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Management of pomegranate (*Punica granatum*) orchards alters the supply and pathway of rain water reaching soils in an arid agricultural landscape

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ABSTRACT

Arid pomegranate (*Punica granatum*) orchards are frequently rainfed. In these systems, orchard managers might be able to manipulate a stand's canopy structure (*e.g.*, thinning, pruning) to improve rainfall water input to the soil. The aim of this research was to determine how changes in management activities in rainfed pomegranate orchards in arid regions of Central Iran affects rainfall partitioning into throughfall, stemflow, and rainfall interception loss. We monitored gross rainfall, throughfall, stemflow and rainfall interception loss in three stands with varying levels of thinning and pruning. Management practices sufficiently altered the stand and canopy structure of pomegranate orchards to impact the quantity and pathway (throughfall v. stemflow) of rainfall reaching the ground. Decreases in tree height, canopy cover, crown length and LAI were correlated to a significant increase in rainfall reaching the forest floor. Results indicate that orchard managers may be able to prune 40% of the live crown and thin 70% of the stand if the objective it to significantly increase water inputs into the soil. Future research should focus on the impact of canopy management on soil moisture content and soil evaporation and transpiration.

1. Introduction

Pomegranate (*Punica granatum* L.) is a small (3–8 m tall) tree that is extremely long-lived (Fawole and Opara, 2013), and mainly grown in the semiarid, mild-temperate to subtropical climate zones of Iran, Turkey, and Mediterranean countries (Galindo et al., 2014a,b). Pomegranate is an alternative fruit tree for many areas where poor soil conditions or the poor quality of irrigation water prevents the profitable operation of other fruit trees (Costa and Melgarejo, 2000). It is also tolerant to drought, salinity, iron chlorosis and alkaline soil (Costa and Melgarejo, 2000). It requires high summer temperatures to ripen properly so commercial production is limited to areas with hot summers (Parvizi et al., 2016), and can be grown in areas where the winter temperatures drop to −15 °C and central Asian cultivars can even tolerate temperatures of −30 °C (Aleksandrov, 1950). Global production and consumption of pomegranate fruits is increasing (Mditshwa et al., 2013) because the fruit has many usages, including fruit juice, conservatives, vinegar, citric acid and medicinal qualities (*e.g.*, Lansky and Newman, 2007; Mditshwa et al., 2013). Thus, pomegranate is currently ranked 18th in terms of fruit consumed annually in the world (Sudharshan et al., 2013) and it is predicted to become the 10th most consumed fruit by 2018 (Sudharshan et al., 2013). The global importance of this fruit tree is apparent in its cultivation area being well above 300,000 ha, of which more than 76% is concentrated in five countries: India, Iran, China, Turkey and the USA (Melgarejo et al., 2013).

The origin of pomegranate is likely the Transcaucasia-Caspian region of Central Asia (such as Turkey, Azerbaijan, Georgia, and Iran) (Levin, 2006). Over 1000 cultivars of *P. granatum* have been identified globally (Levin, 1994). 'Malas-e-Torsh-e-Saveh', 'Rababe-Neiriz', 'Malas-e-Yazdi', 'Shishe-Cap-e-Ferdows', and 'Naderi-e-Natanz' are the most important cultivars of *P. granatum* in Iran (Caliskan and Bayazit, 2013). One of the popular and commercial pomegranate cultivars in arid and semiarid regions of Iran is 'Malas-e-Torsh-e-Saveh' (Varasteh et al., 2006; Hasani et al., 2012). Iran is one of the main pomegranate producing countries and is currently the biggest producer and exporter in Asia and Europe (Hakimi, 2015). Average pomegranate yield in Iran is 13,000 kg ha^{-1} year^{-1}, which is a large enough to influence

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continental (*i.e.*, European) and global pomegranate markets (Hakimi, 2015). 60% of pomegranate orchards depend on the efficient use of rainfall for their productivity and sustainability. In recent years, reduction in groundwater resources and severe droughts have destroyed some of the Iranian pomegranate orchards (Parvizi et al., 2014). Considering the lack of alternative water resources, the optimal use of existing rainfall is vital for pomegranate growers in the semiarid and arid regions of Iran. Iran has located in desert belt where desertification, drought, water table reduction and flooding increment, vulnerability of land resources are the most relevant phenomena (Shahbazi and De La Rosa, 2010). The impact of climate change in Iran includes changes in precipitation and temperature patterns (Attarod et al., 2016) and water resources, a rise in sea level, and an agricultural impact affecting food production, bioclimatic deficiency, land capability, agroecological field vulnerability and possibly more frequent droughts (Shahbazi and De La Rosa, 2010). Literature reviews about climate change in Saveh (study site) showed that the mean of minimum air temperature increased due to climate change, and studying of precipitation parameter indicate a negative trend from June to September and no obvious trend was observed for mean of maximum air temperature (Ataee and Fanaee, 2012).

With increasing population pressures, most agriculture in the arid and semiarid regions is confronted with the challenges of producing more per unit land with uncertain and dwindling supplies of water. In areas with fertile soil and sufficient rainfall or irrigation in Iran, pomegranate trees are planted densely (3 × 3 m), however, in areas with less fertile soils and low rainfall, planting density is reduced (6 × 6 m; Hakimi, 2015). Traditionally, pomegranate farmers apply pruning and thinning to adjust the trees to the climatic conditions of the area and increase orchard's productivity. The aims of pruning are to: (1) balance vegetation with fruit yield, (2) minimize the non-productive period, (3) prolong the productivity of the trees, (4) delay senescence, and (5) save soil water, a critical factor in non-irrigated orchards. Pomegranate farmers traditionally have avoided tree death in the very dry years by a combination of sparse planting, thinning and heavy pruning. During the last decade, some of the farmers increased tree density and reduced pruning to increase the efficiency of water use. As the density and canopy structure of agricultural crops have been shown to significantly affect the amount of rainwater reaching soils (Van Dijk and Bruijnzeel, 2001), it is important to know how orchard management practices influence the canopy's rainfall partitioning in rain-dependent pomegranates orchards.

Canopy rainfall partitioning is the redistribution of rainfall (P_g) into throughfall (*TF*), stemflow (*SF*), and interception (*I*) by vegetation as water passes through the canopy. The important role that rainfall partitioning is very relevant in areas where water is a limiting factor for economic development and life itself, making it a priority to research the canopy ecohydrological processes underlying *TF*, *SF* and *I* in arid/semiarid regions (Sadeghi et al., 2016, 2017). *TF* is the quantity of P_g that falls through tree canopy gaps or from its surfaces. *SF* is the quantity of P_g that is intercepted by the tree canopy and flows down to the ground via the stem. Therefore, the actual amount of P_g that reaches the forest floor ($TF + SF$) is understory rainfall, or net rainfall (P_{net}; $P_{net} = TF + SF$). *I* is the proportion of P_g that is intercepted by the canopy and evaporates back into the atmosphere. P_{net} is, in the case of rainfed pomegranate orchards, the principal water supply to soils.

Improvement of orchard management practices aimed at increasing P_{net} may be beneficial for farm-scale water management. Generally, arid and semiarid orchard managers will manipulate their stand's structural characteristics if it will increase P_{net}. However, increasing P_{net} by removing canopy material (pruning, thinning, etc.) may increase soil evaporation through greater sunlight exposure, balancing or counteracting the P_{net} gain. Although the study of rainfall partitioning dates back to the early 1900s (Horton, 1919) and still remains a growing area of research, to our knowledge, no studies have been performed in rainfed orchards to evaluate the impact of different management methods on rainfall partitioning in pomegranate orchards. Hence, the purpose of this study was: (i) to determine P_g partitioning into *TF*, *SF*, and *I* for *P. granatum* (cv. Malas-e-Torsh-e-Saveh) trees in arid, Central Iran, (ii) to compare P_g partitioning across stand structural characteristics typical of management practices in rainfed orchards, (iii) and discuss how these stand characteristics can be incorporated into planting, pruning, and thinning processes for pomegranates.

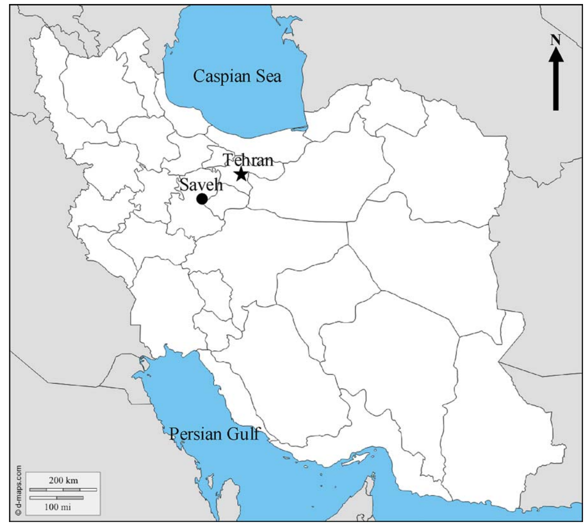

Fig. 1. Location of study sites in Saveh city, Iran.

2. Materials and methods

2.1. Site information

The study plots were situated in Saveh city, located about 100 km southwest of Tehran (capital of Iran), in the Markazi province of Iran (50°21′E, 35°01′N) (Fig. 1). The study sites were located in an arid region (De Martonne Aridity Index: 7.6) at an altitude of 1100 m asl, where average annual precipitation is 214.1 mm (1994–2016), annual air temperature is 18.1 °C, and summers (July, August, and September) are particularly hot and dry (mean summer temperature = 29.8 °C and mean summer precipitation = 1.1 mm).

Three separate 500 m^2, topographically flat plots with similar planting time were selected due to their different management-related stand structural characteristics (Table 1). Distances between plots were 120 m. Management of plot I (hereafter PI) produced the largest diameter at breast height (DBH), shortest tree height, lowest basal area, farthest between-tree spacing, thinnest canopy cover, shortest crown

Table 1
Stand characteristics and management summary of the three *Punica granatum* plots in Saveh, central Iran.

Stand parameters	PI	PII	PIII
Management summary:			
Stand thinning	Heavy (70%)	Moderate (44%)	None
Pruning (% live crown)	40%	20%	0%
Stand Age (years)	15	13	15
Mean DBH (cm)	16	12	10
Basal area ($m^2\,ha^{-1}$)	42.0	58.9	87.2
Tree height (m)	2.3	2.5	2.9
Planting distance (m)	5.5	4.0	3.0
Canopy cover (%)	31 (40[a], 25[b])	41 (55[a], 30[b])	46 (60[a], 35[b])
Mean crown length (m)	1.3	1.5	1.8
Mean bark thickness (cm)	1.5	0.8	0.8
LAI ($m^2\,m^{-2}$)	2.33	3.01	3.19

[a] Leafed period.
[b] Leafless period.