Research Paper

The Kordofan melon and pastoralist water strategy in Sudan: Potential for climate change adaptation and sustainable livelihoods

By Hussein M. Sulieman and Maryam Niamir-Fuller

On the Ground

- The traditional cultivation of wild melon varieties to feed and water animals during the dry season has proven to be economically sound and environmentally sustainable.
- The practice is an example of mutual benefit and cooperation between settled agropastoral communities and mobile transhumant pastoralists.
- Although the practice of cultivating local melon varieties to feed animals appears to be currently thriving, it might become endangered in the future because of the introduction of mechanization of crop farming as well as the increasing cultivation of hybrid melons that have brought new pests and diseases.

Keywords: Climate change, Pastoralism, Watering livestock, Wild watermelon.

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Background

Significance of pastoralism

Pastoralism in Sudan was practiced long ago by the Beja tribes of the Red Sea and the people of the Butana region during Merotic times (ca. 540 BCE–350 CE), but it is believed to have spread to many parts of the Sudan after the 10th century CE, when the Arabs began to enter the Sudan in large numbers.[1] The Kordofan area in Sudan consists of North, West, and South Kordofan States (Fig. 1). Mobile pastoralists dominate in the drier areas. Elsewhere, the populations are fully or partially settled (crop farmers and agropastoralists, respectively). However, all pastoralists will cultivate when necessary for additional cash income or to produce supplemental feed.

Pastoralism occupies an important place in the cultural and economic life of the Sudan. According to official statistics, in 1955–1956, pastoralists in Sudan constituted about 14% of the total population, but by 1973, this number fell to 11%. However, it is generally believed that pastoralists were underenumerated in 1955–1956 and the 1973 censuses.[1] In 1997, the total population of the three combined States of the Kordofan area was 3.6 million,[1] and in 2008 this number increased to 4.3 million.[2] It is not known what percentage of this population was settled agropastoralist compared to mobile pastoralist.[2]

The primary owners of livestock in Sudan are pastoralists and agropastoralists. Livestock contributes to about 60% of the agricultural gross domestic product (GDP) of Sudan and about 25% of the national GDP.[3] The total number of livestock in 1974 was estimated at 40 million heads of animal,[1] which increased to 109 million in 2019 and consisted of about 31 million cattle, 40 million sheep, 32 million goats, and 4.9 million camels.[4] In 2010, North Kordofan was estimated to have about 37% of the national livestock.[5]

Rainfall variability and unpredictability impacts the income balance from year to year among cereal crops, livestock, cash crops, and nontimber products (mostly gum Arabic from *Acacia senegal* and fruits from *Ziziphus spina-christi* and *Balanites ægyptiaca*). But not all impacts can be attributed to rainfall variability. The area is well connected to the north–south trade routes and to urban centers and is subject to national economic stresses. For example, in 1997, when millet production was high, people had less cash for food purchases due to low prices for the main cash crops and for gum Arabic and livestock. This has been linked to domestic recession and reduced export earnings, which caused depressed demand for these cash sources.[6]

Pastoralists raise mostly camels, sheep, and goats. Forty percent of Sudan's camel exports came from Dar Kababish in 1964, and the Kababish were by far the largest producers of

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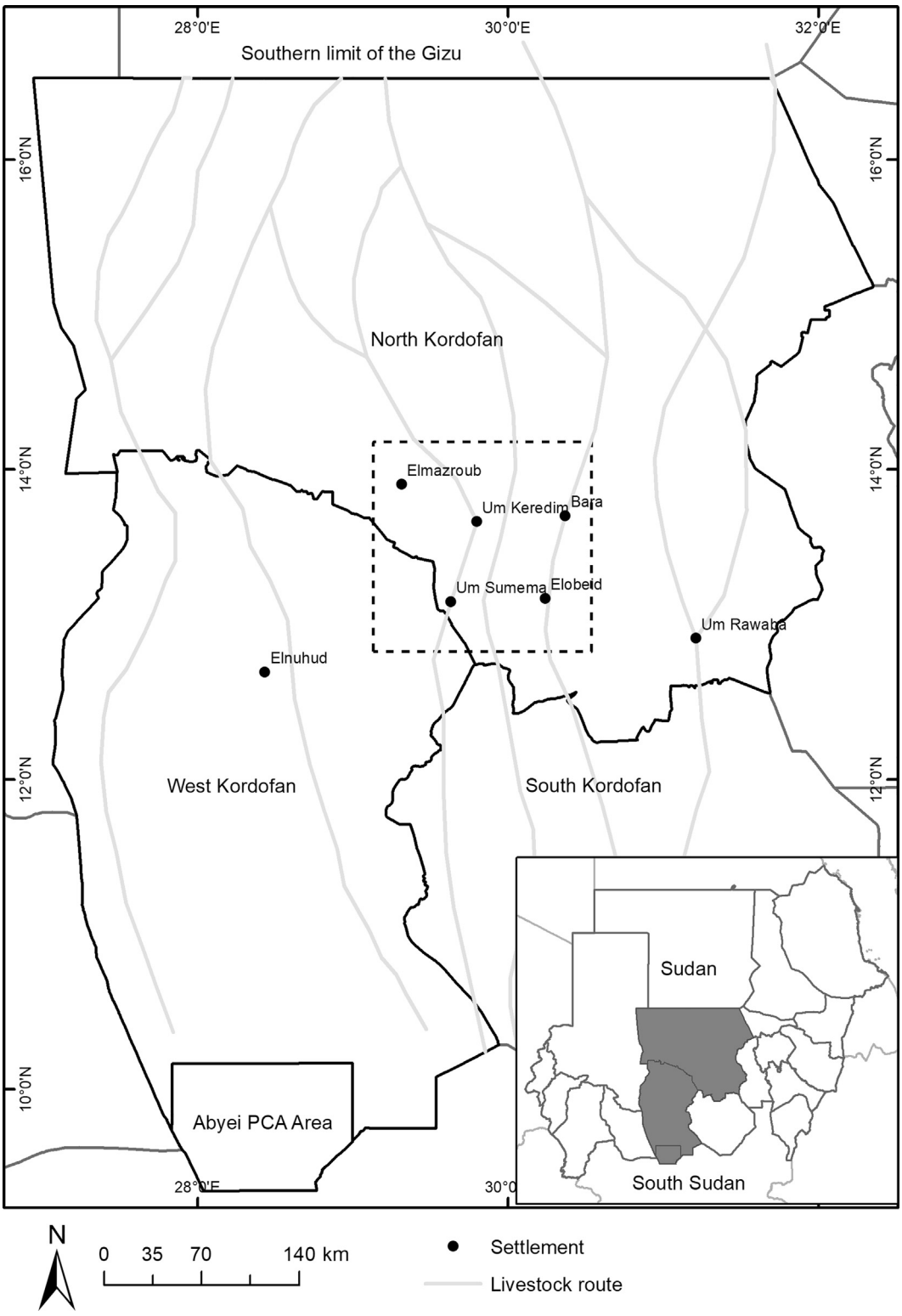

Figure 1. Study area map showing the southern limit of the gizu, major livestock transhumance routes (gray lines), settlements (black dots), and the regions of North and West Kordofan. Satellite Precipitation Estimate data (Figs. 3 and 4) were collected for the dashed area in the center. Inset map indicates the location of the study area within Sudan.

camels.[6] But currently the most exported type of animal from Sudan is sheep; since 2000 the export of sheep and mutton has increased about threefold.[3]

Wet-season transhumance grazing is centered on rain-fed pools found in the northern rangelands, including in the gizu, which stretches across North Kordofan, North Darfur, and northern states. Dry-season grazing is mostly in the central and southern parts of North Kordofan State and is centered on permanent wells that are either traditional hand-dug or boreholes established by the government. This mobility is a

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response to climate variability as well to distribute the pressure on grazing resources.[7]

The gizu is a remarkable form of ephemeral vegetation excellent for grazing with high moisture content for both wildlife, such as oryx (*Oryx gazella*) and Soemmerling's gazelle (*Nanger soemmerringii*), and livestock. The gizu vegetation appears at irregular intervals and locations in northern drier areas of North Kordofan and North Darfur and in the Sahara Desert and is influenced by dew and ambient moisture. It can support animals for 3 months and, sometimes more, without the need for water. Livestock are taken to the gizu mainly for fattening. Grazing in the gizu leads to good nutritional status, high birth rates, earlier onset of puberty, little if any livestock disease, reduced cost of animal feeding and watering, and better general security conditions (e.g., livestock looting, farmer–herder conflict).[7]

Development policies for pastoral areas have either had single-sector objectives (i.e., water and livestock vaccinations) or been a complete reinvention of pastoral economies based on negative perceptions of pastoralism, such as "the cattle complex" or pastoralists are "backward and irrational people." Financially, the Sudanese government spending on the livestock sector was only 0.65% from 1960 to1970, but by 1983, it had increased to 13.0%. This is in stark contrast to the contribution of livestock to the GDP of Sudan.[8]

Animal vaccination campaigns, the first of which started in Darfur in 1947, were not accompanied by policy measures to encourage marketing and offtake of surplus animals, which led to rangeland degradation.[9] Policies promoting group ranching among the Baggara of Southern Kordofan have failed to provide economic security to pastoralists because the person-to-land ratio was drastically lower than the traditional mobile livestock system, which had led to income inequality, out-migration, and unemployment.[10] Similarly, policies to settle pastoralists led to environmental degradation in Darfur and Kordofan.[10]

In recent years, and especially after Sudan lost the revenue from petroleum with the secession of South Sudan from Sudan in 2011, the contribution of the livestock sector to the national economy has increased to around 25% of the GDP.[11] Consequently, livestock production, which continues to be done primarily by pastoralists, is gaining more national attention. However, this attention is focusing on livestock and not on pastoralists and their pastoral production system.[11] The aim of the 2007–2011 National Strategy Plan was to increase the Sudan's agricultural exports, including livestock, through modernization of the agricultural sector.[12] However, this was mainly viewed as the introduction of new breeds, land privatization, and adoption of settled mixed farming, to increase incentives for pastoralists to settle.[11]

Water management

Water is a limiting factor in pastoral areas, and the choice of technology has historically determined not only ownership but also grazing pressure. Rain-fed pools are mostly ephemeral (except for a few notable lakes in southern North Kordofan) and their use is opportunistic. Traditional hand-dug wells are complex to construct and require skilled knowledge, such as the wells dug in sandy areas lined from the top downward with roots and branches of Sidr trees (*Ziziphus spina-christi*) or similar species. Tribes such as the Hamar hollowed trunks of Tebeldi (*Adansonia digitata*) to store water for the dry season.[13] Plastic water bladders and containers have become ubiquitous in the past 2 decades, which pastoralists have traditionally used to transport water in North Kordofan to areas with no reliable local supply. The cultivation of wild cultivars of watermelon (i.e., melon; *Citrillus lanatus*)[14] is another traditional water-storage technology and the focus of our article. These natural and traditional sources of water for livestock are decentralized and help to spread grazing pressure across the rangeland.

The introduction of modern boreholes in Sudan dates back to 1918 and led to centralization of water resources. Successive governments have focused on borehole construction to meet the health and production requirements of the human and livestock population. However, boreholes attract more people, animals, and settlements than the ecosystem can support and have led to land degradation.[12,15] This phenomenon has also been observed elsewhere in Africa.[16] With climate change, the negative impacts from stable and centralized boreholes will only increase.

Pastoralists in Sudan are not strangers to community-based laws and regulations for rangeland and water use. Records of the 17th century show that Sultan Dali's laws and regulations were perhaps the best example of codes passed and enforced with the intention of protecting natural resources in Darfur.[13] The powers of traditional leadership were intended to regulate the use of the environment and to prevent its destruction. The 1932 Forest Ordinance gave traditional leadership the right to arrest any person reasonably suspected of having been involved in a forest offense.[17] In annual tribal conferences, many problems related to tribal boundaries, nomadic migration routes, water supply, and grazing appropriation were settled, in addition to trying theft, unpaid rent, unpaid taxes, and deliberate setting of wildfires.[13]

However, the 1971 People's Local Government Act weakened the authority of lower government levels, creating a vacuum for the supervision of resource use according to both laws and traditional customs. The power to protect and guide annual use, punish, or arbitrate vanished, with the end result that competition and conflict have increased.[13] Agricultural development projects in the 1970s and 1980s largely focused on enhancing production of cereals and cash crops with mechanization and little integration of livestock issues. Agropastoralists became dissatisfied, which led to a survey of the Shukriya people in Eastern Sudan who expected to benefit from two such schemes that showed 46% of respondents preferred not to have government involvement in livestock development.[18] Such sectoral schemes have the potential to weaken the traditional crop–livestock interface.

Despite these changes, the cultivation of wild melon endures today as a traditional cooperative practice between pastoralists and settled farmers. It reflects other traditional prac-

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tices of mutualism between farmer and pastoralist, such as the Fulani practice of grazing livestock on crop stubble after a harvest, both for animal fodder as well as depositing manure for soil fertilization.[19] *C. lanatus* is an annual species that occurs in cultivated, semidomesticated or wild forms and is widely distributed in tropical and subtropical areas of Africa.[20]

Our premise is that the cooperative practice of melon cultivation and consumption enhances the adaptive capacity of pastoralists to climate change, while also conserving biodiversity, supplementing rangeland resources, generating income for crop farmers, and sustaining animal health and productivity. It is a traditional rangeland management practice that has endured over centuries, but will it be sustained into the future and, if so, how?

Methodology

Description of study area

Within the three Kordofan States, the two main melon-producing areas are North and West Kordofan States (Fig. 1). Field surveys for our study were conducted in the Um Keredim area in the southern part of North Kordofan State, which is more favorable for cultivation than in the north. Um Keredim was selected because it lacks an adequate permanent water supply during the dry season.

The climate of the area is a typical Sahelian climate characterized by high temperatures and a long dry season. The dominant soil type is sandy soil, and undulating dunes are common in the landscape. The area is typically a semiarid Sahelian ecosystem mostly covered by grasses and scattered trees and shrubs.[21] The grass cover is dominated by annual species such as *Cenchrus biflorus, Schoenefeldia gracilis*, and *Aristida* spp. The woody cover is dominated by *Acacia* such as *tortilis*, *senegal*, and *seyal* var. *seyal*. Other tree species include *Commiphora africana*, *Balanites aegyptiaca*, *Faidherbia albida*, and *Boscia senegalensis*.

The main pastoralist groups that use our study area are the Kababish, Majanin, Kawahla, Bani Jarar, Shanabla, and Dar Hamid. Their transhumance movement takes them on a north–south trajectory, and they pass through the Um Keredim area in June (on their way north) and from November to January (on their way south; Fig. 1). The settled farmers in Um Keredim are Dar Hamid.

Field data collection

Our first survey was conducted in Um Keredim and the surrounding areas during December 2022 to meet farmers cultivating wild melon and other crops. In March 2023, a second field visit was organized to Elobeid, the capital of North Kordofan State, to meet pastoralists benefiting from the wild melon. Since 2023, we have been unable to access our study site because of violence, road closures, and safety concerns. We report our preliminary findings and hope we can collect more data once the situation improves.

In total, we conducted 19 interviews with study participants: 10 with small-scale agropastoralists, 8 with pastoralists, and 1 with a watermelon seed breeder in Elobeid Agricultural Research Station, North Kordofan State. All were from the Dar Hamid tribe. We held a focus group discussion with a group of settled farmers in Um Keredim, and we discussed topics including main livelihood activities practiced by local communities, cropping systems, types of melon cultivated in the area, farming of melons for livestock, dealing with transhumant pastoralists benefiting from melon, and threats facing local melon varieties. Our interviews with pastoralists were conducted in Elobeid livestock market (Fig. 2), and we discussed topics including ethnic background, livestock species raised, annual cycle of mobility, benefits of wild melon for livestock, trends of melon use, and types of deals and agreements between pastoralists and farmers to access melon fields. Although the focus of our study is Um Keredim and Elobeid, we also obtained information from agropastoralists and government officials in other melon-production areas such as Elnuhud and Um Rawaba (Fig. 1).

We used the monthly satellite precipitation estimate data from the Climate Hazards Group Infrared Precipitation with Stations (CHIRPS) version 2.0 dataset[22] to calculate the annual and monthly rainfall averages. The precipitation analysis was conducted in a 150 × 150 km^2 (93.2 × 93.2 square miles)

Figure 2. Elobeid livestock market in North Kordofan, Sudan. Courtesy of H. Sulieman.

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area in which we conducted our field surveys (Fig. 1). The CHIRPS dataset is explicitly designed for monitoring agricultural drought and global environmental change.

Results and Discussion

Climate variability and climate change

Rainfall during the rainy season of April to October is unpredictable and highly variable in Kordofan (Figs. 3 and 4). Even though the long term (1981–2022) is increasing, variation within and across years is apparent. The long-term annual average is 321 mm, with an interannual rainfall coefficient of variation (CV) average of 24%. In 19 of the last 42 years, the total annual rainfall was below the long-term average. Half of these years occurred in the 1980s (Fig. 3). There is high interseasonal rainfall variability, ranging from 17% to 63%, with most of the rain falling in July and August (Fig. 4).

Model projections of climate change for Sudan show substantial warming across the country with a projected increase of temperature between 1.5°C and 3°C, but there is no clear trend in rainfall patterns. The model projections depict both an increase and a decrease with relatively small absolute change. However, large year-to-year rainfall variability is expected.[23] Thus, a twofold impact is predicted; 1) higher temperatures will result in increased evaporation and increased heat stress which will negatively impact water availability, and 2) year-to-year variability in amount and timing of rainfall will increase. Both will negatively impact agricultural production, pastoralist livelihoods, and food security.[24] Pastoralists have lived with uncertainty for ages and have developed

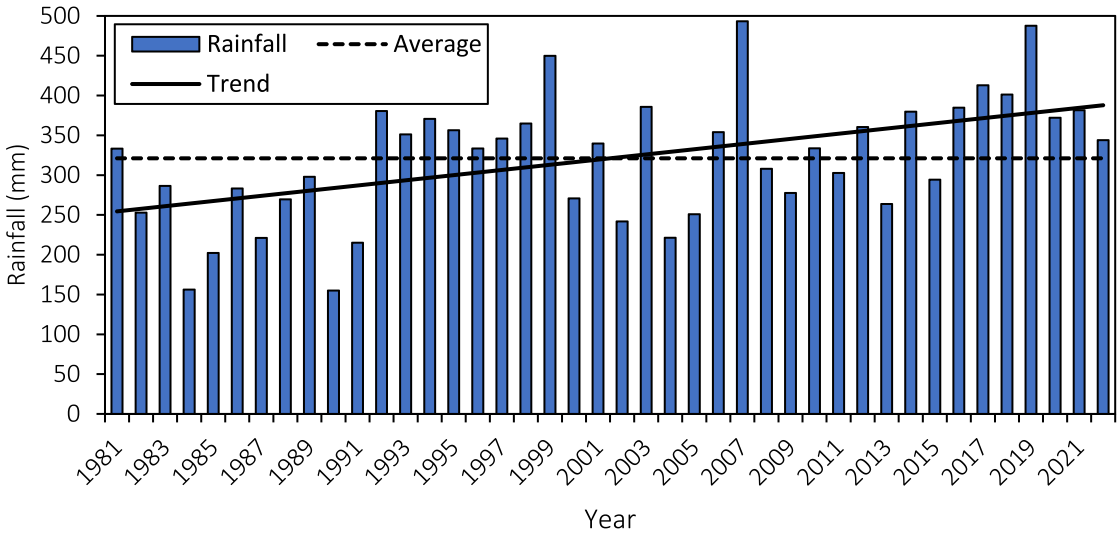

Figure 3. Annual amount, mean, and trend in rainfall from 1981 to 2022 for Kordofan, Sudan. Data source: Climate Hazards Group Infrared Precipitation with Stations (CHIRPS) version 2.0 dataset.[22]

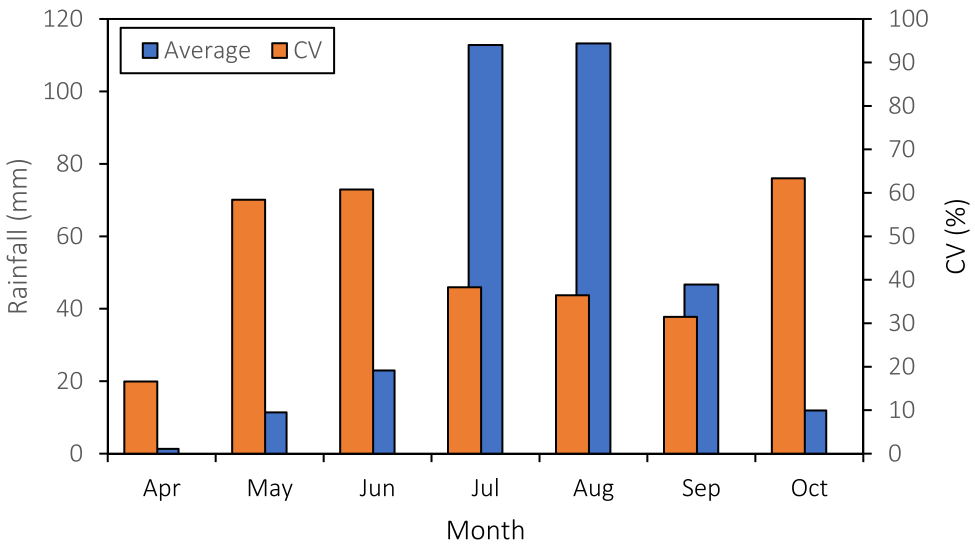

Figure 4. Monthly amount and coefficient in variation (CV) of rainfall from 1981 to 2022 in Kordofan, Sudan. Data source: Climate Hazards Group Infrared Precipitation with Stations (CHIRPS) version 2.0 dataset.[22]

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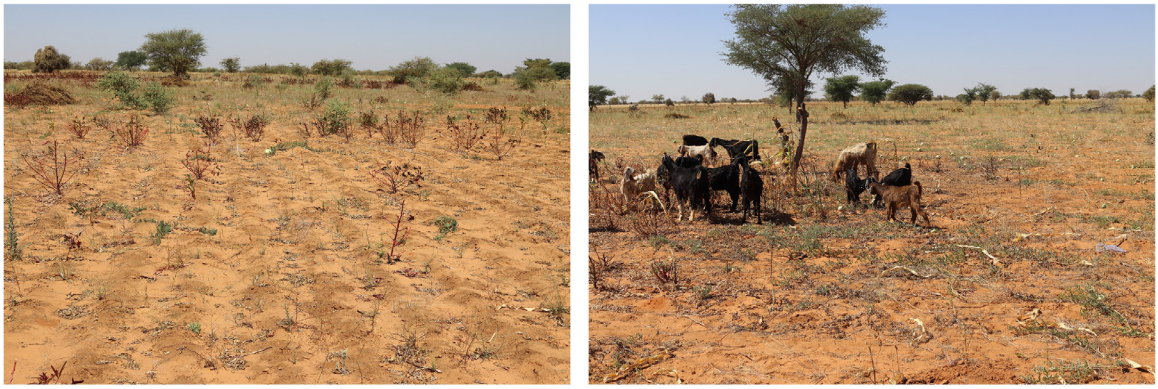

Figure 5. Intercropping with melons, trees, and livestock grazing in an agricultural field in Um Keredim in North Kordofan, Sudan. Courtesy of H. Sulieman.

traditional mechanisms to adapt to it.[25,26] The question is whether their traditional mechanisms, such as feeding wild melons to their livestock, have survived given changes in land use, and whether these mechanisms can continue to maintain the resilience of pastoral livelihoods into the future.

Main livelihood activities

Traditionally the main livelihood activities practiced by the people in North and West Kordofan States were: 1) agropastoralism (i.e., small land holder with rain-fed crop farming and sedentary livestock) and 2) transhumant pastoralism.

Settled agropastoralism — The production system in the Um Keredim area can be described as agro-silvo-pastoral. Rain-fed farming is practiced for subsistence as well as for cash crops. In an average year, cultivation normally starts around June, and harvest is from December to January of the next year. Millet and sorghum are staple crops. Households also grow melon, groundnuts, sesame, hibiscus, and okra. Other minor crops include cowpea, musk melon (*shamam*), and chickpea. These crops are cultivated using a traditional intercropping system, sometimes including the *A. senegal* tree.

The main livestock species raised by agropastoralists are sheep and goats. Animals commonly graze on crop residue and on vegetation in abandoned or fallow cropland (Fig. 5). In a study among agropastoralists to the west of Elobeid, the distance trekked by livestock to water sources almost tripled during drought times (5.5 km in a typical year to 15 km in a dry year).[27] Our study participants confirmed this occurrence and defined a "dry year" as the year when they do not expect their crop harvest and rangeland resources to last until the following rainy season. During a dry year, the distance to grazing sites also increase (5.5 km on average in typical year to 20.4 km in a dry year). Unfortunately, we were unable to gather statistical information on production rates of local melons in dry compared to typical years or whether the availability of local melons for fodder affects the distances traveled in dry years.

Transhumant pastoralism — According to our interviews, pastoralist groups such as the Kababish, Majanin, Kawahla, Bani Jarar, Shanabla, and Dar Hamid benefit from and use the white melon. They are mainly camel breeders, but they also raise sheep and goats. Most family members are partially settled, and the mature male family members are mobile with the herds and flocks. Only among the Shanabla are there completely mobile households. Traditionally, a herder is expected to manage 60–100 camels while on transhumance,[28] a figure confirmed by our study participants. Transhumant pastoralists move much longer distances than agropastoralists.[27] Although the pastoralists also practice rain-fed crop farming, their main source of income is from livestock. The area they cultivate is much smaller compared to agropastoralists, and they cultivate a more limited number of crops, mainly millet and melon.

Mechanized crop farming — In the last 15 years, mechanized crop farming has been introduced in many areas in North and West Kordofan States by wealthier farmers in local communities. As a result, there has been rapid expansion of cultivation into rangeland. The machinery used consists mainly of tractors and ploughers and, in some cases, harvesters and threshers. A recent study revealed that expansion of cultivation is one of the main reasons for natural vegetation clearance in North Kordofan.[29]

Cultivation of melons

There are three main types of melon currently cultivated by farmers across North and West Kordofan States; hybrid varieties imported from abroad since the early 2000s, local varieties with inner red/reddish pulp, and local varieties with inner white pulp. The hybrid melon is typically marketed as a commercial fruit. The local reddish melon is sweet, whereas the white melon is nonbitter, slightly sweet, or tasteless.

The white melon, known botanically as the Kordofan melon, is the closest relative of domesticated watermelons. Iconography of Egyptian tomb paintings indicates watermelon was consumed in Ancient Egypt 4300 years ago, and these archeological records are consistent with the Kordofan melon being a direct progenitor of the cultivated watermelon.[30] *C. lanatus* is native to Africa, Middle East, and South Asia. A variety of *C. lanatus* introduced into Australia is also white fleshed but has a bitter taste and is an invasive species.[31]

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Figure 6. Examples of white melons showing morphological differences. All these white melons were collected in one agricultural field in the Um Keredim study area, North Kordofan, Sudan. Courtesy of H. Sulieman).

C. lanatus may have been originally selected from *Citrullus colocynthis*, a wild relative with rippled green ripening to yellow with very bitter white flesh.[32] Wild crop relatives are imperative resources for breeding and domestication.[30] We found that progenitor populations of Kordofan wild melon still exist in the African Sahel. Those wild melon varieties hold different potential characteristics such as disease resistance alleles compared to domesticated types.[27] This characteristic was also observed by our study participants.

There is no systematic documentation of the geographical extent of local melon cultivation, but it has been recorded in Elodaya in southern Kordofan[33] and is generally known to be widespread in Darfur and the three Kordofan States. The names of these local melons vary by locality, and there is no catalog of the many different varieties of local melons across Kordofan. According to Abdalla et al.,[34] the local melons have a wide range of varieties and differ in several morphological and physiological characteristics (Fig. 6). Farmers typically grow mixtures of these varieties, and it is difficult to differentiate between them due to the high natural cross-pollination

The local red/reddish-fleshed varieties of melons are consumed by local people and are traditionally cultivated by intercropping with millet, sorghum, groundnuts, and hibiscus. Cultivation starts at the onset of the rainy season. Farmers report that local varieties of melon need minimal water compared to other crops. Therefore, they often sow the melon seeds just prior to the rainy season to maximize the benefit from the early showers in April and May.

The local white (sometimes light yellow) fleshed melon is mainly cultivated for seed production and for feeding and watering animals. It has different local names across Kordofan, such as *wed abu aagul*, *kashir*, and *kajerki*. It can be monocropped in fields distant from the villages or intercropped with other seasonal crops or inside *A. senegal* tree gardens. The soil under an *A. senegal* garden has been shown to have twice as much nitrogen and carbon content as adjacent lands.[35] The white melon is normally sown at the same time as other crops or delayed toward the second half of the rainy season after cultivation of other crops is completed. Study participants mentioned that two to three rains are enough to obtain a harvest with many melons, which indicates its adaptability to this region. Participants stated that, in general, the cultivation of white melon is flourishing among agropastoralists and among transhumant pastoralists.

The mechanized cultivation of the hybrid melon varieties started early in the 2000s in Kordofan and is widespread across the entire area. Elnuhud is the most famous area in Kordofan for the commercial production of hybrid melons (Fig. 1). Commercial production is done through monocropping with pesticides. The local white melon is also being grown by wealthy farmers commercially as a large-scale monocrop on farms that can extend to hundreds of hectares (Fig. 7).

Harvest and use of local melons

There can be up to three harvests of both the local reddish and white melons per year. Traditionally, the melons are collected and stored in pyramids near the homestead or under shelters to minimize evapotranspiration (Fig. 8).

In addition to being consumed by the farmers and sold as a whole fruit in local markets, the local melon also has other uses. Records from Kordofan indicate goats graze on

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Figure 7. Large-scale monocropping of white melons in the western Bara area, North Kordofan, Sudan, in 2022. Courtesy of O. Idris.

Figure 8. Local white melons stored inside a homestead in the Um Keredim study area, North Kordofan, Sudan. Courtesy of H. Sulieman.

the leaves of the wild melon, livestock consume the fruit, and in times of famine, people eat the seeds after boiling them.[35] Farmers thresh the fruit to extract the seed and, in this process, use the pulp and outer rind to feed animals, and they collect the water in cans and boil it to become concentrated and consumed as honey. Farmers store the melon's outer rind to feed their animals later in the dry season or even sell it at the local market. The extracted seeds are kept for the next season or sold in local markets. In the past 10 years, a mechanical melon thresher has been introduced to extract the seed and is currently widely used, especially in large-scale commercial melon farming.

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The flesh of the white melon is tasteless and lightly sweet and used primarily to feed and water livestock. Normally, the harvest starts after the end of the rainy season in October and continues until the dry season is over in March the following year. Farmers use the fruits for their own animals and store the surplus to be used later in the dry season when they lack fodder and water for the livestock. Some crop farmers will sell pastoralists an entire melon field, including the melon leaves and vines which are also used for fodder. Depending on their need or which is more profitable, farmers may sell the entire crop to pastoralists, or they may first harvest some melons themselves and then sell the remaining crop to pastoralists. They may also first thresh and sell the seed commercially and then sell the flesh and rind to pastoralists to water and feed their animals. Sometimes the extracted seed is divided between the farmer and the pastoralist based on agreement.

Our interviews with pastoralists provided a record of how pastoralists use the white melon. A pastoralist animal trader from Majanin, who owns a camel herd and sheep flock, said that 5 years ago he moved from his home area in Elmazroub to Um Sumema (Fig. 1) and settled there with his family. He bought some land and now cultivates an area of about 100 ha mainly with white melon, millet, and sorghum. In addition to using the melons he cultivates; he also buys more melon fields from farmers in the neighboring area. He first extracts the melon seed and then feeds the flesh to fatten those animals he wants to sell before taking them to market. He sends the rest of the animals to graze on natural pastures and waters them using a plastic water bladder. This allows him to extend the melon harvest season from October to May of the next year. He uses the profit from the animal trade and from the melon seed to buy more animals and adds them to his herds.

Benefits of melons for pastoralists and their livestock

Study participants stated the practice of feeding and watering livestock on white melons is in their history. All parts of the white melon plant benefit pastoralists: the seeds, pulp, water, and rind of the fruit as well as the leaves and vines. In a focus group discussion, the farmers ranked melon as number three after millet and sesame in terms of importance for their livelihoods. This high importance is due to the wide range of uses and benefits of melon. The most common livestock fed on melons in our study area were sheep and camels. The most important benefit for livestock is the high water content of the melons. From October to March or even May of the following year, pastoralists need water after the ephemeral rivers and ponds created by the rains dry up. In addition to using water from hand-dug wells and permanent boreholes throughout the rangelands, the melon-cultivating zones have traditionally been built into the pastoralists' transhumance routes. The melon's ability to store water so efficiently with minimal evapotranspiration and to be grown dispersed along the grazing routes helps to distribute grazing pressure and avoid land degradation.

With the advent of the threshing machine, the water and pulp of the melon are consumed immediately at the time of the threshing process, and the rind is usually stored for later use in the dry season. After extraction, the seeds are sun dried before being packed in sacks and sent to markets. This practice diminishes the benefit of the melon in distributing grazing pressure throughout the dry season, especially for large-scale farms, because the water and pulp must be consumed quickly rather than stored for later in the dry season.

The white melon is an important fodder resource to fatten animals and improve their health condition. Pastoralist participants regarded the white melon as equally useful as the gizu in many respects. According to their perception, feeding on white melon doubles the animal's weight compared to not feeding on melon. Sheep tend to benefit faster than camels, with on average 3–4 weeks of grazing on melons being enough to fatten sheep for the market. Feeding on melons also doubles milk production of all livestock. In general, the typical pregnancy rate among breeding female camels is about 50% of the herd. Feeding on melon increases this to 100%. The fertility rate among female sheep (i.e., ewes) is high without feeding on melon, but they most often produced twins and triples when fed on melon. Feeding on melons throughout the dry season accelerated the onset of puberty and the age of reproduction for sheep and goats. The perceptions of our participants are yet to be verified because data on animal productivity are not collected by local Extension offices.

The traditional practice of cultivating and harvesting the white melon and other local melon varieties is a means of coping with historical droughts and climate variability. An agropastoralist participant reported that when they believe the year will be dry (e.g., less rain, more erratic rainfall, and late onset of the rainy season), they will increase the area in which melons are grown because it is more drought tolerant. Maintaining this traditional practice can be an important adaptation to climate change. The ability of the locally adapted white melon to grow with minimal rainfall and no pesticides, as compared to hybrid melons and other crops, makes it a veritable example of sustainable agriculture.

Recent trends in cultivating white melons

Investing in white melon cultivation is becoming an attractive business for some pastoralists, especially those oriented toward animal trading. For them, there are two equally important objectives for white melon cultivation: 1) to reduce the cost of watering livestock during the dry season and 2) to fatten their animals before market. In many cases, they own their own farm and buy additional melon harvests (not the land) from other farmers.

An agropastoralist participant in Um Keredim mentioned that some farmers cultivating the white melon for commercial purposes do not wait for pastoralists to arrive in the area. They use a mechanical extractor to extract the seed and sell it at a high price in the market. The seed is processed into different products (e.g., seed cake) and roasted and sold as a snack.

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The areas where currently large-scale mechanized monocropping of hybrid and white melon is practiced were previously excluded from mechanization because the amount of rainfall was too low and erratic for large-scale crop production and the soil too fragile to withstand heavy machinery. These rangelands are suitable for rain-fed small-scale farming. The northern border for mechanized agriculture in North Kordofan defined by law corresponds roughly to 13°N latitude.[36] Nevertheless, mechanized cultivation has expanded beyond this latitude due to high prices in urban markets for melons. The exact area and impact of such expansion is yet to be fully documented. Grazing areas to the west of Elobeid are declining due to this mechanization and access is restricted because of political instability.[27] The loss of natural grazing resources is not fully compensated by the availability of melons, and mechanization is expected to have detrimental impact on the environment in the long term.

Additionally, the increasing cultivation of hybrid melons may be posing a problem. Only 10% of our participants said they plant the hybrid melon in addition to the local varieties, but it is increasing among commercial growers. Therefore, the newly introduced hybrid melon varieties for commercial production might compete with the local types for land area. The shift is primarily due to the high prices hybrid melons can obtain in markets. However, more data from a larger sample size and land use change analysis are needed to explore this further.

According to Abdalla et al.[34] continuous cultivation of the commercial melon varieties has led to some areas in North Kordofan being infested with the melon bug (*Cordinus viduatus*). Although data are limited, there is a risk that the local wild melon varieties might be negatively affected and become extinct in the area.

Conclusions and recommendations

The production and feeding of local white melons appear to be profitable and beneficial traditional practices for pastoralists and agropastoralists in Kordofan. Melon production allows adaptation to climate variability and climate change because it supplements both feed and water for animals during the dry season. The transhumance routes of mobile pastoralists can change flexibly depending on the availability of and productivity of the dispersed melon harvest by farmers practicing small-scale rain-fed cropping. By storing water and feeding efficiently throughout the dry season, this practice helps distribute grazing pressure and thereby reduces the risk of land degradation. The practice is also an example of mutualism and cooperation between settled and mobile peoples.

The exact extent of the practice is yet to be documented but is thought to occur in Darfur and Kordofan. The practice continues to thrive even with the introduction of mechanization and hybrid melons. However, the future of melon production will be determined by at least five factors: 1) whether increasing impacts of global climate change will negatively or positively affect the melon plant and its production; 2) the impacts of the new melon pest brought in with the hybrid melons on the local varieties; 3) increasing large-scale cultivation of rangelands north of the 13°N latitude, resulting in environmental degradation and rangeland conversion; 4) market demands for hybrid vs local varieties of melon, and the relative prices of other supplemental feed and sources of water; and 5) policies affecting the future of pastoralism and agropastoralism in Kordofan.

Our study reports on preliminary documentation of an evolving traditional practice. More research will be needed to verify and confirm many of our observations and findings. In addition, the following areas of further in-depth research can be foreseen:

- Tracing the history of the traditional practice, including better understanding of the process of domestication at the center of origin of the watermelon,
- Better understanding of the nutritional benefits of the melons, and the problems faced by growers, such as postharvest loss,
- Better understanding of the contribution of melon consumption to the seasonal water needs of different species of livestock and its influence on grazing patterns,
- Beneficial environmental impacts of growing local melon varieties, including their value as feed for wildlife and erosion control in sandy dunes,
- Trends in large-scale mechanization and impacts on local melon production,
- Extent of resistance, if any, of local varieties to the melon bug, and sensitivity to water stress, including identifying beneficial genetic traits,
- Cataloging the varieties of the melon, including systematic precautionary ex-situ conservation, given the unclear future of the plant and how it is used, and
- Price differences and elasticity of the different melon varieties locally grown, and profitability, in relation to climate variability.

Declaration of competing interest

The authors declare that they have no conflict of interest.

CRediT authorship contribution statement

Hussein M. Sulieman: Writing – review & editing, Writing – original draft, Methodology, Conceptualization. **Maryam Niamir-Fuller:** Writing – review & editing, Writing – original draft, Methodology, Conceptualization.

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References

1. Khogali MM. *Nomads and Their Sedentarization in the Sudan*. Sudan: United Nations University Workshop at University of Khartoum; 1978. https://archive.unu.edu/unupress/unupbooks/80044e/80044E05.htm. Accessed 9 February 2023.
2. Population Census Council. *5th Sudan Population and Housing Census –2008. Priority Results*. Khartoum, Sudan: The Government of Sudan; 2009.
3. Humphrey AC, Jaquez S, Levine C, Stull-Lane HM, Sulieman S, Wiggins S. *Impacts of Disruptions to Livestock Marketing in Sudan*. UK: Overseas Development Institute; 2021. https://www.sparc-knowledge.org/sites/default/files/documents/resources/impacts-of-disruptions-to-livestock-marketing-in-sudan-final.pdf.
4. Fao. *2019 FAO Crop and Food Supply Assessment Mission to the Sudan: Special Report*. Rome, Italy: FAO; 2020. doi:10.4060/ca7787en.
5. Undp. *Socio-economic and Opportunity Mapping Assessment Report for North Kordofan State*. New York, NY: NSD-DRC NKS-SC/UNDP; 2010. https://www.undp.org/sites/g/files/zskgke326/files/migration/arabstates/report-NKS.pdf.
6. Asad T. Seasonal movements of the Kababish Arabs of northern Kordofan. *Sudan Notes Rec*. 1964; 45:48–58. http://www.jstor.org/stable/41716858. Accessed 9 Feb. 2023.
7. Wilson RT. The 'gizu': winter grazing in the South Libyan desert. *J Arid Environ*. 1978; 1:327–344.
8. Abdel-Ghaffar MA. Planning and the neglect of pastoral nomads in Sudan. In: Haaland G, ed. *Problems of Savannah Development: The Sudan Case*, Department of Social Anthropology, University of Bergen; 1980:19:39–54.
9. Gillespie LA. The nomads of the Sudan and their livestock in the 20th Century. *Sudan J Vet Sci Animal Husb*. 1966; 7(2):13–25.
10. Haaland G. *Problems of Savannah Development: The Sudan Case*. Department of Social Anthropology, University of Bergen, Norway; 1980.
11. Young H, Sulieman HM, Behnke R, Cormack Z. *Pastoralism in Practice: Monitoring Livestock Mobility in Contemporary Sudan*. Feinstein International Center, Tufts University, Boston, MA.; 2013.
12. Government of The Sudan/Ncsp. *The Five Year Plan for Sudan (2007–2011)*. Khartoum, Sudan: National Council for Strategic Planning (NCSP); 2007.
13. El-Arifi SA. *Some Aspects of Local Government and Environmental Management in the Sudan*. United Nations University Workshop at University of Khartoum, Sudan; 1978. https://archive.unu.edu/unupress/unupbooks/80044e/80044E05.htm. Accessed 9 February 2023.
14. Plants of the World online. *Citrullus lanatus* (Thunb.). https://powo.science.kew.org/taxon/urn:lsid:ipni.org:names:291938-1. Accessed 9 February 2023.
15. Mohamed YA. *Impact of Improved Rural Water Supplies on Settlement Distribution in Western Sudan: The Case of East Kordofan and El-Fasher Districts*. United Nations University Workshop at University of Khartoum, Sudan; 1978. https://archive.unu.edu/unupress/unupbooks/80044e/80044E05.htm.
16. Niamir-Fuller M. *Managing Mobility in African Rangelands: The Legitimization of Transhumance*. London, UK: Intermediate Technology Publications; 1999. Accessed from: African Studies Review, Cambridge Core. https://www.cambridge.org/core/journals/african-studies-review/article/abs/maryam-niamirfuller-ed-managing-mobility-in-african-rangelands-the-legitimization-of-transhumance-london-intermediate-technology-publications-1999-xiv-314-bibliography-index-2995-paper/3570749A673ABF1AFE556A26002AFAE4.
17. Government of the Sudan. *Forest Ordinance*. Sudan: Government publishing house; 1932.
18. Abu-Sin MH. *Livestock, Economy and Attitude of Tenants, Rahad and Khashm el-Girba Projects: A Comparative Study*. Khartoum, Sudan: University of Khartoum; 1983.
19. Benoit M. Le chemin des Peul du Boobola. In: *Trav Et Doc*. Paris, France: ORSTOM; 1979:1010.
20. Jeffrey C. Cucurbitaceae. In: Hanelt P, ed. *Mansfeld's Encyclopedia of Agricultural and Horticultural Crops*. Berlin, Germany: Springer; 2001:1510–1557.
21. Olsson K, Rapp A. Dryland Degradation in Central Sudan and Conservation for Survival. *Ambio*. 1991; 20(5):192–195.
22. Funk C, Peterson P, Landsfeld M, et al. The climate hazards infrared precipitation with stations—A new environmental record for monitoring extremes. *Sci Data*. 2015; 2. doi:10.1038/sdata.2015.66.
23. Ipcc. *Fifth Assessment Report of the Intergovernmental Panel on Climate Change*. Climate Change 2013: the Physical Science Basis: contribution of Working Group I. New York, NY: Cambridge University Press; 2013.
24. World Food Programme (Wfp). *Food Security and Climate Change Assessment: The Sudan*; 2016. Rome, Italy: https://www.wfp.org/publications/sudan-food-security-and-climate-change-assessment.
25. Scoones I., ed. *Living with Uncertainty: New Directions in Pastoral Development in Africa*. Rugby, UK: Intermediate Technology Publications; 1995. https://practicalactionpublishing.com/book/1264/Living-with-uncertainty.
26. Scoones I., ed. *Pastoralism, Uncertainty and Development*. Practical Action Publishing; 2023. doi:10.3362/9781788532457.
27. Maryoud AMBM. Agro-pastoralists livestock keeping strategies and their impact on environment in Sahel Zone: a case study of North Kordofan State, Sudan. *Egypt J Environ Change*. 2016; 8(1):19–28.
28. Tubiana M-J, Tubiana J. *The Zaghawa from an Ecological Perspective*. Rotterdam, The Netherlands: Balkema; 1977.
29. Adam HE, Aya Y, Tutu SO, Suliman SM, Mohammed MH, Sahoo UK. Spatio-temporal analysis of land use and land cover changes in Shiekan Locality, North Kordofan State, Sudan, using remote sensing. *Int J Nat Resource Ecol Manage*. 2023; 8(2):49–55.
30. Renner SS, Wu S, Pérez-Escobarc OA, Silbera MV, Fei Z, Chomickie G. A chromosome-level genome of a Kordofan melon illuminates the origin of domesticated watermelons. *Proc Natl Acad Sci*. 2021; 118:1–9.
31. HerbiGuide Australia. Camel melon. http://herbiguide.com.au/Descriptions/hg_Camel_Melon.htm. Accessed 19 September 2022.
32. Plants of the World Online. Kew Royal Botanical Gardens. https://powo.science.kew.org/taxon/urn:lsid:ipni.org:names:291930-1. Accessed 20 September 2022.
33. Mohammed M el HA. *Conventional and Non-Conventional Approaches in Natural Resource Management in the Sudan: The Case of El Odaya*. University of Khartoum; 1990.
34. Abdalla EA, Abdulgalil DF, Magdi AE. *Selection of local watermelon inbred lines with quality standards for the export mar-*

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ket. Sudan: Report of the Variety Release Committee meeting. Khartoum, Sudan: Agricultural Research Corporation, Ministry of Agriculture and Forestry; 2008.
35. Seif el Din AG. *The gum Hashab and land tenure in western Sudan. International Workshop on Land Tenure Issues in Agroforestry*. Nairobi, Kenya: International Center for Research on Agroforestry; 1985.
36. Babiker M. *Communal Land Rights and Peace-Building in North Kordofan: policy and Legislative Challenges. Sudan Working Paper: 3*. Chr. Michelsen Institute, Bergen, Norway; 2008.

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