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Apple trees rainfall interception during the leafed and leafless phases of the annual cycle

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Abstract: For apple orchards cultivated in semi-arid climates, the study of rain water distribution into the three main fractions - "throughfall", "stemflow", and "interception" by the trees - is very relevant to enhance the sustainability of apple growing and water resources. This is particularly true in the current climate change scenario. Therefore in this study, measurements of rainfall, throughfall, stemflow, and interception were carried out between January and December 2022 in an apple orchard located in the Aures (northeastern Algeria). The results revealed that the rain received by the orchard (200.7 mm) were reduced by 40.7% compared to the 20-year average (2000-2019). In addition, the fraction of throughfall and stemflow were around 78.8% and 2.5%, respectively, whereas, the average interception fraction was 18.7% of the total rainfall with a significant difference between the leafed and leafless phases of the annual tree cycle. The models generated in the present study showed that throughfall occurred when the amount of rainfall was higher than 1.6 and 0.3 mm during leafed and leafless phases, respectively. Furthermore, rainfall triggered the stemflow when its intensity was higher than 5.0 and 10.9 mm during the leafless and leafed phases, respectively. The results of our study revealed that rainfall with less than 5 mm produced little or no throughfall and stemflow in apple orchards, and this highlighted the necessity of adopting irrigation in these regions, particularly during the leafed phase.

Keywords: Algeria; *Malus domestica*; semi-arid; stemflow; water resources.

1. Introduction

Rainfall is the main input to the soil water balance and plays an important role in the water cycle, in tree growth and yield (Llorens and Domingo, 2007; Yang et al., 2023; Zore et al., 2022), particularly in arid and semi-arid environments, which represent a third of the world's land area (Mirzabaev et al., 2022). The success of crop production and the efficient use of water do not depend only on rainfall and irrigation (Li et al., 2020; Wang et al., 2013; Zhang et al., 2021; Zhang et al., 2023; Zheng et al., 2018) but also on the ability to redistribute the rainfall into three fractions: the first passes through the tree crowns (throughfall), the second flows along the tree trunks (stemflow), and the third is lost either through storage within the tree canopy or through evaporation (interception) (Llorens and Domingo, 2007; Benhizia et al., 2018). Plant canopy structure in agricultural settings differs markedly from forests and shrub lands, especially for herbaceous crops; therefore, croplands are expected to partition rainfall and sprinkler-irrigation waters differently (Lin et al., 2020). Certainly, the vegetation cover controls the amount of rainfall reaching the ground, affects the amount of water recharging groundwater, and constitutes an important component of the regional water cycle (Wang et al., 2022; Zhang et al., 2021; Zore et al., 2022).

Air temperature, rainfall, the frequency of extreme weather events, and the amounts of net throughfall recharging groundwater aquifers may be affected by climate change, and this may have a significant impact on water dynamics, rainfall interception, plant water requirements, and plant phenology (Yang et al., 2023; Zore et al., 2022). Fruit tree orchards are not immune to climate change particularly in the Mediterranean basin (Abed et al., 2019). In Algeria, and in some apple production areas, the analysis of average annual air temperatures over 36 years (1980 to 2016) revealed a significant warming (Abed et al., 2019). In recent years, apple orchards have widespread considerably in Algeria, passing from 14040 ha of area harvested in 2001 to 31171 ha in 2021 (FAOstat, 2023). This gradual evolution of apple tree cultivation area can significantly increase rainfall interception and change hydrological regimes at the regional scale (Dzikiti et al., 2018). The expansion of apple cultivation strongly depends on irrigation, which is one of the major cultural practices to ensure fruit quality and productivity, especially in arid and semi-arid regions (Dzikiti et al., 2018). Unfortunately, the small water availability, of which rainfall is the main source (Wang et al., 2022), are subject to strong and increasing pressure and competition between the different users (forest ecosystems, agriculture, population, and industry) (Midgley et al., 2014). For example, blue and green water are highly requested by apple growers to ensure the irrigation of their orchard (Bakhtache and Hadjene, 2023; Zella, 2012). In fact, the lack of a global vision of water use is reflected on the ground by the overexploitation of water wells and boreholes (Zella 2012; Bakhtache and Hadjene 2023) and this situation can lead to the depletion of water resources.

Therefore, the sustainability of water resources and their efficient use are a very important topics for the scientific community, especially in semi-arid and arid climates. Indeed, several researchers around the world recently agreed on the importance of finding a balance between the demand for water by population, agriculture, and land cover (Wang and Wang, 2019; Yang et al., 2022). This balance can be achieved if the efforts focus better on water interception in order to understand the action of the main land covers in each region (Wang et al., 2022; Yang et al., 2023; Zhang et al., 2023). Despite the importance of rainfall interception by fruit tree orchards, few studies have been carried out on this topic (Calheiros de Miranda and Butler, 1986; Wang et al., 2022; Wang and Wang, 2019; Zhang et al., 2021; Zhang et al., 2023). Besides, in Algeria there are no previous research conducted to investigate the rainfall interception by apple trees, although the socio-economic importance of this crop.

Thus, the purpose of this work is (i) to determine, for the first time, the different rainfall fractions and their variations, in an apple orchard located in the Aures region (northeastern Algeria) characterized by a semi-arid climate, and (ii) to exploit the obtained data to develop mathematical models predicting the interception of rainfalls, during the leafed and leafless phases of the apple tree annual cycle. This information can be used to predict the rainfall volumes that can contribute to the water and mineral demand of apple trees.

2. Materials and Methods

2.1. Study site

The present study was carried out between January and December 2022 in Tazoult, province of Batna (Northeast Algeria) (Latitude: 35.499281N; Longitude: 6.24907E; Altitude: 1099 m above sea level). The measurements were taken in an orchard of ‘Golden Delicious’/MM106 apple (*Malus domestica* Borkh.) trees planted in 1994 with a spacing of 4 × 3 m. ‘Golden Delicious’ is one of the three varieties dominating the Algerian apple growing (Abed et al., 2019). Apple is the most cultivated fruit tree in the province of Batna with an area of 5338 ha and an average apple yield of 3.1 metric tons/ha (DSA Batna, 2022).

In the studied orchard, the trees had a height ranging between 2.5 and 3.0 m, and they were characterized by an open-vase training system. We estimated by allometry the following canopy architectural parameters: a mean brunch width of around 8-17 cm; an average brunch length of about 160-240 cm; a basal area of the apple orchard of 29.58 m^2/ha. The experimental site was located in a semi-arid climate region characterized by an average rainfall of 338.3 mm and mean annual temperature of 15.7 °C according to the data recorded at the Batna meteorological station over a 20-year long period (2000-2019).

2.2. Measurements of rainfall, throughfall, stemflow and interception

In order to quantify the rainfall (P), throughfall (TF), stemflow (SF) and rainfall interception (I), 100 plastic containers equipped with a top collection funnel were installed under the crowns of the trees to measure the TF. The number of containers and the reception surface (2.2 m^2) adopted in the present study, were sufficient for a correct estimation of TF waters (Llorens and Domingo, 2007; Yang et al., 2023). Moreover, 14 plastic collars were fixed with mastic on the tree trunks to measure SF, whereas P volumes were evaluated by placing 25 plastic containers randomly distributed in an area of bare ground (without trees), approximately 10 m away from the apple trees. The top collection area of each container was 227 cm^2.

After each rainfall event, the volumes of water (P, TF, and SF) were measured in the orchard with a test tube. The volumes of water collected were then converted into millimeter using the equation (Vialard-Goudou and Richard, 1956):

$$P\ (mm) = 10 \times V/\ S \qquad \text{(eq. 1)}$$

Where S is the receiving surface (cm^2) and V is the volume of water collected (cm^3). The surfaces of apple tree crowns were considered as receiving surfaces for TF water (Livesley et al., 2014).

The percentage of TF and SF (%TF and %SF) were calculated using the following equations:

$$\%TF = (TF/P) \times 100 \qquad \text{(eq. 2)}$$

$$\%SF = (SF\ /P) \times 100 \qquad \text{(eq. 3)}$$

The quantity of water intercepted (mm) was estimated using the following equation (Llorens and Domingo, 2007; Yang et al., 2023):

$$I\ (mm) = P - (TF + SF) \qquad \text{(eq. 4).}$$

Regular field observations of the apple orchard allowed the identification of the leafed from the leafless phase. The number of rainfall events during the two stages (leafed: from late March to early November 2022; leafless: from January to early March and from late November to December 2022) was recorded separately.

2.3. Data analysis

P, TF, SF, and I data were subjected to the analysis of variance (ANOVA), using SPSS version 10.0.5 (IBM). The relationships between P and TF, SF, and I were studied by linear regression, carried out with Excel 2013© (Microsoft, Redmond, WA, U.S.A.).

3. Results and Discussion

3.1. Rainfall (P)

The total rainfall events received by the orchard during the year 2022 were 31, with a total rain water amount of 200.7 mm (an average of 6.7 mm per event) (Table 1). Throughout the study, rainfall events varied between 0.5 and 23.0 mm (Table 1).

Table 1. Daily rainfall frequency and accumulation during the study.

Daily rainfall range	Frequency (Days)	Cumulative rainfall	
		mm	%
0-5 mm	16	40.0	20.0
5-10 mm	9	65.6	32.6
10-20 mm	4	50.1	25.0
20-40 mm	2	45.0	22.4
Total	31	200.7	100.0

The total rainfall recorded in the present study (200.7 mm) was 40.9% lower than the regional average measured between 2000 and 2019. Out of the 31 rainfall events, most of them had an intensity lower than 5 mm (16 rainfall events), whereas 13 events had an intensity between 5 and 20 mm. The total rainfall events recorded for this study were very low compared to the results of Benhizia et al. (2018; 2023) who revealed, between 2011 and 2020, more rainfall events (51-135) in the same region. In this context, Zhang et al. (2023) reported that because of climate change, rainfalls can be concentrated in a short period. In the present study, the number of rainfall events with amounts greater than 20 mm was very low (2 days only) which is consistent with the results of previous studies (Benhizia et al., 2018; Benhizia et al., 2023; Pérez-Suárez et al., 2013) indicating that P values above 20 mm are rare in semi-arid climates.

Rainfall effectiveness for apple orchards depends on many factors such as the number of events occurring and their intensity, the characteristics of the soil, the climate, and the soil slope (Ali and Mubarak, 2017). Indeed, intense rainfalls cannot be fully utilized by the apple orchards, especially when they are located on steep slopes due to the runoff and the migration of underground rainwater, while light rains are often intercepted by tree canopies and do not reach the orchard floor. According to previous studies (Calheiros de Miranda and Butler, 1986; Zheng et al., 2018), daily rainfalls between 2.5 and 5 mm do not have any significant impact on soil moisture, and they do not even reach the 15-25 cm soil layer, especially during dry periods. Conversely, only daily rainfall above 30 mm significantly increases water content in the 15-25 cm soil layer (Klamkowski et al., 2011). Assuming that effective rainfalls should have an intensity of minimum 5 mm, we can hypothesize that among 31 rain events recorded during the present study, only 15 events could have been beneficial for the apple orchard.

3.2. Throughfall (TF)

Out of 31 rain events, 29 were able to trigger TF that fluctuated between 0.8 and 18.9 mm with an average of 5.1 mm. The average %TF was 78.8%. This result is in agreement with Zhang et al. (2021) who reported, for apple trees grown in a semi-arid climate in China, that %TF fluctuated between 0.0 and 97.9%.

On the other hand, differences were found in the average TF between the leafed and the leafless phases. The TF amount during the leafless phase (6.8 mm) was higher than that measured during the leafed phase (3.55 mm). When separating the two phases, the results showed that %TF was higher during the leafless phase than during the leafed phase (85.9% and 67.1%, respectively). These results are consistent with Sun et al. (2017), who previously reported that the TF in apple orchards increases when leaf area index (LAI) decreases.

TF is affected by the amount of rainfall and the time between two successive rains, the canopy density and architecture (Wang and Wang, 2019; Yang et al., 2023), and the apple tree phenological stage (leafed and leafless phases). Leaves and flowers appearance (occurring typically in late March to early April for ‘Golden Delicious’) contributes to the change in %TF. Indeed, apple tree phenology depends on climatic parameters such as temperature, rainfall, and sunlight (Hamdani et al., 2018). It is relevant to point out here that during the leafed phase, the TF brings water and nutrients to the orchard soil, and can also affect various biological processes, such as the dispersal of pathogens (Boutry et al., 2022; Tyagi et al., 2017).

The results obtained in our experiment on P events and TF are in agreement with the study of Zhang et al. (2021). Rainfall events with less than 5 mm produce little or no TF in apple orchards. Our results on TF and those of previous studies (Calheiros de Miranda and Butler, 1986; Zhang et al., 2021; Zheng et al., 2018) suggest that rainfalls between 5 and 7 mm are not beneficial for apple orchards. Small intensity rainfall, especially when they occur just after pesticide sprayings, can reduce the effectiveness of phytosanitary products and provide the soil with chemical elements that can be toxic at high concentrations. In this context a rational application of apple tree pruning plays a major role to (a) increase %TF (Wang et al., 2022) and (b) improve canopy aeration that can decrease the risk of pathogen attacks (Dzikiti et al., 2018; Zhang et al., 2021).

Several authors suggested that the use of the rainproof covers can be very beneficial for modern apple growing (Boutry et al., 2022; Tyagi et al., 2017). Our results on TF suggest that the use of covers may be interesting especially when rainfall events with less than 7 mm occur. The use of the rainproof covers may be very beneficial for several reasons. Firstly, rainfall events of small intensity are not useful for recharging the water content in apple orchards, but they can cause the emergence of fungal infections such as apple scab and rotting diseases, especially when followed by high temperatures in dense tree canopies (Boutry et al., 2022; Tyagi et al., 2017). In addition, several studies (Boutry et al., 2022; Tyagi et al., 2017) claimed that the use of rainfall covers could reduce fungal infections, as most fungi require water to infect plants. Furthermore, these low-intensity rainfall events can also cause the accumulation of pesticides in the superficial soil layers when they occur after phytosanitary treatments. Therefore, the use of rainproof covers can be advisable when low rainfall events are expected to occur. Nevertheless, based on our results and those of Vicente et al. (2018) who reported that the rainfalls capable of recharging the water table in the Mediterranean start from 15 mm, we suggest that the use of rainproof for rainfalls greater than 15 mm is strongly discouraged in semi-arid climates, where water resources are limited, and their use can affect negatively the recharge of groundwater and the sustainability of water resources.

3.3 Stemflow (SF)

TF, SF, and I vary greatly across crop types, storm magnitudes, and crop growth stages; this is especially true for SF (Lin et al., 2020). In our experiment, the number of rainfall events that generated SF was 7 out of a total of 31 rainfalls occurred. The average SF was 0.31 mm. It should be noted that the highest SF (1.8 mm) was obtained during a rainfall event of 23.0 mm. Moreover, the average SF during the leafless phase was 0.3 mm, while it was 0.1 mm during the leafed phase. Nevertheless, the ANOVA did not reveal a significant difference in this parameter between the two phases (Table 2).

Table 2. Effect of the phenological phase (leafless and leafed and phases) on total rainfall (P) and its three fractions, throughfall (TF), stemflow (SF), and interception (I) measured in an apple orchard. The significance of the effect of the phenological phase (ANOVA; $p < 0.05$) was reported.

Phase	P (mm)	Rainfall fraction (mm)		
		TF	SF	I
Leafless phase	7.5	6.4	0.3	0.8
Leafed phase	5.3	3.6	0.1	1.6
Significance	*0.299*	*0.130*	*0.191*	*0.003**

* Significant at $p < 0.05$.

The average %SF represents only a small proportion of the rainfall falling on the orchard (2.5%), whereas the comparison between the two studied apple phases indicated that the %SF during the leafless phase is almost three times greater than that in the leafed phase. According to Calheiros De Miranda and Butler (1986), the redistribution of rainfall in the orchard is affected by foliage density and orientation. %SF was 1.1% and 3.1% in the in leafed and in the leafless phase, respectively. These values are within the range found for apple trees in a semi-arid Chinese climate (0.0%-3.3%) (Wang and Wang, 2019; Zhang et al., 2021). Zhang et al. (2021) claimed that the SF in apple orchards does not increase significantly even with heavy rains.

3.4. Interception (I)

In the present study, %I was 18.7%. This parameter during the leafless phase was reduced by 11% compared to that in the leafless phase. The %I measured in the present study was high compared to that reported for apples by Wang et al. (2022) who reported an annual percentage ranging between 7.1% and 10.7%. The difference between the two studies can be attributed, in addition to the difference in total rainfall (264.6-388.7 mm vs. 200.7 mm in the present study), to the difference in tree age (28-years in our study and 8-18 years in the previous study). This may be related to thicker and taller branches and trunks in mature trees compared to younger ones. Moreover, the annual water interception by apple orchard canopy changes due to variations in rainfall, its incident distribution and intensity, and LAI (Wang and Wang, 2019; Wang et al., 2022). He et al. (2022) reported that rainfall intensity was responsible for more than 40% of variations in interception, whereas temperature contributed for more than 40%, particularly for arid and semi-arid regions. Other factors including wind speed, relative humidity, solar radiation, and normalized difference vegetation index (NDVI) also contributed less than 20% to the interception variation (He et al., 2022). In contrast, our results are consistent with the results by Ma et al. (2012) indicating identical rainfall interception (18%) in apple orchards.

The average I was 1.1 mm per rainfall event, with significant difference between the leafed and leafless phases (Table 2). Indeed, the average interception in the leafless stage was 0.8 mm, while it rose to 1.7 mm in the leafed phase. Zhang et al. (2021) reported that, during the LAI peak phase, light rainfall events contributed to the storage of water on the dense canopies. Several authors (Nanko et al., 2016; Zabret et al., 2018; Zore et al., 2022) confirmed that this variation was affected by different factors including the rainfall regime and kinetic energy, relative humidity, wind speed, temperature, and the vegetative characteristics of the specific phenophase (vegetation height, leaf properties during the leafless and leafed phases). Significant changes in phenology lead to a change in the LAI and therefore in rainfall interception. In Algeria, as a consequence of climate change, winters are less rainy, whereas autumns, springs, and summers are warmer. This can affect apple phenology and consequently the monthly fluctuation in rain-water interception by the trees (Bakhtache and Hadjene, 2023). These changes affect I and the hydrological regime of the soil occupied by the apple trees, in addition to their productivity.

3.5. Relationship between rainfall and TF, SF

Among the total 29 TF events occurred at the experimental site, ten were recorded during the leafed phase. The linear regressions of rainfall with TF events are presented in Figure 1. The regression line reported in Figure 1 suggests that theoretically the TF may be triggered starting from 1.6 mm of rainfall during the leafed phase. This amount is superior to those reported by Calheiros De Miranda and Butler (1986) who worked on the rainfall interception by apple trees, for a period of three summer months. These authors reported a rainfall amounts of 0.5 mm were enough to trigger TF. This difference may be due to differences in rainfall frequency (42 rainfall events during three months against 31 events during one year for the present study). Concerning the leafless phase, the equations presented in Figure 2 show that the TF is triggered when rainfall intensity is higher than 0.28 mm.

On the other hand, no correlation was found between P and SF during the leafed phase ($R^2 = 0.04$; $p = 0.485$), while there was a strong correlation between these two parameters during the leafless phase (Figures 1 and 2). The equations shown in Figure 1 revealed that the rainfall ideally required to trigger

SF in apple orchards during the leafed phase is approximately 10.9 mm. Whereas, this threshold is around 5 mm during the leafless phase (Figure 2). These results are quite consistent with the results reported by Calheiros De Miranda and Butler (1986). These authors claimed that no SF was recorded with less than 1.5 mm of total rainfall.

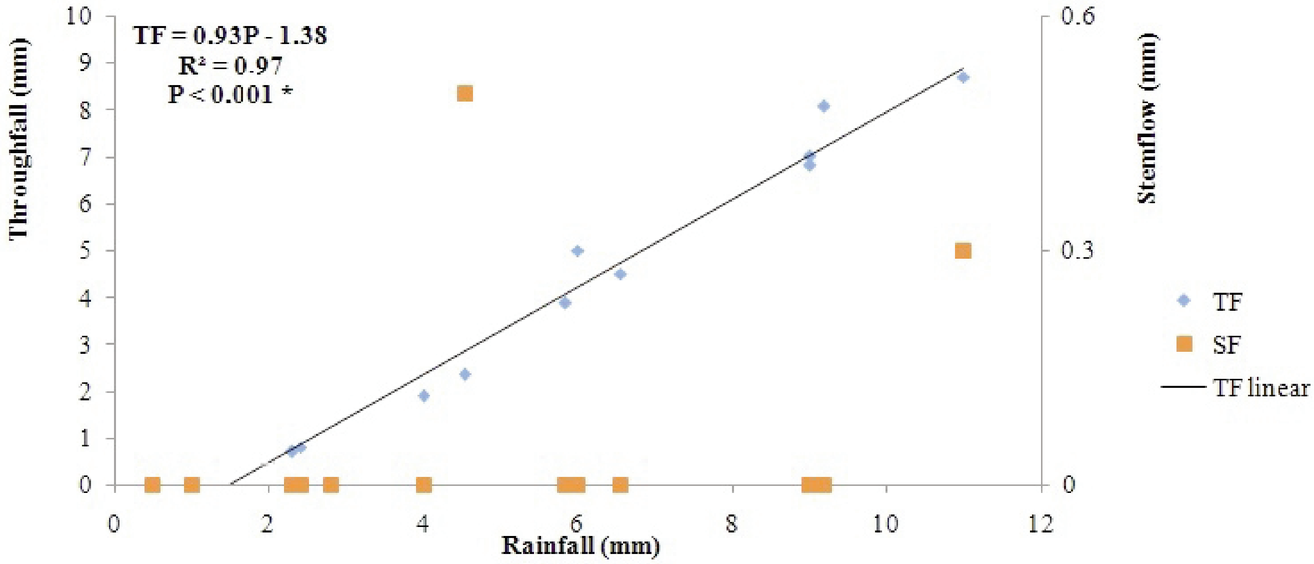

Figure 1. Relationship between P and the other parameters (TF and SF) at the apple orchard in the leafed phase.

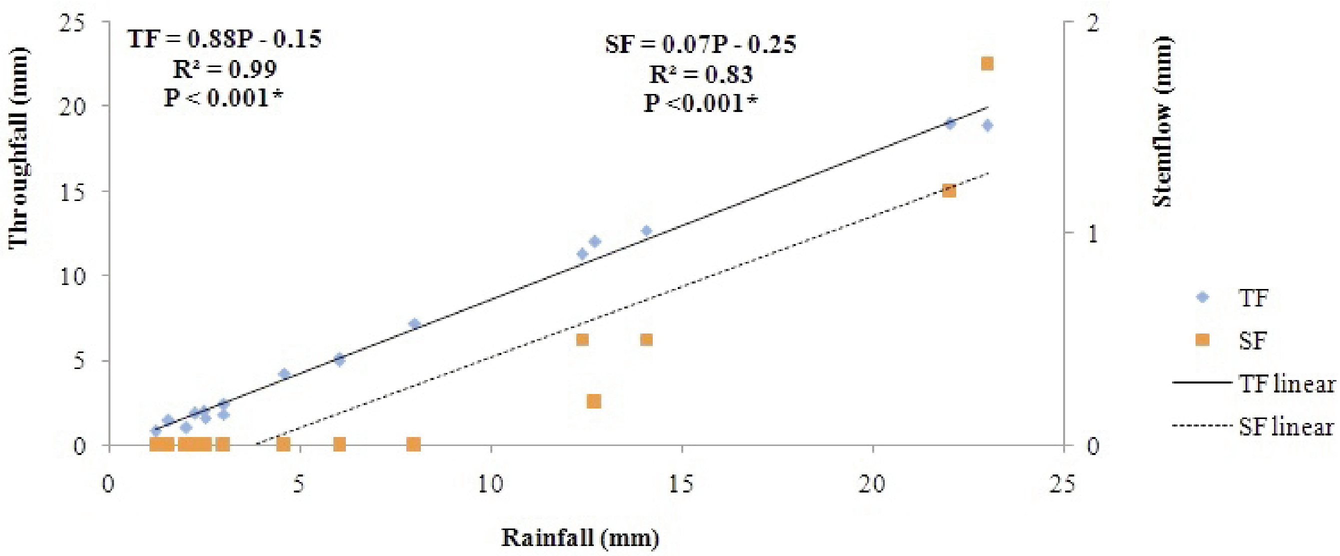

Figure 2. Relationship between P and the other parameters (TF and SF) at the apple orchard in the leafless phase.

The correlations found in the present study are consistent with the results of Wang and Wang (2019) and Wang et al. (2022) who worked on the interception of rainfall in apple orchards grown in a Chinese semi-arid climate.

4. Conclusions

The present study provides for the first time in the southern Mediterranean region, detailed data on rainfall interception by apple trees. The results revealed that the average %TF and %SF were around 78.8 and 2.5%, respectively, whereas %I was 18.7% of total rainfall. Our results also revealed that the rainfall redistribution changes considerably in the apple orchard between the leafed and leafless phases. Indeed, passing from the leafed to the leafless phases, %TF increased from 67.1% to 85.9% and %I decreased from 31.0% to 11.0%. The regression equations obtained can be used to estimate the fractions of rainfall that reach the orchard soil during the leafed and leafless phases.

Assessing and modeling rainfall interception for apple orchards provide useful information to (a) allow a more effective selection of appropriate management practices to reduce unproductive water flows (interception) and to recharge the groundwater and fully exploit the productive potential of apple orchards; and (b) improve our understanding of the effect of planting apple orchards on regional water management. We suggest that the use of rainproof is strongly discouraged in semi-arid climates when heavy rainfalls are expected to occur, because in these conditions their use can disturb the recharge of groundwater and the sustainability of water resources. The meteorological conditions examined in this study were limited to rainfall quantities and the number of rainfall events; however, other parameters, such as air temperature and wind, are known to influence the patterns of TF and SF and deserve future investigation.

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Conflicts of Interest: The authors declare no conflict of interest.

References

Abed, A., Bonhomme, M., Lacointe, A., Bourgeois, G. and Baali-Cherif, D. (2019) ‘Climate change effect on the bud break and flowering dates of the apple trees in mountainous and plain regions of Algeria’, *Advances in Horticultural Science*, 33(3), pp. 417-431. doi: 10.13128/ahs-24618

Ali, M.H. and Mubarak, S. (2017) ‘Effective rainfall calculation methods for field crops: An overview, analysis and new formulation’, *Asian Research Journal of Agriculture*, 7(1), pp. 1-12. doi: 10.9734/ARJA/2017/36812

Bakhtache, R. and Hadjene, O. (2023) ‘The repercussions of climate change on the agricultural and hydraulic sectors in Algeria (2010/2022)’, *Revue Cahiers Economiques*, 14(1), pp. 80-95.

Benhizia, T., Lebbal, S. and Abaidia, A. (2023) ‘First data on rainfall interception in an Atlas cedar forest (*Cedrus atlantica* Manetti) in the Aurès (eastern Algeria)’, *Austrian Journal of Forest Science*, 140(3), pp. 189-212. doi: 10.53203/fs.2303.2

Benhizia, T., Oudjehih, B. and Lebbal, S. (2018) ‘Variation de l’interception des précipitations dans une chênaie à *Quercus ilex* L. des Aurès (Est algérien)’, *Ecologia Mediterranea*, 44(1), pp. 97-108.

Boutry, C., Kelderer, M., Holtz, T., Baumgartner, F. and Friedli, M. (2022) ‘Testing the effect of a rainproof protection net on the apple production regarding disease and pest damages’, *Proceedings of the 20th International Conference on Organic Fruit-Growing*, pp. 101-106.

Calheiros de Miranda, R.A. and Butler, D.R. (1986) ‘Interception of rainfall in a hedgerow apple orchard’, *Journal of Hydrology*, 87, pp. 245-253. doi: 10.1016/0022-1694(86)90017-X

DSA (Direction des Services Agricoles) Batna (2022) ‘Surface et production des arbres fruitiers dans la wilaya de Batna’, *Bilan de statistiques agricoles*, 2p.

Dzikiti S., Volschenk T., Midgley S.J.E., Lötze E., Taylor N.J.T., Gush M.B., Ntshidi Z., Zirebwa S.F., Doko Q., Schmeisser M., Jarmain F.C., Steyn W.J. and Pienaar H.H., (2018) ‘Estimating the water requirements of high yielding and young apple orchards in the winter rainfall areas of South Africa using a dual source evapotranspiration model’, *Agricultural Water Management*, 208, 152-162. doi: 10.1016/j.agwat.2018.06.017

FAOstat (2023) Crops and livestock products. Available at: https://www.fao.org/faostat/en/#data/QCL, Accessed: 09 October 2023.

Hamdani, M., Elbahi, S., Lagueague, S., Hoceini, F., Sellami, M. and Cherief, A. (2018) *Étude du comportement de deux variétés de pommier Malus pumila mill vis-à-vis des paramètres climatiques en conditions semi-arides dans la région de Boussaâda (M'Sila), Algérie*.

He, W., Jing, Y., Jiang, Z.-Y., Liao, C.-M., Yu, Y., Peng, J.-H., Zhang, Y.-D., Hou, G.-L. and Zhang, S.-Y. (2022) 'Spatiotemporal Variations in Vegetation Canopy Interception in China Based on a Revised Gash Model', *Forests*, 13, 1404. doi: 10.3390/f13091404

Klamkowski, K., Treder, W. and Tryngiel-Gać, A. (2011) 'Influence of mulch on rainfall interception in apple orchard', *Sodininkystėir Daržininkystė*, 30, pp. 15-21.

Li, Y., Li, J., Are, K.S., Huang, Z., Yu, H. and Zhang, Q. (2020) 'Livestock grazing significantly accelerates soil erosion more than climate change in Qinghai-Tibet Plateau: evidenced from ^{137}Cs and ^{210}Pbex measurements', *Agriculture, Ecosystem and Environment*, 285, 106643. doi: 10.1016/j.agee.2019.106643

Livesley, S.J., Baudinette, B. and Glover, D. (2014) 'Rainfall interception and stem flow by eucalypt street trees: The impacts of canopy density and bark type', *Urban Forestry & Urban Greening*, 13(1), pp. 192-197. doi: 10.1016/j.ufug.2013.09.001

Lin, M., Sadeghi, S.M.M. and Van Stan, J.T. (2020) 'Partitioning of rainfall and sprinkler-irrigation by crop canopies: A global review and evaluation of available research', *Hydrology*, 7(4), 76. doi: 10.3390/hydrology7040076

Llorens, P. and Domingo, F. (2007) 'Rainfall partitioning by vegetation under Mediterranean conditions: A review of studies in Europe', *Journal of Hydrology*, 335(1-2), pp. 37-54. doi: 10.1016/j.jhydrol.2006.10.032

Ma, S., Wu, W., Chang, J., Ma, Z., and Liu, H. (2012) 'A canopy interception model and its application for apple tree in semi-humid areas', *Journal of Irrigation and Drainage*, 31(2), pp. 116-119.

Midgley, S.J.E., New, M., Methner, N., Cole, M., Cullis, J., Drimie, S., Dzama, K., Guillot, B., Harper, J., Jack, C., Johnston, P., Knowles, T., Louw, D., Mapiye, C., Oosthuizen, H., Smit, J. and van den Broeck, D. (2014) *A Status quo review of climate change and the agriculture Sector of the Western Cape Province. Report*, University of Cape Town.

Mirzabaev, A., Stringer, L.C., Benjaminsen, T.A., Gonzalez, P., Harris, R., Jafari, M., Stevens, N., Tirado, C.M. and Zakieldeen, S. (2022) 'Cross-Chapter Paper 3: Deserts, Semiarid Areas and Desertification', in Pörtner. H.-O., Roberts D.C., Tignor, M., Poloczanska, E.S., Mintenbeck, K., Alegría, A., Craig, M., Langsdorf, S., Löschke, S., Möller, V., Okem, A. and Rama, B. (eds.) *Climate Change 2022: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge: Cambridge University Press, pp. 2195-2231, doi: 10.1017/9781009325844.020

Nanko, K., Hudson, S.A. and Levia, D.F. (2016) 'Differences in throughfall drop size distributions in the presence and absence of foliage', *Hydrological Sciences Journal*, 61, pp. 620-627. doi: 10.1080/02626667.2015.1052454

Pérez-Suárez, M., Arredondo-Moreno, J.T., Huber-Sannwald, E. and Serna-Pérez, A. (2013) 'Forest structure, species traits and rain characteristics influences on horizontal and vertical rainfall partitioning in a semiarid pine–oak forest from Central Mexico', *Ecohydrology*, 7(2), pp. 532-543. doi: 10.1002/eco.1372

Sun, Z., Li, Z., Li, B., Sun, T. and Wang, H. (2017) 'Factors influencing corn canopy throughfall at the row scale in Northeast China', *Agronomy Journal*, 109, pp. 1591-1601. doi: 10.2134/agronj2016.02.0116

Tyagi, S., Sahay, S., Imran, M., Rashmi, K. and Mahesh, S.S. (2017) 'Pre-harvest factors influencing the postharvest quality of fruits: A review', *Current Journal of Applied Science and Technology*, 23(4), pp. 1-12. doi: 10.9734/CJAST/2017/32909

Vialard-Goudou, A. and Richard, C. (1956) ‘Étude pluviométrique, physico-chimique et économique des eaux de pluie à Saigon (1950-1954)’, *Agronomie Tropicale*, 11(1), pp. 78-92.
Vicente, E., Vilagrosa, A., Ruiz-Yanetti, S., Manrique-Alba, A., González-Sanchís, M., Moutahir, H., Chirino, E., del Campo, A. and Bellot, J. (2018) ‘Water balance of Mediterranean Quercus ilex L. and Pinus halepensis Mill. forests in semiarid climates: A review in a climate change context’, *Forests*, 9(7): 426. doi: 10.3390/f9070426
Wang, S., Fu, B., Gao, G., Liu, Y. and Zhou, J. (2013) ‘Responses of soil moisture in different land cover types to rainfall events in a re-vegetation catchment area of the Loess Plateau, China’, *Catena*, 101, pp. 122-128. doi: 10.1016/j.catena.2012.10.006
Wang, D. and Wang, L. (2019) ‘Canopy interception of apple orchards should not be ignored when assessing evapotranspiration partitioning on the Loess Plateau in China’, *Hydrological Process*, 33, pp. 372-382. doi: 10.1002/hyp.13330
Wang, D., Wang, L. and Zhang, R. (2022) ‘Measurement and modeling of canopy interception losses by two differently aged apple orchards in a subhumid region of the Yellow River Basin’, *Agricultural Water Management*, 269, 107667. doi: 10.1016/j.agwat.2022.107667
Yang, J., He, Z., Feng, J., Lin, P., Du, J., Guo, L., Liu, Y. and Yan, J. (2023) ‘Rainfall interception measurements and modeling in a semiarid evergreen spruce (Picea crassifolia) forest’, *Agricultural and Forest Meteorology*, 328, 109257. doi: 10.1016/j.agrformet.2022.109257
Yang, T., Li, Y., Ouyang, X., Wang, B., Ge, X. and Tang, L. (2022) ‘Rainfall physical partitioning and chemical characteristics in evergreen coniferous and deciduous broadleaved forest stands in a high nitrogen deposition region, China’, *Forests*, 13, 1644. doi: 10.3390/f13101644
Zabret, K., Rakovec, J. and Šraj, M. (2018) ‘Influence of meteorological variables on rainfall partitioning for deciduous and coniferous tree species in urban area’, *Journal of Hydrology*, 558, pp. 29-41. doi: 10.1016/j.jhydrol.2018.01.025
Zella, L. (2012) *Les bases de l’irrigation*. Algiers: OPU.
Zhang, R., Wang, D., Yang, Z., Seki, K., Singh, M. and Wang, L. (2021) ‘Changes in rainfall partitioning and its effect on soil water replenishment after the conversion of croplands into apple orchards on the Loess Plateau’, *Agriculture, Ecosystems and Environment*, 312, pp. 1-13. doi: 10.1016/j.agee.2021.107342
Zhang, Y., Yuan, C., Chen, N., Levia, D.F. (2023) ‘Rainfall partitioning by vegetation in China: A quantitative synthesis’, *Journal of Hydrology*, 617, 128946. doi: 10.1016/j.jhydrol.2022.128946
Zheng, J., Fan, J., Zhang, F., Yan, S. and Xiang, Y. (2018) ‘Rainfall partitioning into throughfall, stemflow and interception loss by maize canopy on the semi-arid Loess Plateau of China’, *Agricultural Water Management*, 195, pp. 25-36. doi: 10.1016/j.agwat.2017.09.013
Zore, A., Bezak, N. and Sraj, M., (2022) ‘The influence of rainfall interception on the erosive power of raindrops under the birch tree’, *Journal of Hydrology*, 613, 12847. doi: 10.1016/j.jhydrol.2022.128478