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How Does Livestock Contribute to the Efficiency of the Oases' Farming Systems?

Mohamed Taher Sraïri[1]*, Salah Mansour[1], Mohamed Benidir[2], Mohammed Bengoumi[3] and Véronique Alary[4]

[1] Hassan II Agronomy and Veterinary Medicine Institute, Department of Animal Production and Biotechnology, Madinate Al Irfane, Rabat, Morocco.
[2] Regional Office of Agricultural Development in Ouarzazate, Morocco.
[3] Sub regional office of the Food and Agriculture Organization, Tunis.
[4] International Center for Agricultural Research for Development (CIRAD), Montpellier, France, currently based at the International Center of Agricultural Research in Dry Areas (ICARDA), Rabat, Morocco

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ABSTRACT

Multiple constraints, such as increased demographic pressure and growing competition for limited water resources, are significantly affecting farming systems in the oases. The combination of these constraining factors impacts the efficiency of inputs' uses and hampers the incomes from agricultural activities. Livestock has always been a component of the oasis farming systems, covering a wide range of functions: transportation, soil preservation, income generation through meat and milk, draft, and saving. Faced with the recent changes, this study aimed to characterize the roles and contribution of livestock on the overall performances of the oasis farming systems. To do so, twelve farms illustrating four types of livestock systems were selected. Within each farm, we calculated common agricultural efficiency indicators to assess the use efficiency of the most critical production factors in the oasis: land, labor, water, and capital. The results demonstrated that efficient oasis farming systems rely on the crops/livestock association. Thereby, while providing self-consumed food products, livestock intensified farming systems (D'man prolific sheep with off-farm feed resources and dairy cattle) allow an increase in crops' yields and their incomes. This is particularly obvious for date palms' incomes, which benefit from the surplus irrigation of the underlying lucerne. In parallel, in specific contexts of the oases where the intensification of agriculture is quite impossible (for instance within areas with scarce groundwater or saline water, or in farms with limited capital) livestock remains the main source of income, adding value to the vast pastoral areas and the by-products of crops (wastes of dates, wheat bran, and straw, etc.).

Keywords: Ecological intensification, farms' incomes, farming systems, livestock, oasis.

INTRODUCTION

The oases can be defined as areas with intense farming activities located in a desert or a very arid environment, creating hostile conditions for human development (Jouve, 2012). As a consequence, water deficits are frequent, implying further stresses for crop yields, particularly date palm trees (Carr, 2013). Under these trees, which are often the dominant species in this kind of farming system many crops (fruit trees, fodder, and cereals) are cultivated to form

* Corresponding author. E-mail: mt.srairi@iav.ac.ma

a stage of vegetation, which allows a relatively favorable agro-ecosystem for cropping activities in comparison to the surrounding desert areas (Dollé *et al*., 1989). Livestock has often been associated with the sustainability of the oasis farming systems, allowing biomass recycling through manure which increases soil fertility (Liu *et al*., 2011), as well as providing draft power for cropping purposes. Livestock also contributes to the enhancement of local populations' livelihoods by adding incomes to the ones generated by crops, mainly through sales of live animals, excess milk after satisfying the household's needs, as well as hides and skins (Alary *et al*., 2014). As a consequence, oasis farming systems can be considered as an example of ecological intensification of agriculture, although they remain highly vulnerable to the scarce resources' availability. Recently, the oasis systems have been affected by significant changes which have hindered renewable decisive resources availability for farming systems (i.e. capital, labor, land, and water) (Schiere *et al*., 2002). For instance, the effects of climate changes have exacerbated the challenges specific to these areas, adding pressure on scarce water sources and hindering vital crops' yields (Schilling *et al*., 2012). In addition, demographic growth coupled to legitimate demands of increased revenues of the oasis dwellers has recently implied frequent emigration (de Haas, 2006). This trend has however generated financial transfers towards the oases, most of them used for the intensification of the existing farming activities, and even the emergence of new cropping patterns, such as watermelon, dense palm groves, and vegetables (Rignall, 2015). However, some studies have criticized the emergence of such new crops, particularly as they imply an increased pressure on already limited water resources (Chelleri *et al*., 2014). Many studies have been devoted to the peculiarities of the oasis crops in North Africa, particularly its date palms and its pests (mainly a fungus disease, caused by *Fusarium oxysporum sp.albedinis*) which has seriously affected the date palm grove resilience (Sedra *et al*., 1998). Other studies have been conducted on the animal resources, such as the D'man sheep breed, globally known for its prolificacy (Jorio *et al*., 1991), or the roles of the dromedary as this species is often reared in rangelands around the oasis, contributing to the supply of high-quality milk and meat (Faye *et al*., 2017). However, few references exist on the overall crop/livestock systems' yields and economic performances of the oases' farms and the way the crop/livestock association makes use of the assets involved in the farming system, like capital, labor, land, and water. Moreover, in the Middle Drâa valley (Southeastern Morocco), recent research has emphasized the risks due to the decrease in water availability because of climate change and increased demand and their effects on the possibilities to maintain sustainable agricultural activities (Johannssen *et al*., 2016). In fact, with scarce water, and land resources, as well as a limited capitalization, it is a real challenge for farming systems in the oasis to make efficient use of these assets. The present study, therefore, aims to characterize the efficiency of farming systems in oases of Middle Drâa valley, and their variability, with a scope on the possibilities of improving their ecological intensification through insight on the roles of livestock.

Methodology

The study was conducted in the Drâa Valley (Zagoura Province, South East of Morocco), where the annual rainfall average level does not exceed 110 mm and summer temperatures are often above 45°C. The valley consists of a series of seven palm groves along with a distance of 200 km following the Drâa River, covering a total arable land area of 26,000 ha (Figure 1). The crop component is dominated by date palm trees (1,421,900 trees), with a lower layer of fruit trees (apple, apricots, and almonds, a total of about 107,000 trees), cereals (barley and wheat - 18,300 ha), and fodder, mainly lucerne, covering 3600 ha (ORMVAO, 2016). Sraïri *et al*. (2017) established a typology of livestock systems in the same valley. Four types were identified to represent the four oasis livestock systems, defined as follows: (*i*)

Multispecies livestock rearing (sheep and cattle as well as sedentary goats of the Drâa breed), (*ii*) *Cattle based livestock activities*, (*iii*) *Sheep intensification* and (*iv*) *Rangeland systems*. These four livestock systems were identified through the weight of each animal species (cattle, dromedaries, goats, and sheep), herd and flocks performances, as well as feed autonomy in the farm. In the present study, three representative farms were chosen for each type, with the help of the local agricultural development office. Therefore, the total study sample consisted of 12 farms. The structural parameters of the farms (i.e. arable land, type of crops, number of livestock units, etc.) are reported in Table 1. The majority of farms among the study sample are mainly made of smallholder units, as the arable land did not exceed a mean value of 5.3 ha (standard deviation: 4.4 ha) and a number of livestock units (LU - defined as a local breed cow of 400 kg -) below 9.5 ± 11.0. Other species' correspondence to one LU was as follows: one sheep: 0.12 LU, one goat: 0.10 LU, and one dromedary: 0.8 LU. The typology of livestock systems in the Middle Drâa oasis also insisted on the specific localization of types of farms: *Multispecies livestock rearing* and *Sheep intensification* types in all the palm groves of the region, *Cattle based livestock activities* near the city of Zagora (which means the Ternata and Fezouata palm groves) as it hosts the unique dairy processing unit of the area, and *Rangeland systems* downstream the valley, near the wide desert rangelands next to the village of M'hamid El Ghizlane (Figure 1).

Table 1. Structural parameters (arable land, herd, and capital invested) of farms' types

Farm type	Multispecies	Cattle based	Sheep intensification	Rangeland systems
	(Average value ± Standard deviation)			
Arable land (ha)	4.2 ± 1.0	10.6 ± 5.1	8.0 ± 4.1	3.2 ± 1.9
Fodder area (ha)	1.8 ±0.8	4.3 ± 3.5	3.4 ± 4.0	0.1± 0.1
Cereal area (ha)	1.7 ± 0.6	4.1 ± 2.6	2.0 ± 1.8	2.5 ± 1.3
Palm trees (units)	107 ± 40	302 ± 20	183 ± 94	45 ± 25
Wells (units)	2.0 ± 0.6	3.0 ± 1.1	3.0 ± 0.6	0.3 ± 0.6
Total Livestock Units	10.7 ± 6.3	18.2 ± 10.5	7.9 ± 3.3	1.8 ± 0.9
Cattle Livestock Units	2.6 ± 1.1	11.9 ± 6.4	0.9 ± 1.5	0
Animal load (LU/ha fodder)	5.9	4.2	2.3	18.0
Family workers	2.3 ± 1.7	2.7 ± 1.6	3.6 ± 1.7	2.3 ± 2.5
Total capital (x 103 US $)	157.3± 40.7	144.8± 72.4	77.4± 17.5	26.5 ± 6.7

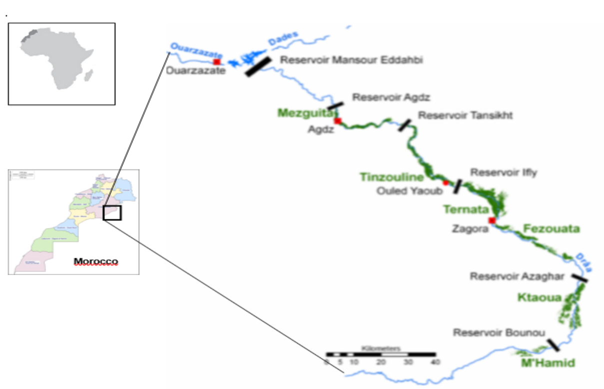

Figure 1. Geographic localization of the study area

After the sample selection, a protocol of farm follow-up was performed, with one monthly visit from September 2015 to August 2016, in which surveys were conducted coupled to regularly cultivated plots, flocks, and herds' observations. During these visits, in each farm and for each crop, the uses of inputs were characterized through inquiries and observations and sometimes measurements (for diets): seeds, fertilizers, water volumes, pesticides, etc. Water volumes were determined thanks to a detailed follow-up of on-farm irrigation practices. In each cultivated plot, a regular assessment of water fluxes from wells and boreholes was realized, and it was coupled to the measurement of the duration of irrigation. Further, the evaluation of water volumes released from the dam upstream the valley was obtained from the local agency in charge of surface irrigation.

Inputs' uses tracking was similarly adopted for the flocks and the herds, as the feeds used were characterized throughout the whole year by a follow-up of the diets used for each species and type of animals (lactating females, growing calves or lambs, etc.). Veterinary treatments and other inputs were also recorded. Finally, for each crop as well as for livestock, the main products and by-products (straw for cereals, date wastes, etc.) were quantified and the incomes from sales were calculated.

For the efficiency analysis, we have determined a list of efficiency indicators, which are related to the most critical production factors (i.e. water, capital, land, and labor), as follows:

- Ratio of the raw margin of the animal rearing activity over the total capital invested in agriculture: that measures the profitability of the livestock activities with regard to the capital used;
- Ratio of the raw margin of cash crops over the total capital that measures the profitability of the crop activities according to the total capital used in agriculture;
- Total agricultural (crop and livestock) raw margin by the cubic meter of water used to assess the water use efficiency;
- Total agricultural income by ha of arable land that appreciates the land profitability;
- Total agricultural income by day of the total labor (i.e. family and hired) to assess the labor efficiency.

These indicators were calculated in each farm, after the adoption of a series of assumptions and methodological choices. First, the totality of the inputs used to grow date palm trees like water was affected to underlying crops (i.e. fruit trees and cereals or fodder). Local farmers consider that these trees are the main contributors to their incomes, whereas other crops have to support the expenses of inputs. These inputs' allocation results directly from crop management explained by the farmers themselves. Second, the annual feed expenses were determined by the analysis of a single dietary ratio for each group of animals (i.e. species, or growing or lactating groups), since no significant seasonal variations in the diets could be noticed. The economic values of on-farm feed resources' (mainly lucerne fodder, cereals' straw, and date wastes) were considered as equivalent to their market values, i.e. purchasing prices. Third, the calculation of the livestock profitability included the milk economic value (self-consumed or sold), live animals' sales, and subsidies (from the selection of purebred sheep D'man rams and ewes: 60 US $ per ram and ewe, whenever they are selected by a national commission visiting the area), as well as manure sales. Expenses related to the inputs used within the herd were removed from the sum of the above-mentioned economic values to calculate benefits. In doing so, labor costs were only considered for hired off-farm people.

To assess the invested capital within each farm, further hypotheses were adopted. For livestock housing facilities, a value of 500 to 1000 US $ was considered as it was declared by breeders, whereas for wells, a mean value of 1500 US $ was defined, by local references.

With regard to livestock, mean values of live animals were defined as follows:
(i) Cattle. Local strain cow - 700 US $ -; Holstein cow - 1500 US $ -; Calves and heifers - 500 US $;
(ii) Sheep. Ewe - 130 US $ -; ram - 200 US $ -; lamb (male and female) - 50 US $ -; and
(iii) Dromedary. She-dromedary - 1000 US $ -, Sire - 1500 US $; dromedary calf - 600 US $.

These references were established based on the market transaction of animals in our sample.

Finally, the value of the agricultural land was estimated in each farm according to the following field observation: (i) in the Mezguita palm grove, upstream the valley, where water availability is relatively abundant, the mean value of one hectare was considered to be 30,000 US $ according to local land market references, (ii) whereas downstream the valley, in the Mhamid El Ghizlane palm grove which is characterized by scarce water with significant levels of salinity, one hectare of land may not exceed 2000 US $. In addition, the value of the trees planted was mainly related to the date palm variety, as the most valuable one was the 'Majhoul' (almost 500 US $ per producing tree), whereas it did not exceed 200 US $ per tree for the other varieties.

After the calculation of efficiency indicators, we performed an analysis of variance protocol, using the PROC ANOVA procedure (SAS, 2015). Means were compared using the Newman-Keuls test. The different farms' types were compared in terms of their inputs' uses efficiency.

Results

1. Cash crops

The main crops cultivated were date palms, watermelon, onions, henna, lucerne, and cereals (soft wheat). Self-consumed products were not taken into account. All studied farms cultivate soft wheat, but only one sells grains. Date palms are the most important cash crops as they are found in all 4 groups of farms. The profitability of the farm is highly variable, mainly due to differences in the number of trees per farm (varying from 45 to 317 trees as a type of farms' average). The mean raw margin per tree is around 40 US $, with the notable exception of the farms located downstream the valley (palm grove of Mhamid El Ghizlane), where salinity and water scarcity lead to a decrease in yields and incomes from each date palm tree (only 20 US $).The overall raw margin of the date palm trees per group of farms varied from 12,653 US $ in the 'Cattle based' group (with an average number of 317 trees), to only 917 US $ in the 'Rangeland Systems' group, as the mean number of trees only reached 45 (Table 2).

The second main cash crop is watermelon (cultivated in three farms on an average area of 1.17 ha). Watermelon was unprofitable in all the farm types (an average loss of 430 US $ per ha), due to market conditions, as prices fell sharply in spring 2016 due to an excessive output about the demand. In addition, this crop necessitates heavy inputs (seeds, irrigation means, water pumping, etc.), which increases its production costs (Table 2).

Onion was sown in two farms (one in the group 'Cattle based' and another one in the group 'Sheep intensification'), on limited areas (an average 0.55 ha). The raw margin was around 592 US $ per ha for the two farm types. Henna, a special crop within the oasis context as it is destined for specific cosmetics' uses, was also found in two farm types. It showed an average yield of 32 tons per ha. It was highly profitable with an average raw margin of around 3070 US $ per ha.

Finally, lucerne and soft wheat were sold on only one farm. Lucerne was sold as hay, and it generated, in addition to the green fodder used on the farm, a raw margin of 4490 US $ per ha. Soft wheat was cultivated in a 5-ha area. It allowed a raw margin of 441 US $ per ha.

Table 2. Cash crops profitability

Farm type	Multispecies	Cattle based	Sheep intensification	Rangeland systems
Average number of date palms	107	317	183	45
Date palms' profitability(US $)	4267	12,653	7307	907
Watermelon profitability (US $/ha)	- 370 (1.0)*	- 368 (1.2)	-	-
Onion profitability (US $/ha)	-	585 (1.0)*	600 (0.1)*	-
Cereals profitability (US $/ha)	-	441 (5.0)*	-	-
Lucerne profitability (US $/ha)	-	-	4490 (0.2)*	-
Henna profitability (US $/ha)	2900 (1.25)*	2509 (1.0)*	-	-

(1.0)*: Average area is sown per type of farm

2. Herds' productivity and profitability

The analysis of the performances of herds reveals an important variability among groups of farms. This is particularly obvious for the feed autonomy (i.e. the amount of net energy in the feed produced on-farm compared to the overall net energy ingested by the animals), as it only reached 52.7% on the 'Sheep intensification' group of farms, whereas it reached 90.6% in the 'Multi species' group of farms. As a consequence, annual feed costs per LU were significantly variable among groups of farms, as it jumped to 1053 US$ in the 'Sheep Intensification' group, because of off-farm feed purchases. On the opposite, it did not exceed 630 US $ per LU in the 'Multi species' group, because feed autonomy was very high, inducing limited costs.

By contrast, sheep performances were rather homogenous among groups, except the 'Sheep intensification' group, where the reproductive efficiency (fertility x prolificacy) reached a maximum value of 254%. In this group, the lamb mortality rate was also low with an average value of 8.6%, whereas it peaked at 34% in the 'Cattle based' group. However, this group performed better about dairy production, as the average annual milk yield per cow was about 4450 liters. This last group had also the highest live animals' sales values, which equaled 2840 US $ per LU and these were mainly made of calves and very few lambs. This was more than three times the value of sales per LU in the 'Multi species' and the 'Sheep intensification' groups, where sales mainly contained sheep: lambs, and a few ewes and rams.

Table 3. Livestock productivity and profitability for each farm type

Farm type	Multispecies	Cattle based	Sheep intensification	Rangeland systems
Feed autonomy (%)	90.6± 24.3	78.2± 31.0	52.7± 18.0	85.9± 19.6
Sheep Rep. Eff. * (%)	206.7	206.3	254.3	222.2
Lamb mortality (%)	28.7 ± 14.2	34.0 ± 22.1	8.6± 5.5	9.7± 8.7
Milk yield (kg/female**/year)	704 ± 200	4448 ± 2046	2900	710 ± 195
Annual feed expenses (US $/LU)	633	1760	1053	785
Annual drugs' expenses (US $/LU)	190	455	-	87

Farm type	**Multispecies**	**Cattle based**	**Sheep intensification**	**Rangeland systems**
Annual Work expenses (US $/LU)	760	1140	109	102
	877	2840	877	281
Annual milk sales (US $/LU)	-	643	-	5133
Incentives (US $/LU/year)	-	-	128	-
Average raw margin (US $/LU/year)	- 706	128	-157	4434

* Sheep Reproductive Efficiency: Fertility x Prolificacy

** Cow in 'Cattle based' type and she-camel in 'Rangeland systems'

An average annual incentive of 1013 US $ per farm was recorded in the 'Sheep Intensification' group, as it contained in the amount of money for the selection of purebred D'man breed rams and ewes. Farms in the other groups did not get any incentive at all.

Finally, the annual raw margins generated by the livestock activity were highly variable among farms. They were, on average, negative on both the 'Multi species' and 'Sheep Intensification' groups of farms (respectively - 7550 US $ and - 1240 US $), whereas they reached positive values in the 'Cattle based' and 'Rangeland systems' groups (with respective values of 2320 and 7982 US $). It is therefore remarkable that the group with the least investments shows the highest raw margin in livestock rearing, mainly because of very limited expenses.

3. Extra-agricultural incomes

The extra-agricultural incomes are directly about the number of family members who have an off-farm activity. This source of income concerned 4 farms (1 in the 'Multi species' group, 2 in the 'Cattle based' group, and 1 in the 'Rangeland Systems' group), for a total of 7 persons. The off-farm jobs are essentially located in cities far from the Drâa valley, in sectors such as trade, garden keeping, etc. The average number of persons and the annual incomes obtained with such off-farm activities and that are further invested in agricultural activities are presented in table 4. For instance, the annual mean income per farm from these activities varied from 0 ('Sheep intensification' group) to 2933 US $ ('Cattle based' group). Marked differences may be noticed among groups with regard to the amount of money from these extra agricultural incomes invested in the farms, as the number of people involved is not equal (from 0 to 2 persons per farm). Moreover, the annual incomes per person are not similar.

Table 4. Extra agricultural work (employment) and incomes invested in the different farm groups (US$)

Farm type	**Multispecies**	**Cattle based**	**Sheep intensification**	**Rangeland systems**
Number of persons concerned	0.67 ± 1.15	1.00 ± 1.00	-	0.67 ± 1.15
Annual incomes invested (US $)	600 ± 1039	2933 ± 4244	-	2020 ± 3499

4. Farming systems' efficiency with regard to livestock orientation

The sample of farms reveals marked differences between each type of livestock system, as 'Rangeland systems' are based on limited total capital (a mean value below 27,000 US $), whereas 'Multi species' and 'Cattle based' systems show respective average values of the capital of 155,300 and 144,800 US $. Such differences are related to the number of LU, the area of agricultural land, and the level of investments in wells.

Wide differences in efficiency were noticed while comparing groups of farms with regard to their livestock orientation. It appeared that the livestock efficiency, evaluated through the indicator 'Livestock raw margin/Capital' was significantly higher in the 'Rangeland systems' farms' group (30.1%), in comparison to the other types of farms: respectively -1.6, 1.6 and -4.8% in the 'Multi species', 'Cattle based' and 'Sheep intensification' groups. This result highlights the characteristics of the 'Rangeland systems' group, based on minimum feed expenses, and with a high value of its products, particularly dromedary milk, sold at a mean price of 2.5 US $ per liter(five-fold the price of cows' milk). Otherwise, the crops efficiency proxy, approached by the 'Crops raw margin/Capital' ratio was higher in the 'Cattle based' group, with a mean value of 11.3% (Table 5). That was related partially to the profitability of date palm trees in this group of farms (a mean value of 12,653 US $ per farm). This ratio was also high in the 'Sheep intensification' farms, with a mean value of 9.4%, as these farms had also a high profit from date palms (7307 US $). Finally, this indicator reached almost the same low value in the 'Multi species' and 'Rangeland systems' groups, not exceeding 3.7%.

Table 5. Indicators of efficiency in different farms groups

Farm type	Multispecies	Cattle based	Sheep intensification	Rangeland systems
Livestock raw margin/Capital (%)	- 1.6^{a} ± 2.9	1.6^{a} ± 2.2	- 4.8^{a} ± 0.6	30.1^{b} ± 16.9
Crops' raw margin/Capital (%)	3.3 ± 0.8	11.3 ± 4.8	9.4 ± 3.2	3.7 ± 2.3
Water used per ha (cubic meters)*	6410 ± 3119	7240 ± 3270	9969 ± 4224	1657 ± 1895
US $ per cubic meter of water	0.11 ± 0.29	0.32 ± 0.27	0.16 ± 0.11	8.8 ± 7.6
Raw margin/ha (US $)	640 ± 11 78	2056 ± 1667	1890 ± 2035	4797 ± 4754
Income per day of work (US $)	0.8 ± 2.3	6.6 ± 4.6	2.4 ± 1.8	7.8 ± 2.4

$^{a, b}$: means with different superscript letters in the same line are significantly different ($P < 0.05$)

* Water used per ha (cubic meters): including rainfall

In link with the water use efficiency, determined through the 'Raw margin per cubic meter of water, there was no significant difference between the farm types, at the notable exception of the 'Rangeland systems. This can be explained by the limited amount of water used annually in this kind of farms (only 1657 cubic meters per ha), which are all situated downstream the valley, where groundwater is less abundant, in comparison to the other groups of farms (at least 6400 cubic meters per ha per year). As a consequence of water use volumes and the raw margins of livestock and crops, the economic water productivity (expressed by the proxy 'Raw margin (US $) per cubic meters of water) was the highest (8.8 US $) in the 'Rangeland systems' groups. In fact, virtual water (i.e., the water from outside the farm which was used on very wide rangeland areas to get feed resources for the dromedaries) had allowed compensation for the very limited on-farm water availability. In the other groups of farms (i.e. 'Multi species', 'Cattle based', and 'Sheep intensification'), the proxy which reflects water economic productivity was not significantly different. It reached 0.32 US $ per cubic meter in the 'Cattle based' system farms, but it was two times lower (0.16 US $ per cubic meter) in the

'Sheep intensification' group and even three times lower (0.11 US $ per cubic meter) in the 'Multi species' group.

Finally, the evaluation of the on-farm work remuneration, assessed through the indicator 'Income per day of work' shows that the average figures are quite different among groups of farms. In fact, the minimum value was recorded in the 'Multi species' group (only 0.8 US $ per day of work), far from the minimum guaranteed wage per day of work in the agricultural sector in Morocco, guaranteed by the official legislation (6.3 US $ per day of work). Otherwise, this proxy slightly overpassed the minimal guaranteed wage in two groups: 'Cattle based' and 'Rangeland systems' with a respective value of 6.6 and 7.8 US $ per working day. Altogether, these results reveal a wide variation in choices in the oases farming systems. Although they are all considered as located in the same quite homogenous area, the oases' farms have to deal with specific exogenous constraints, such as salinity, water availability according to the localization in the valley, or the proximity to wide rangelands, which become a safety net for livestock activities in cases of erratic rainfall. In addition, the oases' farmers have also to cope with some endogenous characteristics, such as land availability, the number of on-farm workers or the capital invested. It is this variability of structural and strategic parameters and how it is managed through livestock intensification which will be further discussed.

Discussion

The main scope of this research was to assess the potential impacts of livestock on the overall performances of the oasis farming systems. To do so, first, a typology of livestock systems was established (Sraïri *et al.*, 2017), with four different types identified. Two of these systems were considered as more intensive, namely 'Cattle based' and 'Sheep intensification', because of more frequent uses of off-farm feed resources, as well as an increased milk yield.

After defining a sample of three farms representing each of these four systems, we further tried to analyze the performances of the crops, livestock, and extra agricultural activities. The first striking result of this research is the highest profitability of date palm trees within groups of farms with more intensive animal production systems, i.e., 'Cattle based' and 'Sheep intensification' farms. This intensification is mainly reflected by the animal load (i.e. the number of LU per ha of fodder) and to a lesser extent by feed purchases per LU, which are quite higher in these groups of farms in comparison to the others. As a consequence, farmers rely on intense irrigation of lucerne to get optimal fodder yield to feed their animals and this allows subsequent irrigation volumes on the covering trees, most of all date palms. In fact, in the two groups of farms with intensive livestock systems (i.e. 'Cattle based' and 'Sheep intensification'), the number of wells is higher than in other groups (3 vs. 1) and the annual volumes of water used per ha (respectively 7240 and 9969 cubic meters in the 'Cattle based' and the 'Sheep intensification' systems) are higher than the average value in the sample study (6139 cubic meters per ha per year). Therefore, in a context of very limited amounts levels of rainfall (no more than 1100 cubic meters per ha per year), groundwater relatively allows to overcome the water scarcity, as well as salinity, and it, therefore, allows sustainable yields (Haj-Amor *et al*., 2016). Moreover, these two systems present a common factor in water use in the sense that the costliest and limiting factor is water is allocated to livestock activities (through fodder production), and this ensures reaching an increased yield of date palm trees. Therefore, a direct transfer of profitability from livestock to palm can be identified in this case, thanks to water. Finally, the raw margin considered by each activity constitutes a bias at the detriment of livestock, without taking into account the significant soil enrichment in nitrogen, due to lucerne, as a leguminous fodder plant (Ghimire *et al*., 2014).

The results also show that the mean profitability of livestock rearing is sometimes negative, as it was only positive in two groups of farms, i.e. 'Rangelands system' and 'Cattle based systems'. This may be explained by the non-market products and functions of livestock that were not considered in the calculations of the raw margins: manure used on-farm and not sold, milk-drunk by calves and self-consumed within the farms by family members, means of savings whenever incomes from crops or off-farm work increase, etc. (McNeilly, 2017). The same observation applies to systems where the ovine species was the most important component of the animal wealth (i.e., 'Multispecies systems' and 'Sheep intensification systems'), as the livestock raw margin was negative, and it even could not be balanced by the subsidies, in the case of the 'Sheep intensification systems'. Such observations converge towards previous findings with regard to recent evolutions in animal production in North Africa, as mutton has lost its leading position as a source of meat, and that has depressed its competitiveness in front of beef, poultry, and fish (Sraïri, 2011). Otherwise, systems with a more dairy orientation, whether intensified cattle or extensive dromedaries, generate positive economic results, and this can be a consequence of the higher efficiency in converting net energy to lactation rather than fattening (Vermorel and Coulon, 1998). Moreover, the high market value of dromedary milk sometimes constitutes an alternative to cow milk for classes of consumers with high incomes (Kempen *et al*., 2016), such as foreign tourists and domestic visitors from large cities.

Another finding of this study is related to the significant highest economic efficiency in the 'Rangeland systems' in comparison to the other livestock systems in the oasis context. This proxy illustrated the reduced capital invested in the 'Rangeland systems' as well as its interesting raw margin because of reduced uses of inputs (feed purchases and water). Such results are in total agreement with the general assumption that extensive camel breeding systems might represent a sustainable way of getting high-value products from harsh environments, although they may be threatened by changes in production patterns (Faye, 2013).

The study also reveals high variability in the economic water productivity through farming, as it fluctuates from 8.8 to 0.11 US $ per cubic meter used. The best value is obtained once again in farms belonging to the Rangeland systems' style of livestock and this can be explained by the limited use of irrigation, and also the integration of virtual water (i.e., the water used outside the farm to get feed resources from the wide rangelands). On the opposite, farms with more cropping activities, mainly based on groundwater or surface irrigation, have got much lower results of the economic water productivity (between 0.11 and 0.32 US $ per cubic meter used). Such findings are almost similar to the one reported by previous studies on the economic value added through irrigation in large scale schemes in other regions in Morocco (Moughli and Benjelloun Touimi, 2000), as well as specific studies targeting the water productivity of cattle farming (Sraïri *et al*., 2016). The variability between systems is mainly explained by productivity gaps (in the case of the 'Multispecies group, where crops and livestock raw margins are limited), in comparison to crops and livestock potential, as well as in some cases by excess water uses (as in the case of the 'Sheep intensification' systems), where it may not significantly improve the yield of date palm trees, as reported in other contexts (Chao and Krueger, 2007).

Finally, our results also reveal variable work remuneration in farming activities within the oases contexts. The worst remuneration (less than 1 US $ per day of work) was observed in 'Multi species' livestock systems and they reflect the low yields in crops combined with several setbacks in animal husbandry (a very low annual milk yield per cow and also a very high mortality rate in lambs). These results confirm the acute economic vulnerability of such farms, where some of the members have to emigrate to improve the livelihoods of the rest of the family, as the daily incomes are below the poverty line (Chen and Ravaillon, 2004). On the opposite, farms with higher investments in dairy cattle production and better raw margins in crops (particularly date palms) or fewer workers (particularly in 'Rangeland systems' with camels wandering in desert rangelands) manage to get a remuneration of work almost equal to the guaranteed wage in agriculture by the Moroccan law (6.3 US $ per day). Such levels of variability in work remuneration have also been reported in other kinds of crop-livestock systems in Morocco, particularly in a large scale irrigation scheme (Sraïri and Ghabiyel, 2017), and they imply further difficulties for the farming sector to attract workers, as it has been noted in developed countries (Kroone and Paauwe, 2014). Altogether, the results imply a severe vulnerability of the farming systems in the oases context. However, some systems manage to cope better than others with the harsh environment and the numerous constraints in resources. It would be therefore highly recommended to promote the best management practices adapted for each distinct area in the oasis and for the several crops and livestock activities to enhance the overall agricultural productivity of these areas.

Conclusion

The present study shows that livestock intensification, whenever possible through increased fodder production and purchases of feed, has an impact on the overall productivity of the oases' farming systems, particularly through higher incomes from date palms. On the opposite, in systems where such livestock intensification is not possible, because of scarce arable land, water, and capital, the incomes from date palms are reduced, and therefore extensive livestock (sheep in 'Multi species or dromedary in 'Range land' systems) combined to extra agricultural labor represent the main source of incomes. The perspectives drawn by this research demonstrate the extreme vulnerability of most of the systems, because of poor remuneration of family members' work, particularly in the farms where sheep is the most important component of the animal wealth (i.e. 'Multi species' and 'Sheep intensification' systems). These limited incomes are mainly explained by the high mortality rates recorded in sheep and its limited feed conversion efficiency, particularly in farms with limited technical support ('Multi species'). From the data analyzed in this research, it can be concluded that the improvement of the efficiency of the existing farming systems in the oases areas requires trans-disciplinary approaches, involving agronomy, animal husbandry, water management, and socioeconomics. These should bear in mind the marked constraints of the area, and the vulnerability imposed by limited assets, which implies that relying on cash crops' intensification in the extension areas of the oases might amplify the pressure on water resources and jeopardize the sustainability of these agro-ecosystems.

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كيف تساهم الماشية في كفاءة أنظمة الزراعة في الواحات؟

محمد الطاهر السرايري[1]، صلاح منصور[1]، محمد بنيدير[2]، محمد بنگومي[3]، ڤيرونيك آلاري[4]

[1]معهد الحسن الثاني للزراعة والبيطرة، الرباط، المغرب

[2]المكتب الجهوي للاستثمار الفلاحي ووزارات، المغرب

[3]المنظمة الأممية للأغذية و الزراعة، تونس

[4]المركز الدولي للبحث الزراعي للتنمية، منبوليي، فرنسا، حالياً متواجدة بالمركز الدولي للبحث الزراعي في المناطق الجافة، تونس.

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ملخص

يعتبر كل من النمو الديموغرافي السريع و المنافسة المتزايدة على موارد الماء من المعيقات المتعددة التي تؤثر سلباً على الأنظمة الزراعية في الواحات... وهذه العوامل تقلص من نجاعة استعمال المتدخلات و تنقص أرباح الأنشطة الزراعية. الإنتاج الحيواني مكون أساسي في أنظمة الزراعة في الواحات، حيث يقوم بعدة وظائف مهمة : المحافظة على خصوبة التربة، المساهمة في مداخل المزارعين ,والأخذ بعين الاعتبار المتقلبات الحديثة تهدف هذه الدراسة إلى تشخيص الأدوار الحقيقية للإنتاج الحيواني في الأنظمة الزراعية في الواحات من أجل هذه الغاية، وقمنا بمعاينة اثنى عشرة ضيعة زراعية حيث ضبطت معايير الإنتاجية المتعلقة بالأرض، الماء، العمل، و رأس المال... وأثبتت النتائج أنَّ أنجع الأنظمة الزراعية في الواحات هي التي ترتكز على الجمع بين الزراعات، والإنتاج الحيواني، وزيادة عن تزويده لأفراد عائلات المزارعين بأغذية ذات جودة عالية، ويمكن الإنتاج الحيواني المكثف(الأغنام من سلالة الدمان، و الأبقار الحلوب) من الزيادة في محاصيل الزراعات ومداخلها النقدية، ويبدو هذا أساساً بالنسبة لنخيل التمر الذي يستفيد من المياه الإضافية المستعملة لري الفصة و بالموازاة عن ذلك، في المجالات التي لا يمكن تكثيف الأنشطة الزراعية فيها (مثلاً في المناطق دون مياه جوفية أو ذات ملوحة عالية) يظل الإنتاج الحيواني أهم مورد للدخل بالنسبة للمزارعين، إذْ يثمن موارد المراعي الشاسعة ومخلفات الزراعات (تمر غير صالح للاستهلاك، تبن الحبوب...).

الكلمات الدالة: الواحات، أنظمة الإنتاج الزراعي، مداخل الضيعات الزراعية، إنتاج حيوان، نجاعة استعمال المتدخلات.