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# EVALUATION OF CROP ROTATION SUITABILITY IN FOOD LILY (*LILIUM DAVIDII* VAR. UNICOLOR)

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**Abstract**

Evaluation the interactive allelopathy between different crops is a wise strategy for determining the advantageous effects and avoid the disadvantageous effects among plants in short times. Lanzhou lily (*Lilium davidii* var. unicolor) is the only one edible sweet lily cropped in Western China, and there must exist different allelopathic relationship between the lily and some other crops. In order to explore suitable rotation crop of the lily to achieve the soil remediation, we investigated the interactive allelopathic effect between the lily and three other main crops (potato, peas, "Dang shen" (*Codonopsis pilosula (Franch.) Nannf.* ) by soil extract solution irrigation treatments. The experiment was designed as donor crop (lily)-receptor crops (potato, peas, "Dang shen") combination and donor crops (potato, peas, "Dang shen", lily)-receptor crop (lily) combination. The allelopathic effect was evaluated using the allelopathic effect index (RI) and synthetical allelopathic index (SE). The results showed that in the donor crop (lily)-receptor crops (potato, peas, "Dang shen") combination, at the concentration of 0.1g/ml,0.3g/ml, 0.5g/ml, lily enhanced peas growth (SE was 0.0193, 0.0543, 0.0367, respectively), while it enhanced potato at lower concentration and inhibited it at high concentration (SE was 0.0433, 0.0727,-0.0560, respectively), and completely inhibited "Dang shen" (SE was -0.0675,-0.1215,-0.1920, respectively). But in the donor crops (potato, peas, "Dang shen", lily)-receptor crop (lily) combination, at the concentration of 0.1g/ml,0.3g/ml,0.5g/ml, peas completely enhanced lily (SE was 0.056,0.102,0.004 respectively), while potato enhanced lily at lower concentration and inhibited it at high concentration (SE was 0.026,0.012,-0.074 ,respectively), so did "Dang shen"- lily combination ( SE was 0.039,-0.111,-0.171, respectively). In addition, dynamics of receptor plantlets POD, SOD, CAT activities and MDA content, which reflected if receptor crops got hurt and the adverse stress degree suffered from the donor crops, were consistent with the seedling growth performance. Therefore, these three crops have different effects for the lily rotation. The results suggested that among the three crops, peas is the most suitable as a rotation crop for alleviating the adverse effect of continuous cropping while "Dang shen" is unsuitable for this rotation system.

**Key words:** Edible lily; Potato; Peas; "Dang shen"; Allelopathy; Rotation.

## Introduction

Lanzhou lily (*Lilium davidii* var. unicolor) is the only edible sweet lily in China and it is commonly cultivated in the hilly region of the central Gansu Province, which belonged to the arid area in western China (Chen *et al.*, 2014). The unique climate in the region gives the lily a special sweet taste and quality; hence, it is popular in southern China, Korea and Japan. As a result of the high economic value of the crop and limited land for crop cultivation, the crop is commonly put under long term continuous cropping system. The adverse effect of this system on the crop is declining yield and poor quality of the harvested produce (Wu *et al.*, 2015). In order to overcome this problem, local famers usually adopt rotation with crops such as potato, Chinese traditional medicine herb, wheat, maize, peas and some vegetable crops. However, being not sure the suitability of the crops used in this rotation system, the local farmers have different statements on it, and some of them go by contrary. Thus, it is necessary to research the suitable rotation crops in this system.

Evaluation the interactive allelopathy between the lily and these other crops is a wise strategy for answer this questions in short times. Allelopathy is a phenomenon, in which plant releases the chemical substance to the environment that can lead to harmful or helpfully function to own or periphery plants including microorganism indirectly through leaching, volatility, the remnant body decomposition and the root system secretion (Bais *et al.*, 2006; O Duke & Stephen O. 2010) The allelopathic relationship between different crops reveals important significant to the aspects such as building the harmonious countryside, preventing plant diseases and pests, increasing output and enhancing quality. So many researches focused on allelopathy to determine the advantageous effects and avoid the disadvantageous effects among plants, which aids in keeping the diversity of biology, improving the sustainable agricultural development and guiding about the scheme of plantation (Cheng *et al.*, 2005; Li *et al.*, 2010; Cheng *et al.*, 2011; Zhou *et al.*, 2013 & Asao *et al.*, 2017).

Lanzhou lily is cultivated perennial (typical 3 years), and during all this period, its stem and root stayed in the field without any removal when it is dried up every winter. Researchers including our team has proved that the auto-toxicity resulted from the remnant plant decomposition and root exudate is one of the main reason for its continuous cropping problems, and phthalic acid (PA) and palmic acid were identified from the lily root exudate by GC-MS, and these two chemical substrates have allelopathic effect on lettuce and radish seedling (Wu *et al.*, 2015; Chen *et al.*, 2016), moreover, It is proved that phthalic acid had allelopathic effects on *Fusarium oxysporum*, which is one of the main pathogen of lily wilt disease (Li & Li, 1996; Wu *et al.*, 2015; Bian *et al.*, 2016). However, we still know little about the lily allelopathy on other crops. In addition, in the Lanzhou lily production area, except the lily, the first dominant crop is potato, the second one is Chinese traditional medicine herb (the main kind one is “Dang shen”, the smallest amount crops are pea, maize, wheat, alfalfa and so on. Many papers reported that subsequent cereal yields usually increases in legume–cereal rotations (Fu *et al.*, 2011; Moulin *et al.*, 2011). Thus, in order to achieve the lily soil remediation, we selected potato, peas and “Dang shen” as the rotation crops to research their interactive allelopathy. And we made a hypothesis that the lily must exist different interactive allelopathy with these three crops. The objective of this study was: i) to determine the different allelopathy between Lanzhou lily and these three selected crops (potato,”Dang shen” and “Dang shen”); ii) to determine which crop is suitable for lanzhou lily rotation.

## Material and Methods

**Experimental design and plant materials**: The experiment was designed as two parts based on three rotation systems: lily-potato–lily , lily- “Dang shen”-lily, lily-peas–lily , compared with no rotation system: lily-lily–lily.

The first part was to investigate donor crop (lily) allelopathy on receptor crops (potato, peas, “Dang shen”). The lily variety is “Lanbai1”, soil was collected from 3 years continuous cropping fields to get its soil extracts, potato variety was “ Favorita” and the tuber seed was about 5g, peas and “Dang shen” varieties were unknown local varieties.

The second part was to investigate donor crops (potato, peas, “Dang shen”, Lanzhou lily) allelopathy on receptor crop (lily). Potato, peas , “Dang shen” and lily soil were collected from one year cropping fields to get its soil extracts, the potato variety was” Qingshu 9” , peas and “Dang shen” variety were unknown local varieties. the lily variety was “Lanbai1 "and the bulblet seed was about 17g.

## Measurements and Methods

**Field description and soil sampling:** Soil samples were collected at Bao jiashan village, Lintao county, Gansu province (western China,103°53′12″～103tern Chi，353tern C～353tern Chin1910 m elevation).The soil is locally known as Huangmian soil and it has a deep soil layer, high water–storage capacity, pH7.8 and organic matter,13g.kg-1.The site has been utilized for the cultivation of Lanzhou lily for over 140 years.

The soil samples were collected on July 10th, 2016 (budding stage for lily and “Dang shen”, tuber expansion stage for potato, pod formation stage for peas) according to Sun *et al.* with minor changes. For each donor crops, we selected four plots, Soil augers (6 cm diameter and 20 cm long) were used for soil sampling. In each plot, eight soil cores (“W” sampling method) were collected to a depth of 20 cm. The sample was air-dried, ground, sieved (mesh size 1×1 mm2) to remove root fragments away .We dissolved 500g soil sample into 1L water, and vibrated the solution for 24h, then filtered the solid particles away from the solution, finally we got 0.5g/ml solution ,and sealed and stored it at 4℃ temperature for determination of enzyme activities and MDA contents.

**Allelopath assay:** The donor plants soil extract solution concentration were designed as the following: 0g/ml (CK)、0.1g/ml、0.3g/ml、0.5g/ml. As receptor crops, Lanzhou lily, potato and peas sprouted seedling were planted in pots (10 cm diameter × 10 cm height, V roseite: V perlite =3:1, the volume of soil in each port is about 630cm$^3$, one seed each pot) and irrigated the soil extraction solution every 3-4 days. For potato and peas, the solution volume was 30ml each time. Each experimental unit had 20 pots which were replicated 3 times. After 10 times of irrigation (about 40 days later), data from 10 plantlets of the same size were recorded.

Because “Dang shen” seed was too small to plant into pot, the bioassay was carried as method described by ZhaoLi *et al.* (Zhao *et al.*, 2010). The seeds were surface sterilized in a solution of 10% (v/v) $H_2O_2$ for 10 min, washed thoroughly in distilled water, and placed on filter paper in the bottom of beaker and added 2 ml soil extract solution, then the beaker was placed inside incubator for 15 days (16 h light/8 h dark, 25°C). Each treatment was with 3 replications. After fifteen days of culturing, the data was recorded.

Stem diameter, root length were measured by vernier calipers straight edge. Root morphology indexes were measured by Root scanner (model: Epson7500，resolution ratio 400bpi), the image was processed by the software (WinRhizo Pro Vision 5.0a). Root activities, SOD, CAT, POD , MDA were tested by the methods described by Sun *et al*., (Pinheiro *et al.*, 2004).

Allelopathy was measured as allelopathic effect index (RI) described by Williamson and Richardson (Williamson & Richardson, 1988 ): when T≥C, RI = 1－C/T (T was the treatment data, while C was the control data); when T＜C, RI = T /C－1. RI＞0 means the enhanced allelopathic effect, RI＜0 means inhibitory allelopathic effect. Allelopathy was also measured as synthetical allelopathic index (SE) described by Shen *et al.* (Shen *et al.*, 2005), which value was the average R1 .Both R1 and SE value were consistent with allelopathy degree (Williamson & Richardson, 1988; Shen *et al*., 2005).

## Statistical analysis

The SPSS statistical software (SPSS software, 19.0, SPSS Inst. Ltd., USA) was used for the Analysis of Variance and treatment means comparison was done by the Duncan’s multiple range test ($p$<0.05).

## Results

**Donor crop (Lanzhou lily) allelopathy on receptor crops (potato, peas, “Dang shen”) Lily soil extract effect on potato, peas, and “Dang shen” seedling growth:** Lanzhou lily had different allelopathy on these three receptor crops (Table 1 and Fig. 1). Its soil extract had enhanced effects on potato seedling growth at lower concentration, but had inhibitory effects at high concentration. At the concentration of 0.1g/ml，0.3g/ml, the stem length, stem diameter and root length increased, both RI and SE were positive, while at the concentration of 0.5g/ml, these three indexes significantly decreased by 8.2%、10.7%、10.1%, respectively compared to the control ($p$<0.05), and both RI and SE were negative.

The lily soil extract enhanced the growth of peas and increasing the concentration of the extract resulted in increased stem length, stem diameter and root length. In addition, both RI and SE were positive. At the concentration of 0.3g/ml, these three indexes reached the highest value and significantly increased by 3.3%、6.1%、8.1%, respectively compared to the control.

The lily soil extract had inhibitory effects on "Dang shen" seedling growth, and with the concentration increasing, stem length and root ength decreased constantly, both RI and SE were negative .At the concentration of 0.5g/ml, these two indexes reached the lowest value and significantly decreased by 17.1%、21.3%, respectively compared to the control. However, the stem diameter was too small to record.

**Table 1. The donor crop (Lanzhou lily) allelopathy on receptor crops (potato, peas, "Dang shen").**

| donor crop-receptor crop combination | donor soil extractconcentration | stem length (cm) | stem diameter (mm) | root length (cm) |
|---|---|---|---|---|
| lily-potato | 0 g/ml(CK) | 16.83 ± 0.45b | 3.91 ± 0.04b | 9.04 ± 0.15c |
| | 0.1g/ml | 17.25 ± 0.30ab | 4.02 ± 0.03a | 9.82 ± 0.16b |
| | 0.3g/ml | 17.60 ± 0.13a | 4.08 ± 0.03a | 10.4 ± 0.41a |
| | 0.5g/ml | 15.83 ± 0.31c | 3.59 ± 0.06c | 8.83 ± 0.17c |
| lily-peas | 0 g/ml(CK) | 26.47 ± 0.20b | 2.31 ± 0.02c | 9.14 ± 0.20c |
| | 0.1g/ml | 26.48 ± 0.35b | 2.40 ± 0.03b | 9.34 ± 0.15bc |
| | 0.3g/ml | 27.37 ± 0.33a | 2.45 ± 0.01a | 9.88 ± 0.17a |
| | 0.5g/ml | 26.75 ± 0.21b | 2.44 ± 0.01a | 9.60 ± 0.12b |
| lily-"Dang shen" | 0 g/ml(CK) | 2.28 ± 0.09a | — | 1.22 ± 0.11a |
| | 0.1g/ml | 2.12 ± 0.07b | — | 1.14 ± 0.01ab |
| | 0.3g/ml | 2.06 ± 0.07b | — | 1.04 ± 0.06bc |
| | 0.5g/ml | 1.89 ± 0.09c | — | 0.96 ± 0.03c |

Notes: "Dang shen" stem diameter was too small to record; CK means control treaments;" ±"means range from measurement index

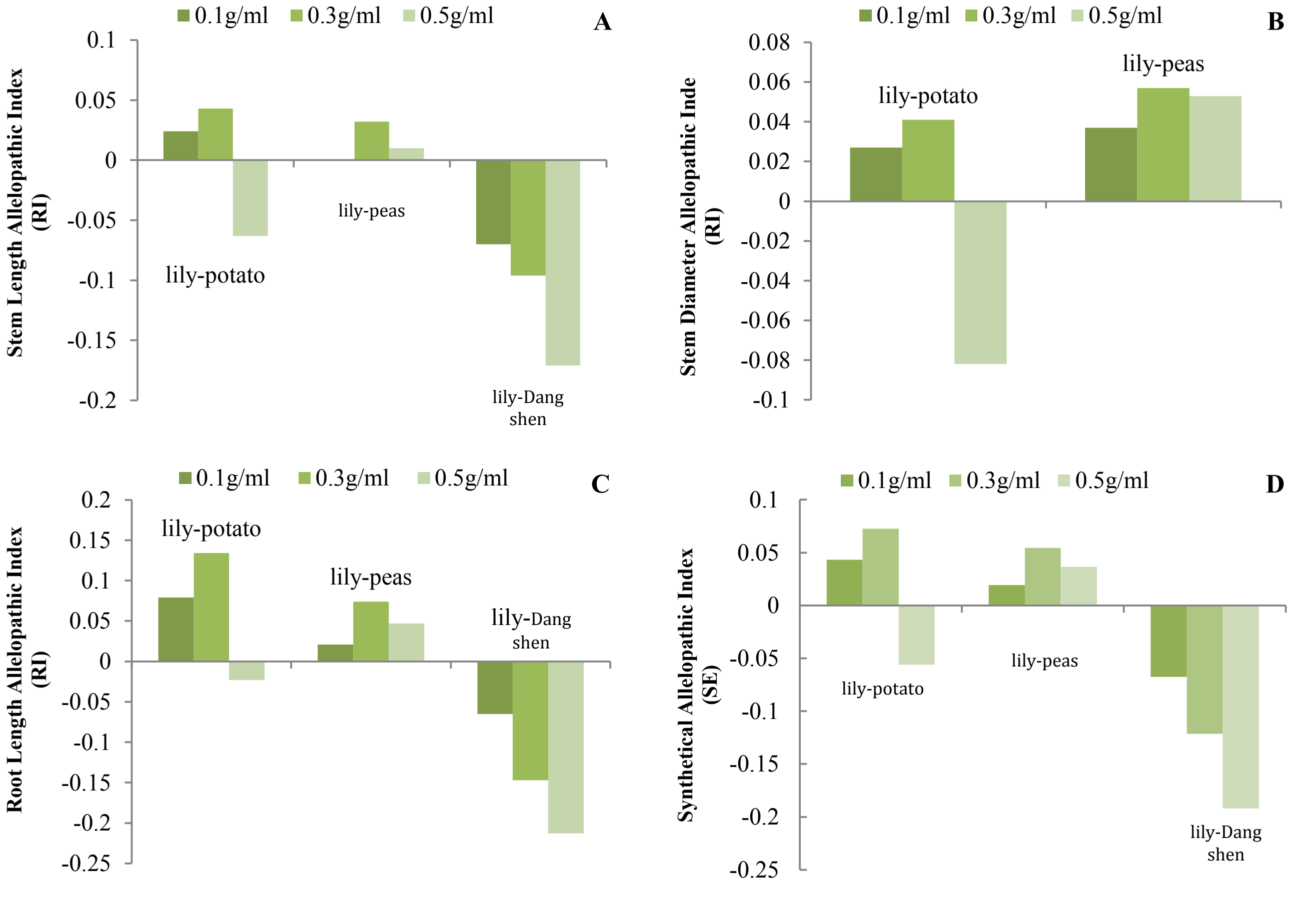


Fig. 1. Allelopathic Index (RI) and synthetic allelopathic index (SE) of Lanzhou lily on potato , peas, and "Dang shen": "Dang shen" stem diameter was too small to record (Fig. 1B).

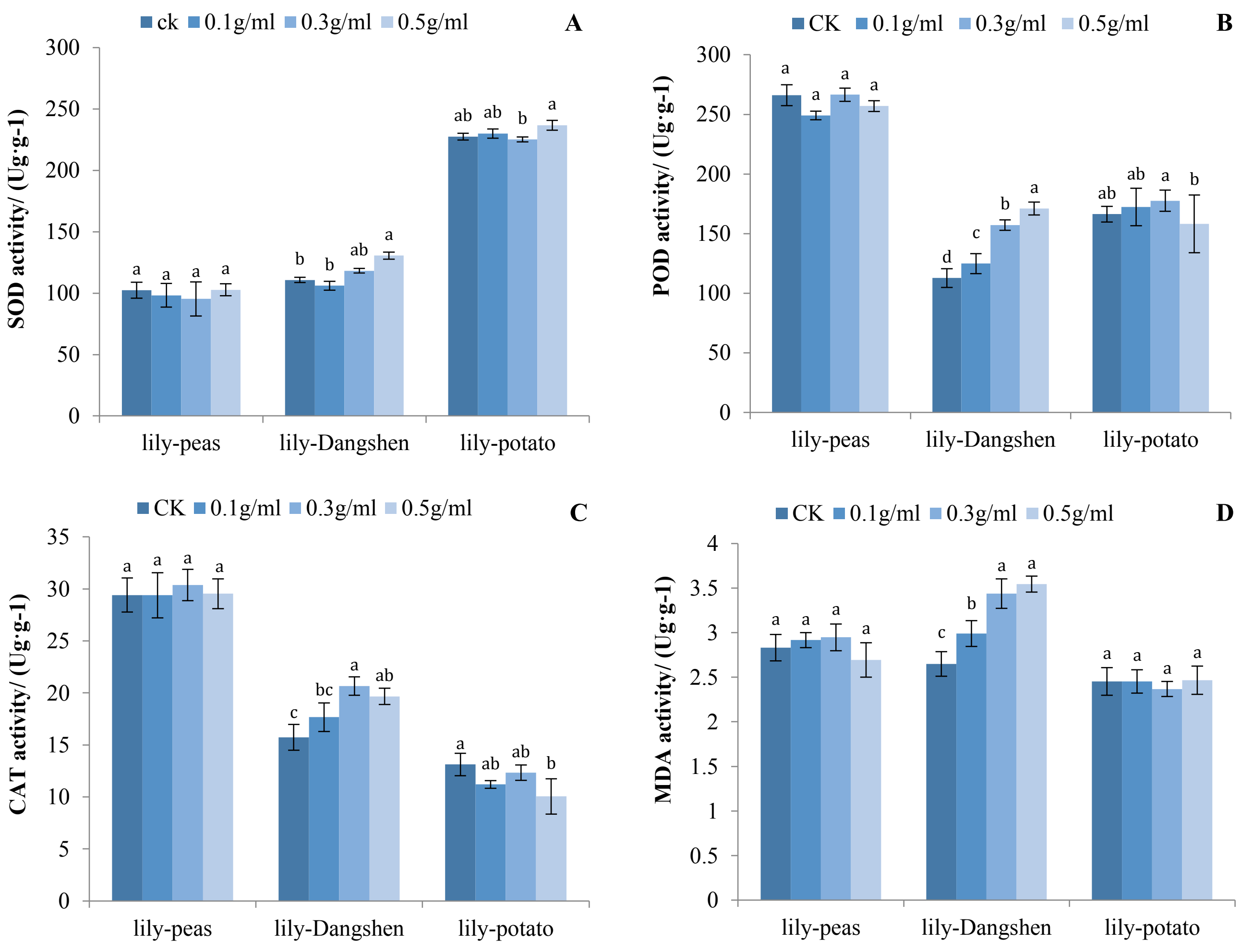


Fig. 2. Effect of Lanzhou lily soil extract solution on potato, peas, and "Dang shen" seedling peroxidation enzymes and MDA content.

**Lily soil extract effect on potato, peas, and "Dang shen" seedling peroxidation enzymes and MDA content:** Lanzhou lily had different effect on SOD activities of the three receptor crops (Fig. 2A). The soil extract significantly increased SOD activities in "Dang shen" compared to the control, at the concentration 0,3 g/ml and 0.5g/ml. The SOD activities increased by 6.8% and 18.1% compared with the control, respectively, while there was no significant effect on the SOD activities in peas and potato compared to the control.

The lily had different effect on the POD activities the three receptor crops (Fig. 2B). The soil extract induced POD activities significantly in "Dang shen" , at the concentration 0.1 g/ml, 0.3g/ml ,0.5 g/ml. The POD activities increased significantly by 10.7%, 39.4%,51.6% , respectively compared to the control, but there was no significant effect on pea and potato SOD activities, compared to the control.

The lily had different effects on the CAT activities of the three receptor crops (Fig. 2C). The soil extract increasedCAT activities significantly in "Dang shen" , at the concentration of 0.3g/ml and 0,5 g/ml, CAT activities significantly increased by 31.5%, 25%, respectively compared to the control. But potato CAT activities decreased, and at the concentration of 0.5 g/ml, CAT activities significantly decreased by 23.3%, and for peas, its CAT activities did not change, compared to the control.

The lily had different effect on the MDA contents of the three receptor crops (Fig. 2D). The soil extract increased MDA content in "Dang shen" significantly.At the concentration 0.1g/ml, 0.3g/ml and 0,5 g/ml, MDA content increased by 12.8%, 29.9% and 33.9%, respectively compared to the control. But MDA contents in pea and potato did not change compared to the control.

**Donor crop (potato, peas, and "Dang shen", Lanzhou lily,) allelopathy on receptor crops (Lanzhou lily) Donor crop soil extract effect on Lanzhou lily seedling growth:** These four donor crops (including Lanzhou lily) had different allelopathy on Lanzhou lily (Table 2, Fig. 3). At the concentration of 0.1g/ml, these four donor crops stem diameter and root activities significantly increased compared to the control. At the concentration of 0.5g/ml, for potato-lily treatments, stem diameter, stem length and root activities were significantly decreased 4.5%, 4.4%, 7.0%, respectively, compared to the control, and for "Dang shen"-lily treatments, all these 6 indexes were significantly decreased by 8.4%, 6.9%, 15.7%, 15.1%, 23.0%, 7.5%, respectively, compared to the control, and for lily-lily treatments, all these 6 indexes were also significantly decreased by 14.7%, 5.3%, 19.7%, 18.9%, 24.2%, 10.0%, respectively, compared to the control. But for peas-lily treatments, all these 6 indexes did not significantly changed.

In total, potato, “Dang shen”, Lanzhou Lily soil extract had enhanced effects on the lily at lower concentration. With increasing concentration, the donor crops SE became into negative from positive, and at he highest concentration of 0.5g/ml, the SE of Potato-lily, “Dang shen”-lily, lily-lily treatments were -0.074, -0.128, -0.171, respectively, which mean that the inhibitory effects became more and more intensive. But peas extract had enhanced effects at all the concentrations because all the peas-lily treatments SE were positive (Fig. 3G). Furthermore, the dynamics of RI of each combinations showed the similar results (Fig. 3A, B, C, D, E, F) .The individual index demonstrated the same result (Table 2).

**Donor crop soil extract effect on Lanzhou lily seedling peroxidation enzymes and MDA content:** The four donor crops had different effect on Lanzhou lily peroxidation enzymes (Fig. 4A, B, C). At the concentration of 0.3g/ml and 0.5g/ml, lily, “Dang shen” and potato soil extract induced the lily SOD，POD，CAT activities insignificantly increased. And at this concentration, the lily induced itself SOD, POD, CAT activities significantly increased by 32.07%、60.04%、53.88%, respectively, compared to the control “Dang shen” induced lily SOD,POD,CAT activities significantly increased by 30.37%、50.26%、41.26%, respectively. Potato increased SOD, POD, CAT activities in lily significantly by 22.74%、43.79%、31.73% , respectively. But for peas-lily treatment, peas did not significantly changed lily SOD,POD,CAT activities at all the concentration.

These four donor crops had different effect on Lanzhou lily MDA content (Fig. 4D). Compared to the control, at 0.3g/ml, lily and “Dang shen” significantly increased MDA content in lily. ). At the 0.5g/ml, lily, potato and “Dang shen” significantly increased MDA content in lily. However, peas-lily treatment, did not changed MDA content in lily at all the concentrations.

**Table 2. The donor crop (potato, peas, “Dang shen” and Lanzhou lily) allelopathy on receptor crops (Lanzhou lily) seedling growth.**

| Donor crop-receptor crop combination | Donor soil extract concentration 0f | Stem diameter (mm) | Stem length (cm) | Total root length (cm) | Root volume ($cm^{3)}$ | Root tips number | Root activities ($\mu g \cdot g \cdot h^{-1}$) |
|---|---|---|---|---|---|---|---|
| Water-lily( CK) | 0 g/ml | 3.34±0.02c | 24.99±0.11ab | 114.32±4.47bc | 1.06±0.05bc | 256±16abc | 35.66±0.37de |
| lily-lily | 0.1g/ml | 3.47±0.04ab | 25.34±0.47ab | 116.5±5.73abc | 1.08±0.08abc | 262±18abc | 40.6±0.32ab |
| | 0.3g/ml | 3.00±0.04e | 24.01±0.22cd | 96.38±5.05d | 0.90±0.03de | 219±18cd | 33.12±1.07fg |
| | 0.5g/ml | 2.85±0.01f | 21.16±0.50e | 91.75±3.1d | 0.86±0.05e | 194±26d | 32.08±0.83g |
| “Dang shen”-lily | 0.1g/ml | 3.50±0.02a | 25.32±0.41ab | 115.74±7.27abc | 1.08±0.03abc | 243±15bcd | 36.8±0.53cd |
| | 0.3g/ml | 3.20±0.03d | 23.88±0.23cd | 101.92±3.52cd | 0.95±0.02cde | 242±18bcd | 33.52±0.5efg |
| | 0.5g/ml | 3.06±0.06e | 23.26±0.14d | 96.34±4.73d | 0.90±0.08de | 197±20d | 32.98±0.92fg |
| potato-lily | 0.1g/ml | 3.58±0.07a | 25.29±0.43ab | 115.7±2.14abc | 1.08±0.04abc | 247±11bcd | 38.82±0.59abc |
| | 0.3g/ml | 3.46±0.03ab | 25.09±0.10ab | 106.84±1.43bcd | 1.03±0.02bcd | 284±16ab | 35.7±0.65de |
| | 0.5g/ml | 3.19±0.02d | 23.87±0.65cd | 101.96±7.72cd | 0.97±0.05cde | 233±16cd | 33.15±1.53fg |
| peas-lily | 0.1g/ml | 3.54±0.02a | 25.59±0.20ab | 121.57±4.46ab | 1.13±0.07ab | 273±10abc | 38.4±0.79bc |
| | 0.3g/ml | 3.59±0.02a | 25.93±0.15a | 131.11±2.59a | 1.21±0.05a | 292±13a | 40.99±0.32a |
| | 0.5g/ml | 3.36±0.06bc | 24.90±0.16bc | 115.78±4.01abc | 1.08±0.05abc | 251±17bcd | 34.37±0.98efg |

## Discussion

Many research studies have demonstrated that the allelopathy of donor plants to its receptor plants is very selective and specific (Li *et al*., 1996; Wu *et al*., 2015; Bian *et al*., 2016; Asao *et al*., 2017). This study also agreed with this opinion. In the combination of donor crop (potato, peas, “Dang shen” , Lanzhou lily)-receptor crops (Lanzhou lily) , peas completely enhanced Lanzhou lily, while potato, “Dang shen” ,Lanzhou lily had enhanced effects on lily at lower concentration and inhibitory effects at high concentration. TAt 0.5g/ml, the most inhibitory donor was Lanzhou lily, the next one was potato, and the last one was “Dang shen”. On the other side, in the combination of donor crop (Lanzhou lily) - receptor crops (potato, peas, “Dang shen”), the lily completely enhanced peas and inhibited “Dang shen”, while it enhanced potato at lower concentration and inhibited potato at high concentration.

Root exudates component plays important roles in allelopathy, some of them may have directly allelopathic effect on receptor, some of them may have allelopathic effect by soil microbial or combination with other soil chemicals substance. Xu and Cheng proved that dibutyl phthalate ( DBP) was one of ornamental lily allelopathic root exudates (Xu *et al*., 2011; Cheng & Xu, 2012), It was shown that DBP and cetylic acid were Lanzhou lily root exudates with autointoxication by GC-MAS analysis (Chen *et al*., 2016). In soil, DBP is the precursors of phthalic acid (PA) and it degrades to PA by microorganism (Xu *et al*., 2008). PA is auto-toxic chemical of root exudates in Lanzhou lily, which can accumulate in lily monoculture soils (Xu *et al*., 2008 & WU *et al*., 2015) proved that DBP and cetylic acid were potato allelopathic root exudates (Shen *et al*., 2015). From this data, we speculate that it may be the same auto-toxic chemical from root exudates, such as DBP and cetylic acid existed in donor and receptor crops, resulting in interactive inhibition between Lanzhou lily and potato.

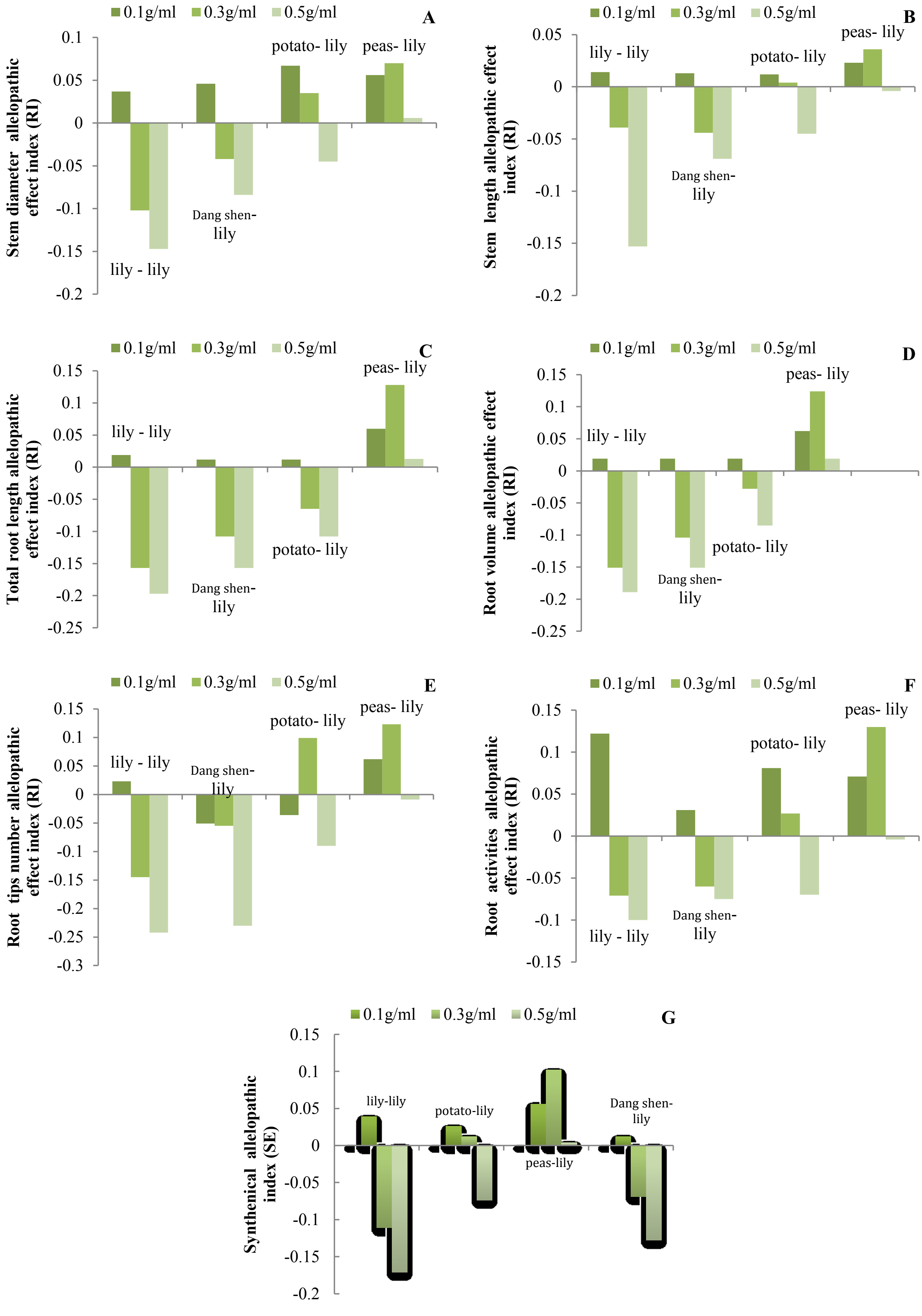


Fig. 3. Allelopathic Index (RI) and synthetic allelopathic index (SE) of Lanzhou lily, potato, peas and "Dang shen" on Lanzhou lily.

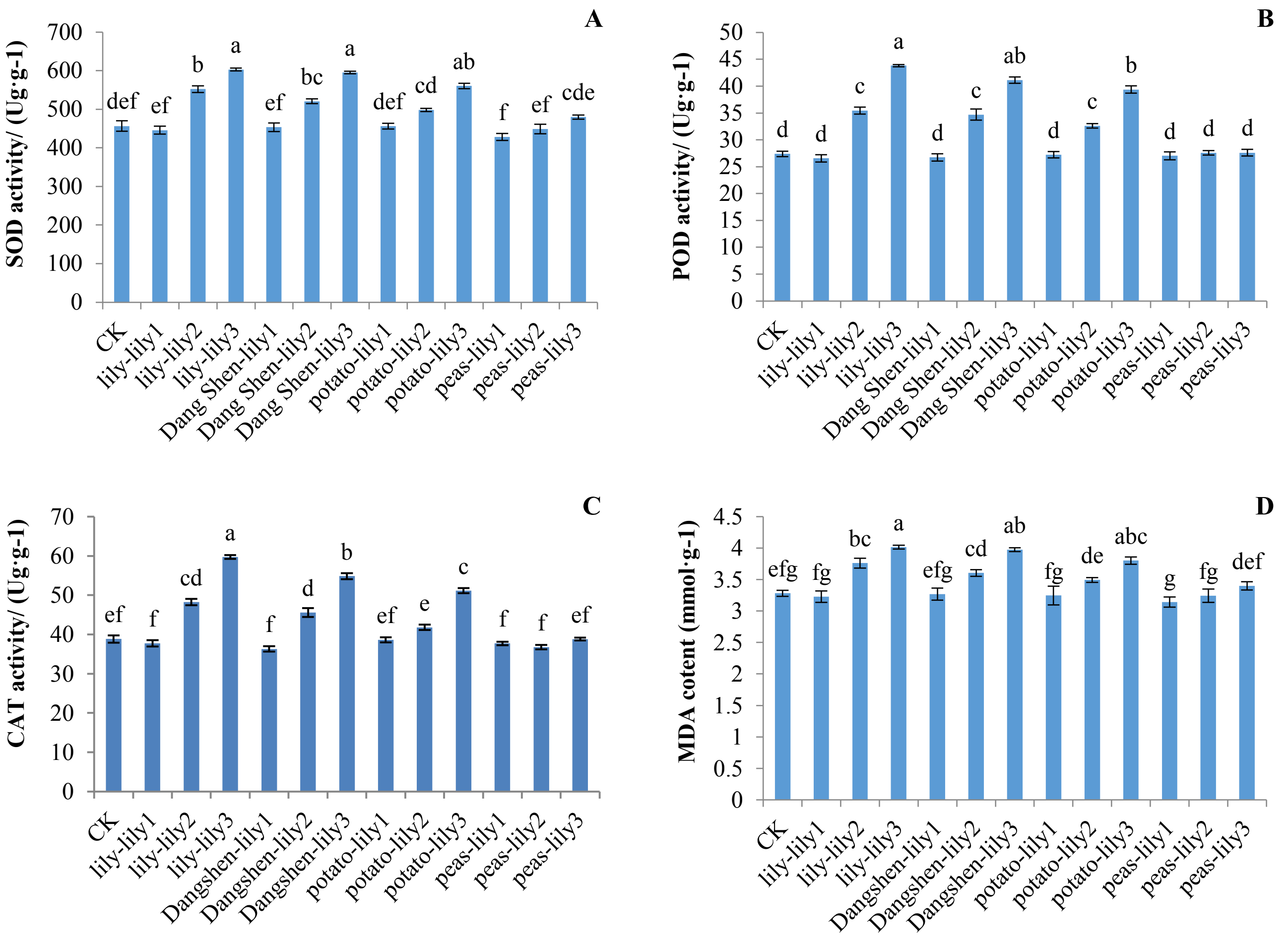


Fig. 4. Effect of Lanzhou lily, Potato, peas, and "Dang shen" soil extract solution on Lanzhou lily seedling peroxidation enzymes and MDA content: lily-lily1,lily-lily2, lily-lily3 represent the treatment of Lanzhou lily soil extracts solution concentration of 0.1g/ml, 0.3g/ml、0.5g/ml, respectively; "Dang shen"-lily1. "Dang shen"-lily2. "Dang shen"-lily3 represent the treatment of "Dang shen" soil extracts at 0.1g/ml, 0.3g/ml、0.5g/ml, respectively; potato-lily1. potato -lily2. potato-lily3 represent the treatment of potato soil extracts solution concentration of0.1g/ml, 0.3g/ml、0.5g/ml, respectively; peas-lily1. peas -lily2. peas-lily3 stood for the treatment of peas soil extracts solution concentration of 0.1g/ml, 0.3g/ml、0.5g/ml, respectively; CK represent irrigation with water.

For peas, It was reprted that its autointoxication and identified 7 auto-toxic chemical (Benzoic, cinnamic, p-hydroxybenzoic, 3,4-dihydroxybenzoic,vanillic, p-coumaric and sinapic acids) from the phytotoxic acidic fraction of the root exudates (Yu & Yoshihisa, 1999). In a comparison of the auto-toxic chemical in peas with that identified in the lily (Xu *et al*., 2008; Xu *et al*., 2011; Cheng & Xu, 2012; Chen *et al*., 2016), we did not find the same auto-toxic chemical between them. So, we speculate that this may be one of the reason why that Lanzhou lily and peas have no antagonistic reactions. "Dang shen" is a kind of Chinese traditional medicines herbs cultivated in western hilly area in China.It is reported that its root exudates had inhibitory effect on its seeds germination, but the identification of root exudates has not been reported (Wang *et al*., 2007; 2015). Therefore, little is known about the interaction between "Dang shen" and the lily. However, being soil extract contains complex substances including chemical and biological substance both from soil and from plants, it is necessary to measure the compounds released by plants and to identify the specific allelopathy compounds in future research.

Reasonable rotation system is an important basis for preventing the adverse effects of continuous cropping obstacles and for improving crop production (Kong *et al*., 2010). As reported in previous research, subsequent cereal yields usually increases in legume-cereal rotations due to the increased availability of mineral nitrogen provided by mineralization of legume residues (Gan *et al*., 2014;Gan *et al*., 2015), and as well as the improvement of soil biological properties and availability of nutrients (Meng *et al*., 2012). Our results confirms the previous reports. The results showed that compared to the intensive autotoxicity of Lanzhou lily, which was also proved by hydroponics in our previous research (Chen *et al*., 2016), peas completely enhanced Lanzhou lily. Thus, the results also agreed with previous report by Trabelsi *et al*., who found that crop rotation with legumes could significantly increase the productivity of the non-leguminous crops, and also increased both economic and environmental benefits. Moreover, In another research, it was reported that legume rotation induced cereal growth and yield increases seemed to depend on the ability of the legume to suppress nematodes and to enhance early N and P availability for the subsequent cereal (Acosta-Martínez *et* *al*., 2010; Meng *et al*., 2012). At the same time, rhizosphere studies showed that the effects on soil pH and acid phosphatase activities were secondary causes for the observed growth difference between rotated cereals and continuous cereals (Bürkert *et al*., 2001; Gan *et al*., 2015).

Many studies have shown that plants can minimize the toxicity through an antioxidant system, which including peroxidase (POD), catalase (CAT), superoxide dismutase (SOD) (Qiu *et al*., 2021) and MDA and OH (Ou *et al*., 2017). Dynamics of receptor plantlets POD, SOD, CAT activities and MDA content, which reflected if receptor crops got hurt and the adverse stress degree suffered from the donor crops (Zhang *et al*., 2001; Ahmad *et al*., 2010). García *et al* pointed out that plant root exudates probably make 90% contribution to soil enzyme activities. Our team's previous research showed that being autointoxication, lanzhou lily root exudates can increase itself POD, SOD, CAT activities and MDA content , decreased the plant weight at high concentration (Chen *et al*., 2016). This study also showed that potato, "Dang shen", Lanzhou Lily soil extracts increased the four physiological peroxidation indexes of lanzhou lily, which demonstrated that the soil extract used in irrigating crop adversely affected the receptor crops. But peas did not change the four physiological indexes, which was consistent with its growth performance. In another combination with the donor crops and receptor crops interchanged, the dynamics of these four physiological peroxidation indexes of receptor crops were also consistent with their seedling growth perfomance.

## Conclusions

Our results suggested that in the lily-peas-lily rotation system, Lanzhou lily had slight effect on peas seedling whiles peas had greater enhanced effect on Lanzhou lily; In the lily-potato-lily rotation system, the donor crop had enhanced effects on the receptor at lower concentration and inhibitory effects at high concentration.In the lily-"Dang shen"-lily rotation system, Lanzhou lily had inhibitory effects on "Dang shen" while "Dang shen" had enhanced effects on Lanzhou lily at lower concentration and had inhibitory effects at high concentration. We, therefore, conclude that among the three kinds of rotation crops for Lanzhou lily, peas is the most suitable for alleviating continuous cropping stress and improving the yield of Lanzhou lily. Potato is the second most suitable crop whiles "Dang shen" may not suitable for this rotation system.

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