ISSN 0100-2945 369 http://dx.doi.org/10.1590/0100-29452017369

'FUJI' APPLE TREE RESPONSE TO PHOSPHORUS FERTILIZATION[1]

GILBERTO NAVA[2], MARLISE NARA CIOTTA[3], GUSTAVO BRUNETTO[4]

ABSTRACT - The aim of this work was to evaluate the effects of orchard fertilization with increasing rates of phosphorus (P) on yield and critical levels of P in the soil and in the leaf of 'Fuji' apple trees. The experiment was conducted in São Joaquim, state of Santa Catarina, southern Brazil, from 2010 to 2015, in an Inceptisol soil. The three apple orchards were planted in 2004 with the Fuji cultivar grafted on Marubakaido/M9 rootstock and grown under a high-plant-density system (1984 trees ha^{-1}). Annual fertilizer levels of 0, 40, 80, 120 and 160 kg ha^{-1} of P_2O_5 (as triple superphosphate) were applied to the soil surface, without incorporation, in a randomized block design with five replicates. In the first and last years (2011 and 2015), soil samples were collected from 0-10, 10-20 and 0-20 cm layers and the available P content was analyzed. Annually, whole leaves were collected and analyzed for P content. The number and weight of fruits per tree and hfruit yield were also evaluated. Application of P increased the content of available P in the soil, but this increase was not accompanied by increased leaf P content nor by increased fruit yield. This suggests that, in soils with medium to high content of organic matter and well fertilized with P before planting, there is no response of apple trees for P reapplication in the 10 subsequent years.
Index terms: *Malus domestica* Borkh, yield, critical level, leaf analysis.

RESPOSTA DA MACIEIRA 'FUJI' À ADUBAÇÃO FOSFATADA

RESUMO – O trabalho objetivou avaliar a resposta da macieira (*Malus domestica* Borkh) à adubação fosfatada e estabelecer o nível crítico de fósforo (P) no solo e nas folhas das plantas. O experimento foi conduzido em um Cambissolo Húmico entre os anos de 2010 a 2015, no município de São Joaquim (SC). O pomar foi implantado em 2004 com a cultivar 'Fuji' sobre o porta-enxerto Marubakaido/M9, num sistema de alta densidade de plantio (1984 plantas ha^{-1}). Os tratamentos foram cinco doses de P_2O_5 (0; 40; 80; 120 e 160 kg ha^{-1}), aplicadas anualmente na forma de superfosfato triplo sobre a superfície do solo, em delineamento de blocos ao acaso com cinco repetições. No primeiro e último anos de avaliação (2011 e 2015), foram coletadas amostras de solo nas camadas de 0-10, 10-20 e 0-20 cm e efetuadas análises de P disponível. Anualmente, foram coletadas folhas inteiras que foram submetidas à análise do teor de P. Avaliaram-se anualmente o número e a massa dos frutos por planta, e a produção de frutos. A aplicação de P incrementou o teor de P disponível no solo, mas este incremento não foi acompanhado do aumento do teor foliar, bem como dos componentes de produção e da produção de frutos. Isto sugere que, em solos com médio a alto teor de matéria orgânica e que tenham sido corrigidos com P na implantação, não há necessidade de nova aplicação do nutriente nos dez anos subsequentes ao plantio da macieira.
Termos de indexação: *Malus domestica* Borkh, nível crítico, produção, análise foliar.

[1](Paper 229-15). Received September 29, 2015. Accepted February 02,2016.
[2]Agronomist, Doctor in Soil Science and Plant Nutrition, Researcher of the Centro Nacional de Clima Temperado, Pelotas, RS-Brasil, E-mail: gilberto.nava@embrapa.br
[3]Agronomist, Doctor in Soil Science, Researcher of the Empresa de Pesquisa Agropecuária e Extensão Rural de Santa Catarina S.A. (EPAGRI). São Joaquim, SC-Brasil, E-mail: marlise@epagri.sc.gov.br
[4]Agronomist, Doctor in Soil Science, Prof. of the Rural Sciences Dep. and of the Graduate Studies Program in Soil Science of the Universidade Federal de Santa Maria, Santa Maria-RS, Brazil. Fellowship Holder in Research Productivity from the CNPq, Email: brunetto.gustavo@gmail.com

INTRODUCTION

In traditional apple (*Malus domestica* Borkh) producing countries, fertilization with phosphorus (P) in orchards has received less attention in relation to fertilization with other macronutrients, such as nitrogen (N) and potassium (K), partly due to the lower demand of P by the culture (NEILSEN; NEILSEN, 2003). While the ideal foliar concentrations of N and K take values between 20 to 25 and 12 to 15 g kg^{-1}, respectively, the normal concentration of P in the leaves of apple trees is lower than 3.0 g kg^{-1} (CQFS-RS/SC, 2004). This does not eliminate the need for addition of P to the soil, especially in tropical and subtropical regions, where much of the P can be absorbed to the functional groups of soil colloids, which decreases its availability to plants (GUARDINI et al., 2012).

Phosphorus is part of numerous organic compounds in plant metabolism such as nucleotides, phosphoproteins, lecithin and phytin. Phosphorous participates in several biochemical reactions like respiration, wax metabolism and energy transformation and is a constituent of most enzymes (MARSCHNER, 2012). In the apple tree, P deficiency reduces root growth, causing premature leaf abscission as well as negative effects on flowering and fruiting (SUZUKI; BASSO, 2002).

The states of Rio Grande do Sul (RS) and Santa Catarina (SC) account for over 90% of the apple produced in Brazil, mostly using cultivars ‘Fuji’ and ‘Gala’. Most soils in these regions are medium-textured, medium or high organic matter content, acidic and have very low or low available P content (OLIVEIRA et al., 2014). Hence, liming and fertilization correction with P are performed prior to the transplant of apple trees. The amount of P is set based on nutrient and clay content in the soil. For the same P content in the soil, the higher the clay content, the greater the amount of P required to be added (CQFS-RS/SC, 2004). On the other hand, after the orchard is implemented and fruit production starts, the definition of the need for P fertilization and the P dose for maintenance fertilization, which is carried out on the soil surface and without incorporation, is established based on the analysis of nutrient levels in the leaves and soil, as well as plant age and productivity.

The P applied on the soil surface during maintenance fertilization can be adsorbed with high binding energy with the mineral fraction surface of the soil (SCHMITT et al., 2013; BRUNETTO et al., 2015). However, successive applications of P onto the soil surface may cause the occupation of adsorption surfaces, decreasing their adsorption energy, which can enhance desorption and therefore migration in the soil profile, increasing the P amount in deeper layers. With the increase of available P content in the soil, it is expected that part of the nutrient can move closer to the outer surface of the roots and be absorbed, increasing its levels in the plant (BRUNETTO et al., 2015). This can increase the production components, such as the number and mass of fruits, which can affect the productivity (DAR et al., 2015). However, information is scarce on responses of P fertilization on apple trees in Brazil, which justifies the medium or long-term experiments. This work aimed to evaluate the response to P fertilization and the establishment of the critical level of P in the soil and leaves of the ‘Fuji’ apple tree grown in a soil from the southern region of Brazil.

MATERIAL AND METHODS

The experiment was conducted in a commercial orchard from 2010 to 2015, in São Joaquim, Santa Catarina State, Brazil, (28°17’25” S; 49°56’56” W; altitude 1200 m). According to Köppen, The climate of the region is classified as humid mesothermal (Cfb), with mild summers and harsh winters. The annual average temperature is 13°C and the average pluvial precipitation is 1,600 mm per year. Table 1 shows the precipitation and temperature data during the experiment period.

The orchard was planted in 2004 with the ‘Fuji’ cultivar grafted on Marubakaido/ M9 rootstock (20 cm of M9). The spacing was 4.2 m between rows and 1.2 m between plants, totaling 1984 plants per hectare. The soil is a Humic Cambisol (EMBRAPA, 2013), which, previously the transplanting seedlings in 2004, was subjected to liming to raise the pH in water up to 6.5, as well as P and K contents, in accordance with the recommendation suggested by CQFS-RS/SC (2004) for the culture of apple trees. The limestone and fertilizers were incorporated in the entire orchard area up to approximately 40 cm deep through a sequence of operations of subsoiling, tillage, and harrowing. At the time of experiment installation, the soil showed the following chemical-physical characteristics analyzed according to Tedesco et al. (1995): 470 g dm^{-3} of clay; 48 g dm^{-3} of organic matter; pH in water of 6.4; 6.7 mg dm^{-3} of P and 2.46 $mmol_c$ dm^{-3} of K (both extracted by Mehlich-1); 0.0 $mmol_c$ dm^{-3} of Al, 115 $mmol_c$ dm^{-3} of Ca, 43 $mmol_c$ dm^{-3} of Mg (both extracted by KCl 1 mol L^{-1}).

In June 2010, the P doses (0, 40, 80 120 and 160 kg ha^{-1} of P_2O_5) were applied to the experiments.

The doses were applied as triple superphosphate to the soil surface without incorporation, within a range of 2.2 m wide centered along the line of planting. The experimental design was randomized blocks with five replicates, with each repetition composed of seven plants, using the five central plants for evaluation. Throughout the experiment, the management practices recommended by EPAGRI (2002) were adopted in the orchard of apple trees.

The yield was assessed annually by counting the total number of fruits per plant and multiplying by the average mass of 100 fruits per plot, randomly sampled. In March 2011 and 2015, during the fruit harvesting, soil sample was collected from the 0-10, 10-20 and 0-20 cm layers in the planting line. The soil was air-dried, ground, sieved through a 2 mm mesh and subjected to the analysis of available P by the Mehlich-1 extraction method. From January 15 to February 15 of each year, 40 samples of whole leaves and with petiole were collected, in the middle third part of branches located at average height and on opposite sides of the plant, which were washed with mild detergent and rinsed with distilled water. The leaves were then dried in an oven with forced air at 65°C to reach constant weight, ground and analyzed for the P content (TEDESCO et al., 1995).

The results were submitted to the variance analysis and when the effects were significant, polynomial regression equations ($P<0.05$) were adjusted. The relative yield (*rr*) was calculated using the equation $rr=(rt/rm)*100$, where *rt* is the yield of the treatment and *rm* is the maximum yield. The *rr* results were related to the available P content and to the total leaf P content in the whole leaves and with petiole, to obtain a sufficient level for *rr* of 90%. The mathematical adjustment between the variables was carried out using the Mitscherlich model, $\hat{y}=a(1-b^x)$, where $\hat{y}$ represents *rr*, *a* and *b* are constants, and *x* is the quantity of the nutrient in the soil or in the whole leaf.

RESULTS AND DISCUSSION

The levels of available P increased with increasing doses of P fertilization, in both years analyzed, in the 0-10 and 0-20 cm layers. In the 10-20 cm layer, there was no increase in the available P, even after five years of successive applications of P fertilization (Table 2), indicating that P is strongly retained in most superficial layer of the soil. The P forms an inner-sphere complex with functional groups of reactive soil particles, which decreases its mobility in soil solution and encourages its buildup in more superficial layers (BRUNETTO et al., 2015). In addition, the accumulation of available P in the 0-10 cm layer could have occurred because P fertilization was applied on the soil surface and without incorporation, in addition to the cycling of P promoted by the species of ground cover plants that lived together in the orchard or by the apple trees. With the senescence and deposition of aerial parts of ground cover plants and senescent leaves of apple trees onto the soil surface, part of the P in these tissues may have been released into the soil, increasing its content in more superficial layers (MARTINS et al., 2008; TEIXEIRA et al., 2012, DIEL et al., 2014).

The addition of P onto soil did not affect the leaf total P content in any of the crops (Table 3). In all crops, the P content in leaves were found within the sufficient range between 1.5 and 3.0 g kg^{-1}, considered normal (SUZUKI; BASSO, 2002) and, in most cases, the P content was greater than 2.2 g kg^{-1}, above the level proposed as suitable to obtain high yield in the cultivation of apple trees in soils in Canada (NEILSEN et al., 2008).

In all crops, P fertilization did not affect the number of fruits per plant, fruit mass nor fruit productivity of the apple trees (Table 3). Productivity of crops ranged from 25.8 to 64.1 Mg ha^{-1}. The lowest yields were obtained in the 2012/2013 and 2014/2015 harvests, because of the damage caused by a hailstorm, which demanded the removal of the bruised fruit in the 2012/2013 harvest, as well as the irregular distribution of rain, affecting floral differentiation and quality of fruit buds in the last harvest (Table 1).

Fruit trees, in general, show a little response to maintenance P fertilization conducted along the productive period of the plants (LONGLINERS et al., 2004; BRUNETTO et al., 2015). This low response can be attributed to the perennial feature, which allows a longer period of nutrient absorption from the soil (ERNANI et al., 2000), also the distribution of roots at greater depths in the soil profile, which enables nutrient absorption not only from the soil surface layer (AMARANTE et al., 2015). Another factor that reduces the response of fruit trees to P fertilization is the association of the roots with hyphae of arbuscular mycorrhizal fungi (JEFFRIES et al., 2003), which increases the volume of soil explored, maximizing the uptake of soil nutrients, especially P (PLENCHETTE, et. al., 1981; MILLER et al., 1985; MIRANSARI, 2010).

Another factor associated with the absence of response to P fertilization can be the soil organic matter content, which in the experiment was 48 g kg^{-1}, very close to the level considered high (> 50 g kg^{-1}) (CQFS-RS/SC, 2004), and represents an important reserve of organic fractions of P. During the organic matter mineralization and the release of inorganic P into the soil solution, humic substances that compete for the functional groups of the reactive particles with the P ion are produced (SETHI et al., 2004). Thus, the higher available P content in the soil is expected, even in soils that did not receive the addition of the nutrient. Some works carried out in Poland and in Canada report response of the apple tree to P fertilization because of low organic matter content of the cultivated soil (WOJCIK; WOJCIK, 2007; NEILSEN et al., 2008).

Because there was no response between fruit production and P fertilization in the soil, it was not possible to establish the critical level of the nutrient between the relative yield of fruits and the P content in the 0-20 cm layer (Figure 1a), which is the diagnostic layer of the available P content in the soil for fruit trees in the states of Rio Grande do Sul and Santa Catarina (CQFS-RS/SC , 2004), nor between the relative yield of fruits obtained in the five harvests with the total P content in whole leaves (Figure 1b). According to Brunetto et al. (2015), in a pear tree orchard submitted to the addition of P in the soil, in the same soil type and region as that in this study, it was not possible to establish the critical level of P in the soil and leaves, which was partly explained because the soil samples were collected only within the canopy projection range where P was applied and because the roots can also absorb P not supplied by the fertilizer from the areas located between the plant rows.

TABLE 1-Monthly averages of temperature (Temp.) and pluvial precipitation (Prec.) during the experiment years (2010 to 2015).

Month	2010		2011		2012		2013		2014		2015	
	Temp. (ºC)	Prec. (mm)	Temp. (ºC)	Prec. (mm)	Temp. (ºC)	Prec. (mm)	Temp. (ºC)	Prec. (mm)	Temp. (ºC)	Prec. (mm)	Temp. (ºC)	Prec. (mm)
January	18.3	205.3	16.5	147.8	16.1	66.5	16.1	66.5	19.0	155.0	17.9	263.5
February	17.6	354.0	18.6	198.1	16.3	247.1	16.3	247.1	18.2	254.2	17.1	151.2
March	15.5	188.8	16.0	180.0	16.1	167.2	16.1	167.2	15.9	147.7	15.8	149
April	13.4	233.7	14.2	118.8	13.7	88.8	12.9	48.5	16.0	163.6	13.5	93.4
May	10.7	179.6	10.0	100.1	11.2	31.9	11.3	75.6	11.1	203.8	-	-
June	9.9	140.7	8.5	143.3	10.1	154.3	10.2	184.6	10.4	430.1	-	-
July	10.1	187.5	9.8	239.6	8.6	168.3	9.2	67.6	9.8	80.4	-	-
August	9.9	83.4	9.8	368.8	12.8	19.1	9.6	402.4	11.7	106.6	-	-
September	11.9	246.4	11.2	145.2	12.3	146.4	11.8	236.4	13.1	214.3	-	-
October	11.6	121.3	13.7	168.4	14.9	181.2	12.5	124.9	15.4	219.8	-	-
November	14.1	180.4	14.1	76.3	15.1	50.7	14.9	121.6	15.3	138.7	-	-
December	16.3	166.0	15.4	167.8	18.6	178.0	17.2	154.8	16.7	252.3	-	-

TABLE 2- Available P content (Mehlich-1 Extractor) in soil cultivated with apple trees and submitted to the addition of doses of phosphorous fertilization, and the regression equations adjusted to the polynomial model with the dose of P_2O_5 as independent variable (x).

Dose kg ha^{-1} P_2O_5	Layer (cm) 0-10	10-20	0-20
	Available P (mg kg^{-1})		
2011			
0	9.00	3.70	6.35
40	10.1	5.10	7.60
80	10.7	6.50	8.60
120	22.8	5.40	14.1
160	27.6	6.78	17.2
Regression	6.06 + 0.1248x	ns	y = 5.13 + 0.0705x
R^2	0.85*	-	0.92**
2015			
0	8.67	4.73	6.70
40	21.38	4.76	13.07
80	28.28	5.30	16.79
120	37.90	5.45	21.67
160	44.97	5.53	25.25
Regression	y = 10.42 + 0.222x	ns	7.558 + 0.114x
R^2	0.99**	-	0.99**

^{ns} = non-significant; *,** = significant at 5% and 1% error probability, respectively, by the F-test.

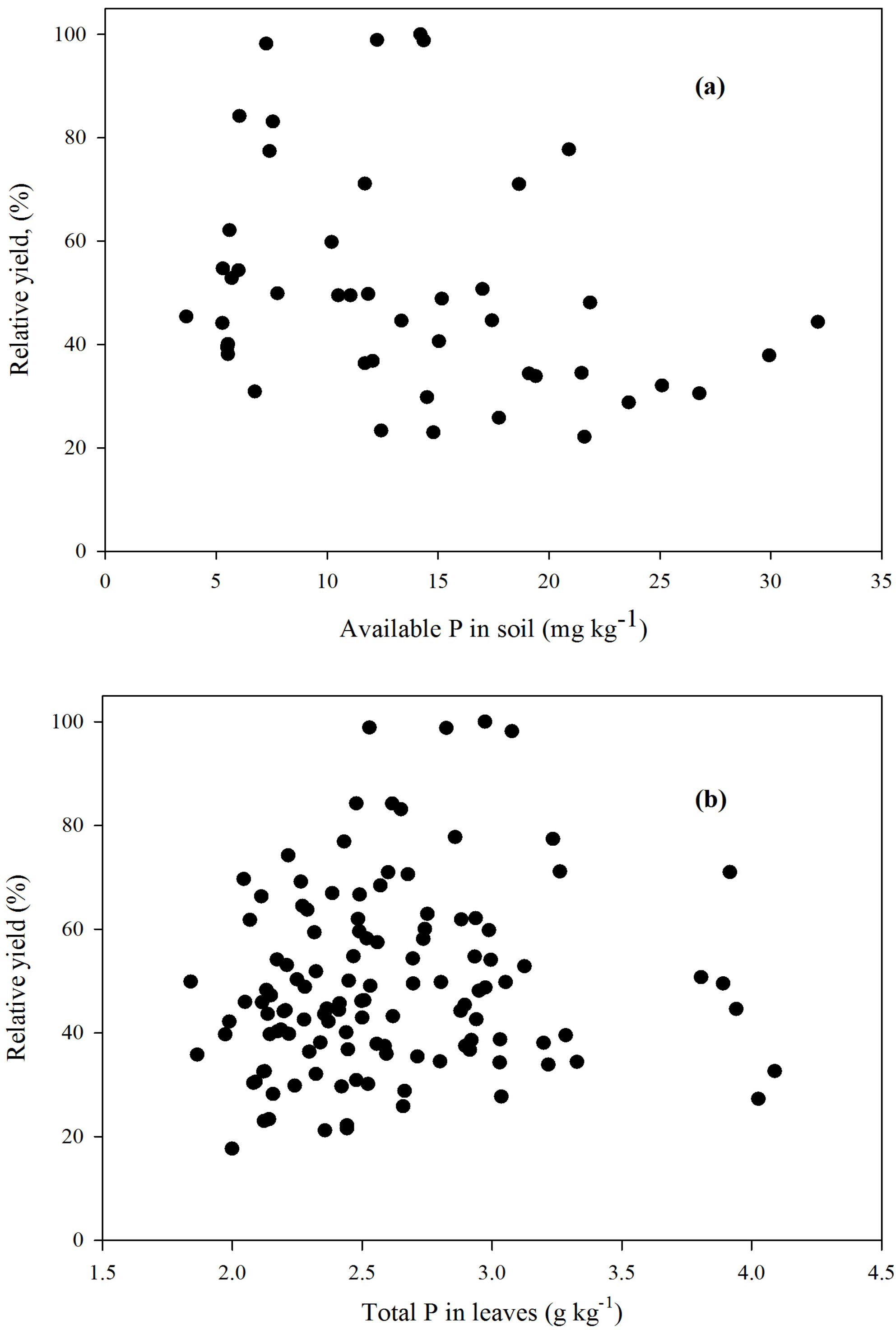

FIGURE 1- Relationship between the relative yield of 'Fuji' apple trees and (a) The available P content (Mehlich-1) in the 0-20 cm layer of soil during 2011 and 2015 years and (b) the total leaf P content during 2010 to 2015 years.

TABLE 3-Total leaf P content, number of fruits per plant, average fruit mass and yield in apple trees subject to application of doses of phosphorous fertilization. Adjustments to the Mitscherlich model, with the dose of P_2O_5 as the independent variable, were not significant.

Dose kg ha^{-1} P_2O_5	Total leaf P (g kg^{-1})	Fruits per plant (number)	Fruit mass (g)	Yield (Mg ha^{-1})
		---------------------Harvest 2010/2011 --------------------		
0	2.86	202	147.2	59.1
40	3.24	184	142.4	52.2
80	2.92	182	151.6	55.3
120	3.10	220	146.4	64.1
160	3.38	175	146.8	51.3
		-----------------------Harvest 2011/2012 ----------------------		
0	2.46	143	118.4	33.4
40	2.59	149	118.8	35.1
80	2.65	168	112.0	37.0
120	2.85	132	117.6	30.6
160	2.78	168	115.6	38.1
		-----------------------Harvest 2012/2013 -----------------------		
0	2.11	191	122.0	46.4
40	2.37	175	119.0	41.5
80	2.26	137	122.7	34.3
120	2.35	211	120.0	50.2
160	2.46	162	122.7	40.4
		-------------------------Harvest 2013/2014 -------------		
0	2.45	262	95.2	49.4
40	2.52	269	92.8	49.6
80	2.34	283	92.4	51.1
120	2.49	252	94.4	46.7
160	2.49	270	92.4	49.0
		--------------------Harvest 2014/2015 ---------------		
0	2.37	130	142.0	33.8
40	2.34	112	141.2	31.5
80	2.49	96	142.4	26.8
120	2.33	127	138.4	35.1
160	2.51	89	136.4	25.8

CONCLUSIONS

The application of phosphorus increases the available P content (Mehlich-1) in the soil. However, this increase was not accompanied by an increased P content in the leaves nor by increased fruit yield, not allowing to establish the critical level of P in the soil and tissue.

The absence of response of apple trees to P fertilization indicates that in soils with medium to high levels of organic matter, which have been corrected with P at the orchard deployment, do not require new additions of P in the next ten years following the planting.

REFERENCES

AMARANTE, C.V.T do; ROSA, E.F.F.da; ALBUQUERQUE, J.A.; FILHO, O.K.; STEFFENS, C.A. Atributos do solo e qualidade de frutos nos sistemas convencional e orgânico de produção de maçãs no Sul do Brasil. **Revista Ciência Agronômica**, Fortaleza, v.46, n.1, p. 99-109, 2015.

BRUNETTO, G.; NAVA, G. AMBROSINI, V.G.; COMIN, J.J.; KAMINSKI, J. The pear tree response to phosphorus and potassium fertilization. **Revista Brasileira de Fruticultura**, Jaboticabal, v.37, n.2, p.507- 516, 2015.

CQFS - Comissão de Química e Fertilidade Do Solo. **Manual de adubação e calagem para os estados do Rio Grande do Sul e de Santa Catarina**. 10.ed. Porto Alegre: SBCS - Núcleo Regional Sul/UFRGS, 2004. 400 p.

EMBRAPA - Empresa Brasileira de Pesquisa Agropecuária. **Sistema brasileiro de classificação de solos**. 3.ed. Brasília, 2013. 353p.

DAR., M.A.; WANI, J.A.; RAINA, S.K.; BHAT, M.Y.; MALIK, M.A. Relationship of leaf nutrient content with fruit yield and quality of pear. **Journal of Environmental of Biology**, Lucknow, v.36, p.649-653, 2015.

DIEL, D.; BEHLING, M.; NETO, A.L. de F.; ISERNHAGEN, E.C.C. Distribuição horizontal e vertical de fósforo em sistemas de cultivos exclusivos de soja e de integração lavoura-pecuária-floresta. **Pesquisa Agropecuária Brasileira**, Brasília, DF, v.49, n.8, p.639-647, 2014.

EPAGRI. **A cultura da macieira**. Florianópolis: GMC/Epagri, 2002. 743 p.

GUARDINI, R.; COMIN, J.J.; SCHMITT, D.E.; TIECHER, T.; BENDER, M.A.; RHEINHEIMER, D.S.; MEZZARI, C.P.; OLIVEIRA, B.S.; GATIBONI, L.C.; BRUNETTO, G. Accumulation of phosphorus fractions in typic Hapludalf soil after long-term application of pig slurry and deep pig litter in a no-tillage system. **Nutrient Cycling in Agroecosystems**, Dordrecht, v.93, p.215-225, 2012.

ERNANI, P.R.; DIAS, J.; BORGES, M. A aplicação de nitrogênio ao solo em diferentes estádios não afetou o rendimento de frutos de cultivares de macieira. **Ciência Rural**, Santa Maria, v.30, n.2, p.223-227, 2000.

JEFFRIES, P.; GIANINAZZI, S.; PEROTTO, S.; TURNAU, K.; BAREA, J.M. The contribution of arbuscular mycorrhizal fungi in sustainable maintenance of plant health and soil fertility. **Biology and Fertility of Soils**, Dordrecht**,** v.37, p.1-16, 2003.

MARTINS, C.R.; MELO, G.W. de; FARIA, J.L.C. Modificação química no solo em pomares de macieiras conduzidos em quatro diferentes sistemas de produção frente às características naturais dos seus entornos. **Revista Brasileira de Agrociência**, Pelotas, v.14, n.4, p.128-131, 2008.

MARSCHNER, H. **Mineral nutrition of higher plants**. London: Academic, 2012. 652p.

MILLER, D.D.; DOMOTO, P.A.; WALKER, C. Colonization and Efficacy of Different Endomycorrhizal Fungi with Apple Seedlings at Two Phosphorus Levels. **New Phytologist**, Lancaster, v.100, p.393-402, 1985.

MIRANSARI, M. Contribution of arbuscular mycorrhizal symbiosis to plant growth under different types of soil stress. **Plant Biology**, Malden, v.12, p.563-569, 2010.

NEILSEN, G.H.; NEILSEN, D. Nutritional requirements of apple. In: FERREE, D.C.; WARRINGTON, I. J. (Ed.). **Apples, botany, production and uses**. Oxon: CABI Publishing, 2003. p.267–302.

NEILSEN, G.H.; NEILSEN, D.; TOIVONEN, P. Annual bloom-time phosphorus fertigation affects soil phosphorus, apple tree phosphorus nutrition, yield, and fruit quality. **Hortscience**, Cambridge, v.43, n.3, p.885-890, 2008.

OLIVEIRA, L.B. de; TIECHER, T.; QUADROS, F.L.F. de; TRINDADE, J.P.P.; GATIBONI, L.C.; BRUNETTO, G.; SANTOS, D.R. dos. Formas de fósforo no solo sob pastagens naturais submetidas à adição de fosfatos. **Revista Brasileira de Ciência Solo**, Viçosa, MG, v.38, n.3, p.867-878, 2014.

PLENCHETTE, C.; FURLAN, V.; FORTIN, J.A. Growth Stimulation of Apple Trees in Unsterilized Soil under Field Conditions with VA Mycorrhiza Inoculation. **Canadian Journal of Botany**, Ottawa, v.59, p.2003-2008, 1981.

QUAGGIO, J.A.; MATTOS J.D.; CANTARELLA, H.; STUCHI, E.S.; SEMPIONATO, O.R. Sweet orange trees grafted on selected rootstocks fertilized with nitrogen, phosphorus and potassium. **Pesquisa Agropecuária Brasileira**, Brasília, DF, v.39, n.1, p.55-60, 2004.

SCHMITT, D.E.; COMIN, J.J.; GATIBONI, L.C.; TIECHER, T.; LORENSINI, F.; MELO, G.W.B.; GIROTTO, E.; GUARDINI, R.; HEINZEN, J.; BRUNETTO, G. Phosphorus fractions in sandy soils of vineyards in Southern Brazil. **Revista Brasileira de Ciência do Solo**, Viçosa, MG, v.37, p.472-481, 2013.

SIQUEIRA, J.O.; ANDRADE, A.T.; FAQUIN, V. O papel dos microrganismos na disponibilização e aquisição de fósforo pelas plantas. In: YAMADA, T.; ABDALLA, S.R.S. (Ed.). **Fósforo na agricultura brasileira**. Piracicaba: ESALQ/USP, 2004. p.117-156.

SUZUKI, A.; BASSO, C. Fertilidade do Solo e nutrição da macieira. In: EPAGRI. **Manual da cultura da macieira**: Florianópolis: Epagri, 2002. p.341-381.

TEDESCO, M.J.; GIANELLO, C.; BISSANI, C.A.; BOHNEN, H.; VOLKWEISS, S.J. **Análises de solo, plantas e outros materiais**. 2.ed. Porto Alegre: UFRGS, 1995. 174 p.

TEIXEIRA, M.B.; LOSS, A.; PEREIRA, M.G.; PIMENTE, C. Decomposição e ciclagem de nutrientes dos resíduos de quatro plantas de cobertura do solo. **Idesia**, Arica, v.30, n.1, p.55-64, 2012.

WOJCIK, P.; WOJCIK, M. Response of Mature Phosphorus-Deficient Apple Trees to Phosphorus Fertilization and Liming. **Journal of Plant Nutrition**, Athens, v.30, n.10, p.1623-1637, 2007.