

## Suitable Regions for Rain-Fed Tree Culture in Central Zagros (Chaharmahal-Bakhtiari Province of Iran)

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### Abstract

There are many slopping lands in Chaharmahl-Bakhtiari Province of Iran, located in the central Zagros, which have suitable conditions for production of rain-fed horticultural products. This study was an attempt to determine the appropriate regions for almond and vine rain-fed cultivation in this province. Water requirement (ET) of the trees was calculated by local information of weather and plants. Annual precipitation (P) and ET were probabilistically analyzed. Required area for micro-catchment ( $A_c$ ) and suitable regions for rain-fed gardening were then determined at different probability levels ( $p$ ) or return periods (T). Finally, average expected yields of almond and grape was estimated. Mapping the gardening-suitable area showed that inappropriate regions for rain-fed almond and vine culture are concentrated in the eastern part of the province due to less P and higher ET. Moreover, almond generally needed larger  $A_c$  than vine (about 43%) due to higher ET. Results also showed that increasing runoff coefficient (C) was more effective than enhancing water storage efficiency (E) in reducing required  $A_c$ , therefore, increasing 10% and 20% of C and E lead to 48% and 28% smaller  $A_c$ , respectively. Average required  $A_c$  for almond was calculated as 17.4 m<sup>2</sup> which resulted in production of 549.0 kg/ha with  $p=50\%$  (T=2). The corresponding values for the grape were 9.5 m<sup>2</sup> and 2,128.8 kg/ha. Overall, the western areas in the province were more appropriate for rain-fed almond culture, whereas rain-fed vineyard gardens are preferred to be constructed in the eastern parts of the province.

**Keywords:** Chaharmahl-Bakhtiari Province, Micro-Catchment, Water Harvesting, Rain-Fed Gardening, Zagros Mountains, Almond, Grape.

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### Introduction

Iran is located on the dry belt of the earth with the annual precipitation of less than one-third of the world and the evaporation capacity of more than 2000 mm. Because of non-uniform spatial and temporal distribution of the precipitation, Iran is a country with restricted water resources. Many regions of the country receive most of the precipitation in winter and early spring months which is not coincided with the maximum water

requirement period in agriculture. Agriculture is the largest water consumer in Iran, and the highest requirement of water in this sector occurs in late spring and summer months. Therefore, most of the agricultural products are severely dependent on irrigation. The agricultural productions in mountain regions, where the irrigation is impossible, would be mainly related to the collected precipitation *via* water harvesting (WH) systems which increase water supply

for crop production. In order to supply the growing need for food, WH recently has gained more interest for crop production due to simplicity of installation and low maintenance costs. Fruit trees are suitable candidate for WH techniques in mountains and uneven areas. There are different ways for tree establishment using WH systems. Construction of micro-catchment is an efficient way of rain WH for crop production as well as other purposes (combined utilization such as toilet, laundry, and irrigation) specially in arid and semi-arid regions and sloping lands (Rahman et al., 2017; Plan and Budget Organization, 2009). Technical specifications of the catchments are an important issue for constructing rain-fed gardens on the sloping land. These catchments should be compatible with climatic conditions specially regarding rainfall-runoff relationships and be able, at least partly, to provide water requirement of the cultivated plants. These plants should survive specially in warm or dry months by using collected and stored runoff in the soil profile of the cultivation pits.

Many studies have been conducted on construction of WH systems for the purpose of rain-fed gardening. Sepaskhah and Fooladmand (2006) introduced a computer model for the design of micro-catchment rainwater harvesting (RWH) system for the rain-fed vineyard. They indicated that building of a small pool for storing and infiltrating collected runoff from micro-catchment area is one of the best ways for cultivation vineyard trees on lands with the suitable slope. Abdelkadir and Schultz (2005) investigated the role of micro-catchment WH for improving fodder production and carrying capacity of dryland in eastern Ethiopia. They indicated that soil moisture content and consequently dry matter production of grass and trees were greater in micro-catchment WH systems than in control plots with no WH structures. Tabatabaei Yazdi et al. (2007) studied the potential use of RWH system for supplemental irrigation of rain-fed wheat and almond in Sisab Research Station of Bojnourd. Their results showed that for the annual crops such as wheat, it was inevitable to accept deficit irrigation of about 35% without preparing storage tank by using small

catchment. However, for almond with dominant water requirement in summer months, large catchment should be prepared accompanied by a storage tank. Mahmoodi (2012) indicated that the precipitation was the main factor in identifying appropriate regions for storing rainwater followed by the soil permeability, soil surface coverage, and land slope, respectively. They finally presented the map of suitable area for harvesting and storing rainwater for rangeland reclamation using GIS. Tavakoli (2013), after six years investigations on collecting rain water for almond in East Azarbayjan Province, reported that a 7×7m catchment with clean and compacted surface was the suitable treatment for the establishment of almond trees. They also indicated that it was necessary to control the evaporation from the surface of the cultivation pit and there was no difference among the shapes of the catchments in performance of harvesting runoff, although square arrangement of the micro-catchments was better than semi-circular bunds. Bayen et al. (2016) reported the results of three soil restoration techniques on establishment and survival of three plant species by rain water harvesting in Burkina Faso. Survival rates of the plant species by using half-moon technique were better than other methods. Finally, they stated that *Acacia nilotica* and *Acacia tortilis* appeared to be promising tree species for rehabilitation of barren and degraded land. The feasibility of RWH originated from rooftops in order to supply the water demand in some arid and semi-arid states of the U.S. was investigated by Tamaddun et al. (2018). They indicated that the collected rooftop rainwater, as a source of water, was extremely dependent to the outdoor water demand such as landscaping and the percentage of existing houses with rooftop RWH.

Successful implementation of the RWH depends on simultaneously doing other crop management practices such as plowing, fertilization, management of soil coverage, crop rotation, application of soil amendments and management of runoff producing surface (Vohland and Barry, 2009). For instance, application of manure and straw mulch had a significant effect on increasing soil water storage, reducing soil evaporation, and

decreasing crop water consumption in a RHW system in Ethiopia (Birru *et al.*, 2012) and in the arid and semi-arid regions of China (Yin *et al.*, 2018). Besides, it has been demonstrated that use of the gravelly filter for infiltrating collected runoff into the cultivation pit significantly increased the growth of almond and pistachio in a RHW system (Yadollahi *et al.*, 2012; Sadeghzadeh Reihan *et al.*, 2013).

One of the most suitable methods to construct rain-fed orchard is micro-catchment WH (Sepaskhah & Fooladmand, 2006). There is a degree of uncertainty in identifying suitable regions for rain-fed tree culture which has been ignored in many studies.

Chaharmahal-Bakhtiari is one of the Iran's Provinces located at Central Zagros Mountains which contains 1% of Iran's area (16,421 km<sup>2</sup>). Almond and vine are two dominant rain-fed trees in the mountainous area of the province. This province is one of the major centers of these two crops production in Iran that includes 1850 and 850 ha rain-fed almond orchard and vineyard, respectively. The total production of almond and grape are annually 22 and 60,000 tons in the Province (Jahad-Keshavarzi Organization, 2019). There is an extension program of rain-fed almond and vine cultivation on the sloping lands in this province.

Hence, this research was an attempt to determine the appropriate regions for constructing of dryland orchard in a semi-arid climate (Chaharmahal Bakhtiari Province) considering uncertainty conditions for precipitation and evapotranspiration which is less considered in previous studies. The arable land area of the province is limited. However, there is a lot of highlands and sloping areas which may be suitable for building rain-fed tree culture. Therefore, appropriate regions for cultivation of almond and vine, as two dominant and expandable plants in the province using micro-catchment WH, were mapped. Besides, a simple probabilistic equation to determine required area for micro-catchment was presented. Finally, the expected yields of the trees were also determined.

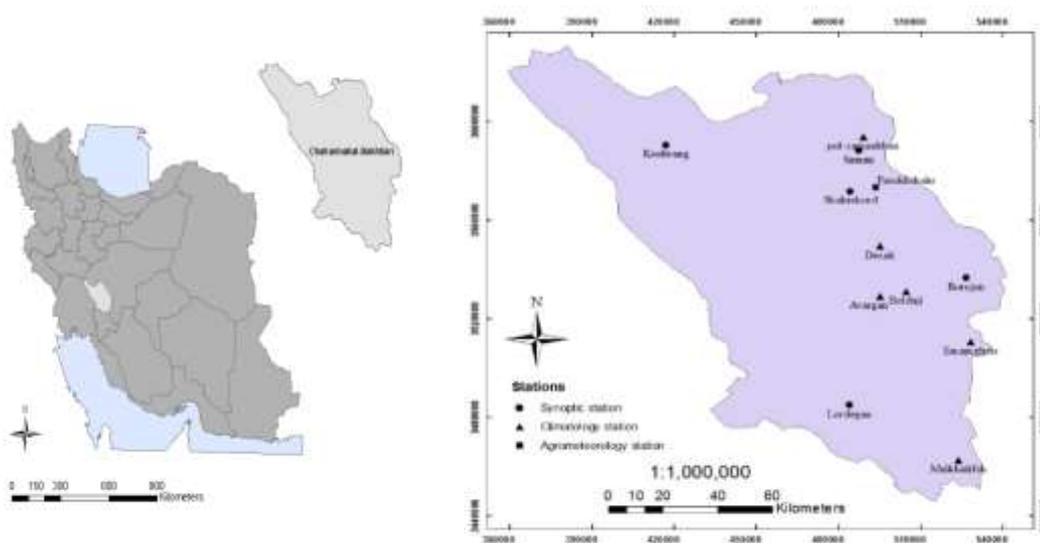
## Materials and Methods

### Geographical Location and Weather of the Region

Chaharmahal-Bakhtiari Province is located between 31° 09' to 32° 48' N latitude and 49° 28' to 51° 25' E longitude with area of 16532 km<sup>2</sup> (Figure 1). Average altitude of the province is 2,153 m above mean sea level. Western parts of the province are more mountainous than eastern areas. Precipitation pattern of the province is mostly influenced by low pressure Mediterranean and Sudanese air systems coming from west and south-west during autumn to the middle of spring. A little amount of the precipitation arises from the low-pressure systems in the summer months. The amount of precipitation decreases from west to east of the province. Average precipitation of the province is annually 560 mm. This province has a diverse climate. Semi-arid climate is dominant in the east; whereas, in the west and south-west of the province there is a warm and semi-humid climate. Besides, the climate in the north-west is cold and mild (Meteorological Organization of Chaharmahal-Bakhtiari Province, 2014). In this research, long-term (16 years: 2001-2015) recorded data of 12 weather stations in the province (Table and Figure 1) were taken from Meteorological Organization of Chaharmahal-Bakhtiari Province.

### Water Requirement Calculation

Water requirement (annual evapotranspiration, ET) of two dominant plants in the province cultivation pattern, almond and vine, was calculated in each weather station using CROPWAT model. For this purpose, daily weather data of the station comprising maximum and minimum air temperature (°C), relative humidity (%), wind velocity (m/day), sunshine hours (hr) and precipitation (mm) were prepared as entrance data to the Model. Crop coefficient, planting date, duration of growing season, and other required data of the plants obtained from FAO paper NO. 56 (Allen *et al.*, 1998). These data were modified in any cases if local information were available (Rahemi and Yadollahi, 2006).



**Fig. 1- Geographical location of the Chaharmahal-Bakhtiari Province in Iran and the weather stations in the province**

**Table 1- Characteristics of the weather stations<sup>1</sup> included in this study**

Station	Station Type	Latitude	Longitude	Elevation (m)
Shahrekord	Synoptic	32.29	50.84	2050
Borujen	Synoptic	31.98	51.30	2260
Emamgheis	Climatological	31.75	51.30	2285
Lordegan	Synoptic	31.50	50.83	1611
Farokhshahr	Agricultural meteorology	32.30	50.93	2073
Dezak	Climatological	32.09	50.96	2054
Avargan	Climatological	31.90	50.95	2410
Pole Zamankhan	Climatological	32.50	50.90	1883
Malkhalifeh	Climatological	31.30	51.25	1762
Boldaji	Climatological	31.93	51.07	2231
Saman	Synoptic	32.44	50.87	2075
Koohrang	Synoptic	32.43	50.12	2285

<sup>1</sup>the duration of the statistical period was 16 years, from 2001 to 2015.

**Micro-Catchment for Rain-Fed Tree Culture**

Micro-catchment is a small square basin comprising a sloping runoff producing area and a cultivation pit located at the end of the slope direction (Figure 2). Collected Runoff is directed to the infiltration pit and is stored in the soil profile for consuming by cultivated trees. In order to provide the annual ET of the planted trees ( $R_s$ , mm), an adequate surface for runoff collection ( $A_c$ ,  $m^2$ ) and acceptable annual runoff production coefficient (C) is necessary. Besides, the storage efficiency of water in the soil of cultivation pit (E) should be as much as high so that the storage water meets the ET of the trees. The relationship among these mentioned parameters and annual precipitation (P, mm) for determining

the micro-catchment area is as follows (Fooladmand & Sepaskhah, 2006):

$$R_s = P(1 + \frac{A_c}{A_{cu}} CE) \tag{1}$$

where  $A_{cu}$  is the cultivated area ( $m^2$ ). The amount of the C coefficient depends on the slope and physical properties of the runoff collecting surface and falls commonly in the range of 0.10 to 0.50 (Fooladmand & Sepaskhah, 2006). Furthermore, the amount of E varies from 0.50 to 0.75. It depends on the evaporation from the soil surface and the percolation deeper from the root zone. Any activity that restricts soil evaporation (such as surface mulching) and increases soil water capacity (such as adding any water absorbing materials to the soil) will enhance the amount

of E. On the other hand, each effort to produce more runoff from collecting area (such as decreasing infiltration *via* compaction) would be a proper action to supply the plant water requirement. The ratio of the  $A_c$  to  $A_{cu}$  is usually 2 to 10 (Sepaskhah, 2014).

### Frequency Analysis of Precipitation and Evapotranspiration

Annual precipitation data of 12 weather stations in the province with the 16-years joint period and also calculated ET of the trees were ranked in a descending order in each station. A number was assigned to each data (ranked number,  $m$ ) and the occurrence probability of a specified amount of precipitation ( $p$ ) and ET was calculated by Weibull equation as follows (Chow *et al.*, 1988):

$$p = \frac{m}{n + 1} \quad (2)$$

Where  $n$  is the number of data. Then a linear equation can be derived between  $p$  and P or ET as:

$$p = a[P \text{ or } ET] + b \quad (3)$$

where  $a$  and  $b$  are the constant coefficients of the equation. These parameters are site specific.

### Probabilistic Determination of Catchment Area ( $A_c$ )

By substituting  $R_s = ET$  (stored water should supply ET of plant), Equation (1) can be changed as:

$$\frac{A_c}{A_{cu}} = \left[ \frac{ET_{pET}}{P_{pP}} - 1 \right] / CE \quad (4)$$

By choosing ET and P with a specified  $p$  ( $pET$  and  $pP$  refers to the occurrence probability of ET and R as decimal, respectively) or T ( $T = 1/p$  is the return period for occurrence a given amount of ET and P) and reasonable value for C and E, the ratio of  $A_c/A_{cu}$  will be determined. At given values for C and E the following equation for calculating  $A_c/A_{cu}$  can be derived:

$$\frac{A_c}{A_{cu}} = a_0 + a_1 p_P + a_2 p_{ET} \quad (5)$$

Where  $a_0$ ,  $a_1$ , and  $a_2$  are constants of the equation. Then  $A_c$  can be calculated by multiplying this ratio by  $A_{cu}$ .

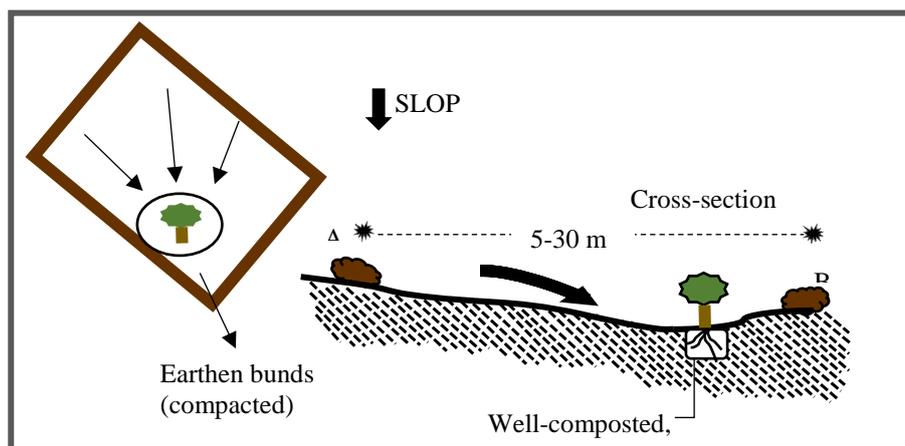


Fig. 2- A schema of the micro-catchment for rainwater harvesting (adapted from Plan and Budget Organization, 2009)

### Mapping the Suitable Regions for Constructing Rain-Fed Orchard

In order to determine the proper regions for building rain-fed almond and vine orchard in the province, the amount of P and ET with a certain value of  $p$  (or T) were selected based on the probabilistic analysis of these factors. Then, the amount of the stored water in the soil profile of the cultivation pit was calculated by considering two runoff coefficients of 0.10 and 0.30, two  $A_c/A_{cu}$  ratios of five and 10 and storage efficiencies of 0.50. Afterwards, the zoning map of the soil stored water in the province was prepared using GIS software and IDW (Invers Distance Weighting) method. The suitable regions for almond and vine cultivation were wherever the water storage layer meet the ET layer of the trees with the same  $p$  (or T) in GIS. Indeed, this probability indicates the successful percentage of trees culture. The suitable area of the micro-catchment was also calculated in each case.

### Estimation of the Grape and Almond Yield

Based on the information of the rain-fed grape and almond production in Chaharmahl-Bakhtiari Province (Jahad-Keshavarzi Organization, 2019), the relationship between the grape and almond production ( $Y$ , kg/tree) and the summation of annual precipitation and collected runoff by water harvesting systems ( $P+R_s$ , mm) was determined as:

$$Y = A_0 + A_1(P + R_s) + A_2(P + R_s)^2 \quad (6)$$

where  $A_0$ ,  $A_1$ , and  $A_2$  are the constant coefficients. Production of the grape and almond can be estimated by applying a specified  $P+R_s$  with a certain level of  $p$  (Equation 3).

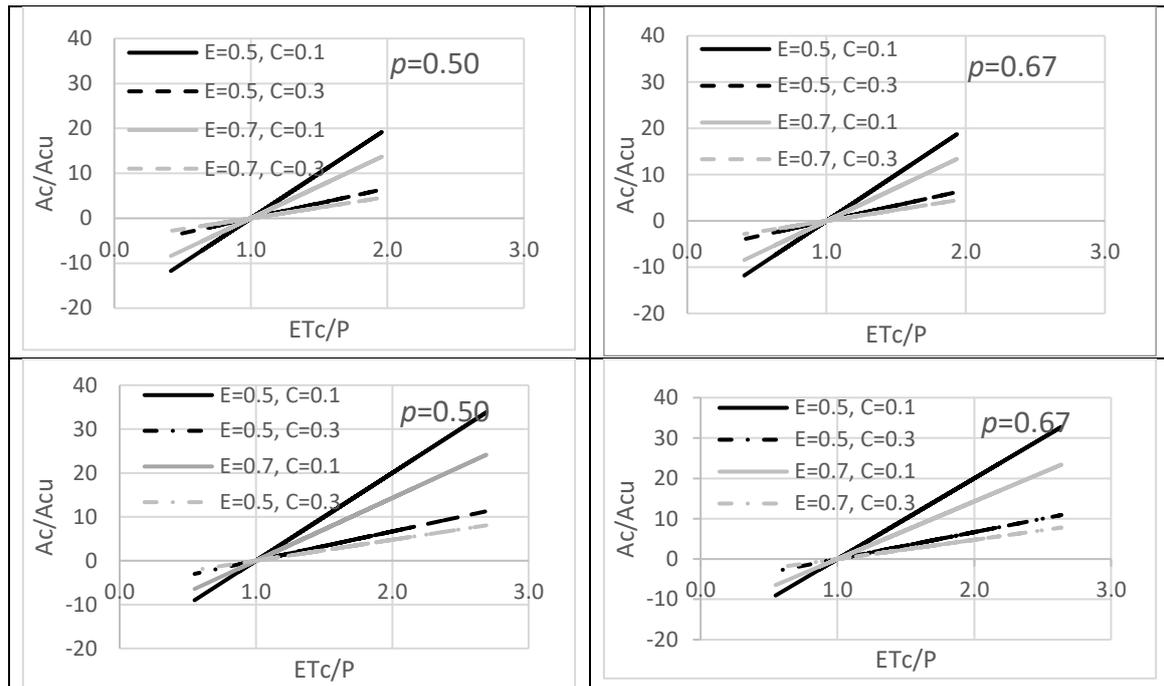
### Results and Discussion

#### Probabilistic $A_c$

Frequency analysis of ET and P in the weather stations of the province was done in the form of Equations (2) and (3). Results of this analysis are shown in Table 2. This analysis revealed that the low values of P and ET occurred with high probability levels (or low return period).

**Table 2- The constant coefficients (a and b for Eq. 3) for probabilistic determining annual precipitation (P) and evapotranspiration (ET) of vine and almond in different regions of Chaharmahal-Bakhtiari province**

Station	Coefficient of equation 3 for P		Coefficient of equation 3 for vine ET		Coefficient of equation 3 for almond ET	
	a	b	a	b	a	b
Shahrekord	-0.0031	1.2664	-0.0022	1.2658	-0.0016	1.2356
Borujen	-0.0045	1.2876	-0.0022	1.2565	-0.0016	1.2637
Emamgheis	-0.0019	1.2625	-0.0021	1.2274	-0.0016	1.2633
Lordegan	-0.0015	1.2669	-0.0021	1.2470	-0.0016	1.2632
Farokhshahr	-0.0034	1.2330	-0.0022	1.2657	-0.0014	1.2372
Dezak	-0.0020	1.2425	-0.0023	1.2877	-0.0017	1.2641
Avargan	-0.0021	1.2269	-0.0023	1.2663	-0.0016	1.2842
Pole Zamankhan	-0.0031	1.2892	-0.0020	1.2565	-0.0015	1.2696
Malkhalifeh	-0.0013	1.2792	-0.0020	1.2477	-0.0016	1.2638
Boldaji	-0.0027	1.2469	-0.0021	1.2279	-0.0015	1.2222
Saman	-0.0029	1.2463	-0.0023	1.2865	-0.0018	1.2640



**Fig. 3- Graphical calculation of  $A_c/A_{cu}$  as a function of  $ET_c/P$  (vine: top and almond: bottom pictures) for two occurrence probability ( $p$ ), runoff production efficiency ( $C$ ) and storage efficiency of runoff ( $E$ ).**

A specified value of  $P$  and  $ET$  can be determined by Equation (3) using coefficients in Table 2 with a certain level of  $p$  or  $T$ . Then the ratio of  $ET/P$  was substituted in the Equation (4) and the ratio of  $A_c/A_{cu}$  was calculated with a given amount of  $C$  and  $E$ . This Equation shows that if  $P > ET$ , then  $A_c/A_{cu}$  is negative. This means that in the case of  $P > ET$ , the annual precipitation can supply  $ET$  of the trees and no area is needed for runoff collecting. In other words,  $A_{cu}$  is considered as a micro-catchment. Similar results have been reported in Fars Province for the rain-fed grapevine (Fooladmand & Sepaskhah, 2006). Generally, the required area of the micro-catchment with a certain  $p$  or  $T$  can be calculated by Equation (4) in different regions of Chahramahal-Bakhtiari Province. Graphical calculation of the Equation 4 has been shown in Figure (3). This Figure shows the calculation of  $A_c$  for two occurrence probabilities of 0.50 (recurrence interval,  $T=2$  or one out of two years) and 0.67 ( $T=1.5$  or 2 out of three years). In other words, if the farmer wants the trees to survive in 50 or 67 percent of the times he should consider the  $A_c$  as much as high that is shown in Figure (3).

In this Figure, the ratio of  $A_c/A_{cu}$  is obtained and then the  $A_c$  can be calculated

using  $A_{cu}$ . It is obvious from this Figure that at two  $p$  level of 0.50 and 0.67 ( $T=2$  and 1.5 years, respectively), the required areas for micro-catchment are roughly equal because the  $P$  and  $ET$  amounts in these two levels of probability or return period are close together. However, the slope of the lines in this figure revealed findings about drought resistance of almond and vine. For example, in the case of  $E=0.5$  and  $C=0.1$  (Continuous black lines in Figure 3), increasing one unit to  $ET_c/P$  increased 1.0% more  $A_c/A_{cu}$  for almond than vine for probability level of 0.67. This is equivalent to 24.7 mm (based on Equation 3 and Table 2) more collecting runoff from unit area of the micro-catchment and confirmed more sensitivity of almond to drought than vine. Figure (3) also shows that if the ratio of  $ET/P$  is less than one  $ET < P$ , then the ratio of  $A_c/A_{cu}$  will be negative. In other words, this Figure shows the fact that if  $ET < P$ , then it is not necessary to construct the catchment for runoff collecting because the annual precipitation provides water requirement of the trees; of course, if all rainwater is stored in the root zone. Assuming 50% probability of yearly  $P$  and almond- $ET$  (Equivalent to  $T=2$  years), if  $A_{cu}=1 \times 1 \text{ m}^2$ , then the  $A_c$  varied between 33.8 in Borujen to 3.2  $\text{m}^2$  in Emamgheis region

while the corresponding value of  $A_c$  for grapevine varied between 19.2 in Borujen to 4.2 m<sup>2</sup> in Boldaji region. There was no need to include an area in Lordegan, Malkhalife and Koohrang for almond and in Lordegan, Emamgheis, Dezak, Avargan, Malkhalife and Koohrang for vine rein-fed culture at  $p=50\%$  ( $T=2$  years). Local farmers in the Bajgah Region of Fars Province have constructed micro-catchments with area of 9 m<sup>2</sup> for rain-fed vine. Moreover, the most appropriate squared micro-catchments area for the rain-fed vine culture in this region (with 350 mm annual precipitation) was calculated as 9 m<sup>2</sup> at the occurrence probability of 50% or return period of two years (Fooladmand & Sepaskhah, 2006). These values are in accordance with the findings reported here (in sub-section 3.1). The differences in the area are mainly due to the differences in the climate conditions.

To facilitate the calculation of micro-catchment areas in the whole of the Province, Equation 5 was determined. Table (3) shows the results for different values of C and E. The positive and negative signs for  $pP$  and  $pET$ , respectively, indicates the reverse role of P and ET in determining the micro-catchment area. In other words, the greater amounts of P and ET lead respectively to a smaller and larger area for micro-catchment. Similar equation has been reported for vine

trees in Fars Province (Fooladmand & Sepaskhah, 2006).

According to Table (3), almond trees generally require larger catchment area (about 43%) than vine trees due to higher water requirement. This means that almond is more sensitive to drought than vine since it requires more runoff collecting area. Besides, under lower runoff production (less C values) and high water loss (less E values), larger area of catchment is needed. From these results, regardless the type of trees, another point is that in a given runoff production efficiency, increasing storage efficiency by 20% (from 0.5 to 0.70) allows the smaller area (as 28%) for the catchment to be selected. However, for a given water storage efficiency (E), if runoff production enhances by 10% (from 0.10 to 0.20), the catchment area can be selected 48% smaller. This illustrates more dominant role of the runoff production in the catchment size selection for rain-fed gardening as compared to the reserving water. As formerly mentioned, increasing storage efficiency can be achieved by enhancing water holding capacity of soil in cultivation pit for example by increasing the organic matter. On the other hand, increasing runoff production can be attained by decreasing soil permeability in the catchment area for example by compacting the surface layer.

**Table 3- Equations\* for determining  $A_c/A_{cu}$  for different probabilities (in decimal) of yearly water requirement ( $pET$ ) and annual precipitation ( $pP$ ) under different runoff coefficient (C) and water storage efficiency (E)**

	C	E	Equation	R <sup>2</sup>	Ac** (m <sup>2</sup> )
Almond	0.10	0.50	$[Ac/Acu]=18.83+46.50pP-49.38pET$	0.85	17.4
	0.20	0.50	$[Ac/Acu]=9.58+22.83pP-24.29pET$	0.84	8.9
	0.10	0.70	$[Ac/Acu]=13.54+32.98pP-35.04pET$	0.85	12.5
	0.20	0.70	$[Ac/Acu]=6.93+16.07pP-17.12pET$	0.84	6.4
Grape	0.10	0.50	$[Ac/Acu]=10.18+28.25pP-29.71pET$	0.78	9.5
	0.20	0.50	$[Ac/Acu]=5.47+13.50pP-14.43pET$	0.77	5.5
	0.10	0.70	$[Ac/Acu]=7.60+19.75pP-21.06pET$	0.77	6.9
	0.20	0.70	$[Ac/Acu]=4.06+9.34pP-10.04pET$	0.75	3.7

\* Equation refer to the Equation 5, for all regression equations:  $n=25$ ,  $p<0.001$

\*\* For calculating  $A_c$ ,  $A_{cu}$  is assumed to be  $1 \times 1$  m<sup>2</sup>

### Mapping the Suitable Regions for Vine and Almond Rain-Fed Culture

Based on the described method, the suitable regions for cultivation of vine and almond trees ( $p=0.50$  for P and ET occurrence,  $T=2$  years) using micro-catchment are shown in Figures (4) and (5), respectively. Suitable areas (Green color) for constructing micro-catchment generally located in the east of the Province. These Figures also show that there are more suitable regions for vine cultivation rather than almond in Chaharmahal-Bakhtiari Province. Besides, suitable regions (green color) increased with increasing runoff production in the province (left maps in the Figures 4 and 5 compared with the right ones).

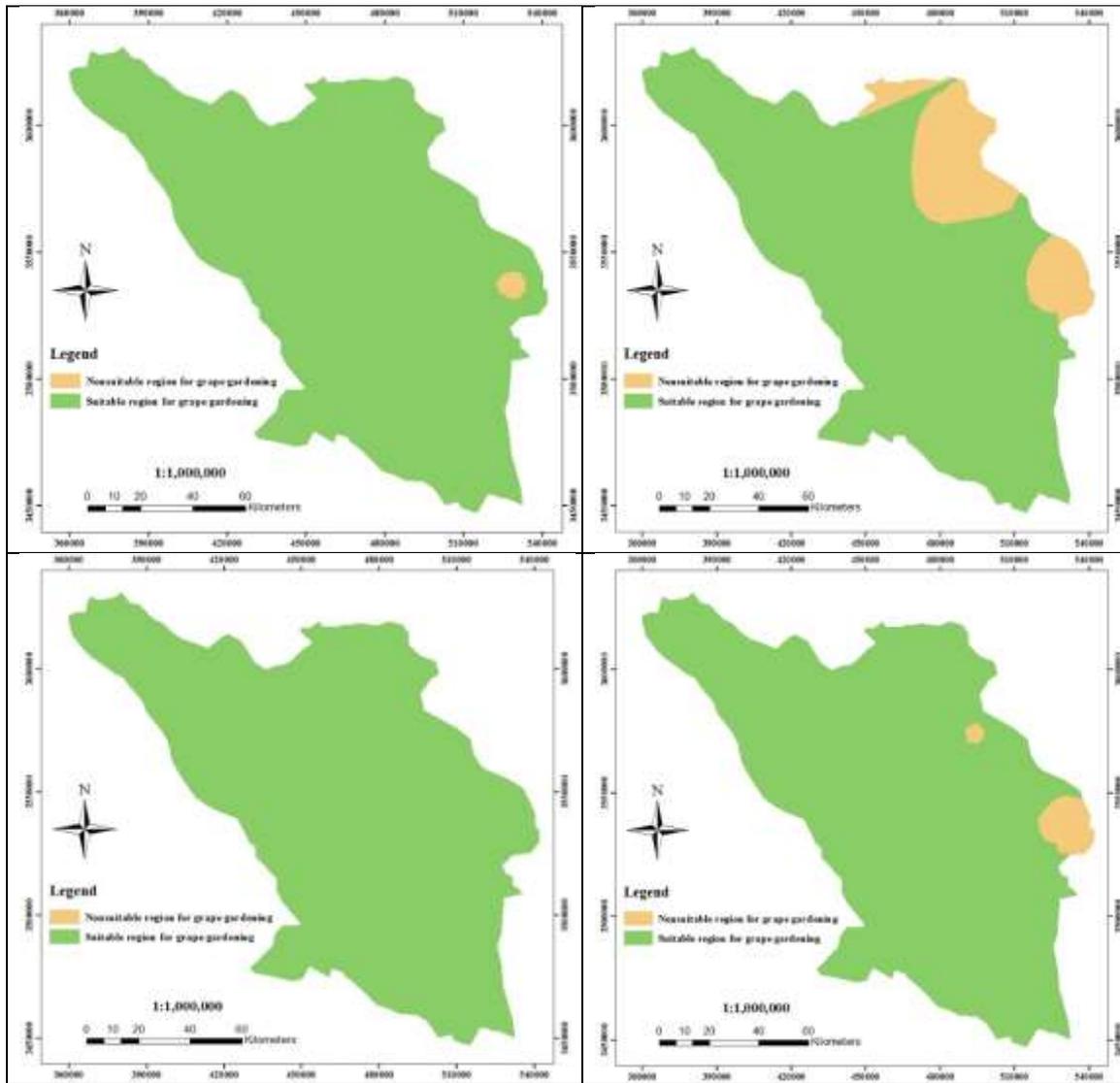
In addition, selecting a larger value of  $A_c/A_{cu}$  (10.0 rather than 5.0) lead to the more suitable area (bottom maps compared to the top ones in the Figures 4 and 5) for the vine and almond cultivation in the province. There were no unsuitable regions for the vine and almost almond cultivation throughout the province if runoff production efficiency is 0.30 and the catchment area is selected 10 times larger than cultivated area (bottom-left maps in the Figures 4 and 5).

In Chaharmahal-Bakhtiari Province, since annual precipitation decrease from west to the east, hence, inappropriate areas (yellow color in Figures 4 and 5) for constructing micro-catchment located more in the east. Furthermore, the higher suitable regions for vine cultivation rather than almond in Chaharmahal-Bakhtiari Province is due to lower water requirement.

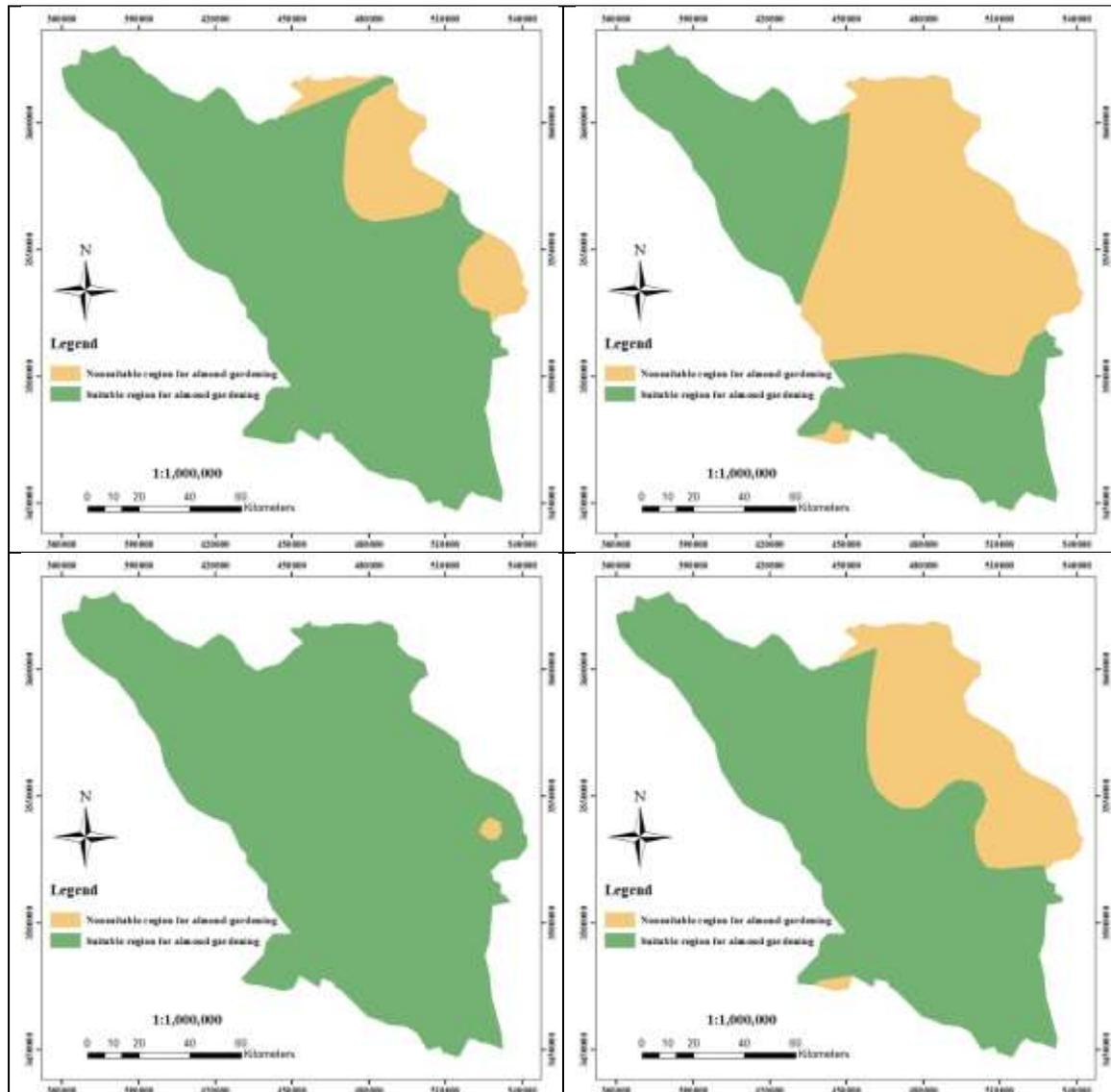
Figures (4) and (5) were presented for two amounts of C and E. Appropriate regions for

vine and almond cultivation would be different from what is seen in the maps if another values for C and E are taken. Runoff production can be increased by reducing permeability of the catchment soil using chemical and mechanical operations. Runoff production efficiency and E values could be used as two management tools for constructing micro-catchments. Arar (1994), while discussing the cost of runoff collection, introduced the mechanical (changing the ground surface and catchment area and ground leveling) and chemical (covering the ground surface using asphalt, plastic, paraffin, and other chemicals) operations that used for increasing runoff production from the catchment. Sepaskhah (2014) reported different experiments in which diverse treatments such as furrowing and soil compaction had been used for enhancing runoff production in the catchment as well increasing the soil organic matter for enhancing water storage in the cultivation pit.

On the other hand, the role of catchment area to supply water requirement of plant has been reported by Sepaskhah (2014). He demonstrated that the larger area of the catchment leads to the more amount of collected runoff. For this reason, by selecting larger area for catchment, enhancing runoff production and storage efficiency of water, the unsuitable region for rain-fed tree culture may become appropriate area for cultivation. Anyway, the eastern areas in the province are preferred for vine gardening because its lower ET matches the lower rainfall of these areas. So they are cost-effective regions for the vine rather than almond gardening.



**Fig. 4- Suitable regions for rain-fed vine culture ( $p=50\%$ ) with runoff coefficient of 10 ( $C=0.10$ , right maps) and 30% ( $C=0.30$ , left maps)  $A_c/A_{cu}$  ratio of 5 (top maps) and 10 (down maps) in Chaharmahal-Bakhtiari Province**

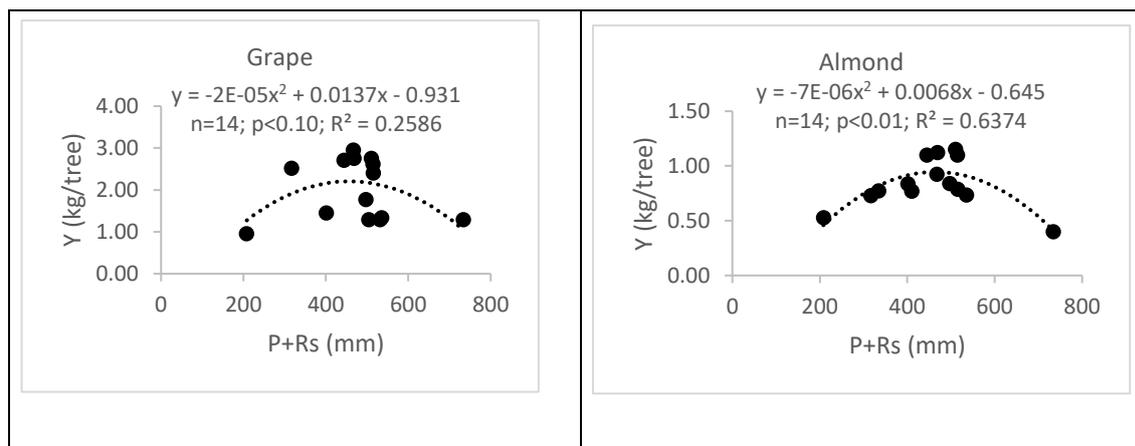


**Fig. 5-** Suitable regions for rain-fed almond culture ( $p=50\%$ ) with runoff coefficient of 10 ( $C=0.10$ , right maps) and 30% ( $C=0.30$ , left maps)  $A_c/A_{cu}$  ratio of 5 (top maps) and 10 (down maps) in Chaharmahal-Bakhtiari Province

### Estimation of the Grape and Almond Yield

The relationship between grape and almond yield ( $Y$ , kg/tree) and water requirement of the trees ( $P+R_s$ , mm) were derived as Figure (6) (Equation 6). This relationship was in the form of a quadratic polynomial equation and it was statistically significant. Micro-catchment area for cultivation of almond and vine trees in the province are estimated 17.4 and 9.5 under probability level of 50% ( $T=2$  years) while runoff production and water storage-

efficiency are 10 and 50 percent, respectively. Hence, the density of almond and vine trees will be 575 and 1053 tree per hectare, respectively. Based on the 50% probability level ( $T=2$  years), water requirement of almond and grapevine in the province are expected to be 457.7 and 344.9 mm, respectively (Table 4). By supplying these requirements using micro-catchments, almond and grape production is estimated be 549.0 and 2128.8 kg/ha. These amounts are equivalent to \$10980 and \$7096 per hectare at current prices, respectively.



**Fig. 6-** The relationship between summation of annual precipitation and collected runoff (P+Rs) and grape (left picture) and almond (right picture) yield

**Table 4-**The Amounts of micro-catchment area( $A_c$ )\*, annual precipitation (P) and water requirement of trees (ET) with 50% probability level (T=2 years) and expected yield (Y) of almond and grape in Chaharmahl-Bakhtiari Province

	$A_c$ (m <sup>2</sup> )	R <sub>50%</sub> (mm)	ET <sub>50%</sub> (mm)	Y (kg/ha)
Almond	17.4	366.5	475.7	549.0
Grape	9.5	366.5	344.9	2128.8

\*  $A_{cu}$  is assumed to be  $1 \times 1$  m<sup>2</sup>. K and E are considered by 10 and 50%, respectively.

The production functions of the almond and grape yield were estimated as quadratic polynomial equations (Figure 6). Therefore, these functions would have a maximum mathematically. In these conditions, the maximum yield of the almond and grape are expected as 1.006 and 1.415 kg per tree. Average productions of rain-fed almond and grape in Chaharmahal-Bakhtiari Province are 451.0 and 2346.8 kg/ha (Jahad-Keshavarzi Organization, 2019). These values are close to those ones calculating here (section 3.3) with 50% probability. Furthermore, an economic analysis can say that that which tree has to be planted and how much area for the micro-catchment should be selected.

### Conclusion

This study proved that Chaharmahal-Bakhtiari Province of Iran with 580 mm average annual rainfall and many sloping lands has the potential to rain-fed almond and vine culture. Since precipitation and evapotranspiration are probabilistic variables and they are the main factors affecting the size of micro-catchment, therefore, micro-catchment areas determined in different probability levels (accompanying return period) of R and ET. Runoff production efficiency from the catchment area and water

storage efficiency in the soil of cultivation pit are also two main factors influencing required area for micro-catchment. Results also showed more dominant role of the runoff production in the catchment size selection for rain-fed almond and vine gardening as compared to the reserving water. Furthermore, unsuitable areas for constructing micro-catchment are located in the east-part of the province at a certain probability level. It is also concluded that the eastern parts of the province will be cost-effective areas for vine gardening than almond culture. Two quadratic equations were obtained for almond and grape yield as a function of harvested rainwater based on the existing information in the province. At probability level of 50% or return period of 2 years, the annual precipitation was 366.5 mm and ET of almond and vine were 475.7 and 344.9 mm, respectively. Generally, if 10% of rainfall is turn to the runoff and 50% of runoff is stored in the cultivation pit, then the required area for almond and vine cultivation by using micro-catchment were 17.4 and 9.5 m<sup>2</sup>, respectively. In these conditions, production of 549.0 kg almond and 2,128.8 kg grape per hectare is expected. However, further work should be focused on determining the economic area of the micro-

catchment in the province, as well as on the uncertainty analysis of runoff coefficient by measuring this parameter in different conditions.

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