XXXV Congresso Brasileiro de Ciência do Solo
CENTRO DE CONVENÇÕES - NATAL / RN
O SOLO E SUAS MÚLTIPLAS FUNÇÕES
02 a 07 DE AGOSTO DE 2015

Effects of Potassium Fertilization and Throughfall Exclusion on the Hydraulic Redistribution of Soil Water in *Eucalyptus grandis* Plantations(1)

Verónica Asensio(2); Jean-Paul Laclau(3); Jean-Christophe Domec(4); Lionel Jordan-Meille(5); Jean-Pierre Bouillet(6); Yann Nouvellon(7); Cassio Hamilton Abreu-Junior(8)

(1) Work funded by the project FAPESP 2013/25998-4 and USP-COFECUB No Uc Sv 134/12
(2) Postdoctoral FAPESP fellow; Centro de Energia Nuclear na Agricultura – Universidade de São Paulo (CENA-USP); Piracicaba, SP; vfandino@cena.usp.br; (3) (6) (7) Researchers; CIRAD Montpellier, France; (4) (5) Professors; Bordeaux Sciences Agro, France; (8) Professor, CENA-USP; Piracicaba, SP.

ABSTRACT: The transport of water from moist soil layers to dry through the roots of some species is an important process for plant survival during long dry periods. The objective of the present study was to evaluate if *Eucalyptus grandis* roots growing in a tropical region characterized by long dry periods passively move water from deep to shallow soil layers, which is known as "hydraulic redistribution". The experiment was carried out at the Itatinga experimental station (SP, Brazil) that included four contrasting experimental plots resulting from the combination of two set of treatments: with/without potassium fertilization (+K/-K, respectively) and with/without throughfall exclusion (+W/-W, respectively). Sap flow was measured in superficial *Eucalyptus* coarse roots from the end of the 2014 dry season to the end of the 2015 rainy. We detected reverse sap flow (water in superficial roots going to the soil surface far from the trunks) all of the months, even during the rainy season, and in all the treatments, except in -K-W, where reverse flow started two months after the beginning of the rains (January). The lowest flow densities in superficial roots were observed in -K and/or -W, but reverse flow occurred in more roots or during more days per month than in treatments +K and +W.

Keywords: water stress, trees, root sap flow.

INTRODUCTION

During long drought periods, plants must find water at deep soil layers or make more conservative use of it. As water shortage is expected to increase over the next decades in many tropical regions due to climate change (Sheffield e Wood, 2008), it is important to assess how plants will adapt to this new climate scenario. Roots of some plant species can transport water from the water table or from moist soil layers to dry soil layers, where it can be used when water demand increases. This passive movement of water, which is due to water potential gradients in the soil-plant interface, is called hydraulic redistribution (HR) (Jackson et al., 2000).

On the other hand, nutrients can interact positively with water to reduce the negative effects of water stress. Potassium fertilization can have a positive effect on plant water use efficiency through improved stomatal regulation (Cakmak, 2005).

The interaction between nutrients and water availabilities on plant functioning is little documented. There is also limited number of studies showing HR in plants. Moreover, sap flow sensors have rarely been used in eucalyptus roots to measure HR. The main objective of the present study was to investigate hydraulic redistribution in *Eucalyptus grandis* plantations established on a K-poor soil in a tropical region with long dry seasons. We hypothesized that trees growing at soils without K fertilization and with throughfall exclusion have reverse flow in more roots and for more days than trees in the opposite conditions since, in the first case, trees grow in areas with drier soil surface.

MATERIAL AND METHODS

The *Eucalyptus grandis* plantation was located at the Itatinga Experimental Station of the University of São Paulo (23°020S; 48°380W). Two seasons can be distinguished: the dry season from June to September, and the rainy season characterized by high precipitation, temperature and global radiation from October to March. The soils are very deep Ferralsols (> 15 m) developed on Cretaceous sandstone, Marília formation, Bauru group, with a clay content ranging from 14% in the A1 horizon to 23% in deep soil layers. The mineralogy is dominated by quartz, kaolinite and oxyhydroxides, with acidic soil layers (pH 4.5-5). Exchangeable K and Na concentrations were 0.02 $cmol_{(+)}kg^{-1}$ on average in the upper soil layer and < 0.01 $cmol_{(+)}kg^{-1}$ between 5 and 1500 cm depth (Laclau et al., 2010).

Soil treatments and sampling

A split-plot experimental design was set up in June 2010 at the Station with highly productive *E. grandis* clones used in commercial plantations by the Suzano Company (SP, Brazil). Four treatments were applied as follows:

-K+W: no application of K and no throughfall exclusion (control treatment).

+K+W: 0.45 mol K m^{-2} applied as KCl (non-limiting in terms of the availability of K for tree) and no throughfall exclusion.

-K-W: no application of K and throughfall exclusion (33% of rainfall exclusion).

+K-W: 0.45 mol K m^{-2} applied as KCl and throughfall exclusion.

The field measurements were carried out from October 2014 to March 2015. Sap flow sensors were installed in six lateral roots per treatment (each root from a different tree) with the aim of estimating if hydraulic redistribution occurred in superficial roots. Sensors were made by following the Granier thermal dissipation probe method (TDP) (Granier, 1985) adapted for root measurements, according to the technique described by Brooks et al. (2002) and Domec et al. (2010). Raw data of difference in temperature (ΔT, in mV) were logged every 30 min with a datalogger (CR1000, Campbell Scientific Ltd), and hourly root sap flow density (cm h^{-1}) was calculated using the original empirical calibration (Granier et al. 1985). The daily reverse flow density (which is going opposite to the trunk) was calculated for each root, as well as the percentage of this reverse flow related to the total daily flow.

Leaf water potentials were measured in order to estimate plant water status and the degree of water stress of the *Eucalyptus* trees. Predawn leaf water potential (Ψ_{pdw}) was measured monthly before dawn in four trees per treatment accessed by scaffold tower in each subplot, with a pressure chamber (PMS Instrument Company, Albany, OR, USA). Midday leaf water potential (Ψ_{mid}) was measured the same day on another leaf of the same trees between 12 and 14 h. The hydrodynamic water potential gradient from roots to shoots ($\Delta\Psi_{plant}$) was calculated as the difference between Ψ_{pdw} and Ψ_{mid} (Franks et al., 2007). Meteorological data were measured at the meteorological station located at the experimental place.

RESULTS AND DISCUSSION

The end of the dry season in year 2014 occurred on November (**Figure 1)**. From the end of the dry period to the end of the rainy period (March 2015), the studied roots of shown reverse flow every single month in the treatments fertilized with potassium, both with and without throughfall exclusion (+K+W and +K-W) as well as in the control treatment (-K+W) (**Table 1**). The trees in -K-W had not reverse flow until January.

By taking into account the number of days per month where reverse flow was detected (**Table 2**), it can be observed that from October to December, the treatments +K+W and -K-W had fewer days with reverse flow than the other two treatments. From January to March, the number of days with reverse flow in the superficial roots significantly increased in +K+W, but remained low in -K-W.

Table 1 - Number of roots with reverse flow per month in each soil treatment.

Year	Month	Treatment			
		-K+W	+K+W	-W-K	+K-W
2014	Oct	3[/1]	3	0	1
	Nov	6	2	0	1
	Dec	5	1	0	1
2015	Jan	5	3	3	2
	Feb	4	5	1	3
	Mar	3	5	3	1

[/1] Six roots per treatment were monitored.

Table 2 - Number of days with reverse flow per month in each soil treatment.

Year	Month	Treatment			
		-K+W	+K+W	-K-W	+K-W
2014	Oct	2-7[/1]	3-7	0	2
	Nov	4-30	1-7	0	22
	Dec	3-30	6	0	26
2015	Jan	1-21	5-28	1-3	21
	Feb	1-25	3-28	2	13-26
	Mar	5-25	3-31	2-7	6

[/1] Minimum and maximum number of days with reverse flow per month, by taking into account 6 roots per treatment.

There were fewer days with reverse flow from October to December in +K+W because they had more roots doing that phenomenon and also higher flow density per root than in the other three treatments. We can observe that in **Figure 2**, where is compared the reverse sapflow density of -K+W with +K+W during November 2014. There were fewer days and fewer roots with reverse flow in the -K-W likely because trees were smaller and their demand in water was lower. Reverse flow occurred more frequently and in more roots in -K+W than in the other treatments. The trees in the +K-W plot had more number of days than +K+W because they had fewer roots doing reverse flow, lower root flow density and, moreover, they needed to locate more water on the soil surface because of the throughfall exclusion.

The water potentials measured at midday and predawn (**Figure 3**) show that the leaves of the studied *E. grandis* trees experienced high water stress on October than the subsequent months, which is in accordance with the high vapor pressure deficit (VPD) and low precipitations during that month (**Figure 1**). In spite of the increase in rainfall and, consequently, the storage of water at soil surface, there were roots doing reverse flow in all the treatments. This observation suggests that the soil surface still remained with low water potential after rainfall events and, as leaf water potential decreased over the rainy season, water from the water table went to the soil surface and not to leaves, according to the theory of the hydraulic redistribution made by roots (Burgess et al., 1998).

Hydraulic redistribution in *E. grandis* trees could have an important functional role to make available nutrients in the top soil during dry periods. Such a mechanism was demonstrated by Prieto et al. (2012) in *Retama sphaerocarpa* (L.) Boiss plants. Therefore, the soil nutrients that would not be used because the surface is dry when there is no rain events can be used by plants after roots make reverse flow (McCulley et al., 2004).

CONCLUSIONS

Roots of four-year-old *Eucalyptus grandis* trees in a deep Brazilian Ferralsol make reverse flow every month from the end of the dry season to the end of the rainy.

Roots can solubilize nutrients into the soil surface by making reverse flow, even during the rainy season.

The trees in treatment with some deficit (poor in potassium or throughfall exclusion) have roots with lower flow density than the trees in the treatments with better conditions, but they have more roots doing reverse flow or during more days per month. That could implies that, independently of the root flow density, the amount of water transported through roots from deep and moist soil layers to soil surface is the adequate for eucalyptus trees demand.

ACKNOWLEDGEMENTS

Authors specially thank Dr. Juan Delgado Rojas for his valuable help with sap flow measurements. We are also grateful to Manoel Almeida, Gustavo Diniz and Leticia Carvalho for their technical help, as well as to the staff at the Itatinga station.

REFERENCES

Brooks JR, Meinzer FC, Coulombe R, Gregg J. Hydraulic redistribution of soil water during summer drought in two contrasting Pacific Northwest coniferous forests. Tree Physiol. 2002;22:1107–17.

Burgess SSO, Adams M a., Turner NC, Ong CK. The redistribution of soil water by tree root systems. Oecologia. 1998;115:306–311.

Cakmak I. The role of potassium in alleviating detrimental effects of abiotic stresses in plants. J Plant Nutr Soil Sci. 2005;168:521–530.

Domec J-C, King JS, Noormets A, Treasure E, Gavazzi MJ, Sun G, McNulty SG. Hydraulic redistribution of soil water by roots affects whole-stand evapotranspiration and net ecosystem carbon exchange. New Phytol. 2010;187:171–83.

Franks PJ, Drake PL, Froend RH. Anisohydric but isohydrodynamic: Seasonally constant plant water potential gradient explained by a stomatal control mechanism incorporating variable plant hydraulic conductance. Plant, Cell Environ. 2007;30:19–30.

Granier A. Une nouvelle méthode pour la mesure du flux de séve brute dans le tronc des arbres. Ann des Sci For. 1985;42:81–88.

Jackson RB, Sperry JS, Dawson TE. Root water uptake and transport: using physiological processes in global predictions. Trends Plant Sci. 2000;5:482–488.

Laclau J-P, Ranger J, de Moraes Gonçalves JL, Maquère V, Krusche A V., M'Bou AT, Nouvellon Y, Saint-André L, Bouillet J-P, de Cassia Piccolo M, Deleporte P. Biogeochemical cycles of nutrients in tropical Eucalyptus plantations. For Ecol Manage. 2010;259:1771–1785.

McCulley RL, Jobbágy EG, Pockman WT, Jackson RB. Nutrient uptake as a contributing explanation for deep rooting in arid and semi-arid ecosystems. Oecologia. 2004;141:620–628.

Prieto I, Armas C, Pugnaire FI. Hydraulic lift promotes selective root foraging in nutrient-rich soil patches. Funct Plant Biol. 2012;39:804–812.

Sheffield J, Wood EF. Projected changes in drought occurrence under future global warming from multi-model, multi-scenario, IPCC AR4 simulations. Clim Dyn. Department of Civil and Environmental Engineering, Princeton University, Princeton, NJ 08544, United States; 2008;31:79–105.

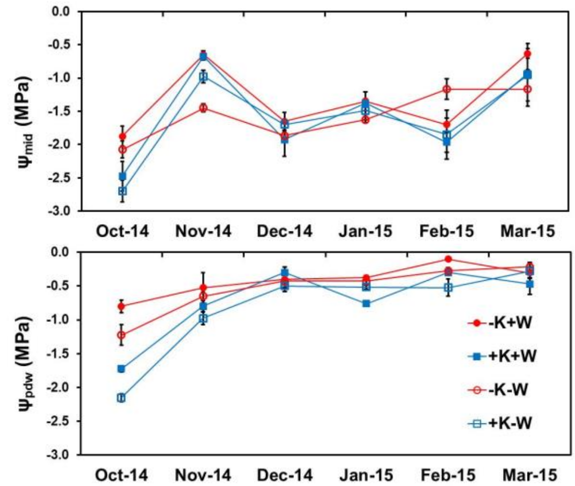

Figure 3 – Midday and predawn water potential (Ψmid and Ψpdw) of leaves at E. grandis trees from October 2014 to March 2015.

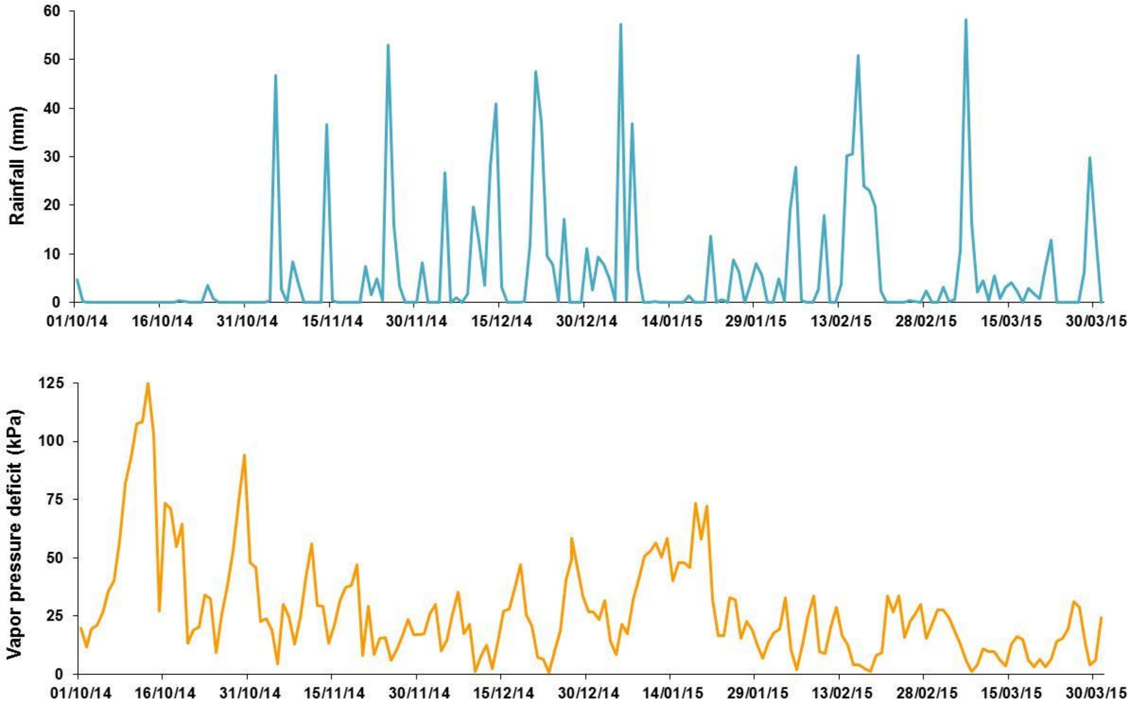

Figure 1 – Rainfall (mm) and vapor pressure deficit (kPa) at the experimental site during the time of collection of data for the present study.

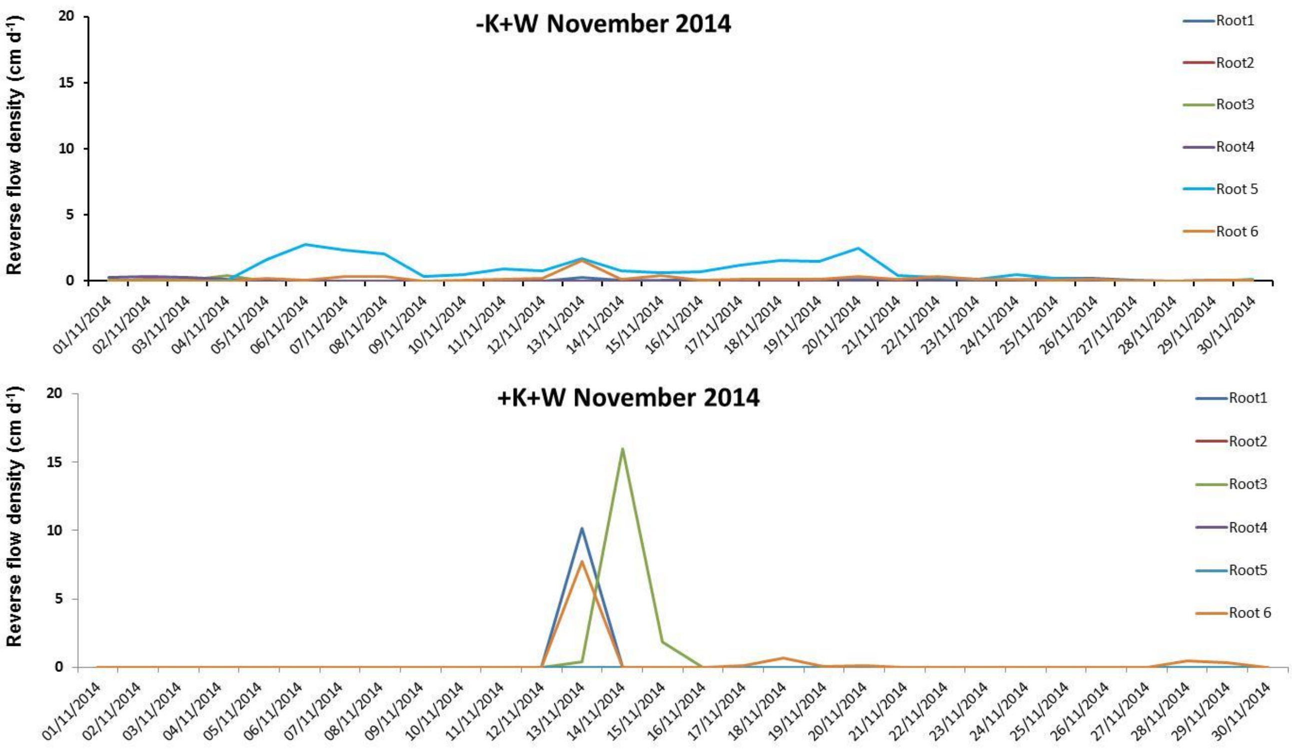

Figure 2 – Reverse flow density in the roots of *Eucalyptus grandis* trees in November 2014. Treatments where eucalyptus was located consist on K fertilization (+K), no K fertilization (-K), and no throughfall exclusion (+W).