 1-mm meshes. All the roots were collected using a piece of gauze and washed clean. Oil sunflower root was dark brown in color, fine, and hard in texture, while that of pumpkin was yellow-white in color, thick, and soft. It was easily separated. The roots samples were scanned by scanner (Epson perfection 1670) in gray mode, and the images were saved in TIFF format. The WinRHIZO root analysis system was used to measure the root length, surface area, and volume. After scanning, the roots were oven-dried at 65°C.

2.3.2 Measurement of yield

Plants were harvested at the same time as root digging. The shoot (vine) was decomposed, and the fresh and dry weights were measured.

2.3.3 Data analysis

The experimental data in 2006 and 2007 were very similar, so the average value from the 2 years was used in this paper. All data processing and statistical analysis were performed using Excel and DPS 7.05 for Windows.

3 Results and analysis

3.1 Variation of pumpkin root parameters in different treatments

Table 3 shows the distribution of the root system of pumpkin in 0- to 40-cm soil layers, indicating that the root growth and development of pumpkin was remarkably restricted by the intercropping crop oil sunflower. Compared with the intercropping pattern, pumpkin sole cropping (ND) possessed the heaviest and longest root and the largest root surface area and volume in the 0–40 cm soil layer. Root dry weight of ND was 1.5 and 1.9 times as much as that of J1 and J2, while the root length, surface area, and volume were 1.02 and 1.13 times, 1.04 and 1.26 times, and 1.22 and 1.22 times as much as that of J1 and J2, respectively. The biggest difference in root characteristics of pumpkin in different planting modes appeared in the 0- to 10-cm soil layer. In the pumpkin-oil sunflower intercropping system, oil sunflower was found dominant over pumpkin in getting water, nutrition, and sunlight due to the restrained root growth of pumpkin.

The root biomass of pumpkin was decreased along with the deepening of the soil layer in a vertical direction (Table 3 and Fig. 1). They were mainly distributed in the 0- to 20-cm soil layer, accounting for 84.7%–88.7%, 65.4%–89.3%, 67.8%–73.4%, and 56.6%–87.0% of the total amount of root dry mass, length, surface area and volume in the 0- to 40-cm layer, respectively. Therefore, the roots of pumpkin took up water and nutrition mainly in the 0- to 20-cm soil layer.

Table 3 Root parameter variation of pumpkin in different treatments and in different soil layers

root parameter	treatment	0–10 cm	10–20 cm	20–30 cm	30–40 cm	0–20 cm	0–30 cm	0–40 cm
	J1	7.16bB	0.43aA	0.23bB	0.08abAB	7.59bB	7.81bB	7.89bB
fresh weight/g	ND	13.38aA	0.40aAB	0.33aA	0.11aA	13.78aA	14.11aA	14.23aA
	J2	5.43cC	0.33bB	0.10cC	0.05bB	5.77cC	5.87cC	5.92cC
	J1	1.15bB	0.40bB	0.21aA	0.08bAB	1.55bB	1.75bB	1.83bB
dry weight/g	ND	1.78aA	0.58aA	0.27aA	0.11aA	2.36aA	2.63aA	2.74aA
	J2	0.95cC	0.31cC	0.10bB	0.06bB	1.26cC	1.36cC	1.42cC
	J1	5659.53bB	2438.36bB	2338.66aA	1949.67aA	8097.88bB	10436.54bB	12386.21bB
root length/cm	ND	7148.12aA	2221.21cC	1891.74bB	1352.24cC	9369.33aA	11261.70aA	12613.31aA
	J2	4861.36cC	2771.40aA	1953.78bB	1595.48bB	7632.76cC	9586.53cC	11182.01cC
	J1	2915.60bB	1268.26bB	1152.26aA	838.39aA	4183.86aA	5336.13aA	6174.52bA
root surface area/cm^2	ND	3849.60aA	1048.08cC	909.58bB	608.36bB	4897.56aA	5807.14aA	6415.50aA
	J2	2120.85cC	1544.38aA	781.14cC	643.73bB	3665.23bB	4446.37bB	5090.10cB
	J1	54.16cC	42.72bAB	46.69aA	27.66aA	96.89cC	143.57bB	171.23bB
root volume /cm^3	ND	111.79aA	36.92bB	35.89bB	24.55aA	148.71aA	184.60aA	209.15aA
	J2	73.19bB	50.51aA	25.71cC	22.36aA	123.7bB	149.41bB	171.77bB

Note: Values followed by different small letters and capital letters represent significance at 0.05 and 0.01 probability levels according to LSD test (the same as below).

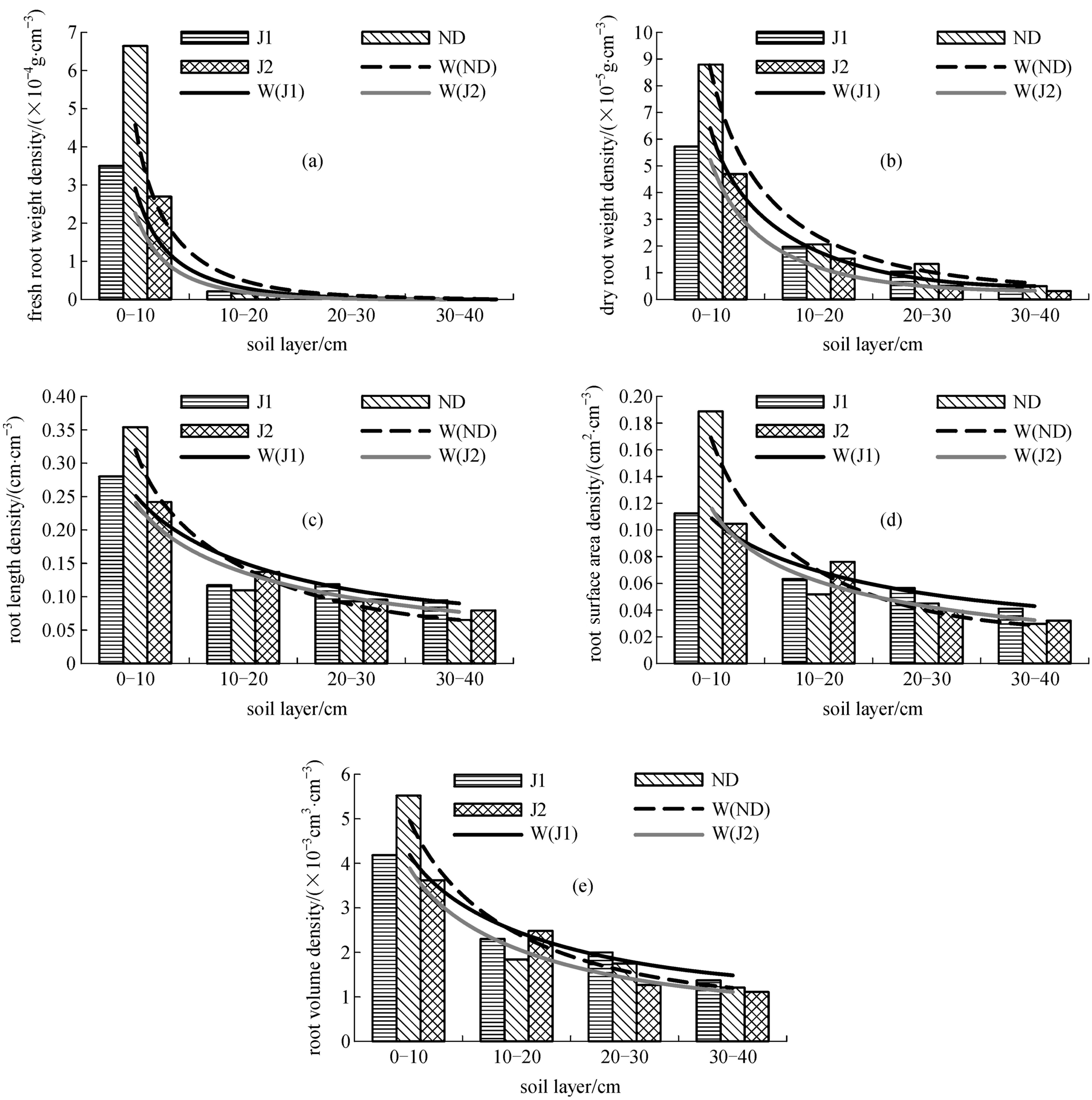

Fig. 1 Root parameter variation of pumpkin in different soil layers and in different treatments

The root length, surface area, and volume of pumpkin in J1 were more remarkable than those in ND at the layers below 20 cm. Additionally, the root dry weight, length, surface area, and volume of pumpkin in J1 and J2 took about 37.16% and 33.1%, 52.7% and 56.5%, 52.8% and 58.3%, 68.4% and 57.4% of the total in the 0- to 40-cm layers, respectively, while those in ND were 35.04%, 43.3%, 40.0%, and 46.6%, respectively. As oil sunflower took the advantage over pumpkin in the competition of roots in the 0- to 10-cm layer under intercropping conditions, pumpkin roots went down into the deeper soil layers to absorb the needed water and nutrients; hence, the nutrition-using area enlarged.

Root density of pumpkin decreased by a power function with layers of vertical direction (Fig. 1). The simulating model could be indicated by the following equation:

$$y = ax^b, \tag{1}$$

where y is the density of root weight, length, surface area, or volume, respectively; x is soil layer depth; and a and b are regression coefficients. From the model parameter of root density vertical distribution of pumpkin (Table 4), it was found that the simulating equations were very accurate ($P < 0.01$). Therefore, the equations could reflect the patterns of pumpkin root parameters in their vertical distribution.

Table 4 Model parameter of root density vertical distribution of pumpkin of different treatments

item	treatment	*a*	*b*	R^2	*P*
	J1	0.00036	–0.00001	0.8000	0.0018
fresh density	J2	0.00028	–0.00001	0.8003	0.0018
	ND	0.00067	–0.00002	0.7857	0.0025
	J1	0.000065	–0.0000017	0.9165	0.0000
dry density	J2	0.000053	–0.0000014	0.9014	0.0001
	ND	0.000099	–0.0000026	0.9076	0.0000
	J1	0.2909	–0.0055	0.8381	0.0007
root length density	J2	0.2691	–0.0052	0.9369	0.0000
	ND	0.3745	–0.0088	0.8511	0.0005
	J1	0.154	–0.00312	0.8789	0.0002
root surface area density	J2	0.127	–0.00257	0.9683	0.0000
	ND	0.166	–0.00383	0.8610	0.0003
	J1	0.00305	–0.000037	0.8433	0.00057
root volume density	J2	0.00431	–0.000088	0.9594	0.0000
	ND	0.00583	–0.00013	0.8444	0.0005

3.2 Variation of oil sunflower root parameters in different treatments

Unlike pumpkin, oil sunflower showed a significant dominant position in this intercropping system on root parameters in the 0- to 40-cm soil layers (Table 5). Root dry weight of oil sunflower in treatments J1 and J2 were 2.5 and 1.83 times as much as that in YD, respectively, while the root length, root surface area, and root volume in J1 and J2 were 1.25 and 1.27 times, 1.20 and 1.14 times, and 1.53 and 1.44 times as much as those in YD, respectively. Most roots of oil sunflower were distributed in the 0- to 20-cm soil layers. When comparing the root weight distribution in soil layers in intercropping with that in YD, it could be found that upper layers contained a much higher ratio of roots in intercropping than in YD. Root dry weight in the 0- to 10-cm soil layer in J1 increased by 4.4% higher than that in YD, while in the 10- to 30-cm soil layers in J2, it increased by 0.5% higher than that in YD. Oil sunflower in the intercropping system lowered the competition between the two varieties and increased the dominance of pumpkin compared to YD. Hence, root development of oil sunflower showed remarkable advantages.

Root density of oil sunflower decreased by exponential function in layers of vertical direction (Fig. 2) and can be simulated with the following equation:

Table 5 Oil sunflower root parameters in different treatments and in different soil layers

root parameter	treatment	0–10 cm	10–20 cm	20–30 cm	30–40 cm	0–20 cm	0–30 cm	0–40 cm
	J1	150.81aA	2.56bA	0.23bB	0.11aA	153.37aA	153.60Aa	153.72aA
fresh weight/g	J2	108.97bB	5.14aA	3.82aA	0.21aA	114.11bB	118.94bB	119.14bB
	YD	76.18cC	5.10aA	0.20bB	0.41aA	81.28cC	81.48cC	81.89cC
	J1	32.99aA	0.83bB	0.19bB	0.09bB	33.82aA	34.01aA	34.11aA
dry weight/g	J2	23.11bB	1.35aA	0.48aA	0.14aA	24.46bB	24.93bB	25.07bB
	YD	12.62cC	0.75bB	0.18bB	0.11abAB	13.37cC	13.55cC	13.67cC
	J1	67666.5aA	5694.1cC	2368.8cC	1836.6bA	73360.5aA	75729.3aA	77565.9aA
root length/cm	J2	51505.1bB	12724.6aA	11453.1aA	2695.9aA	64229.7bB	75682.8aA	78378.7aA
	YD	42759.5cC	9977.2bB	6404.5bB	2760.5aA	52736.7cC	59141.2bB	61901.7bB
	J1	36818.4aA	2763.7cB	1110.2cC	938.0bB	39582.1aA	40692.3aA	41630.3aA
root surface area/cm^2	J2	28920.3bB	4971.5aA	4665.6aA	1199.7bAB	33891.8bB	38557.4aA	39757.1aA
	YD	25708.5cB	4510.7bA	2827.0bB	1758.1aA	30219.2cB	33046.2bB	34804.3bB
	J1	1551.2aA	132.2bA	46.2cB	31.9bA	1683.5aA	1729.6aA	1761.5aA
root volume/cm^3	J2	1295.0bA	175.1aA	149.0aA	35.1bA	1470.1aA	1619.1aA	1654.1aA
	YD	852.4cB	163.0abA	85.6bB	48.6aA	1015.3bB	1100.9bB	1149.5bB

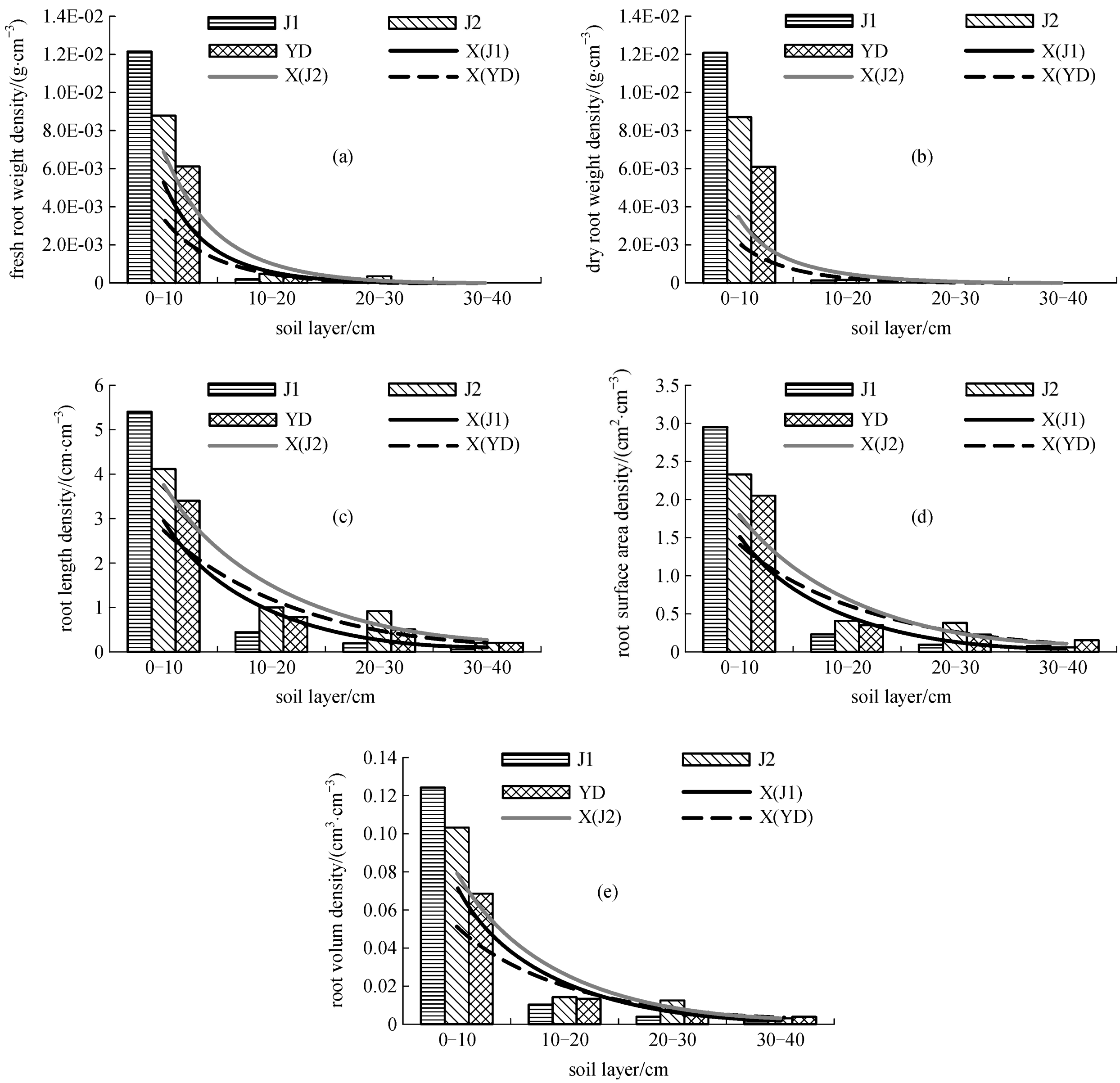

Fig. 2 Root parameter variation of oil sunflower in different soil layers and in different treatments

$$y = ae^{xb}, \quad (2)$$

where y is the density of root weight, length, surface, or volume, respectively; x is the soil layer depth; and a and b are regression coefficients. The model parameters of root vertical distribution of oil sunflower (Table 6) indicated that the simulating equations were very accurate ($P < 0.01$). Therefore, the equations could reflect the rule of root characteristic vertical distribution of oil sunflower.

3.3 Biomass variations of pumpkin and oil sunflower

The biomass of pumpkin and the oil sunflower plant was impacted to some extent when they were intercropped. The data of fruit weight, vine weight, and plant biomass of pumpkin were measured (Table 7), indicating that all indexes of pumpkin in intercropping system were lower than those in the sole cropping (ND) system; the differences among treatments were significant ($P < 0.01$). It meant that pumpkin was inferior to oil sunflower in growth and development in the system. Pumpkin grew better in J1 than in J2. Fruit weight and plant dry biomass of pumpkin in J1 were lower than those in ND, but the difference was not statistically significant. The economic yield of fresh fruit weight in ND increased by 24.5% and 102.6% compared with that in J1 and J2, respectively.

The result for biomass of oil sunflower in intercropping was opposite to that of pumpkin, resulting from edge effect; every item of the indexes in J1 and J2 of oil sunflower was better than that of YD (Table 8). The

Table 6 Model parameter of root density vertical distribution of oil sunflower of different treatments

item	treatment	a	b	R^2	P
	J1	0.0572	−2.3966	0.9103	0.0016
fresh density	J2	0.0435	−1.8868	0.9059	0.0026
	YD	0.0215	−1.8903	0.8200	0.0016
	J1	0.0357	−2.3585	0.8347	0.0025
dry density	J2	0.0275	−2.1104	0.8426	0.0019
	YD	0.0156	−2.0927	0.8276	0.0019
	J1	9.5315	−1.1697	0.8423	0.0016
root length density	J2	8.9518	−0.8955	0.9202	0.0002
	YD	6.5033	−0.8664	0.9509	0.0003
	J1	5.0559	−1.1922	0.8249	0.0018
root surface area density	J2	4.7099	−0.9611	0.9044	0.0006
	YD	3.2943	−0.8515	0.8826	0.0008
	J1	0.2528	−1.2708	0.8781	0.0015
root volume density	J2	0.2317	−1.0994	0.9145	0.0008
	YD	0.1248	−0.9235	0.9262	0.00067

Table 7 Biomass of pumpkin plant

treatment	fresh weight of fruit/g	dry weight of fruit/g	fresh weight of vine/g	dry weight of vine/g	fresh biomass/g	dry biomass/g
J1	741.85bA	207.72aA	488.33bB	87.50bB	1230.18bB	295.22aA
J2	458.10cB	173.69cB	267.33cC	63.5cC	725.43cC	237.19bB
ND	923.49aA	221.64aA	858.33aA	112.5aA	1781.83aA	334.14aA

Table 8 Biomass of oil sunflower plant

treatment	fresh weight of seed/g	dry weight of seed/g	fresh weight of flower plate/g	dry weight of flower plate/g	fresh weight of stem and leaf/g	dry weight of stem and leaf/g	fresh biomass/g	dry biomass/g
J1	130.67aA	76.50aA	421.67aA	46.23aA	346.67aA	114.5aA	899.0aA	237.23aA
J2	110.00aAB	65.17aAB	321.67aAB	36.00bB	273.33aA	86.83bB	705.0bA	188.0bB
YD	73.67bB	44.83bB	195.00bB	26.00cC	153.33bB	58.17cC	422.0cB	129.0cC

difference in every item between J2 and YD was significant ($P < 0.05$), but it reached a very high level between J1 and YD ($P < 0.01$). The seed dry weight of J1 and J2 was 1.71 and 1.45 times higher than that of YD, respectively.

3.4 Root-shoot ratio in the intercropping system

The biomass of root and shoot may reflect the need and competition ability of a crop for water, nutrition, and sunlight. High root-shoot ratio means higher ability of the root to absorb nutrients and water. Figures 3 and 4 show that the root-shoot ratio of pumpkin in the intercropping system was lower than that in ND, i.e., J2 < J1 < ND, while that of oil sunflower was the opposite, i.e., YD < J2 < J1. Compared with YD, the growth conditions of oil sunflower intercropped with pumpkin changed a lot and increased the absorption of nutrition and water, while the status of pumpkin in the system became worse compared with ND. Results also showed that the root-shoot ratio had a close positive correlation with the above-ground dry biomass; the correlation coefficient of pumpkin and oil sunflower was 0.88 and 0.98, respectively.

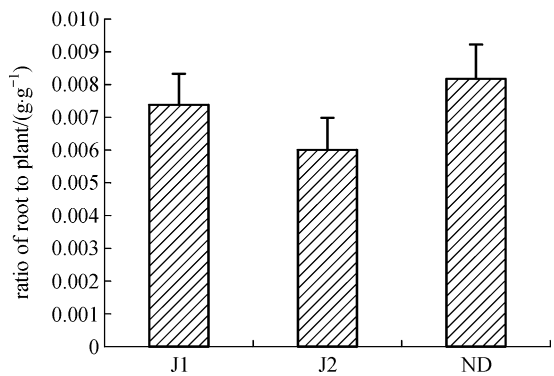

Fig. 3 Ratio of root to plant of pumpkin in 0–40 cm

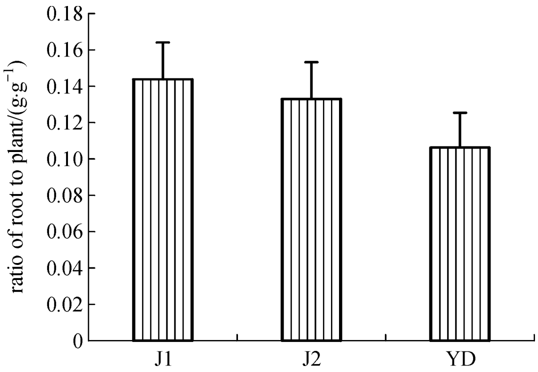

Fig. 4 Ratio of root to plant of oil sunflower in 0–40 cm

4 Discussion

It has been clearly established that, at high densities, the competition for light may change the relationships between the aerial part and the root system, together with the morphology (size, form) of the plant (Jackson et al., 1996; Li et al., 1998). Under light-limited conditions, the growth of roots is reduced more than the growth of the aerial parts, leading to a decrease in the root-shoot ratio (Hébert et al., 2001). In the pumpkin and oil sunflower intercropping system, the distribution of roots was changed by competition for light, water, and nutrition. Our study proved that oil sunflower was dominant in this intercropping system, with better growth and development of root and shoot than in YD, while pumpkin was restrained, with characteristics inferior to those in ND.

As the no-frost duration was short in the plateau of the northwest part of Hebei Province, most plants grew in the same months. Hence, no compensation effect existed in the root growth and development of the two crops when intercropping. This was not the same as the result of Zhang and Huang (2003) in the wheat-soybean intercropping system with double peaks of root growth in the growing period, and it was not the same to the result of Liu et al. (2007a) that maize compensated the spring winter wheat right after harvest in a multi-mature planting system. As the soil became very sterile and crop roots mainly concentrated in the tillage soil layer (Song et al., 2004), the root distribution in the space of the intercropping system was not overlapped. Though the roots of pumpkin showed a downward trend compared with oil sunflower when intercropping, most roots of the two crops concentrated in the 0- to 20-cm soil layers, accounting for about 84.7%–88.7% of the whole roots of pumpkin and 97.8%–99.4% of those of oil sunflower. Therefore, the compensation effect for nutrition and water was not evident.

Under field conditions, the roots were longer in the area of a fertilizer band, but the length of the whole root system was not affected by the fertilizer band at the early growth stage. The distribution of the two crops decreased with the depth of soil layers. Our study was consistent with the study by Wang et al. (2005) on root distribution in the intercropping of wheat with cotton. Analysis on the root distribution of pumpkin and oil sunflower showed that the root density of pumpkin decreased by a power function, while that of oil sunflower decreased by an exponential function. There was a close relation between root and shoot in crop (Yang et al., 2002). The characteristics of the above-ground organ of pumpkin in intercropping were inferior to those in sole cropping, which was opposite to the results for oil sunflower. The root-shoot ratio also showed that oil sunflower was more dominant in the intercropping system than pumpkin.

From this study, it could be found that the growth and development of pumpkin was affected by intercropping with oil sunflower, and this intercropping system was not suitable for the cultivation of pumpkin in the plateau areas of northwest Hebei Province. Fruit weight of pumpkin was found to be positively correlated with root weight and suitable field management schemes. Correct fertilization and soil tillage should be conducted to promote root growth and get a higher yield.

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