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Water footprint and economic water productivity of cattle dairy farms in semi-arid agro-ecological region of Mascara-Algeria

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Informations

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Abstract

Our contribution takes place in a context of water scarcity in a semi-arid area of western Algeria, in order to evaluate the factors influencing water productivity in dairy cattle breeding. A follow-up during the agricultural season 2019-2020 of the practices within dairy barns belonging to two types of breeding systems (intensive and extensive) located in the region of Mascara. The evaluation indicators concern the volumetric use of water for forage biomass depending on the water source (rainfall, irrigation), the share of virtual water contained in extra-agricultural feed, the endogenous and exogenous feeding of the dairy herd and the milk yield achieved. Analysis of data indicates that productivity of fodder in dry matter differ between extensive and intensive systems with values of the order of 12520 to 17188 kg/ha ($p<0.05$) respectively. The milk yield per cow did not exceed an average value of 3680 kg (rang 3240 to 4120 kg). The mean gross margin per kilogram of milk was low, not exceeding 0.17 €. The average WF and EWP of milk recorded are 2.05 m^3/kg milk and 0.07 € per m^3 in semi-arid region, respectively. Green and blue WF represents 57% and 18% of the total WF of milk, respectively and the virtual water with 25%. The WF of milk is dominated by feed production with 82%. Conversely, drinking and servicing water contributed 5% and 11% to the total WF of milk production, respectively. Necessary actions must be taken along the milk production process in order to improve the productivity of water for forage production and the milk which depends in large part on annual rainfall and to a lesser extent on groundwater.

1. Introduction

Algeria is exposed to climate change and water scarcity, the impact of which on fodder production and the technical and economic performance of dairy cattle farming systems is certain. The rise in temperatures in the 20th century was of the order of 0.74 ° C globally and between 1.5 ° and 2 ° C for Algeria, more than double the global average increase, as well as a drop in rainfall of around 10 and 20% [1-2-3].This climatic trend will necessarily have negative consequences on the already scarce water resources. Indeed, Algeria is a country that suffers from significant water stress caused by low levels of rainfall. This water scarcity will certainly be combined with an increase in increasingly strong needs. Water availability in Mediterranean region is declining due to climate change; in particular due to rising temperatures and changing precipitation patterns [4-5-6].The water potential for Algeria is 19 billion m^3 /year, including 14 billion m^3 in the north and 5 billion m^3 in Saharan areas. The availability per year and per capita is 500 to 600 m^3. With regard to the standards of the World Bank, which sets the scarcity threshold at 1000 m^3/year/inhabitant, Algeria is a country poor in water resources, hence the risk of scarcity of the resource in a context of climate change. A similar situation has been reported by [7-8-9], in North Africa where available water resources are heavily exploited, and where climate change could have a negative effect on the economy of these countries.

Dairy cattle breeding in semi-arid conditions are particularly interesting systems for such a study, as it involves the analysis of a series of production functions on the farm, from the use of water for fodder production, to its conversion into food biomass, through the efficiency of feed rations distributed to the herds. Very few publications are available in the literature to clarify the interaction between forage production and milk production in

semi-arid ecosystems, particularly from the point of view of water use and productivity. These complementarities must be taken into account to assess the relative pressure of the two activities on the available water resources (rainfall, surface water and groundwater).

In the context of improving the efficiency of the productivity of dairy farms with an objective of reducing the water footprint per unit of product, the evaluation of water use according to the development phases milk production in order to help breeders and those in charge of dairy sector to develop strategies to improve the efficiency of water use in a situation of climatic constraints and scarcity of water resources. In semi-arid settings, sustainable water use should be encouraged, given the current trend towards depleted groundwater [10]. This contribution deals with the evaluation of the water footprint (WF) and its economic impact on intensive and extensive dairy cattle farms in semi-arid North African ecosystems on the basis of a volumetric concept of WF water used according to the approach adopted by [11-12-13].

2. Materials and methods

Water footprint in dairy cattle farms was studied in semi arid south-Mediterranean conditions. The dairy farms investigated are located in the center of Mascara town. It covers 12 municipalities, with a total area of 1401 km^2 (27. 3 % of the total area) and a density of population of 181 hab/km^2. It receives on average 450 mm / year with semi arid climate. It is a rich agricultural plain, known for its rain-fed farming systems (cereals, vineyard and fruit trees). The total number of farms is around of 11624 divided into 3 categories of status. The distribution of farms shows the dominance of private farms in number 8165 farms which represents 70 %, with an area of 45568 ha, but the collective farms (EAC) accounted for 16 %, with an area of 38157 ha, in number 1890 collective farms. As well as EAI (individual farms) number of 1569 exploitation, represent 14%, with an area of 5217 ha [14]. A benchmark survey of dairy cattle breeders was conducted during 2019-2020 agricultural campaign indicates that all systems selected in this study use groundwater; with 6722 cows 60 % of which is Friesian black magpie of total cows and produce 3400 ±1250 kg average milk yield per cow [14].

The methodology for monitoring the sample in our study consists of a series of routine visits to 2 types of dairy farming systems, one of a intensive (type I) and the other extensive (type II). The sample followed is made up of 20 dairy farms per type to describe the water use productivity in relation with the milk yield, forages practices, dietary rations and costs of forages and milk in dairy farms. The table1 indicates the characteristics of the sample farms with diverse structural, technical parameters and strategic of use of water in dairy husbandry systems. Each farm had an average of 14.5 ha of ARL (range = 8,6 to 16,5 ha), with an average animal stocking rate of 1.84 UGB/ ha of fodder crop (range = 2.1 to 3,06 UGB/ha). Feeding practice in both types of cattle farming systems is shown in Figure 1.

The forage calendar of extensive type shows a use of green fodder limited only in spring, a distribution of straw in summer and which continues until the end of winter as well as a very large use of concentrated foods throughout the year. This type of calendar characterizes farms with a milk tendency based on more concentrate. But the forage calendars intensive type illustrates the use of green fodder during a large part of year-round; straw is limited to only part of summer and winter. It characterizes milk-oriented farms based on fodder.

Table.1: Average structural and technical's parameters of sample farms (μ ± σ)

Parameters	Symbols	Type 1 (n=20) Intensive	Type 2 (n=20) Extensive
surface Arable Land use	ARL	16,5 ± 1.94 ±1.2	8,6
Forage Land (ha)	FL	6 ± 0.75	3 ±0.73
Sorgho (ha)		1,75 ± 0.19	*0,75*±0.21
Lucerne (ha)		1, 5 ± 0.17	*0,50* ±0.19
barley (ha)		2,75 ± 0.15	*1,75* ± 0.17
Number of Cows	NCW	12,6 ± 1.66	9.2 ± 1.45
Stocking rate/ ha fodder	UGB/ ha	2.1 ± 0.28	3,06 ± 0.23
Average milk/cow/year	APM	4120 ±604.6	3240 ± 710.2
milk concentrates /cow	UFLcc	5.5 ± 0.86	7,6 ± 0.78
Food cost total inputs %	FCT	62.8 ± 9.2	68.7 ± 8.7
Cost 1 liter milk (€)	PCM	0.52 ± 0.07	0.61 ± 0.09
1 € = 132 DA. (DA: Dinar Algerian, €: euro).			

The practice of fodder crops on the sampled farms is dictated by the availability of irrigation water (rainwater, underground), the modality of use of this water and the costs of milk production. About 41 % of the total arable land was cultivated with rain-fed (oats – *Avena sativa*; barley *Hordium vulgare*) or irrigated forage (Sorgho *Sorghum sp,* lucerne – *Medicago sativa*). In north Africa, dairy cows farms uses also cereal straw, which is considered locally as a strategic fiber resource [14-15-16].

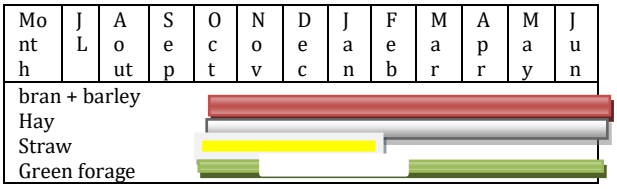


Fig 1: Forage calendar of dairy farms in study region.

The parameters measured were water volumes used WU/ha of forage by cultivated species and origin of

irrigation (rainfall and groundwater), estimate of forage biomass from irrigated plots and contribution of rations exogenous feeds and the milk yield obtained per systems. The estimation of the volumes of water used by breeders was based on the flow of water from the irrigation wells, the time and frequency of irrigation by irrigated forage plots and by farm. Rainfall data were obtained from the local meteorological station, which was located at a maximum distance of 9 km from farms. The exogenous rations (cereals and bran) were converted into equivalent virtual water according to international standards 1m^3 of water per kilogram of cereals [17].

The method used to determine the biomass of fodder grown on the farms monitored is inspired by that cited by [18], which consists to weighing plant samples harvested from each plot within a 1 m^2 quadrat at each harvest. Subsequently, the nutrient value of all forages supplied by this biomass was estimated. The average dry matter (DM) and net energy content of forage crops in the context of north Africa were adopted from [15-19]; for all the fodder identified in the surveyed holdings in the absence of a forage analysis, we refer to other analyzes carried out in Algeria relating to these forages [20-21].These average nutrient values were used to calculate nutrient yields per hectare in each farm. All of the herds were on "zero grazing" and consumed distributed rations (green, dry and concentrated fodder) according to the forage management specific to each farm. The economic assessment in terms of gross margins for milk production was determined by the difference between income and expenses related to food, veterinary care and other livestock costs. Water productivity of milk production (m^3/kg) and economic water productivity of milk in (€/m^3) were also calculated.

2.1 Statistical data processing

A descriptive analysis was performed for the evaluation of averages, standard deviations, minimum and maximum of the various parameters chosen. Then a factor analysis of variance (XL.STAT) was applied to the results according to the model: $Y_{ij} = \mu + \alpha_i + e_{ij}$; Or: Y_{ij} is the explained variable;μ: the general average, α_i : the factor effect and e_{ij}: the residual error of the model. Then, the Student test compared the factors two to two.

3. Results and discussion

The objectives of the study were to characterize the use of water in the dairy farming process in semi-arid areas with irrigation possibilities and its impact on water productivity and milk production. The breeding practice within the region is characterized by poorly diversified fodder crops and a contribution of exogenous food resources to the farm which makes the analysis of these systems more complex to determine the productivity of water. According to [20-22], similar situation was reported on dairy farms in a semi-arid climate where the use of concentrates is practiced on all farms to varying degrees. The study sample was explicitly designed to represent the reality of farming in terms of structural parameters in semi arid plain of Mascara where the study was conducted [14]. From water volumes and their origins to forage biomass Water volumes applied to fodder crops varied widely among farms and were largely determined by irrigation practices. The results of monitoring the two types of farming indicate that the total water use for summer fodder (Sorghum and Lucerne), was (4350; 4160) and (3150; 3050) m^3/ha respectively for in types I and II. A comparison of the irrigation practice between the two types of dairy farms indicates a variation of around 27% (7320 to 10160 m^3/ha) in favor of type I.

The maximum value was recorded on Type I (intensive system), which was the only one equipped with drip irrigation. According to the precipitation recorded during our monitoring, water consumption for oats is relatively constant with an average value of 3740 and 2950 m^3 / ha respectively for the intensive and extensive systems. The productivity of fodder in dry matter differ between the two systems with values of the order of 12520 to 17188 kg/ha respectively for type II and I. This difference is due to the mode of management of the fodder crops and the volume of irrigation water applied, in the same way a relative shift of the vegetative cycles was observed within the dairy farms.

Our assessment of water productivity based on the contribution of rainfall, the possibility of irrigation and the share of virtual water, indicates the existence of variability in the water used between dairy farms. The water productivity of the various cultivated forages presents a variation between farms of the order of 0.84 and 1.04 m^3/kg DM) respectively for the intensive and extensive system (Table 2). The results obtained are slightly higher than those reported by [23-24] under irrigated conditions in Morocco (0.33 to 0.54 and 0.33 to 0.54 m^3/ kg DM). Our results on the yield of DM from Lucerne are poor (4960 kg of DM/ha) compared to those obtained in a semi-arid irrigated land of Morocco in order of 9190 kg / ha and 6820 kg of DM / ha [23] and in Tunisia with 8000 to 13400 kg of DM / ha [9]. This can be explained by the rainfall regime of each zone. For the water productivity of this species (0.76 m^3/kg DM) was lower than that reported by [23-9-25].

Table.2: Water productivity of fodder in the study farms

	Type I Intensive system			Type II Extensive system		
Parameters	WU m^3/ ha	DMY kg/ ha	WPDM m^3/kg DM	WU m^3/ ha	DMY kg/ ha	WPDM m^3/kg DM
Sorgho	4350 [a]	3260 [a]	1.33[a]	3150 [b]	1460 [b]	2.15 [b]
Lucerne	4160 [a]	5458 [a]	0.76[a]	3050 [b]	4460 [b]	0.68 [b]
Barley green	1650 [a]	2600 [a]	0.63 [a]	1120 [a]	1850 [a]	0.60 [a]

WU: water use; **DMY** : Productivity of fodder in dry matter ; **WPDM** : water productivity
a, b, means for each parameter with different letters across a row are significantly different p<0.05

For all the parameters characterizing the use of water, the oat crop had a relatively homogeneous use of water and a yield of DM per hectare quite similar between farms. This is explained by the technical mastery of the cultivation of this species in the northern Mediterranean production systems. With regard to the other fodder species requiring water, the technical route remains poorly controlled, which significantly affects yields by crop and exploitation within the same agro-ecological zone. In addition, profitability of using irrigation is affected by other factors relating to the mastery of the cultivation techniques of the fodder used. Similar trend results have been reported in the semi-arid North African zone with regard to the use of irrigation water [8-23]. According to the same source, precipitation in semi-arid regions significantly affects the extent of irrigation use with an interval of the order of 82% to 87.9% of the total amount of water used to irrigate fodder crops. , which implies great pressure on the groundwater of crops in regions with a semi-arid climate. In their work on dairy farming, [26] in temperate zones indicate that the development of intensive fodder systems based on the irrigated fodder in this case maize plagues groundwater.

3.1. Relationship between distributed off-farm exogenous ration and milk performance

Monitoring the consumption of rations distributed on dairy farms indicated seasonal variability, with a peak achieved in spring (March to May), followed by regression until the end of winter. This observation is linked to the availability of green according to the forage calendar practiced by dairy farms and the participation of exogenous distributors, which is strongly linked to the prices of the concentrated foods purchased. In addition, the quantities of DM ingested did not cover the optimal needs of the cows mainly due to the average rate of the animal load practiced 1.84 UGB/ ha and the variability of the fodder yield in green realized in the semi arid conditions. The characterization of the distributed rations reveals a quantitative and qualitative imbalance of the rations which affects the efficiency of transformation of the rations into milk. The participation of the rations ingested by the dairy herds reveals that the contributions of the rations are deficient in DM. moreover, the food balance of the distributed ration is unbalanced, causing the fall in dairy performance of cows. This deficit necessitates the use of quality concentrate supplements to correct food rations. Similar observations have been reported by [8], who recommend the need to generalize the formulation of complementary feeds within dairy farms to increase milk production.

3.2. Water use productivity and profitability margin for dairy cows

In terms of feeding practice strategies, breeders always seek to reduce food production costs, by reducing the quantities of concentrates distributed during periods of green availability. This leads to a reduction in milk production per cow, although the breed exploited allows production of around 20 Kg / day under semi-arid breeding conditions. The decline in dairy performance continues during the summer period. The milk yield per cow did not exceed an average value of 3680 kg (rang 3240 to 4120 kg (Table 3). The mean gross margin per kilogram of milk was low, not exceeding 0.13 euro.

Table. 3: Virtual water use and cattle performance variability among farms

Parameters	Systems types		
	Intensive	Extensive	Average
Total WU off-farm feed uses (kg)	3780 [a]	4970 [b]	4375
Virtual water for lactation (m^3/cow)	1220 [a]	1090[b]	1155
Average milk (kg/cow per year)	4120[a]	3240 [b]	3680
Milk profitability margin (€ / kg)	0.15[a]	0.12[b]	0.13

a, b, means for each parameter with different letters across a row are significantly different p<0.05

In system Type I, which had the highest average annual milk yield per cow, the economic results from the herd were the highest compared at systems type II with lowest average milk yield per cow.

The estimate of the value of the water footprint at the dairy farm level indicates an average of the order of 2.05 m^3 / kg of milk (with a margin varying from 1.96 to 2.15). The contribution of rainfall is estimated at 57% the rest is represented by the participation of irrigation and Virtual water with 18% and 25% respectively. This trend indirectly affects purchases of exogenous fodder resources on the farm. The results obtained in this study indicate a variation between dairy farms in terms of the percentage of dependence on rainfed crops to produce rougher fodder intended to feed their dairy herd. Economic productivity based solely on irrigation water revealed that to produce fodder for dairy barns, the use of 1 m^3 of irrigation water generates an average

gross margin of around 0.17 €. Our results agree with those indicated by [27-28-8] which reports the existence of a variation between dairy farms due to the management practices of all production functions for water and livestock products.

Table. 4: Water productivity characteristics in milk, in the study farms

Parameters	Systems types	
	Intensive	Extensive
Total WU per kg of milk (m^3)	2.15 [a]	1.96 [b]
costs of total WU in milk (€ / m^3)	0.08 [a]	0.06 [b]
costs of irrigation WU in milk (€ /m^3)	0.15 [a]	0.20 [b]

a, b, means for each parameter with different letters across a row are significantly different p<0.05

The extensive system is the least efficient in terms of water productivity and the highest stocking rate, which considerably affects food autonomy. Moreover, within this system, poor practice in the management of fodder crops generates low water productivity in irrigated forages. Conversely, the intensive system was the most efficient in terms of milk water productivity with a lower storage rate and better performance in the productivity of water from forage crops. The comparison between the two farming systems in semi-arid region indicates that the system (type I) is characterized by greater food autonomy, allowing it to achieve good performance compared to the average of the sample studied and have the highest economic costs. The best results have been observed for the intensive system, which stands out for its good practice along the process chain, from irrigation management to farming. Intensive farming is the most specialized in milk production which is considered a strategic activity within the agricultural production system applied in the semi-arid zone. On a global scale, dairy farming systems seek to achieve food self-sufficiency to improve the gross margin per dairy barn. The scientific work of [29-30-31-8] indicates that the farms with the best agro-environmental indicators and optimal management fodder resources.

This thematic contribution converges with the directions of recent research indicating the urgency of adding value to green water rather than blue water in order to solve the problem of food security in the 21st century [32]. Overall, the results obtained reveal that within dairy farms in a semi-arid climate the need to assess the contribution of the various water sources integrated into the milk production process. The analysis carried out confirms the limited pressure of dairy cattle farming on groundwater, due to its dependence on rainfall and the regulation possibilities enabled by virtual water (exogenous food on the farm). In addition, pastoralists should improve forage autonomy through good control of fodder crops and off-farm food stocks, to support the sustainability of their livestock in the face of climate change affecting the semi-arid regions of North Africa.

4. Conclusion

The study describes on the one hand, the relationship between milk production in dairy cattle stalls and the use of different water resources and on the other hand it characterizes the impact of livestock activity on the productivity of the in semi-arid regions. A large variation between the stables was recorded in the amount of irrigation applied according to the forage calendars practiced; this indicates that the water footprint within the farms is less effective. Other factors of variation were determined indicating a great weakness in the management and management of the cultivated fodder, and the insufficient rationing of the herds. The results reflect variability in the use of total water, whatever its origin. The activity of dairy farming in the study region depends mainly on rainfall but supported by irrigation water whose pressure is less on groundwater compared to fodder crops. Consequently, the prospects for the resilience of dairy production systems for cows in semi-arid conditions vary from medium to good, but the improvement in water productivity remains insufficient and requires further research on the interactions between fodder crops, irrigation water and agronomic factors.

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