Characteristics of phosphorus uptake by plants in soybean (Glycine Max L. merr) and citrus (Citrus poonensis Hort ex Tanaka) intercropping system

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Abstract: The characteristics of $^{32}$P uptake by soybean and citrus among monoculture and intercropping systems were studied with field micro-plot trials and $^{32}$P isotope technique. A field experiment was conducted at Taoyuan Experimental Station of Agro-ecosystem Research of CAS from April to Jun in 2001. The experimental soil is acidic with pH of 4.45. The citrus tree was planted in plots of 3m×3m in row and line distance in Dec. 1995. The soybean was seeded 4 round around citrus tree within diameter of 3m on 15th April 2001. $^{32}$P was applied at three distances (27.5, 62.5 and 97.5 cm) from the cent of citrus tree and three depths (15, 35 and 55 cm) below the surface. Sixty equi-spaced holes of each plot were dug to the required depth in certain distances according to the treatment protocol. Into each soil hole, a PVC access tube was inserted leaving about 10cm of the tube length above the soil surface. In each hole, 20 mL...
$^{32}$P solution was dispensed into the access tube on 10th May 2001 with radioactivity of three depths (15, 35 and 55cm) being 13.5mCi, 20.0mCi and 28.4mCi, respectively. The samples of plant and soil were collected on 25th June 2001. The samples were dried at 80°C, wet digested (H$_2$SO$_4$ and HClO$_4$) and the total P were determined with colorimetric method. The radioactivity of $^{32}$P was radioassayed with FH408 and FJ-367 counting technique in a scintillation system.

The planting mode and $^{32}$P applying depth significantly affected the characteristics of phosphorus uptake by soybean and citrus. Under soybean-citrus intercropping, considerable competition could be observed when the $^{32}$P fertilizer was applied at topsoil (15cm) so the recovery rate of $^{32}$P fertilizer by soybean and citrus declined 41.5% and 14.7%, respectively, and the supplying amount of $^{32}$P fertilizer in topsoil to soybean and citrus decreased 346.8mg/plot and 148.1 mg/plot, respectively. comparing with monoculture. It was possible the recovery of $^{32}$P fertilizer by soybean was promoted when $^{32}$P fertilizer was applied at deeper soil layer (35cm or 55cm) under soybean-citrus intercropping, the $^{32}$P fertilizer was hardly used by soybean after $^{32}$P fertilizer was applied at 55cm or below 55cm layer so its recovery rate was less than 0.1% under soybean monoculture, while the recovery of $^{32}$P fertilizer by soybean was 0.253% under intercropping. The capacity of P uptake by citrus was larger than by soybean when P was applied at the deeper soil layer so the recovery rate of $^{32}$P fertilizer were less 25.6% and 878.3% while that of $^{32}$P fertilizer in 35cm and 55cm soil layer under soybean monoculture than under citrus monoculture, respectively. Considerable increase of $^{32}$P recovery was observed under soybean-citrus intercropping.

**Key words**: soybean; citrus; intercropping ecosystem; $^{32}$P; absorption characteristic

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### 1 Materials and methods

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- (Citrus pannonis Hort ex Tanaka)
- (Glycine max L. merr.)
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- In the field experiment, the plants were grown under a randomized complete block design with four treatments, each with four replicates.
- The treatments were:
  - **Treatment 1**: Control (no fertilizer applied).
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  - **Treatment 3**: $^{32}$P fertilizer applied at the 35cm soil layer.
  - **Treatment 4**: $^{32}$P fertilizer applied at the 55cm soil layer.

#### 1.1.3 Data analysis

- The data were subjected to analysis of variance (ANOVA) using the statistical software package (SPSS).
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1. 2

Table 1: Distribution of intercropping and application of 32P fertilizer location

<table>
<thead>
<tr>
<th>Location</th>
<th>N</th>
<th>K</th>
<th>P4</th>
<th>K4</th>
<th>P4</th>
<th>K4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Crop</td>
<td>100</td>
<td>28.2</td>
<td>43.6</td>
<td>54.8</td>
<td>192</td>
<td>48</td>
</tr>
<tr>
<td>Diameter</td>
<td>225</td>
<td>60</td>
<td>32</td>
<td>16</td>
<td>2.75</td>
<td>0.73</td>
</tr>
</tbody>
</table>

1. 3

Fig. 1 Schematic diagram of soybean-citrus intercropping and application 32P fertilizer location

Fig. 1 Schematic diagram of soybean-citrus intercropping and application 32P fertilizer location

1. 4

Fig. 1 Schematic diagram of soybean-citrus intercropping and application 32P fertilizer location

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1. **Determination of Phosphorus Activity and Dry Powder Sample Preparation**

- **Soil and Plant Activity Measurement**
- **Using a Calibrator and Plastic Scintillation Probe**
- **Standard Samples for Instrumentation Counting Efficiency and Decay Time**
- **Correction of Measurement Results to the Same Time**

2. **Data Processing**

- Following the formula to calculate phosphorus fertilizer utilization rate:
  
  \[
  \text{Phosphate Utilization Rate} = \left( \frac{\text{Total Phosphate Absorbed} - \text{Phosphate Absorbed by Fertilizer}}{\text{Phosphate Absorbed by Fertilizer}} \right) \times 100\%.
  \]

3. **Results and Analysis**

- **Phosphate Absorption Total**
  - The phosphate absorption total clearly affects soybean and citrus phosphorus absorption. In monoculture, the phosphate absorption total is significantly higher than in intercropping.

**Tables and Figures**

**Table 1** Total amount of phosphorus absorption by soybean and citrus plants (g/plot)

<table>
<thead>
<tr>
<th>Treatments</th>
<th>S15</th>
<th>S35</th>
<th>S55</th>
<th>SC15</th>
<th>SC35</th>
<th>SC55</th>
<th>C15</th>
<th>C35</th>
<th>C55</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Soybean</strong></td>
<td>6.84a</td>
<td>6.39b</td>
<td>6.18b</td>
<td>4.61c</td>
<td>4.55c</td>
<td>4.75c</td>
<td>5.125a</td>
<td>4.520b</td>
<td>4.288c</td>
</tr>
<tr>
<td><strong>Citrus</strong></td>
<td>5.125a</td>
<td>4.520b</td>
<td>4.288c</td>
<td>5.033a</td>
<td>5.035a</td>
<td>4.639b</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Note:** Data in a row with various letters are statistically different at 5% of significant level (LSR₀.₀₅).

**Table 2** ³²P recovery rate by soybean and citrus %

<table>
<thead>
<tr>
<th>Treatments</th>
<th>S15</th>
<th>S35</th>
<th>S55</th>
<th>SC15</th>
<th>SC35</th>
<th>SC55</th>
<th>C15</th>
<th>C35</th>
<th>C55</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Soybean</strong></td>
<td>5.421a</td>
<td>1.473d</td>
<td>0.092f</td>
<td>3.832b</td>
<td>1.948c</td>
<td>0.255e</td>
<td>2.308b</td>
<td>1.612d</td>
<td>0.696f</td>
</tr>
<tr>
<td><strong>Citrus</strong></td>
<td>2.308b</td>
<td>1.612d</td>
<td>0.696f</td>
<td>2.647a</td>
<td>1.849c</td>
<td>0.900e</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>5.421b</td>
<td>1.473f</td>
<td>0.092h</td>
<td>6.140a</td>
<td>3.559c</td>
<td>0.949g</td>
<td>2.647d</td>
<td>1.849e</td>
<td>0.900g</td>
</tr>
</tbody>
</table>

**Note:** Data in a row with various letters are statistically different at 5% of significant level (LSR₀.₀₅).
间作同样显著提高了磷肥的总利用率！
与大豆和柑桔单作系统相比，间作系统对中层施磷的总利用率分别提高了
和
表
深层施磷的利用率从表看出，在单作条件下，大豆基本上不能有效吸收施于土层的磷肥，其利用率仅为
而与柑桔间作时，其利用率显著提高，达到了
柑桔对深层施磷的利用率则是单作显著高于间作，大豆
柑桔间作系统对磷肥的总利用率与柑桔单作系统没有显著差异，
肥料贡献率

植物体吸收的磷有来自肥料和土壤两个方面，来自肥料的磷占植物吸收总磷量的百分率称为肥料磷的贡献率，

图
肥料的供应量和贡献率

从图可以看出，无论是单作还是间作，大豆对肥料磷的绝对吸收量以及肥料磷的贡献率都随磷肥施用深度增加而降低，但是，在间作条件下，施于各土层的磷肥对大豆植株磷的贡献率均比单作时明显提高，间作大豆对表层肥料磷的吸收量小于单作大豆而对施于和土层的肥料磷的吸收量则明显大于单作大豆，柑桔对肥料磷的吸收量随施肥深度的增加而显著降低，间作柑桔对肥料磷的吸收量又明显地小于单作柑桔，磷肥的贡献率总体上也是随施肥深度增加而降低，在两种种植模式中，浅施和深施磷肥对单作柑桔植株磷的贡献率大于间作柑桔而2)0土层磷肥对单作柑桔磷的贡献率小于间作柑桔

图
根系分布特征
大豆
从表可以看出，大豆J1&左右的根系都分布在1K(1/0土层，约21&的根系分布在(1K#1/0土层，种植模式和磷肥施用深度对大豆根系分布有一定地影响，单作大豆根系的生物量显著地高于间作大豆，而无论是单作还是间作，随着磷肥施用深度的增加！1K(1/0土层的根系分布量显著降低！1K#1/0土层的根系分布量则呈增加趋势，单作大豆在1K(1/0土层的根系占总根量的比例高于间作，其中深施磷肥处理两者的差异达到了统计学显著水平，相反，1K#1/0土层根系占大豆总根量的比例则是间作高于单作，其中只有浅层施磷处理的差异没有达到统计学显著水平，很显然，在本实验中，磷肥是诱导大豆根系生长下扎的一个重要因素，

柑桔
本试验利用的柑桔树已经种植&?根系生长基本定形，试验种植模式与磷肥施用深度对柑桔根系的生长没有明显影响。
结果未列出。
所有供试柑桔树的根系平均值见表，从中可以看出，供试柑桔的根系在1K(1/0土层中的分布量最大，占总根量的3L&以上，显著地高于其它土层，直径M00的粗根在(1K#1/0和#1K%1/0土层中的分布量没有显著差异，各占"&左右，而直径N00的细根在(1K#1/0土层的分布量则显著高于#1K%1/0土层，在%1KL1/0土层中，柑桔根系的分布量很少，只有总

图
23P
Fig. 2 Supplying amount and contribution rate of 32P fertilizer
表3 大豆根系在土体中的分布

<table>
<thead>
<tr>
<th>Depth (cm)</th>
<th>Items</th>
<th>Root biomass (g)</th>
<th>Percentage of the total root biomass</th>
</tr>
</thead>
<tbody>
<tr>
<td>0~20</td>
<td></td>
<td>155.4</td>
<td>73.4</td>
</tr>
<tr>
<td>20~40</td>
<td></td>
<td>56.2</td>
<td>26.6</td>
</tr>
</tbody>
</table>

表4 柑桔根系在土体中的分布

<table>
<thead>
<tr>
<th>Depth (cm)</th>
<th>Coarse root (g)</th>
<th>Percentage of total root biomass</th>
<th>Fine root (g)</th>
<th>Percentage of total root biomass</th>
</tr>
</thead>
<tbody>
<tr>
<td>0~20</td>
<td>190.2</td>
<td>33.7</td>
<td>138.8</td>
<td>24.6</td>
</tr>
<tr>
<td>20~40</td>
<td>65.2</td>
<td>11.6</td>
<td>50.8</td>
<td>9.0</td>
</tr>
<tr>
<td>40~60</td>
<td>61.9</td>
<td>11.0</td>
<td>34.4</td>
<td>6.1</td>
</tr>
<tr>
<td>60~80</td>
<td>15.4</td>
<td>2.7</td>
<td>7.2</td>
<td>1.3</td>
</tr>
</tbody>
</table>

讨论

陈铨荣的试验结果显示，大豆对肥料磷的总利用率小于对于以下土壤深处的标记肥料的利用率。等报道，灌木对磷肥的利用率随磷肥施用深度及离树距离的增加而降低。

在本试验中，无论单作还是间作，磷肥的利用率随着磷肥施用深度的增加而降低。土层磷肥的利用率小于，且大豆在单作时基本不能吸收土层的磷肥。其利用率小于表。可能由于磷在土壤中的扩散系数很小，作物对磷的吸收主要靠根系的接触。大豆的根系主要聚集在土层，而柑桔的根系主要聚集在土层的缘故。农林间作系统中，作物和树对磷肥的总利用率往往高于各自单作时对磷肥的利用率。

本试验中，间作时大豆和柑桔对表施磷肥的总利用率比单作大豆和柑桔分别提高和施于土层时分别高和。施于土层时，间作总利用率与单作柑桔没有显著差异。大豆吸磷总量中，肥料的贡献率却比单作时提高了。柑桔虽然吸磷总量与单作没有显著差异，但磷肥利用率下降了，且达显著差异水平。这充分说明间作系统中，大豆和柑桔对表施磷肥有强烈的竞争作用。

另一方面，磷在土壤中的扩散系数较小，土壤磷的作物有效性在很大程度上取决于作物根系的生理特性，如根长、根半径、根系比表面积、根构型以及根分泌物等。柑桔的根系分布较深，在土层根系分布量占左右，土层还有以上，有利于其对土壤深层磷肥的吸收利用。而柑桔虽然在土层也聚集了以上的根系，但由于每小区只有一株柑桔，根系的分布密度比大豆小，因而对表层土壤中磷肥的利用率较低。此外，固氮植物对磷的依赖性高，可能是大豆对根圈磷肥竞争性较强的另一原因。另一方面，磷在土壤中的扩散系数较小，土壤磷的作物有效性在很大程度上取决于作物根系的生理特性，如根长、根半径、根系比表面积、根构型以及根分泌物等。柑桔的根系分布较深，在土层根系分布量占左右，土层还有以上，有利于其对土壤深层磷肥的吸收利用。而柑桔虽然在土层也聚集了以上的根系，但由于每小区只有一株柑桔，根系的分布密度比大豆小，因而对表层土壤中磷肥的利用率较低。此外，固氮植物对磷的依赖性高，可能是大豆对根圈磷肥竞争性较强的另一原因。
本试验得到一个有趣结果：间作时大豆对深施KH₂PO₄和NH₄NO₃的利用率显著高于单作大豆对土层磷肥的利用率较单作时高对土层的磷肥利用率虽然只有6.7左右，但单作大豆基本上不能利用该土层深度的磷肥，利用率小于6.4，且均有显著差异，表明浅根性的农作物，大豆与深根性的木本植物，柑桔间作可以改善浅根作物对深层土壤磷的利用，这其中的原因可能比较复杂，但可以假设，在农林间作条件下，深根性的木本植物吸收了土壤深处的养分之后在向各组织器官输送的过程中，部分养分随着根系分泌作用或根毛断裂，根细胞死亡脱落等生理代谢过程释放到浅层土壤之中，而被农作物根系所吸收利用，木本植物地上部分凋落物分解之后释放的养分也能为浅根作物所利用。复合系统中植物之间养分通过根系相互转移的现象早已引起关注，当然浅根作物对深层养分的利用率既取决于木本植物对养分的供给能力，也与其自身对根圈养分的竞争吸收能力有关，复合系统中木本植物对养分的释放及草本作物对养分的竞争吸收机理还有待于进一步深入研究。结论：农林间作是我国红壤丘陵坡地和旱土的主要经营模式之一，豆科作物与经济果树间作是一种用地与养地相结合地复合模式，对于深入了解和探讨此种模式下作物对土壤养分地吸收机制一直是人们关注的焦点。本研究采用KH₂¹⁸O同位素示踪技术进行了初步地研究。农林间作可以提高磷肥的利用率，大豆和柑桔间作虽然大豆和柑桔各自对磷肥的利用率比大豆和柑桔单作磷肥的利用率低，但大豆和柑桔对磷肥利用率之和显著地高于大豆和柑桔单作。浅根性的农作物与深根性的木本植物间作可以提高农作物对深层土壤养分的利用率，大豆和柑桔间作大豆对表层磷肥的利用率显著低于大豆单作，而对深层磷肥的利用率却显著高于大豆单作。

### 参考文献