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## Sustainable coffee agroforestry in adverse climatic conditions in Nicaragua

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Coffee production has been threatened by increasing climate variability. Shaded coffee has been suggested as a promising strategy to cope with the effects of global climate changes. However, potential competition for water between coffee and shade trees and lower coffee yields under shade are among the main constraints of coffee agroforestry. Most advantages attributed to agroforestry are focused on ecological issues; little is published on ecological and economic aspects combined. This investigation analyzed and compared ecological and economic performance of unshaded arabica coffee (NS) and shaded (AFS) by a mixture of evergreen *Simarouba glauca* DC. and deciduous *Tabebuia rosea* Bertol. Both tree species are widely utilized for timber and other products but are poorly studied.

The study was carried out during 2012 and 2013, in a 12-year old agroforestry experiment in sub-optimal coffee growing conditions ($27^0$C mean annual temperature, 455 m altitude and 1470 mm annual rainfall) in Masatepe, Nicaragua. Water consumption by soil evaporation and coffee and tree transpiration was measured by using weighing lysimeters and the stem heat balance sap flow method, respectively. Coffee production over the 10-year period prior to the study was used to determine coffee economic performance. Timber production from four shade trees of each species in the study site was measured and results were extrapolated for the whole plot by using population density.

The AFS system was a more efficient water user than NS. Shade trees had the effect of reducing by 31% water loss from soil evaporation compared to NS, which represented more water available for coffee. Transpiration was greater in AFS plots; however, most of the water was transpired by coffee rather than by shade trees or evaporated from the soil. Temporal complementarity in water use between coffee and shade tree was observed with higher shade tree water consumption in the wet season contrasted with greater water use by coffee in the dry. Contrasting precipitation patterns in the two consecutive years of the study demonstrated competition for water only by the end of the very dry season in 2013. Evergreen shade tree characteristics seemed to be more suitable as coffee shade compared to deciduous in such environmental conditions.

Coffee production in AFS was 18% lower than NS from data averaged over 10 years. However, the lower coffee yield in AFS was compensated by greater productivity of the whole system. By the end of the experiment, 13-year old shade trees produced 125 $m^3$ $ha^{-1}$ of timber from *Simarouba glauca* and 98.5 $m^3$ $ha^{-1}$ from *Tabebuia rosea* (US$173 per $m^3$ local price). Further income could be derived from the firewood extracted over time. Therefore, both ecological and economic aspects showed advantages compared to the no-shade system, which suggests agroforestry with timber trees as an attractive system of land use for farmers in the sub optimal coffee growing conditions studied.