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Climate change-related risks and adaptation strategies as perceived in dairy cattle farming systems in Tunisia

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ABSTRACT

The perception of risks due to climate change by farmers and the measures they take to address those risks are of paramount importance in policy-making if the implementations of targeted adaptation and mitigation strategies are to be economically and environmentally sustainable. This study focused on Tunisian dairy farmers' perceptions of the risks and the actions taken to cope with changes attributable to climate change. Using a bottom-up approach, 566 surveys were carried out randomly among dairy farmers throughout Tunisia. A total of 70 diagnostic variables relating to farm characteristics, resources, management, performances and profit, in addition to climate change risk perception and adaptation strategies, were identified and analyzed. Using multivariate statistical analysis, four dairy farming groups were identified. The largest proportions of farmers belonged to the two above-ground dairy systems: without utilized agricultural areas; and with non-dairy utilized agricultural areas (Clusters 1 and 2). A minority of farmers belonged to medium-sized and large farms that specialized in milk production (Clusters 3 and 4) and has access to sufficient land, water and capital resources. In all the clusters, almost all the farmers perceived that the greatest impact of climate change would be on cow performance and forage production. The attitudes of the farmers towards adaptation to climate change are associated with farm typology. They focused mainly on increasing water capacity for livestock and crop production and improving livestock and housing conditions. The knowledge obtained from this study could be helpful for decision-makers and stakeholders in efforts to develop policies for farm management practices that address climate change and can be adapted to the country's diverse farming systems.

1. Introduction

Against a background of rapid demographic growth and considerable urbanization, since the 1960s many policies have sought to improve self-sufficiency in food production, including milk production (Sraïri et al., 2013). In Tunisia, policies have tended to focus on promoting intensive dairy systems, mainly in the north, and have relied on the import of exotic high-yielding selected breeds and the progressive substitution of local and cross breeds. The proportion of pure breeds increased from 6 to 29% between 1975 and 1992

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(MARH, 2006). The failure of the collectivization system led to the establishment of semi-private company-run large farms, in addition to the many small and medium-sized dairy farms in the Sahel peri-urban regions with zero-grazing systems and other private farms in irrigated regions (Elloumi and Essamet, 1997). Recent decades have been characterised by the spread of dairy farms across the whole country and a huge rise in the number of small farming units. The dairy sector is therefore characterised by a wide diversity of systems in the different agricultural areas.

North Africa, particularly the areas bordering the Mediterranean, has been classified as a climate change 'hotspot' (Giorgi, 2006). The location of Tunisia between the inter-tropical regions and the temperate regions of the northern hemisphere makes its climate particularly variable, and therefore particularly vulnerable to climate change. Tunisia is among the top 10 countries likely to suffer the greatest climate change impact in terms of population and gross domestic product losses (Dasgupta et al., 2009). A report by the German Technical Cooperation Agency showed that the climate change impact in Tunisia will include an increase of 1.1 °C in annual average temperature and a considerable decrease in annual precipitation (GTZ, 2007). There will be a 28% decline in the country's water resources and the loss of arable cropland is expected to be about 20% by 2030. Dairy farms in Tunisia are experiencing warmer temperatures, above the thermo-neutral zone of cows, for more than 5 months each year, which has reduced production efficiency and resulted in significant economic losses (Bouraoui et al., 2002). Drought years are frequent and sometimes occur over 2 consecutive years after no more than 3 consecutive years of normal rainfall. This has led to a reduction in the quality and quantity of fodder, which constitutes a key constraint in livestock farming in the country (Kayouli, 2006). The genetic expression of high-yielding breeds has been hampered and the ability of high-potential cows to cope with these harsh conditions and disturbances is questionable (Hammami et al., 2008). The expected climate change scenarios will accentuate these difficult conditions and affect the natural resource base, animal productivity and health, and the sustainability of livestock-based production systems (Salem, 2011).

Understanding farmers' perceptions and how they are likely to respond to short- and long-term initiatives aimed at helping all stakeholders withstand climate disturbances is a key factor in planning robust strategies for climate change mitigation and adaptation. Depending on their farming system, farmers have specific approaches, targets and solutions for combatting the effects of climate change. Classifying them into clusters and gaining a better understanding of their perceptions of climate change should help in the development of cost-effective policies on climate change resilience. The main objective of this study was to investigate Tunisian farmers' perceptions of the impact of climate change and explore possible adaptation strategies for the various cattle dairy farming systems in the country. A large farm survey was conducted in 19 governorates to establish a typology of Tunisian dairy farms and investigate the climate change-related perceptions of farmers within each type.

2. Materials and methods

2.1. Survey

A questionnaire was conducted among a sample of 566 dairy farmers in the 19 governorates of Tunisia (Fig. 1) over 8 months (May to December 2015). The farmers were selected randomly based on cattle herds enrolled in the national milk recording schemes. Access to registered data on past farming practices, herd management and performance is lacking for most dairy farmers in Tunisia, particularly the smallholders, who represent about 80% of the total number of dairy farmers in the country. We therefore used a bottom-up approach based on a survey of local stakeholders, with the national milk recording operator as an important player in its implementation. The survey was initially validated by a Tunisian consortium of research and development organizations and then tested for 1 month by technicians. It consisted of 70 questions relating to information on: (i) farmer characteristics (e.g., land use, labour capacity, herd size, cattle breeds and species); (ii) dairy housing structure; (iii) animal feed management and organization; (iv) herd health care and disease occurrence; (v) milking management; (vi) milk marketing and processing; (vii) productive and reproductive performance; (viii) farm facilities and machinery; (ix) farm management, and replacement; (x) technical and economic support; (xi) past and future evolution of milk production; (xii) milk production constraints; (xiii) perception of climate change impact; and (xiv) climate change adaptation strategies.

The Livestock and Pasture Office was commissioned to administer and manage the survey. Awareness days were created in order to explain the questionnaire to the technicians and ensure its proper functioning and implementation. The questionnaire was applied during face-to-face interviews, in local languages, and was reinforced by direct observation of the herds and the farm environments. Each farm visit lasted an average of 60 min.

2.2. Statistical analysis

Multiple correspondence analysis was performed to establish a typology of Tunisian dairy farmers. A multiple correspondence analysis reduces the dimensions of contingency tables, gives a graphical representation and allows detecting the factors that best characterised the farms and enabling their uses in the subsequent analyses (Milán et al., 2011).

The most appropriate variables for the typology were selected according to relevance and to data availability and quality. First, variables that lacked variability and made little contribution to distance measurements used to form the clusters were discarded (Escobar and Berdegué, 1990). Second, any variables that were highly correlated to other variables were eliminated, because their contribution to distance measurements was reflected by changes in those other variables (i.e., location, cattle genetic resources, milking process, legal status). In this study, the classification of dairy systems was based finally on criteria relating to the structure of production units (farm size and herd size), as well as on technical criteria related to regional and climate specificities proxies, such as animal feeding (number of months fresh forage was distributed) and diversification of agricultural activities (forage area). The

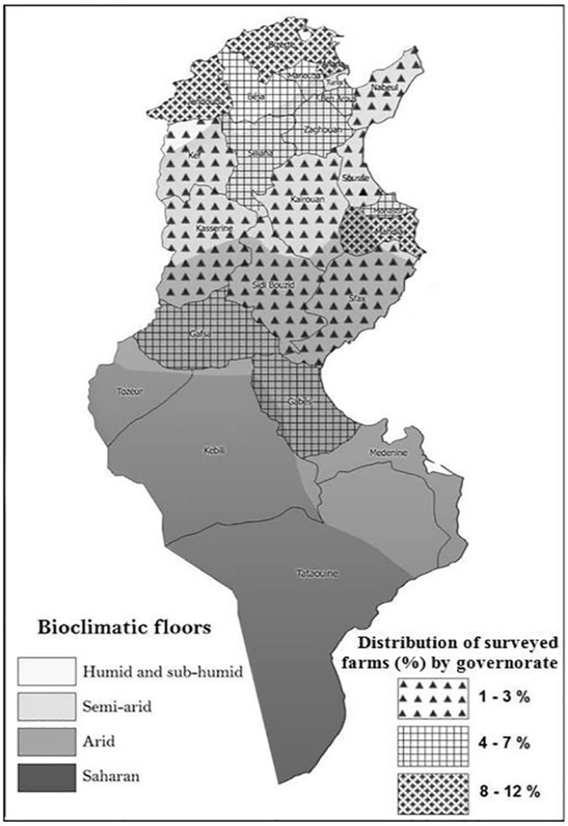

Fig. 1. Study area of Tunisia and bioclimatic floors.

variables were transformed into classes, using the quantile position with respect to the mean. Many authors agree that farm size is one of the most important variables for classification and they use this variable when there are considerable differences among farms (Castel et al., 2003; Nahed et al., 2006; Usai et al., 2006). The diversity of farming activities is such that different authors use different variables (Milán et al., 2006; Usai et al., 2006).

The hierarchical cluster analysis based on Ward's method was done with the first five factors showing the greatest variance, generated by the multiple correspondence analysis. Cluster analysis enabled farms that were similar to each other, but different from others, to be grouped together (Ward, 1963).

Chi-square tests were conducted to evaluate dependence among clusters and among qualitative variables. The differences among clusters obtained from the typology with regard to the continuous variables were contrasted using a mean comparison test. Descriptive and statistical analyses were conducted using SAS (version 9.4).

3. Results

The proportions of farms surveyed in north, central and south Tunisia were of 63, 26 and 11%, respectively (Fig. 1). Of the surveyed farmers, only 10% owned a land area larger than 50 ha, whereas 20% owned between 10 and 50 ha and 70% owned less than 10 ha. In terms of number of cows, 65% of the farmers had fewer than 10 cows, 29% had 10–50 cows and 6% had more than 50 cows. More than 87% of the respondents answered 90–100% of the questions in the survey, reflecting a high response rate and therefore good analysis representativeness.

3.1. Typology of dairy farming systems

The cumulative proportion of variation explained by the first five factors generated by the multiple correspondence analysis was 49.2%. Fig. 2 shows the representation of modalities on axis 1 and axis 2. Axis 1 opposes modalities related to intensification and associated with a large utilized agricultural areas and a large herd size (negative coefficients on the axis) to those describing the lack of intensification and related to a small utilized agricultural areas and no forage area (positive coefficients). Axis 2 is correlated mainly with the modalities associated with forage feed distribution and forage areas.

The means and standard deviations for the most descriptive continuous variables for each of the four clusters are presented in Table 1. The frequencies for the important descriptive categorical variables of the clustered farms are presented in Table 2. Overall,

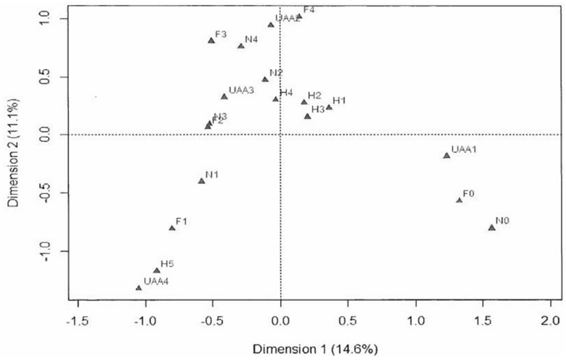

Fig. 2. Graphic representation of modalities on axis 1 and axis 2. Utilised agricultural areas (UAA): UAA1 ≤ 2 ha, 2 < UAA2 ≤ 5ha, 5 < UAA3 < 20 ha, 20 ≤ UAA4; forage area (F): F0 = 0%, 0 < F1 ≤ 25%, 25 < F2 ≤ 50%, 50 < F3 < 100%, F4:100%; herd size (H): H1 ≤ 5 cows, 5 < H2 ≤ 7 cows, 7 < H3 ≤ 10 cows, 10 < H4 < 20 cows, 20 ≤ H5; number of months of distribution fresh forage (N):N0 = 0mo, 0 < N1 ≤ 6mo, 6 < N2 ≤ 9mo; 9 < N3 ≤ 12mo, N4:12mo.

Table 1
Means ± standard deviations of continuous variables in the four clusters and comparisons among them.

Variables	Cluster 1		Cluster 2		Cluster 3		Cluster 4	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Farmer age (year)	48.6[a]	12.1	47.7[b]	14.0	48.7[a]	12.3	47.0[b]	11.7
Experience (year)	18.5[a]	10.3	19.3[a]	12.3	19.4[a]	11.1	14.7[b]	10.2
Labour (worker/month)	–	–	–	–	–	–	–	–
Hired labour	0.6[b]	2.3	1.5[b]	3.8	1.5[b]	4.0	15.6[a]	7.9
Family volunteer labour	1.6[a]	1.2	1.7[a]	1.5	1.5[ab]	1.1	1.2[b]	1.7
Animals (Livestock Unit)	–	–	–	–	–	–	–	–
Cow	9.2[b]	7.2	8.2[b]	2.1	12[ab]	3.6	100.8[a]	53.6
Bull for fattening	1.6[b]	3.0	1.6[b]	2.0	2.4[b]	3.0	8.8[a]	15.9
Sheep	1.0[b]	2.4	1.6[b]	3.5	1.6[b]	3.1	18.3[a]	27.3
Goats	0.0[b]	0.1	0.1[b]	0.2	0.1[b]	0.2	0.4[a]	1.2
Areas (ha)	–	–	–	–	–	–	–	–
Utilized agricultural areas	2.7[b]	4.5	32.4[b]	23.7	17.5[b]	1.8	504.6[a]	101.9
Forage crop area	0.5[b]	0.8	4.2[b]	2.7	8.0[ab]	2.6	229.8[a]	65.0
Irrigated area	0.8[b]	1.4	3.5[b]	4.0	5.2[b]	8.0	91.7[a]	89.9
Cash cereal production	0.0[b]	1.5	9.5[ab]	8.1	3.0[b]	13.5	151.4[a]	505.6
Cash vegetable production	0.1	0.6	1.6[b]	1.8	1.4[b]	4.1	3.0[a]	10.9
Cash forage production	0.1[b]	0.3	0.4[b]	1.5	0.8[b]	3.8	13.9[a]	72.1
Arboriculture	2.1[b]	20.7	0.8[b]	89.3	2.7[b]	14.9	146.1[a]	941.2
Feeding (month)	–	–	–	–	–	–	–	–
Fresh forage	1.0[b]	1.4	4.0[ab]	1.5	10[a]	0.9	12[a]	0
Straw	8.3[a]	5.3	8.6[a]	5.1	8.9[a]	4.8	7.7[b]	5.5
Hay	7.6[a]	5.2	9.3[a]	4.1	9.7[a]	3.6	9.8[a]	4.1
Silage	0[b]	0	0[b]	0.4	1[b]	2.9	5.7[a]	7.1
Concentrate	12[a]	0.8	12[a]	0.2	11.1[a]	3.0	11.5[a]	2.4
Performance	–	–	–	–	–	–	–	–
Milk production (kg/year)	4841[b]	1709	4597[b]	642	4942[b]	975.2	7220[a]	1422
Lactation length (days)	295[b]	153	271[b]	135	294[b]	145	322 [a]	139.5
Age at first calving (month)	32[b]	11.7	38[a]	22.1	36[b]	14.2	29[b]	3.5
Calving interval (days)	419[b]	77.9	369[ab]	56.5	464[a]	140.8	437[b]	103.9
Average insemination/cow	1.7[b]	1.0	1.7[b]	0.4	1.4[b]	0.7	2.7[a]	2.0

[a–b]Means within a row with different superscripts differ ($P < 0.05$).

the four identified clusters shared many common characteristics, with several variables not being significantly different among them. Almost all the respondents (95%) had other economic activities. On the surveyed farms, cattle genetic resources consisted mainly of the Holstein high-yielding dairy breed (Table 2). Straw and hay were commonly used as feed for more than three-quarters of the year by all farmers (Table 1). Most of the surveyed farmers (86%) were enrolled in the milk recording schemes, where the milking process is predominantly mechanical. The selection objectives focused mainly on milk quantity and morphology, and were similar for all farmers in all four clusters (Table 2). These herds were in a continuous state of production expansion, and there was therefore a general trend of increasing milk production regardless on the past (49%) or future (72%) evolution of milk production, and regardless of cluster ($P > 0.05$) (Table 2).

Other characteristics were significantly different in terms of farming typology and were seen as specific to each cluster, as

Table 2
Dairy cattle farm partitioning[1] by qualitative variables for each of the four clusters.

	Cluster				
	1	2	3	4	*P*-value
Legal status	–	–	–	–	< 0.001
Natural person	98	100	98	56	–
Legal person	2	0	2	44	–
Location	–	–	–	–	< 0.001
Village centre	26	19	16	9	–
Village edge	48	44	38	59	–
Far from village	26	37	46	32	–
Importance of the dairy activity	–	–	–	–	< 0.001
Primary activity	87	74	85	86	–
Secondary activity	7	21	12	11	–
Unique activity	6	5	3	3	–
Labour	–	–	–	–	< 0.001
Hired labour	13	20	23	52	–
Family volunteer labour	72	51	58	19	–
Mixed (family and hired) labour	15	29	19	29	–
Breed	–	–	–	–	< 0.001
Dairy	86	75	80	75	–
Dual purpose	9	19	15	24	–
Local and cross	5	6	6	1	–
Ration of dairy cows	–	–	–	–	< 0.001
Fodder < concentrate	60	32	23	21	–
Fodder > concentrate	40	68	77	79	–
Drinking water	–	–	–	–	< 0.001
Ad libitum	46	48	51	85	–
Not *ad libitum*	54	52	49	15	–
Milking type	–	–	–	–	< 0.051
Hand milking	17	18	14	0	–
Mechanical milking	83	82	86	100	–
Cow renewal	–	–	–	–	–
Mainly from own flock	86	88	91	96	0.042
Bought from outside	52	57	56	40	0.308
Building type	–	–	–	–	< 0.001
Completely open building	0	1	3	18	–
Semi-open building	50	36	50	57	–
Closed building	40	56	47	25	–
No building	10	7	0	0	–
Genetic improvement: selection goals	–	–	–	–	–
Milk yield	82	88	89	86	0.061
Quantities of transformable milk solids	5	3	6	14	0.724
Fertility	28	36	29	27	0.028
Longevity	8	8	6	3	0.573
Morphology	43	34	31	50	0.668
Genetic improvement: selection method	–	–	–	–	0.077
Genetic	13	18	29	12	–
Phenotypes of offspring	42	42	37	37	–
Phenotypes of offspring and Genetic	13	15	7	5	–
Past evolution of milk production	–	–	–	–	0.191
Increased the volume of milk produced	49	47	52	47	–
Decreased the volume of milk produced	22	18	25	23	–
A constant milk volume	28	35	22	30	–
Future evolution of milk production	–	–	–	–	0.484
Stopping the dairy production	0	5	5	0	–
A constant milk volume	12	17	6	21	–
Increase the volume of milk produced	74	65	78	70	–
Decrease the volume of milk produced	4	8	9	6	–

[1] Values are in percentages.

described here.

3.1.1. *Cluster 1: Above-ground dairy farms without utilized agricultural areas*

The average herd size in this cluster was nine cows, similar to that of Cluster 2, but significantly different ($P \leq 0.05$) from Clusters 3 and 4 (Table 1). The average utilized agricultural areas was the smallest of all the clusters and comprised 3 ha, of which only 0.5 ha were reserved for forage production. More than 50% of the farmers in this cluster used feeding rations, with the concentrate-to-forage ratio being the highest of all the clusters (Table 2). Due to the small size of the forage area owned by these farmers, there was almost no use of fresh and conserved (e.g., silage) forages in the rations and never for longer than 2 months of the year (Table 1). The hired labour force was about 0.6 persons/month, the lowest of all the clusters. In contrast, Cluster 1 had the highest proportion of farmers (72%) using family and volunteer labour (Table 2). On these farms, the 305-day milk yield averaged 4841 kg. The difference between this milk yield performance and that in Clusters 2 and 3 was not significant ($P > 0.05$), but the age at first calving was significantly different from Cluster 2 (Table 1). The proportion of farmers with *ad libitum* drinking water facilities was limited (46%). The same practices were also followed by farms in Clusters 2 and 3 (Table 2). Overall, Cluster 1 of above-ground dairy farms included 'landless' production systems that often had no any cultivable area. There were 210 dairy cattle farms in Cluster 1, of which 43% were in the Sahel, about 4% in the centre-west of the country, 43% in the north and only 10% in the south.

3.1.2. Cluster 2: Above-ground dairy farms with non-dairy utilized agricultural areas

Although the average herd size (eight cows) was in the same range as that of Cluster 1, farmers in Cluster 2 owned a larger utilized agricultural areas (32 ha), but only small areas of this (13% and 11%) were reserved for forage production and irrigated crops (forage crop, cash vegetable production, arboriculture) respectively (Table 1). On-farm forage production was therefore low, with no more than 4 months of fresh forage and very limited use of silage in the diets throughout the year. Cluster 2 farmers used a mixture of hired workers and family members as a labour force. The milk production level of cows in this cluster was the lowest of all the clusters, whereas the age at calving of primiparous cows was the highest. The average calving interval of about 370 days was the lowest (Table 1). As in Cluster 1, access to *ad libitum* drinking water was possible for only 48% of these farms. The mechanical milking process was common, with only 18% of the farmers using manual practices (Table 2). Cluster 2 included 181 dairy cattle farms located mainly in the north of the country (77%), with a few farms in the centre (12%) and the south (11%).

3.1.3. Cluster 3: Medium-sized farms specializing in milk production

In Cluster 3, the average herd size of 12 cows differed significantly from all the other clusters ($P \leq 0.05$). Nevertheless, the average utilized agricultural areas of 18 ha was in the same range as that in Cluster 2, on-farm feed production was high with about 45% of the utilized agricultural areas used for forage production and mostly irrigated (Table 1). Fresh forage was therefore abundant throughout the year and was used for 10 months of the year on average (Table 1). This was significantly different ($P \leq 0.05$) from Clusters 1 and 2. The labour force consisted of about three workers per farm, equally distributed between family members and hired workers (Table 1). With regard to the average of familiar labour (1.5 persons/month), this was significantly different from all the other clusters ($P \leq 0.05$). On average, the 305-day milk yield was 4942 kg and the lactation length was 294 days in milk (Table 1). The cows owned by farmers in this cluster, however, had the longest calving interval of all the clusters (464 days). Access to drinking water *ad libitum* and mechanical milking processing were possible for 51% and 86% of the Cluster 3 farms, respectively (Table 2). This cluster could be seen as an intermediate cluster between Clusters 2 and 4. It consisted of 103 dairy farms, 75% of which were in the north of country and the rest (15% and 10%) were in the centre and the south, respectively.

3.1.4. Cluster 4: Large farms specializing in milk production

In this cluster the average herd size (100 cows) and the mean utilized agricultural areas (505 ha) were the highest of all the clusters and were significantly different from the other three clusters (Table 1). The area devoted to forage production was about 50% of the utilized agricultural areas and more than 18% of the land was irrigated, a percentage that differed significantly ($P \leq 0.05$) from corresponding areas in the other three clusters. This meant that most of the animal feed was self-generated and the level of external dependence for feeding was the lower than in any other cluster. Only on these farms was there considerable use of silage in the diets, for 6 months of the year on average, in addition to fresh forage incorporated into the rations throughout the year (Table 1). The labour force consisted mainly of unfamiliar hired labour (Table 2) and the average number of hired labour workers (~ 16 workers per farm) was the highest of all clusters and significantly different ($P \leq 0.05$) from the other clusters (Table 1). The average 305-day milk yield of 7220 kg was the highest in the country and the lactation length (322 days in milk) was the longest (Table 1). The cows on these farms systematically produced their first calves at earliest age (29 months). The proportion of farmers with *ad libitum* drinking water facilities was the highest (85%) of all clusters. Cluster 4 was also characterised by an exclusive use of mechanical processes for cow milking, as well as by preventative health programs (Table 2). The farms differed significantly from other clusters in terms of the amount higher of equipment and management services on the farm ($P < 0.001$). Cluster 4 included 72 large farms in the organized sector and intensive systems, most of them in the north of the country (81%), with 16% and 3% in the centre and south, respectively.

3.2. Farmers' perceptions of climate change-related risks

Twelve potential climate change-related risks were reported by the surveyed farmers. The proportions of response for each risk in relation to total response are given in Fig. 3. Overall, all farmers in all clusters perceived the impact of heat waves on milk production and fertility (direct effect) and the availability and cost of feeds (indirect effect) as the major climate change-related constraints facing dairy farming.

Table 3 gives the percentage analysis of farmers' perceptions of climate change-related impacts on animal and forage productions in terms of cluster and potential risks. The perceptions varied in relation to both direct and indirect items and also across the clusters.

3.2.1. Effects on animals

Although some farmers had neutral perceptions about the climate change impact on animals, a large group (> 60%) believed that climate change would hamper productive and reproductive performance (Table 3). About 50% of all respondents felt that the second

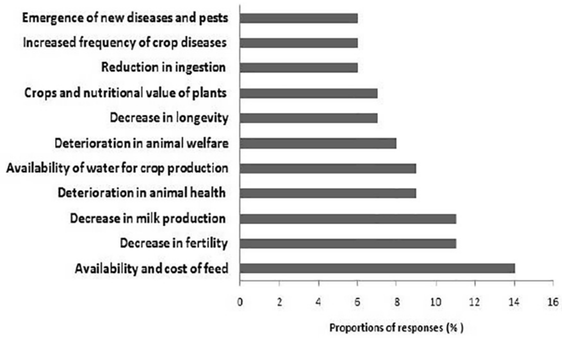

Fig. 3. Proportions of responses on perceived risks in relation to the total responses.

Table 3
Tunisian farmers' perceptions[1] of climate change-related risks.

	Cluster				*P*-value
	1	2	3	4	
Effects on animals					
Decrease in fertility	53	71	64	81	*
Decrease in milk production and composition	47	67	67	73	*
Deterioration in animal health: disease occurrence	45	52	49	59	0.3
Deterioration in animal welfare	46	40	47	69	0.06
Decrease in longevity	31	37	45	53	0.016
Reduction in ingestion (food intake)	28	35	42	57	*
Effects on forage					
Availability and cost of feed	72	81	76	83	0.259
Availability of water for crop production	33	65	65	70	*
Crops and nutritional value of plants	25	51	51	57	*
Increased frequency of crop diseases and pests	26	39	41	51	0.002
Emergence of new diseases and pests	19	40	41	44	*
Deterioration in working conditions and health of agricultural producers and labourers	26	30	34	44	0.064

* $P < 0.001$.
[1] Values are in percentages.

major effect of climate change on animals would be a change in their health and welfare status. Only about 40% of the respondents felt that feed intake and cow longevity would be affected by climate change. For all risks and among all clusters, the highest proportion of farmers who considered that climate change would have a negative effect on animals was in Cluster 4 and the lowest proportion was in Cluster 1. In Cluster 2, more farmers considered that climate change would lead to a decrease in health, reproductive and productive performance (52–71%) than was the case in Cluster 3 (49–67%). The farmers in Cluster 3, however, expressed more concern about deterioration in animal welfare and a decrease in feed intake and cow longevity (42–47%) than those in Cluster 2 (35–40%).

3.2.2. *Effects on forage*

Most of the farmers believed that the main climate change impact would be on the availability and cost of feed (Fig. 3). The scarcity of water needed for crop production as a consequence of droughts was also seen as an important effect of climate change (53%), followed by reduction in crop yields and nutritional value (41%), and increase in crop diseases and the emergence of new crop diseases (36%). Of least concern among the farmers was deterioration in working conditions and personnel well-being (Table 3). With regard to perceptions about the impact of climate change on forage, farmers in Clusters 4 and 1 were the most and least concerned, respectively, about the effect of climate change on forage, whereas those in Clusters 2 and 3 shared similar perceptions.

3.3. *Farmers' perceptions of adaptation strategies in response to climate change*

The survey found that Tunisia's dairy farmers had considered many strategies aimed at limiting the negative effects of climate change on farming systems, with 13 options being reported overall (Fig. 4).

In all four clusters, farmers cited strategies based on implementing management practices to guarantee fodder availability, on environmental and physical adjustments to allow better access to shading during hot periods and on the adoption of *ad libitum* water drinking for cows. Across the 13 options, however, there was a statistically significant variation in the most favoured adaptation strategies among the four clusters, as shown Table 4. In order to increase resilience to seasonal rainfall variations, the highest number of farmers who wanted improve their financial ability to buy fodder was in Cluster 1, and the highest number of farmers who wanted

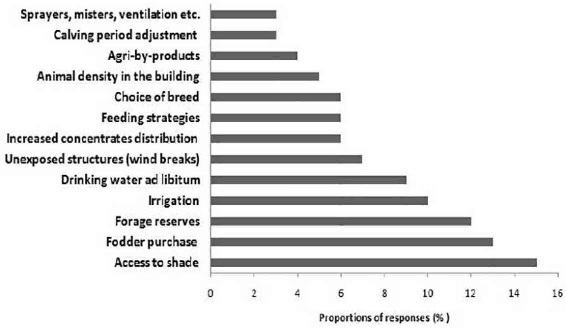

Fig. 4. Proportions of responses on adaptation strategies in relation to the total responses.

Table 4
Adaptation strategies[1] favoured by Tunisian dairy farmers in response to climate change.

	Cluster				*P*-value
	1	2	3	4	
Management practices					
Fodder purchase	75	56	68	37	*
Forage reserves	50	59	62	76	0.001
Irrigation	25	51	71	66	*
Agri-by-products	10	19	38	33	*
Calving period adjustment	11	24	14	13	0.005
Environmental management					
Access to shade	67	71	77	81	*
Unexposed structures (wind breaks)	22	37	46	44	0.058
Animal density in the building	19	27	29	40	0.004
Sprayers, misters, ventilation etc.	1	7	7	11	0.15
Nutritional management					
Drinking water *ad libitum*	39	40	48	70	*
Increased concentrates distribution	32	27	28	26	0.25
Feeding strategies	21	22	32	46	*
Genetic					
Choice of breed	21	35	35	33	0.011

* $P < 0.001$.
[1] Values are in percentages.

to build up their fodder reserves in favourable years was in Cluster 4 (Table 4). The farmers in Cluster 3 were the most interested in improving irrigation potential at farm level, as well as valorising the agricultural by-products. The farmers in Cluster 2 were the most interested in adjusting calving periods by concentrating them within favourable feeding periods (Table 4).

With regard to resilience to an increase in the number of extreme weather events, adjustments of housing facilities and water use by cows were the most commonly identified strategies in all clusters, with 34% of the farmers considering using unexposed buildings. Farmers in all the clusters, especially Cluster 4, saw implementing feeding strategies based on the frequent distribution of concentrates during warm days and on the adjustment of feeding rations as important resilience measures. Only 29% of the farmers, mainly in Clusters 2 and 3 ($P < 0.05$), saw choice of breed as an appropriate adaptation strategy.

4. Discussion

Dairy farm typologies have been widely used in several regions in the world in efforts to strengthen knowledge for various purposes (Gelasakis et al., 2017; Riveiro et al., 2013; Sraïri and Kiade, 2005). Segregating homogenous systems in order to obtain higher representativeness and clear evidence depends on the sampling process of the studied population and the availability, completeness and depth of data collection. Most studies on characterising dairy farming systems have been based on surveying selected representative samples of the population of interest. In Tunisia, there is a lack of comprehensive studies on the characteristics of dairy farming systems throughout the country and in all agricultural zones. Most published works have been based on an expert view (Kayouli, 2006) or on studies involving small samples of herds known by specific practices (Baccouche et al., 2015; Hammami et al., 2013; Kraïem and Aloulou, 2003).

This study sought to gain a better understanding of the resilience of Tunisian dairy farmers to climate change, based on their perceptions of climate change-related risks and the adaptive and adjustment strategies they thought appropriate to address these risks. The study was designed to cover all farmers across the five contrasting bioclimatic areas (Fig. 1). The proportions of surveyed farms with less than 5, 5–10, 10–50 and > 50 ha were 50, 21, 19 and 10%, respectively. These proportions were in the same range of the proportions of farmers at national level in each of these farm size groups (51, 22, 23 and 4%, as reported by MARH, 2006). In terms of distribution of farmers according to herd size, only 0.2% of farmers had more than 50 cows, 16.8% had 5–50 and 83% had less than 5, which differs slightly from the reported national figures (MARH, 2006). Our survey was characterised by a high response rate thanks to good links between farmers and national organizations and, more importantly, to the assistance that consultants gave to herd managers in completing the questionnaire. The data gathered can be considered as highly reliable because it was collected by an experienced and professional team that included milk recording advisors who had long-standing and good relationships with the farmers surveyed.

Kayouli (2006) distinguished only three dairy farming systems based on farm structure and livestock feeding criteria: i) the traditional or extensive system (Group 1), widespread in northern Tunisia and characterised by limited productivity, unirrigated land and family-based labour; ii) the intensive, integrated and organized system in the north, covering 20% of the country's dairy farmers (Group 2); and iii) the semi-integrated and intensive 'landless' system in peri-urban and irrigated areas or under zero-grazing without any cultivable area (Group 3). Our clusters showed some uniformity with some of these groups, but differentiation with others. Our Cluster 4 farms (large farms specializing in milk production) corresponded exactly with Group 2 (intensive, integrated and organized system), as defined by Kayouli (2006). Our Cluster 1 and 3 farms had similar herd sizes and reduced milk yields per cow, but were significantly different in terms of feeding capacities, forage and irrigated land surfaces. The Cluster 1 farms were located mainly around cities in the Sahel (central Tunisia), with almost no land surface and with milk production based on the conversion of concentrates. Farms in Cluster 3 were characterised by adequate fresh and conserved forage throughout the year and were located exclusively in irrigated areas. These two clusters (1 and 3) were put into one group (Group 3: semi-integrated and intensive 'landless' system) by Kayouli (2006). With the extension of irrigated areas, improved milk quality, collection and marketing, and subsides and incentives in recent years, farms in Group 1 (traditional or extensive system), as defined by Kayouli (2006), have changed. In our study, these farms were placed in Cluster 2. Given that our classification was based on a comprehensive survey and took into account of the dynamics of dairy farming developments in recent years, it could be seen as an update of the findings reported by Kayouli (2006). Faced with evolving social demands in terms of the operability of typologies, new methods need to be developed (Landais, 1996). Multivariate statistical techniques provide a means of creating the required typologies and identifying types of farming systems in their respective study areas, particularly when an exhaustive database is available (Köbrich et al., 2003; Pacini et al., 2014). The intensive component of the Tunisian dairy farming system (Cluster 4) is situated mainly in northern Tunisia and accounts for only 0.2% of the country's dairy cattle. This system includes a mixture of state herds (public and semi-public agencies), investors and the Development Corporation, and some private farmers. The main reasons for this intensification relate to the balance between animal and fodder production and to future land, water, financial and marketing facilities. The landless dairy farming system (Cluster 1) is an important sector in Tunisia. The farms are located in the suburbs of industrial and tourist cities. Milk production is based on the conversion of concentrates and hay purchased from the northern region. By simulating an increase of only 20% in the price of the concentrate industry, Rejeb-Gharbi et al. (2007) reported that of the three main farming systems, the highest reduction in gross margins and the economic efficiency coefficient occurred in the landless dairy farming system. This system continues to grow. Currently, for example, the two governorates in the Sahel in central Tunisia (Mahdia and Sfax) rank second as milk suppliers at the national level. The proximity of milk collection cooperatives to smallholders, the technical support provided by those cooperatives and the incentives for milk collection are important stimuli in the preservation and growth of this system. In addition, these farms benefit from additional off-farm income and activities, as well as unpaid on-farm family labour. The spread of this kind of production system and its greater resilience to policy measures and milk market fluctuations, compared with integrated intensive systems, has also been reported in China and Pakistan (Ghaffar et al., 2007; Ma et al., 2012). Chinese suburban dairy farms were more productive than their counterparts in rural provinces, benefiting from the proximity of milk collection and industry (Ma et al., 2012).

Knowledge about how Tunisia's farmers in the various farming systems perceive climate change-related climate risks is of great importance for stakeholders and policy decision-makers. In our study, farmers were asked about their perception of risks due to changes in average weather parameters (e.g., temperature, rainfall), as well as those due to the increased incidence of specific events (e.g., drought). Our results showed that they were generally aware of the likely effects of climate change on their production system. Only 5% of them did not believe in climate change and said they had no perceptions about it. Overall, the farmers voiced concerns about climate change-related risks in the context of changes in climate events in recent years. The most common concerns focused on: i) greater loss in animal performance due to heat waves for long periods each year; and ii) reduced forage productivity due to drought and rainfall scarcity in at least 2 consecutive cropping years (Fig. 3). Although the concerns varied among the farming clusters, overall these concerns were linked to economic rather than climatic factors. Given that Cluster 1 farmers lack land on which to grow fodder and animal feed, it is not surprising that they expressed greater concern about feed availability and cost than about change in animal performance, compared with the concerns expressed by farmers in the other clusters (Table 3). Heat stress was the climate change-related risk most frequently identified by the farmers, who saw it as a threat to cow milk production and quality, fertility, health and longevity. This concern was justified by the evidence from many studies that typical animal responses to thermal stress include slower and inconsistent growth, altered metabolism and body composition, reduced milk synthesis, poor fertility, morbidity and mortality (Baumgard et al., 2012; Nardone et al., 2010). The effects of high temperatures on milk production are probably the most damaging in any animal production system, forcing animals to reduce their feed intake and thus reducing milk yields (Dunn et al., 2014). Heat stress has also been reported to change milk quantity and quality drastically under the Tunisian climate conditions (Bouraoui et al., 2002). In Clusters 2, 3 and 4, the farmers' perceptions about the impact of climate change on forage were linked to water resource availability in terms of irrigation or/and rainfall. Declining precipitation was the second most frequently identified climate change-related risk by farmers in these clusters. The anticipated climate change will adversely affect livestock indirectly by causing feed and fodder shortages, reducing water availability for crop production and increasing the incidence of crop diseases in

Tunisia. Several studies have established that global warming will increase the demand and use of water by crops (Liu et al., 2002). It is also likely that climate change will adversely affect productivity, species composition and quality, with potential effects not only on forage production, but also on other ecological roles of grasslands (Sejian et al., 2015). In all the farming systems, the third most frequently identified climate change-related risk by farmers was disease occurrence. According to Altizer et al. (2013), any major change in climate will influence epidemics of infectious diseases and the routes of infectious transmission.

Our survey showed that farmers were considering adopting a range of practices in order to cope with the threats posed by climate change. An analysis of the survey results highlighted many adaptation strategies (Fig. 4). The farmers noted that climate change affects water availability for forage production and cited it as a reason for making changes to irrigation practices. Practising irrigation is not sustainable for smallholder dairy farmers, however, because they have small or no forage area and, being already poor, would find it harder to pay the additional costs. Two effects of climate change are likely to be reduced pasture availability and an increased need to buy hay in the dryland areas (Harrison et al., 2015). Unlike the other clusters, the most frequently identified strategy cited by farmers in Cluster 1 was the purchase of fodder (Table 4). This difference might be explained by the high need for forage and the high external feed dependence in Cluster 1. On irrigated farms, climate change might have a relatively small impact on forage production and conservation, compared with farms in Clusters 1 and 2. If effectiveness was measured by the ability of an adaptation to alleviate the need to buy fodder, Cluster 4 would appear to be the most beneficial option.

In order to limit the negative effects of high temperature on animals, the farmers surveyed identified various environmental management strategies. Providing cows with access to shady areas was the strategy most often identified by farmers in all clusters (Table 4), because shade is the simplest and cheapest way of reducing the impact of high solar radiation (Renaudeau et al., 2012). Collier et al. (2006) reported improvements in milk yield, reproduction, respiration rate and rectal temperature among shaded dairy cows. The farmers in our study expressed interest in modifying their dairy housing systems (erecting unexposed buildings and looking at such issues as orientation, roof construction and wind breaks). This was among the most frequently identified strategies by Cluster 3 and 4 farmers. Specific design features need to be considered in order to improve the comfort of dairy housing systems and optimize production (Suraj, 2011). Few of the farmers, however, were aware of the benefits of using sprayers, misters, dynamic ventilation and wetting for keeping animals cool. Many studies have reported that applying water directly to the skin of animals and using water spraying alleviates heat stress (Gebremedhin et al., 2010). Increasing air movement by fans in a hot and humid climate reduces rectal temperature, respiration and pulse rates and increases the milk yield of dairy cows (Calamari et al., 1995). Most of these studies have focused on providing artificial shade to cattle and building complex housing structures for reducing heat stress. These measures require huge investments which are beyond the reach of smallholder farmers in Tunisia. They might be appropriate for large farms specializing in milk production, which form the bulk of dairy farms in developed countries, but in Tunisia a high percentage of milk is produced by landless smallholders. Natural shade is more appropriate for these farmers. Trees are an excellent source of shade and, given the choice, cows will generally seek the protection of trees rather than man-made structures (Shearer et al., 1999). In tropical and subtropical climates, the provision of shade might be the most important and economic solution for reducing the effects of high temperatures (Sejian et al., 2015). Some studies have suggested alternatives for smallholder farmers. Verma and Hussain (1988), for example, found that wetting buffaloes before milking increased milk yield. Tunisian farmers are aware that the water requirements of cows increase significantly as temperatures increase and have addressed this by providing drinking water *ad libitum*. In warm climates, a common husbandry practice is to provide an abundant and clean source of drinking water near the feeding area (Sejian et al., 2015). In dairy cattle, milk production lost as a result of heat stress could be recovered through nutritional management (Rhoads et al., 2010). There is growing interest in altering diets in order to improve livestock production under climate change conditions (Shinde and Sejian, 2013). On the Tunisian farms in our study there were some logical and relatively simple alterations in feeding programs aimed at helping animals cope with heat stress. These included providing access to feed only during the fresher periods of the day, which enhanced the ability of animals to cope with heat stress in summer without adversely affecting growth performance (Mader and Davis, 2004). The provision of multiple feedings of fresh feed can encourage frequent feeding and increase daily feed consumption under conditions of heat stress (West, 1999). These feeding management practices are suitable for large specialized farms with the capacity to produce forage, given their large utilized agricultural areas, but are unsuitable for poorer smallholders because of the acute shortage of feed and fodder resources in Tunisia. Other approaches for alleviating heat stress included increasing the proportion of concentrate in diets, which was particularly popular with Cluster 1 farmers. Feeding animals a greater proportion of concentrate at the expense of fibrous ingredients increases ration energy density and reduces heat increment (Knapp and Grummer, 1991). The cost-effectiveness of this strategy, however, is questionable in the context increasing concentrate prices. Highly productive animals are more susceptible to heat stress because of their high metabolic heat production (Wolfenson et al., 2000). The adaptability of different livestock species and breeds to sources of stress varies greatly, with some species, or breeds within species, being more tolerant than others (Sejian et al., 2015). Nevertheless, in their efforts to adapt production systems in order to address the effects of climate change, most Tunisian dairy farmers surveyed chose to adjust farming practices rather than introduce new tolerant breeds or practice genetic improvement for heat tolerance.

5. Conclusions

This study highlighted the diversity of farming systems in Tunisia and provided insights about how the farmers in those systems perceived climate change-related risks and what adaptation strategies they were considering using. The dairy sector in Tunisia was grouped into four milk production systems that differed in terms of land, feed resources, labour and infrastructure. The two main systems were smallholders under zero-grazing conditions and above-ground dairy systems with non-dairy utilized agricultural areas.

All the dairy farmers sought, as a priority, to modify/adapt their current livestock housing infrastructure or to build new ones especially for farmers without livestock housing actually. Other identified strategies related to the storage of forage reserves, the purchase of fodder and the promotion of irrigated areas. Although the climate change-related concerns varied among the farming clusters, in general these concerns were linked to economic rather than climatic factors. There was tendency to focus on short-term environmental modifications rather than longer-term actions, such as choice of livestock breed.

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