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## Irrigation alone cannot counteract adverse climatic effects on macadamia yields in South Africa

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### Abstract

Macadamia is a high value tree nut crop experiencing a considerable rise in global demand. South Africa is the world largest producer of macadamia nuts, with production areas rapidly expanding in the country. However, yields are highly variable and have been declining in recent years, in conjunction with increasingly severe climate change impacts in the region. Therefore, to sustainably increase the productivity and climate-resilience of macadamia orchards, the effect of environmental factors on the trees' vegetative and reproductive cycles needs to be better understood. To this end, we quantified the extent to which climatic and soil factors drive macadamia yields in Levubu (South Africa) along an altitudinal gradient (600–950 m a.s.l.), for irrigated and rainfed orchards, separately. For this we applied mixed-effects models on historical production data for the years 2010–2021 from 247 orchards. On this background, the role of irrigation in counteracting the impact of abiotic stresses on macadamia phenology and productivity was evaluated.

We found a pronounced interannual variability of macadamia yields (from 1.2 to 4.0 tons dry nut-in-shell ha<sup>-1</sup>). Higher yields were found at elevations >700 m a.s.l. and in micro-sprinkler irrigated orchards. Orchard characteristics and environmental variables jointly explained 49% of the yield variability. Cultivar, presence of irrigation, tree age and planting density were found to affect yield, while no significant effect was found for soil variables. High temperatures and low global radiation during the nut development stages, alongside poor rainfall amounts in the dry season, were the climatic factors more severely affecting yields. In particular, low irradiance was the main yield limiting factor in irrigated orchards, while extremely high temperatures and poor rainy seasons were most limiting in the rainfed ones. Increased irrigation amounts, although beneficial, were not fully compensating the impact of climatic factors on productivity. Our findings suggest that irrigation alone cannot counteract adverse climatic effects on macadamia yields. To sustainably increase macadamia productivity and resilience to climate change, abiotic stress impacts will have to be reduced through a combination of improved orchard management and breeding for stress tolerance.

**Keywords:** Abiotic stress impact, altitudinal gradient, climate change, irrigation systems, *Macadamia* spp., yield limiting factors