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Determine a Regression Model between Phosphorus of Soil Saturation Extract and Various Organs of Washington Navel Orange for Recommendation of Phosphorus Fertilizer

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Abstract

Several methods have been proposed for recommendation of phosphorus fertilizers. Each of them only examines the concentration of phosphorus in the soil or plant, while none of them investigates the correlation between phosphorus concentrations in the soil and plant. In this study, a method called "integrated plant and soil system" (IPSS) is proposed to describe phosphorus fertilizer. In this system, for recommendation of phosphorus, the correlation between this element in soil and plant was used. For this purpose, 39 Washington Navel Orange orchards were selected in Jahrom region and from each orchard three trees were chosen. Samples were taken from soil and plants during two consecutive years and their phosphorus was measured. Orchards were divided into two categories, first group high-yield orchards and another includes all orchards. The correlation was run between soil properties and phosphorus of plant organs with the phosphorus of soil saturation extract samples. Factors were selected that shown significant correlation with the phosphorus of soil saturated extract, and multivariate regression was established between them. The results showed a significant correlation between phosphorus of plant organs and soil samples, and the highest correlation was observed between fruit phosphorus and phosphorus of soil saturation extract. Moreover, there was a significant correlation between phosphorus of plant organs, and the highest correlation was observed between fruit phosphorus with other plant organs. A equation was also obtained for each of the two orchard groups, these two equations can calculate the amount of phosphorus required for orange orchards.

Keywords: Fertilizer recommendation, Phosphorous, Regression model, Washington Navel orange.

Abbreviations: IPSS, Integrated Plant and Soil System; **P**, Phosphorus; **WNO,** Washington Navel Orange.

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Introduction

Nutrient elements are one of the most important effective factors on plant growth in sustainable agriculture. Although, these elements increase the growth and improve the quality of agricultural products, they should not accumulate in the plant's organs and do not pollute surface and ground water (Lu et al., 2013; Bujnovsky et al., 2016; Su et al., 2017). There are several methods to determine the status of nutrients in soil and plant, such as morphological signs, soil testing and plant analysis (Sajjadi, 1992; Mourao Filho, 2004; Robinson, 2005). To recommend fertilizer, the data and information of the soil testing and plant analysis are evaluated by some experimental methods such as, Deviation from optimal percentage (DOP) (Montanes et al. 1993), Diagnosis and Recommendation Integrated System (DRIS) (Beufils, 1973; Dow and Roberts, 1982), and Cate and Nelson Method (Cate and Nelson, 1965). These methods have several advantages and disadvantages. Among these methods, DOP and DRIS are more popular among plant nutrition researchers. In DOP method, the nutrient status of plants is expressed in terms of positive, negative and zero indices, so that the negative index indicates a deficiency, a positive index expresses excessive, and zero index for optimum concentration of the element in the plant (Montañes et al., 1993; Monge et al., 1995). Applying this method requires gathering a lot of information about climate, topography, soil, and plant species (Lucena, 1997). Due to these restrictions, farmers are reluctant to use this method (Ciesielska et al., 2002; Garcia-Escudero et al., 2013). The DRIS system is another method for fertilizer recommendation. In this method, the leaf is the most important organ of the plant and the site of the metabolic activities. Therefore, the concentration of the elements in this organ is an indicator of their status in the plant (Bould, 1966). Also in this method, instead of determining the concentration of the elements in the plant, the ratio between them in the plant is used to recommend required element fertilizers. The main disadvantage of this system is that one element cannot be investigated alone, and at least three other elements must be measured to check each element in the plant. Therefore, when needed to examine one, two or three main elements of N, P and K, DRIS method cannot be considered as an effective model (Beufils, 1973). Another major drawback of this method is the complexity that increases the probability of mistakes in interpreting the results and suggestions. In most recommended fertilizer methods, the concentration of elements in the soil or plant is the element's assessment scale, and rarely the correlation between the elements in the soil and plant is examined. In most methods, the concentration of the elements in the leaf indicates the status of the elements in the plant, while the physicochemical properties of each element are different from the other elements. Therefore, the concentration of the elements in the leaf cannot be a suitable indicator for evaluating all of the elements in the plant. Therefore, the objectives of this study were: 1) The use of phosphorus concentration in the soil saturation extract instead of total soil phosphorus to recommend phosphorus fertilizer. 2) To determine a regression model between the phosphorus of plant organs and phosphorus of soil saturation extract.

Materials and Methods

Location of sampling and experimental analysis

Jahrom (N 28°, 19' - 29°, 10'; E 52°, 45'-54°,04') is one of the important agricultural areas of Fars Province in Iran . Its height is about 1050 meters above sea concentration, and the climate is dominantly arid to semiarid, with an average precipitation of about 250 - 300 mm y^{-1} and the average annual temperature is about 21-22 °C.

In different parts of Jahrom 39 Washington Navel Orange (WNO) orchards were selected. The average age of the trees was 10-15 years and the area of each orchard was about 8 to 10 hectares. According to the obtained yield in previous years, orchards were divided into three groups with low, moderate and high yields. Among these orchards, 18 orchards were classified in the high yield group (orchards in which 180-220 kg h^{-1} y^{-1}, ammonium sulfate and triple super phosphate, 250-300 kg potassium sulfate, and 40-70 kg magnesium sulfate were applied, and their yield was about 60-70 t $ha^{-1}y^{-1}$), 10 orchards were classified as moderate group (orchards in which 100-130 kg h^{-1} y^{-1} ammonium sulfate and triple super phosphate, 20-40 kg magnesium sulfate were applied and their yield was about 30-40 t h^{-1} y^{-1}), and 11 orchards were classified in low yield (orchards in which 80-100 kg ammonium sulfate and triple super phosphate were applied, and their yield was about 10-20 t h^{-1} y^{-1}). From each orchard, three trees were selected for two consecutive years (2015-2016) and from each year in late April and early May roots, stems (one-year-old stems), young leaves (the youngest mature leaf), old leaves, fruits and soil of root zone were sampled of each side of the plant. Every time, in four stages from 117 trees samplings were carried out (468 samples). After each sampling step, they were transferred to the laboratory (Carter, 1993). After washing with distilled water, the plant samples were dried in the air (Campbell and Plank, 1998; Jones, 1998), and then dried at 60°C in the oven, and finally were ground (Burton and David, 1991; Fageria et al., 1991; Snowbell and Robson, 1991). The soil samples were stored in a refrigerator at a temperature of about 0-2° C to reduce microbial activity as much as possible, and then the soil extracts were prepared (Estefan et al., 2013; Brady and Weil, 1999). In all plant and soil samples, the amount of phosphorus was measured (Olsen and Sommers, 1982; Estefan et al., 2013). Some Physio-chemical properties of soil samples such as soil texture (Estefan et al., 2013; Bouyoucos, 1962), pH (Ryan et al., 1977; USDA, 1969; Ryan, 2000), CEC (Sonmez et al., 2008; He et al., 2012) and organic matter (Walkley, 1947; FAO, 1974) were also measured.

Data analysis

Data from four stages of sampling were divided into two groups. A group of high-yield orchards (216 trees), and the other was included all the orchards (468 trees). Correlation matrix was determined between soil properties and phosphorus of each plant organ with the phosphorus concentration of soil saturation extract for 468 samples (Table 1). Those variables with significant correlation with the phosphorus of soil saturation extract were chosen (Table 3). Then, a multivariate regression model was run between these variables and the phosphorus of soil saturation extract SPSS-24 and the Enter method. The same method was also used for the high-yield orchards (216 trees).

Results

Regression model for all orchards

As it was shown in Table 1, among the variables studied in 468 samples, the phosphorus of soil saturation extract had significant positive correlations with root (0.214**), old leaves (0.983**), young leaves (0.980**), fruit (0.986**), and significant negative correlation with stem (-0.222**) phosphorus concentrations. Therefore, a multivariable regression equation was obtained between these variables using software SPSS-24 and Enter method (R^2_{adj}= 0.993, N= 468, P<0.001) (Table 2). Although the phosphorus of soil saturation extract had significant correlation with the phosphorus of the stem in the bivariate correlation (-0.210*), but in the multivariate regression they did not show significant correlation (Tables 1, 3). This is because the correlation between soil phosphorus and plant stem was weak and negative. The Enter method keeps that variable to have a high correlation, and it removes variables that have the least correlation with other variables. According to the Table 3, the non-standardized regression coefficient (B) in the model for estimating the phosphorus of soil saturation extract can be as follows:

$$Y_1 = 0.027254 + 0.0634430X_1 + 0.039536X_2 + 0.000693X_3 - 0.063610X_4 \quad (1)$$

Where: Y_1= phosphorous concentration of soil saturated extract, X_1= phosphorous concentration in old leaves, X_2= Phosphorous concentration in fruits, X_3= Phosphorous concentration in roots, X_4= Phosphorous concentration in young leaves.

Table 1. Correlation coefficients of soil factors, plant organs phosphorus and soil saturation

	(SSEP)[a]	OM	pH	EC	CEC	root	steam	Old leaf	Young leaf	fruit
(SSEP)	1	.083	-.063	.075	.024	.214**	-.222**	.983**	.980**	.986**
OM	.083	1	.091	.074	.795**	.071	.069	.077	.081	.082
pH	-.063	.091	1	.081	.789**	-.010	-.052	-.012	-.041	-.061
EC	.075	.074	.081	1	.031	-.077	-.069	-.075	-.084	-.080
CEC	.024	.795**	.789**	.031	1	.018	.067	.079	.015	.074
root	.214**	.071	-.010	-.077	.098*	1	-.071	.198**	.206**	.219**
steam	-.222**	.069	-.052	-.069	.067	-.071	1	-.233**	-.225**	-.213**
Old leaf	.983**	.077	-.012	-.075	.079	.198**	-.233**	1	.998**	.987**
Young leaf	.980**	.081	-.041	-.084	.015	.206**	-.225**	.998**	1	.993**
fruit	.986**	.082	-.061	-.080	.074	.219**	-.213**	.987**	.993**	1

*' ** at the level of 5% and 1%, respectively, have a significant difference.
a: soil saturated extract phosphorous

Table 2. Analysis of variance between phosphorus in plant organs and in soil saturated extract

Model	Sum of Squares	df	Mean Square	F	Sig.	Adjusted R Square
Regression	23402.849	5	4680.570	1.423E4	.000	
Residual	152.007	462	.329			.993
Total	23554.857	467				

Table 3. Regression coefficients of phosphorus in plant organs and in soil saturated extract

Model	Unstandardized Coefficients		Standardized Coefficients	t	Sig.
	B	Std. Error	Beta		
(Constant)	.027254	.167736		.162	.871
P root	.000693	.000315	.008495	2.200	.028
P stem	.000201	.000222	.003511	.906	.365
P old Leaf	.063443	.001663	2.554657	38.140	.000
P young Leaf	-.063610	.001818	-3.125201	-34.986	.000
P fruit	.039536	.000893	1.566921	44.258	.000

As it is clear from Equation 1, phosphorus concentration of soil saturation extract has a significant correlation with the four variables, since the measurement of all these variables is expensive, this equation should be simplified as much as it possible. Fruit phosphorus concentration has the most correlation with the phosphorus concentration of soil saturation extract and phosphorus concentration in other plant organs (Table 1, 3). By dividing the average phosphorus concentrations of each plant organ to the average phosphorus concentration in fruit (Table 4), the ratio of phosphorus between each plant organ and fruits can be obtained. By putting these ratios in the Equation, all X_i is converted to X_1 (phosphorus of fruit), and Equation 1 (multivariate equation) converted to Equation 2 (bivariate equation).

$$\frac{Main\,P\,of\,root}{\text{Main P of Fruit}} = 0.2542 \quad \frac{\text{Main P of Old Leaf}}{\text{Main P of Fruit}} = 1.02906 \quad \frac{Main\,P\,of\,Young\,Leaf}{Main\,P\,of\,Fruit} = 1.23749$$

Y_1= 0.027254 + (0.0634430) (1.02906) X_1 + (0.039536) X_1 + (0.000693) (0.25420) X_1 – (0.063610) (1.23749) X_1

With arithmetic summation of X_1 in the both sides of the model:

$$Y_1 = 0.027254+0.026282X_1 \qquad (2)$$

Y_1= P concentration in the soil saturated extract (mg L^{-1})
X_1= P concentration in the fruits (mg L^{-1})

Table 4. Phosphorus concentrations in the soil and in plant samples

	P-Soil saturation	pH	P-Root	P-Stem	P-Old Leaf	P-Young Leaf	P-Fruit
(Average) (mg L^{-1})	19.536	7.56	188.264	255.964	762.140	916.503	740.615

Regression model for high yield orchards

To determine the correlation between soil properties and phosphorus concentration in plant organs with the phosphorus of soil saturation extract in high yield orchards (60 to 70 t h^{-1}), statistical analyzes were performed. At first, a bivariate correlation was done between soil properties and phosphorus of each plant organ with the phosphorus of the soil saturation extract. Soil pH, phosphorus of young leaves, fruit and old leaves showed significant correlation with the phosphorus of soil saturation extract. Therefore, a multivariable regression equation was obtained between these variables using SPSS-24 and Enter method (R^2_{adj}= 0.982, N= 216, P<0.001) (Tables 5, 6). For the non-regular regression coefficient (Table 6), the estimated model can be presented as follows:

$$Y_2 = 11.330 + 0.0630\,X_1 + 0.0370\,X_2 - 1.345\,X_3 - 0.062\,X_4 \qquad (3)$$

Which: Y_2=concentration of phosphorus in the soil saturation extract, X_1= phosphorous concentration in the old leaves, X_2= phosphorous concentration in the fruits, X_3= pH, X_4= phosphorous concentration in the young leaves.

Equation 3 shows that, phosphorus of soil saturation extract has a significant correlation with other four variables, this equation should be simplified as much as it possible. Since fruit phosphorus concentration has the most correlation with the phosphorus concentration of soil saturation extract and phosphorus concentrations in other plant organs (Tables 1, 6). By dividing the average phosphorus concentration of each plant organ to the average phosphorus concentration of fruit (Table 7), the ratio of phosphorus between each plant organ and fruits was obtained. By putting these ratios in the equation 3, all X_i is changed to X_1 (phosphorus of fruit), and this multivariate equation converted to the bivariate equation (Equation 4).

$$\frac{pH}{\text{Main P of Fruit}} = 0.084667 \quad \frac{\text{Main P of Old Leaf}}{\text{Main P of Fruit}} =$$

$$1.029077 \quad \frac{Main\,P\,of\,Young\,Leaf}{Main\,P\,of\,Fruit} = 1.2375$$

Y_2= 11.330+ (0.0630) (1.029077) X_1 + (0.0370) X_1 – (1.345) (0.0084667) X_1 – (0.0620) (1.23750) X_1

With arithmetic summation of both sides, we will have:

$$Y_2 = 11.330 + 0.013719X_2 \qquad (4)$$

Y_2= P concentration in the soil saturated extract (mg L^{-1})
X_2= P concentration in the fruits (mg L^{-1})

According to Equations 2 and 4, the amount of phosphorus required for each Washington Navel Orange (WNO) orchard in the Jahrom region can be determined. One equation for high-yield WNO orchards (Equation 4), and the other for the entire orange orchards (Equation 2). To recommend phosphorous fertilizer, two samples of fruits are required. A sample of fruits from high-yield orchards and another of an orchard that show phosphorus deficiency and their phosphorus concentration has been measured. By replacing the amount of fruit phosphorus of high yield orchard instead of the X_2 in Equation 4, the phosphorus of soil saturation extract in the high-yield orchard (Y_2) is obtained, and this is the Norm of soil phosphorus for WNO in Jahrom. With putting the phosphorus concentration in fruits of other orchard instead of the X_1 in Equation 2, the phosphorus concentration of soil saturation extract in that orchard is obtained (Y_1). By decreasing Y_1 of Y_2, the amount of phosphorus needed for an orchard that shows phosphorus deficiency was obtained. The above statements and the following examples, make it easy to use the integrated plant and soil system (IPSS) for all plants in everywhere.

Suppose the phosphorus concentration of the fruit is 700 mg kg^{-1} dry matter in one of the Washington Navel Orange orchards of Jahrom, for one kg of soil how much triple super phosphate (28%P) with an efficiency of 60% is needed? Soil texture is loamy and the saturation percentage is 37 percent.

Table 5. Analysis of variance of independent variables and soil saturated phosphorus concentration in high yield orchards

Model	Sum of Squares	df	Mean Square	F	Sig.	Adjusted R Square
Regression	4746.314	5	949.263	2.863E3	.000[a]	
Residual	87.446	210	.416			0.982
Total	4833.759	215				

Table 6. Regression coefficients of phosphorus concentrations in plant organs and phosphorus of soil extract in high yield gardens

Model	Unstandardized Coefficients		Standardized Coefficients	t	Sig.
	B	Std. Error	Beta		
(Constant)	11.3300	2.343		4.836	.000
P old Leaf	.063002	.003	2.698	23.697	.000
P root	0.007551	.003513	.02008	2.139	.033
P young Leaf	-.062001	.003	-3.295	-22.119	.000
P fruit	.037001	.001	1.583	26.673	.000
Soil pH	.000477	.001144	.002221	.417	.238

Table 7. P average concentration in the soil and plant in four sampling in the high yielded orchards

	P-Soil saturation	pH	P-Root	P-Stem	P-Old Leaf	P- Young Leaf	P-fruit
(Average) (mg L^{-1})	23.522	٧.٥٥0	205.268	231.218	917.658	1103.515	891.729

Considering that the average amount of fruit phosphorus in high-yield orchards is 891.729 mg l^{-1} (Table 7). By replacing these values in equation 4, the phosphorus concentration of the soil saturation extract for the WNO in high yield orchards (Y_2) will be 23.564 mg l^{-1} (This is the norm of phosphorus concentration for WNO in this area). Also, if in this sample the phosphorus concentration in fruit is 700 mg l^{-1}, by putting it in Equation 2, the phosphorus concentration of the soil saturation extract in the desired orchard (Y_1) will be 18.425 mg l^{-1}. By reducing the soil phosphorus of this orchard from the soil phosphorus of high-yield orchards (norm), the amount of phosphorus required will be 5.139 mg l^{-1}.

$Y_2 - Y_1 => 23.564 - 18.425 = 5.139$ mg l^{-1} or 0.005139 g l^{-1}

Because the soil saturation is 37%, the amount of phosphorus required is:
$0.005139 * 0.37 = 1.901 * 10^{-3}$ g kg^{-1}
Average phosphorus required per kg of soil

Average triple super phosphate (efficiency of 60% and 28%P), required is:

$$1.901 * 10^{-3} * \frac{100}{28} * \frac{100}{60} = 0.01132 \text{ g kg}^{-1}\text{soil}$$

Discussion

The results of the present study showed that there was a significant positive correlation among phosphorous concentrations in plant organs, and the highest correlation was observed between fruit phosphorus and phosphorus of other plant organs. Also, there was a significant correlation between phosphorus concentration in soil saturation extract and phosphorus concentration in plant organs, and the highest correlation was observed between phosphorus concentration in the fruits and in the soil saturation extract. In some studies, the relationship between elements in plant organs and their absorption and release rates has been shown (Yang et al., 2014; Zhang et al., 2018).

According to the results, it seems that the phosphorus of Washington Navel Orange leaves is not suitable for determining the state of phosphorus, and it is better to investigate fruit phosphorus based on status and recommendation of phosphorus. This is probably due to the role of this element in growth, development and yield of fruits (Saroosh et al., 1991; Lihong and Qiuxi, 2010; Lu et al., 2013), role of phosphorus in the sugar synthesis and the production of other hydrocarbons in the fruit (Zhihong et al., 2017; Martuscelli et al., 2016).

Physicochemical properties of each element are different from the other elements due to their various roles and different absorption and transferring mechanisms (Watanabe, 2007; Elekes, 2010; Sharath, 2015). Therefore, using an organ such as a leaf to study the status of all elements for all plants is not proper procedure. In IPSS, each element is recommended based on the correlation between the concentration of the element in the soil and in the plant organs, not just based on the concentration of the element in the leaf or in the soil (Zhang et al., 2005; Sonmez et al., 2008).

In this study, phosphorus concentration in the soil saturation extract was used instead of total phosphorus. The concentration of phosphorus in the soil saturation extract is the most realistic concentration of phosphorus that can be uptaken by plants. The concentration of phosphorus in the soil saturation extract is very similar to its concentration in the absorbable water by the root. Recent research emphasized on the role of phosphorus in the soil saturation extract as an important indicator for the recommendation of phosphorus (Hooda et al., 2000; Nair et al., 2004; Vadas et al., 2005).

In conclusion, most fertilizer recommendation methods are qualitative, and they cannot determine the amount of fertilizer required by the plant (Beufils, 1973; Dow and Roberts, 1982; Montanes, et al. 1993). But IPSS is quantitative and can determine the amount of element required by the plant.

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