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Livestock and Climate Change in North Africa

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Abstract. A growing body of evidence links livestock to climate change (CC). However, a comprehensive analysis is lacking in North Africa (viz. Algeria, Egypt, Libya, Morocco, and Tunisia). Therefore, this paper analyses the dual relationship between livestock and CC in North Africa, drawing upon a systematic review of 32 documents identified in March 2021 through the Web of Science. Most studies focus on CC adaptation while mitigation is generally overlooked. Livestock contribution to greenhouse gas (GHG) emissions depends on livestock species and pastoral systems. Climate change affects livestock productivity, and fodder and feed production. The livelihoods of North African pastoralists are vulnerable to CC because they are largely based on rainfed mixed and pastoral livestock systems. However, livelihood vulnerability depends on pastoral mobility, farm typology and household livelihood assets. Livestock breeders adopted different strategies to adapt to CC such as herd size reduction and livelihoods diversification. Sustainable management of pastures and rangelands can help not only mitigating livestock-related GHG emissions and increasing carbon sequestration but also improving pastures resilience and pastoral communities' adaptation to CC. Research is needed to accommodate the imperative of CC mitigation while ensuring the adaptation of the livelihoods of livestock farmers and pastoralists to the changing climate in North Africa.

Keywords. animal husbandry, pastoralism, pasture, climate change mitigation, climate change adaptation, Maghreb, Mediterranean.

Élevage et changement climatique en Afrique du Nord

***Résumé**. De plus en plus de preuves établissent un lien entre l'élevage et le changement climatique (CC). Cependant, une analyse complète fait défaut en Afrique du Nord (Algérie, Égypte, Libye, Maroc et Tunisie). Par conséquent, cet article analyse la double relation entre l'élevage et le CC en Afrique du Nord, en s'appuyant sur une revue systématique de 32 documents identifiés en mars 2021 via le Web of Science. La plupart des études se concentrent sur l'adaptation au CC tandis que l'atténuation est généralement négligée. La contribution du bétail aux émissions de gaz à effet de serre (GES) dépend des espèces animales et des systèmes pastoraux. Le changement climatique affecte la productivité du bétail et la production de fourrage. Les systèmes de subsistance des pasteurs nord-africains sont vulnérables au CC car ils reposent en grande partie sur des systèmes d'élevage mixtes et pastoraux qui dépendent des précipitations. Cependant, la vulnérabilité des systèmes de subsistance dépend de la mobilité pastorale, de la typologie des exploitations et des moyens des ménages. Les éleveurs ont adopté différentes stratégies pour s'adapter au CC telles que la réduction de la taille des troupeaux et la diversification des moyens de subsistance. La gestion durable des pâturages et des parcours peut aider non seulement à atténuer les émissions de GES liées à l'élevage et à augmenter la séquestration du carbone, mais également à améliorer la résilience des pâturages et l'adaptation des communautés pastorales au CC. La recherche est nécessaire pour répondre à l'impératif de l'atténuation des CC tout en assurant l'adaptation des moyens de subsistance des éleveurs et des pasteurs au changement climatique en Afrique du Nord.*

***Mots-clés**. élevage, pastoralisme, pâturage, atténuation du changement climatique, adaptation au changement climatique, Maghreb, Méditerranée.*

I - Introduction

Livestock production plays a central role in the social, economic and environmental sustainability of agri-food systems and results essential in the implementation of the 2030 Agenda for Sustainable Development and the Sustainable Development Goals (SDGs) (FAO, 2018a, 2018b; Serra Prieto et al., 2019). Indeed, livestock production has strong linkages with, among others, SDG 1 (No poverty), SDG 2 (Zero hunger), SDG 6 (Clean water and sanitation), SDG 13 (Climate action) and SDG 15 (Life on land) (FAO, 2018b). Livestock has been one of

the fastest-growing agricultural sectors in developing countries and helped decreasing poverty levels (Loayza & Raddatz, 2010; Robinson et al., 2011). Livestock products contribute significantly to the human diet both in terms of calorie and protein intake (Rosegrant et al., 2009). Furthermore, animal-source foods are very rich in nutrients, high-quality proteins and essential micronutrients, which are difficult to obtain from plant-based foods (Murphy & Allen, 2003). However, the total number of live animals has dramatically increased over the last decades (FAOSTAT, 2021b) with a consequent increase in the use of and pressure on natural resources. Moreover, the livestock sector contributes to biodiversity reduction, deforestation and land degradation (Millennium Ecosystem Assessment, 2005; Steinfeld et al., 2006), but also provides invaluable ecosystem services (FAO, 2018b).

A growing body of literature deals with the relations between climate change and agriculture. Agriculture is a major contributor to climate change through greenhouse gases (GHG) emissions (FAO, 2016; HLPE, 2012). Indeed, agriculture, forestry and other land uses (AFOLU) account for about one-fifth of GHG emissions worldwide (FAO, 2016). The GHG emissions from agriculture in Africa are among the fastest-growing in the world (Tongwane & Moeletsi, 2018). Moreover, agriculture is one of the sectors that are most affected by climate change (FAO, 2016; HLPE, 2012). Therefore, agriculture is central both for climate change mitigation and adaptation (FAO, 2016; Torquebiau, 2017). However, the literature on the relations between climate change and agriculture generally overlooks livestock, especially in developing countries (Gautier et al., 2016). The livestock sector contributes significantly to climate change through direct GHG emissions, from manure and enteric fermentation (Gerber et al., 2013; Hickman et al., 2011; Tongwane & Moeletsi, 2018). Moreover, climate change has direct and indirect effects on livestock (FAO, 2018a). Climate change also affects the livelihoods of pastoralists and their food security (Davies et al., 2014; Rivera-Ferre & López-i-Gelats, 2012).

The Mediterranean (cf. North Africa, Near East, Southern Europe and Balkans) is one of the most affected regions by climate change (MedECC, 2019). Data from FAOSTAT show that the region of North Africa has an important livestock flock that is dominated by sheep. Permanent meadows and pastures represent one of the most important land users in the region. Indeed, the share of land under permanent meadows and pastures in land area ranges from 7.56% in Libya to 47.05% in Morocco; while its share in agricultural land ranges from 48.75% in Tunisia to 86.64% in Libya (Table 1). These elements make it clear that livestock has a central role to play both in climate change mitigation (e.g. pasture management affecting GHG emissions) and adaptation (e.g. impacts of climate change on pastoral communities' livelihoods). Research and sound data are essential to elucidate such multifaceted relations. Therefore, this paper analyses research on the relationship between livestock and climate change in North Africa. In particular, it addresses both climate change mitigation and adaptation by analysing the contribution of the livestock to climate change in terms of GHG emissions as well as the adaptation of the North African livestock breeders and pastoral communities to the changing climate.

Table 1. Live animals, pasture and permanent meadows in North African countries.

Items	**Livestock (head) - 2019**				**Share of land under permanent meadows and pastures - 2018**	
	Camels	Cattle	Goats	Sheep	In Agricultural land (%)	In Land area (%)
Algeria	416,519	1,780,591	4,986,116	29,428,929	79.41	13.79
Egypt	119,885	4,898,893	3,462,740	5,132,106	NA	NA
Libya	66,667	229,890	2,663,801	7,562,220	86.64	7.56
Morocco	60,808	3,328,000	5,993,000	21,591,000	69.84	47.05
Tunisia	237,516	645,125	1,163,281	6,370,844	48.75	30.57
Source	FAOSTAT (2021b)				FAOSTAT (2021a)	

NA: No available data.

II - Methods

The paper draws upon a systematic review of all documents (journal articles, book chapters, conference articles) indexed in the Web of Science (WoS). A search was performed on 31 March 2021 using the search query: *(livestock OR animal OR cattle OR sheep OR goat OR camel OR pastoralism OR grazing OR rangeland OR pasture) AND ({climate change} OR "climate variability" OR "global warming" OR "greenhouse gas" OR GHG) AND ("North* Africa" OR Maghreb OR "South* Mediterranean" OR Algeria OR Egypt OR Libya OR Morocco OR Tunisia)*. The search on WoS yielded 229 documents. Two eligibility criteria were considered: geographical coverage (viz. dealing with at least one of the North African countries) and thematic focus (viz. addressing both livestock and climate change). Following the scrutiny of titles, abstracts and full-texts, 197 documents were excluded. Therefore, 32 research articles were included in the systematic review (Table 2).

Table 2. List of the selected documents.

Year	Number	References
2021	1	Aribi and Sghaier (2021)
2020	2	Yawson (2020); Znaidi et al. (2020)
2019	2	Ouled Belgacem et al. (2019); Rouabhi et al. (2019)
2018	4	Amamou et al. (2018); Petit and Boujenane (2018); Semara et al. (2018); Souissi et al. (2018)
2017	2	Ibidhi et al. (2017); Lazarev (2017)
2016	3	Dadamouny and Schnittler (2016); Jaber et al. (2016); Martin et al. (2016)
2015	5	Arabi et al. (2015); El Shaer (2015a); El Shaer (2015b); McCarl et al. (2015); Müller et al. (2015)
2013	4	Annicchiarico et al. (2013); Daoudi et al. (2013); Frenette-Dussault et al. (2013); Ouled Belgacem and Louhaichi (2013)
2012	1	Freier et al. (2012)
2011	4	Annicchiarico et al. (2011a); Annicchiarico et al. (2011b); Freier et al. (2011); Gamoun et al. (2011)
2008	2	Herrero et al. (2008); Thomas (2008)
2003	1	Wellens (2003)
1999	1	Parish and Funnell (1999)

* As of 31 March 2021

III - Results and Discussion

The analysis of the geography of research shows that not the same attention is devoted to the nexus between livestock and climate change in all North African countries (Table 3). Indeed, the highest number of the selected studies was performed in Tunisia, followed by Morocco, Algeria then Egypt. This is rather surprising considering that Egypt is the most populous country in the region with an important research system but rather understandable considering the low share of pastures and rangelands in the country's land. In the meantime, there is no study on the livestock-climate change nexus in Libya, which indicates a huge research gap in the country. This result might be due to the low importance of the livestock sector in the Libyan GDP as well as the unrest situation in the country. Moreover, there is no single article that addresses the relationship between livestock and climate change in the whole of North Africa but there are some multi-country studies (Lazarev, 2017). There are some Africa-wide studies; for example, Herrero et al. (2008) analyse the methane emissions from cattle, goats and sheep from 2000 to 2030 across African regions (East, West, Southern, Central and North Africa, and Horn of Africa). Further articles have a more Mediterranean or global perspective. For instance, Annicchiarico et al. (2013) analyse optimal forage grass germplasm for drought-prone

environments in different Mediterranean countries (viz. Algeria, France, Italy, Morocco and Portugal).

Only a few of the selected articles addresses the contribution of livestock to GHG in North Africa. As in many other regions, livestock has a significant contribution to GHG emissions. Ibidhi et al. (2017) show that regardless of the pastoral system (viz. pastoral system using barley, agro-pastoral system using cereal crop-residues, or agro-pastoral system using barley), sheep meat (28 CO_2-eq/kg) has a higher carbon footprint than chicken meat (3 CO_2-eq/kg) in Tunisia. Among the three pastoral systems, the agro-pastoral system using cereal crop-residues has the highest carbon footprint. In their analysis of methane emissions from African domestic ruminants (viz. cattle, goats and sheep) from 2000 to 2030, Herrero et al. (2008) put that emissions per tropical livestock unit (TLU, 250 kg bodyweight) can vary from 21 to 40 kg per TLU and per year, depending on the production system (emissions being higher in mixed crop-livestock systems than in pastoral systems) and the region (emissions being higher in the Horn of Africa, West and East Africa than in North Africa). The literature also analyses strategies to mitigate GHG emissions from livestock. These include the management of pastures and rangelands. The use of land as pasture decreases its carbon stocks as well as its capacity to sequester organic carbon (Znaidi et al., 2020). The literature also shows the intricate global connections when it comes to climate change. For instance, Yawson (2020) shows that the projected impacts of climate change as well as climate mitigation policies in the UK (cf. Global North) can reduce the land area for barley and create large deficits in supply with a consequent decrease in feed barley exports to Algeria and Tunisia (cf. Global South), which rely on feed barley supply from the UK and Europe, thus increasing their vulnerabilities. Therefore, it is important to combine climate change mitigation with climate justice in order to avoid negative side-effects and externalities.

Table 3. North African countries where research was performed.

Country or region	Number of documents	References
Algeria	4	Arabi et al. (2015); Daoudi et al. (2013); Rouabhi et al. (2019); Semara et al. (2018)
Egypt	3	Dadamouny and Schnittler (2016); El Shaer (2015a); McCarl et al. (2015)
Morocco	7	Freier et al. (2011); Freier et al. (2012); Frenette-Dussault et al. (2013); Martin et al. (2016); Müller et al. (2015); Parish and Funnell (1999); Petit and Boujenane (2018)
Tunisia	8	Amamou et al. (2018); Aribi and Sghaier (2021); Gamoun et al. (2011); Ibidhi et al. (2017); Ouled Belgacem et al. (2019); Souissi et al. (2018); Wellens (2003); Znaidi et al. (2020)
North Africa*	1	Lazarev (2017)
Africa**	1	Herrero et al. (2008)
Global***	8	Annicchiarico et al. (2013); Annicchiarico et al. (2011a); Annicchiarico et al. (2011b); El Shaer (2015b); Jaber et al. (2016); Ouled Belgacem and Louhaichi (2013); Thomas (2008); Yawson (2020)

* This category includes documents dealing with at least two countries from North Africa.
** This category includes documents addressing at least a North African country and another one from Sub-Saharan Africa.
** This category includes documents dealing with at least another country outside Africa.

The analysed literature addresses the effects of climate change on livestock across North Africa as well as adaptation strategies. The impacts of climate change on livestock are both direct and indirect. Direct impacts regard the effects on livestock productivity/performance (Amamou et al., 2018; McCarl et al., 2015). Amamou et al. (2018) argue that the greatest impact of climate change in Tunisia would be on cattle performance. In the Middle East and North Africa (MENA) region, El Shaer (2015b) postulates that "*Grasslands, livestock, and water resources are likely to be most vulnerable to climate change in the region because they are located mostly in marginal areas*" (p. 7). Indirect impacts concern the effects of climate change on the production of fodder and feed as well as on pastures and rangelands. In fact, climate change affects feed

and fodder quantity and quality (Amamou et al., 2018; Annicchiarico et al., 2013; Annicchiarico et al., 2011a; Arabi et al., 2015; Wellens, 2003). Gamoun et al. (2011) found that plant cover, richness, and diversity in arid communal rangeland in southern Tunisia changes with soil and rainfall variations. Amamou et al. (2018) suggest that climate change will affect forage production in Tunisia. The vulnerability of rangeland plant species to climate change changes from a species to another depending, among others, on how broad are ecological niches and species palatability (Ouled Belgacem & Louhaichi, 2013). Referring to the arid steppes of eastern Morocco, Frenette-Dussault et al. (2013) suggest that the "*effects of climate change will strongly modify plant community structure in arid steppes, possibly accentuating the process of desertification, and reducing the pastoral value of the vegetation*". The sustainable management of rangelands is important not only to mitigate GHG emissions but also to improve their resilience and adaptation to climate change, especially in arid environments, such as those of North Africa (Ouled Belgacem et al., 2019).

The literature also addresses the measures and strategies for the adaptation of livestock and pastoral communities to the changing climate. The adaptation of livestock to climate changes from a breed to another. For instance, Petit and Boujenane (2018) show that Timahdite and D'man sheep breeds are more adapted to rainfall change and temperature variation, respectively, in Morocco. In this context, some articles deal with the perceptions of herders and pastoral communities about climate change and variability (Amamou et al., 2018). The same authors put that almost all the surveyed Tunisian dairy farmers perceived the impact of climate change on their farms. Many scholars highlight the vulnerability of the livelihoods of pastoralists and livestock breeders to climate change in North Africa (Aribi & Sghaier, 2021; Daoudi et al., 2013; Martin et al., 2016; Thomas, 2008). Referring to the Arab region, Jaber et al. (2016) argue that "*local livestock production is largely based on rainfed mixed and pastoral livestock systems making it vulnerable to the effects of climate change and water scarcity*" (p. 899). Souissi et al. (2018) assume that 55% of the farms in Tunisia are resilient to climate change as "*They are diversified and mostly grow cereals, vegetables, and forage crops combined with livestock, increasing their capability to mitigate climate change by reorganizing crop activities*" (p. 637). However, livelihood vulnerability is moderated by many factors such as farm typology (Amamou et al., 2018), degree of reliance on family labour (Aribi & Sghaier, 2021), and household livelihood assets (Daoudi et al., 2013). Depending on the pastoral household characteristics, climate change interacts with numerous other endogenous and exogenous sources of variability in determining the level of livelihood vulnerability/security such as income needs and pastoral mobility level (Martin et al., 2016).

Livestock breeders have adopted different strategies to adapt to climate change (Amamou et al., 2018; Daoudi et al., 2013). Tunisian dairy farmers focus on increasing water availability for livestock and crop production, and improving livestock housing conditions (Amamou et al., 2018). Another strategy to cope with climate risk consists in providing livestock with supplementary fodder but this supplementation might result in overstocking and rangeland degradation (Müller et al., 2015). Semara et al. (2018) found that strategies adopted by cattle farmers in Setif (Algeria) to adapt to climate change include the reduction in the herd size. However, the diversity of the livestock farming systems can be among the strategies put in place to adapt to climate change. For instance, referring to the region of Setif (Algeria), Rouabhi et al. (2019) put that "*The main changes in agricultural activities for adapting to climate constraint were a reduction of areas devoted to rainfed crops (cereals) and the adoption of an intensive farming system based on poultry, cattle breeding and intensive crops*" (p. 79). Adaptation strategies can also simply encompass moving from a pastoralism system to another. Freier et al. (2012) show that future livelihood strategies of transhumant pastoralists in semi-arid Morocco include 'sedentarity' and localized pastoralism. Proposals from scholars for improving the adaptation of herders and pastoralists to climate change range from promoting livelihoods diversification and resilience to establishing climate warning systems (Table 4).

Table 4. Proposals for improving the adaptation of livestock breeders and pastoralists to climate change in North Africa.

Adaptation measure	Reference
Providing direct aid to the most affected households	Aribi and Sghaier (2021)
Payment for environmental services (e.g. carbon sequestration) in rangelands	Thomas (2008)
Sustaining households' livelihoods diversification	Aribi and Sghaier (2021) El Shaer (2015a) Thomas (2008)
Developing alternative production and management systems	El Shaer (2015b) Thomas (2008)
Breeding of more drought and heat tolerant germplasm	Thomas (2008)
Reintroducing traditional grazing systems practices for improving rangelands	Ouled Belgacem et al. (2019)
Promoting participatory and inclusive governance systems at grassroots community's level	Lazarev (2017)
Developing early warning systems for climate extremes	Aribi and Sghaier (2021) Thomas (2008)

IV - Conclusions

This paper provides a comprehensive review of the dual relationship between livestock and CC in North Africa. The geography of the research suggests that most studies have been carried out in Tunisia and Morocco. Meanwhile, the analysis of the selected documents shows that most studies focus on CC adaptation while CC mitigation is generally overlooked. The livestock sector has a significant contribution to GHG emissions, especially methane. However, emissions depend, inter alia, on livestock species and pastoral systems. Sustainable management of pastures and rangelands can help mitigating livestock-related GHG emissions. The analysed literature addresses the effects of CC on livestock across North Africa as well as adaptation strategies. The impacts of CC on livestock are both direct and indirect. Direct impacts regard effects on livestock productivity/performance. The adaptation of livestock to CC changes from a breed to another. Indirect impacts concern the effects of CC on the production of fodder and feed as well as on pastures and rangelands. Grasslands and livestock are vulnerable to CC because they are located mostly in marginal areas. CC affects feed and fodder quantity and quality. However, the vulnerability of rangeland plant species to CC changes from a species to another. The effects of CC will likely modify plant community structure and affect the pastoral value of the vegetation in arid and semi-arid rangelands. The literature also addresses the measures and strategies for the adaptation of livestock and pastoral communities to the changing climate. The livelihoods of North African pastoralists and livestock breeders are vulnerable to CC because they are largely based on rainfed mixed and pastoral livestock systems. However, livelihood vulnerability depends on pastoral mobility and is moderated by many factors such as farm typology and household livelihood assets. Livestock breeders have adopted different strategies to adapt to CC such as the reduction in the herd size and the diversification of livelihoods. Given the high vulnerability of North Africa to the adverse impacts of CC, the main focus of the current research is on CC adaptation and resilience. Strategies for CC mitigation and adaptation in the North African livestock sector need to be contextualized and to take into account the diversity of livestock farming systems in the region to achieve effectiveness, efficacy and sustainability. It is important to promote sustainable grassland-based, extensive livestock systems while improving ecosystem services in North Africa. The article suggests that climate mitigation policies should also consider the uneven impacts of CC on the livelihoods of rural communities in North Africa.

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