Typology of production units and livestock technologies for adaptation to drought in Sinaloa, Mexico

Tipología de unidades de producción y tecnologías pecuarias de adaptación a la sequía en Sinaloa, México

Tipologia de unidades de produção e tecnologias pecuárias para adaptação à seca em Sinaloa, México

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Abstract

Drought as an effect of climate change affects the productivity and sustainability of livestock systems. The objective of this study was to analyze how technological land management for adaptation to climate change adopted by livestock farmers in southern Sinaloa, Mexico, corresponds to the typologies identified in the study area. A non-probabilistic sampling was applied, selecting 50 production units (UP) in six municipalities of Sinaloa, whose information was analyzed by cluster analysis and descriptive statistics. It was identified three livestock typologies. Cluster 1 (46 %), was defined as subsistence since its production units (PU) have few animals and showed the smallest total surface area, the producers are the oldest and use the shade in paddocks and the adjustment of stocking rates as drought mitigation practices. Cluster 2 (46 %), showed the medium productive behavior, conformed by younger producers whose PU showed a larger area of crops and rangeland, this group adopted stocking rate adjustment, forage conservation and species diversification as mitigation measures. Cluster 3 (8 %) showed the highest total area, livestock inventory and productivity levels; drought mitigation decisions are focused on stocking rate adjustment and forage conservation. The study identified mitigation practices related to land use from the farmers' point of view. These results can be used to conduct studies in similar environments and to scale adaptation measures for climate change from the local level and by type of farmer.

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Resumen

La sequía como efecto del cambio climático afecta la productividad y sustentabilidad de los sistemas pecuarios. El objetivo de este estudio fue analizar cómo las medidas tecnológicas relacionadas con el uso de la tierra para la adaptación al cambio climático utilizadas por los ganaderos en el sur de Sinaloa, México se corresponden con las tipologías identificadas en la zona de estudio. Se utilizó muestreo no probabilístico seleccionándose 50 unidades de producción (UP) en seis municipios de Sinaloa, cuya información fue analizada por medio de análisis clúster y estadísticas descriptivas. Se identificaron tres tipologías pecuarias. El clúster 1 (46 %), definido como de subsistencia, tiene pocos animales y la menor superficie total, los productores tienen la mayor edad y manejan la sombra en potreros y el ajuste de la carga animal como prácticas de mitigación. El clúster 2 (46 %), de comportamiento productivo medio, son productores jóvenes cuyas UP tienen mayor superficie total para la siembra y agostadero, este grupo utiliza el ajuste de la carga animal, la conservación de forrajes y la diversificación de especies como medidas de mitigación. El clúster 3 (8 %), presenta la mayor superficie, inventario pecuario y niveles de productividad; las decisiones de mitigación a la sequía están centradas en el ajuste de la carga y en la conservación de forrajes. El estudio identificó prácticas de mitigación relacionadas con el uso de la tierra desde la visión de los productores; resultados pueden servir, para realizar estudios en entornos similares y escalar las medidas de adaptación al cambio climático desde lo local y por tipo de productor.

Palabras clave: trópico seco, agostadero, ganadería sostenible, cambio climático.

Resumo

A seca, como efeito das alterações climáticas, afecta a produtividade e a sustentabilidade dos sistemas pecuários. O objetivo deste estudo foi analisar como as medidas tecnológicas relacionadas com o uso do solo para a adaptação às alterações climáticas utilizadas pelos criadores de gado no sul de Sinaloa, México, correspondem às tipologias identificadas na área de estudo. Utilizou-se uma amostragem não probabilística, seleccionando 50 unidades de produção (UP) em seis municípios de Sinaloa, cuja informação foi analisada por meio de análise de clusters e estatística descritiva. Foram identificadas três tipologias de gado. O cluster 1 (46 %), definido como de subsistência, tem poucos animais e a menor área total, os produtores são os mais velhos e utilizam a sombra nos piquetes e o ajuste das taxas de lotação como práticas de mitigação. O cluster 2 (46 %), de comportamento produtivo médio, é constituído por produtores jovens cujas UP têm maior área total para sementeira e pastagem, este grupo utiliza como medidas de mitigação o ajustamento do encabeçamento, a conservação de forragens e a diversificação de espécies. O cluster 3 (8 %) tem a área mais elevada, o inventário de gado e os níveis de produtividade; as decisões de mitigação da seca centram-se no ajustamento da taxa de povoamento e na conservação da forragem. O estudo identificou práticas de atenuação relacionadas com a utilização dos solos na perspetiva dos agricultores; os resultados podem ser utilizados para realizar estudos em ambientes semelhantes e para aumentar as medidas de adaptação às alterações climáticas a nível local e por tipo de agricultor.

Palavras chave: trópico seco, pastagens, pecuária sustentável, mudanças climáticas.

Introduction

Droughts are recognized as an environmental disasters and occur in almost all climate zones, both in areas with high and low rainfall, and are primarily related to the reduction in the amount of precipitation received over a prolonged period, such as a season or a year. (Mishra and Singh, 2010). Globally, the projected effects of climate change (CC), including higher temperatures, increased concentrations of carbon dioxide (CO_2) in the atmosphere, and changing rainfall patterns, will affect the seasonal growth of pastures and livestock production (Cullen *et al*., 2021). By 2100, CC will reduce grass growth, which will affect annual meat and milk production, causing a decline up to 24.9 % (Tapasco *et al*., 2019).

Drought has immediate effects on livestock, including depletion of water resources, crop failure and an increase in food prices, health effects, decreased production and death, in addition to a decrease in prices of livestock prices (Girma and Zelalem, 2022). In Mexico, the states with the highest general degree of vulnerability to drought are especially those located in the northwest (Baja California, Baja California Sur, Sonora and Sinaloa), as well as the north and some in the south of the country (Ortega-Gaucin *et al*., 2018).

Livestock deaths have been observed from climate-induced impacts such as recurrent droughts, which negatively affect the livelihood security of farmers, pastoral and agropastoral communities are particularly vulnerable to climate variability and changes due to their dependence on livestock for food and sustenance (Habte *et al*., 2022). In Sinaloa, livestock farming is associated with dry tropics conditions, which reflects seasonal changes in climate between the dry and wet seasons in relation to the availability of moisture, there may be up to eight months of drought a year in the north of the state (Cuevas-Reyes and Rosales-Nieto, 2018).

The transition process from traditional extensive livestock farming to sustainable livestock farming requires carrying out evaluations related to the use of adaptation and mitigation measures specific to the location and production system, in addition to policies that support and facilitate their implementation (Rojas-Downing *et al*., 2017).

Several studies have proposed adaptation and mitigation measures in the livestock sector (Gerber *et al*., 2013; FAO, 2018; Tapasco *et al*., 2019). However, in Mexico, there is limited information regarding the use of CC adaptation and mitigation technologies in livestock farming from the producer's perspective, and specifically to the problem of drought. The objective was to analyze how the technological measures related to land use for adaptation to climate change used by ranchers in southern Sinaloa, Mexico correspond to the livestock typologies identified in the study area.

Materials and methods

Study zone

The research was carried out in 6 of the 18 Sinaloa state municipalities (Rosario, Mazatlán, Concordia, Elota, San Ignacio and Sinaloa de Leyva), and corresponds mainly to the central-southern area of the state.

The study region borders the north with the municipalities of Culiacán and Cósala, the east with Durango, the south with Nayarit, and the west with the Pacific Ocean. 48 % of the state has a warm subhumid climate, 40 % is a dry and semidry climate, 10 % is very dry and is located in the northern area, the remaining 2 % is temperate subhumid climate located in the high parts of the western Sierra Madre (INEGI, 2023). The extreme geographical coordinates are as follows; to the north 27°02'32", south 22°28'02" north latitude; to the east 105°23'32", to the west 109°26'52" west longitude (INEGI, 2021).

The type of vegetation existing in Sinaloa is known as "agostadero" wich is a rangeland used by livestock and corresponds to the so-called "tropical deciduous forest -BTC-" (Rzedowski, 1978), "seasonally dry tropical forest" (Pennington *et al*., 2000), or also known as "Dry Forests". Mexico's dry forests (or BTC) represent 11.70 % of the national territory and are distributed from the Mexican Pacific slope to Central America (CONABIO, 2022).

Sample selection

A non-probabilistic and intentional sampling was used in order to select the sample, (Quinn, 2002; Hernández, 2021). In the six municipalities there are 7,533 production units with cattle that correspond to 36.8 % of total state, thus the sample (n=50) reached 0.66 % of the total productive units in the study area (INEGI, 2022). This type of sampling was used due to the high costs of carrying out probabilistic sampling, in addition to avoiding or reducing the risk of crime problems when applying the questionnaire. The criteria for selecting the producers were the following: 1) they must be dual-purpose livestock producers (representative system of Sinaloa), 2) they agreed to answer the survey, 3) they have participated in state government rural extension programs. After applying the criteria, 50 producers were interviewed.

Information collection techniques

A questionnaire was developed and applied to obtain information related to the social characteristics of the producer, as well as aspects related to the characterization of the production unit (PU): agricultural resources for the production of forage (total area, sown, area of rangeland), livestock inventory, milking days (refers to the number of days that producers milk), productive aspects of livestock activity and number of months that the PUs have a shortage of forage. To carry out the Cluster analisys, 14 quantitative variables related to the social aspects of the producer, agricultural resources, livestock inventory, and production were selected (table 1). These variables, according to the literature, influence the use and adoption of technology (Feder *et al*., 1985; McNamara *et al*., 1991).

Table 1. Variables used for cluster analysis.

Variables	Units	Media	Mínimum	Máximum	Estandar Desviation
Age	year	55.60	22.0	82.0	15.06
Children	number	2.86	.0	9.0	1.916
Distance	km	19.11	.0	70.0	18.95
Total area	ha	53.80	.0	200.0	44.24
Sown area	ha	18.00	.0	80.0	15.763
Rangeland area	ha	27.70	.0	150.0	35.98
Sires	number	1.58	.0	4.0	.90
Calved cows	number	22.60	2.0	80.0	16.38
Herd	number	62.08	10.0	206.0	46.47
Milking cows	number	9.58	.0	50.0	11.42
Milk Production	L	58.66	.0	300.0	79.41
Lengt of milking period	days	172.42	.0	365.0	164.55
Calves produced per year	number	11.90	.0	55.0	10.62
Forrage shortage	months	3.64	.0	8.0	1.65

Source: own elaboration.

In addition, we asked which technological practices were used for adaptation to drought conditions as a result of CC (we asked whether they used: paddock shading, stocking rate adjustment, species diversification, forage conservation and silvopastoral systems). Thus, the indicators of the technology use for climate change adaptation (drought) correspond to the percentages of PU where these practices were performed. The fieldwork was carried out during the first quarter of 2022.

Data analysis

The clustering criterion was Ward's linkage method and the measure of association was the squared Euclidean distance. In Ward's method, the distance between two clusters is calculated as the sum of squares between groups, and seeks to minimize intragroup variance and maximize homogeneity within groups (Vilà-Baños *et al*., 2014). The standardization of the variables was performed using the Z score in SPSS. When variables are recorded in different units, a Z-score transformation will put the variables on a common scale to compare sets of variables taken with different measurement systems (Pérez, 2008). Subsequently, the dendrogram was elaborated and the typologies were characterized. The description of the groups was carried out using descriptive statistics. The analysis of the drought adaptation technologies indicators was carried out by frequency analysis. The analyses were performed with SPSS 27.0 Windows software (IBM, 2022).

Results and discussion

Typology of Production Units

The cluster analysis allowed classifying the livestock production units into three differentiated groups: Cluster 1 (C1, n=23) comprises 46 % of PU, Cluster 2 (C2, n=23) represents 46 %, while Cluster 3 (C3, n=4) represents only 8 % of total analyzed sample (figure 1).

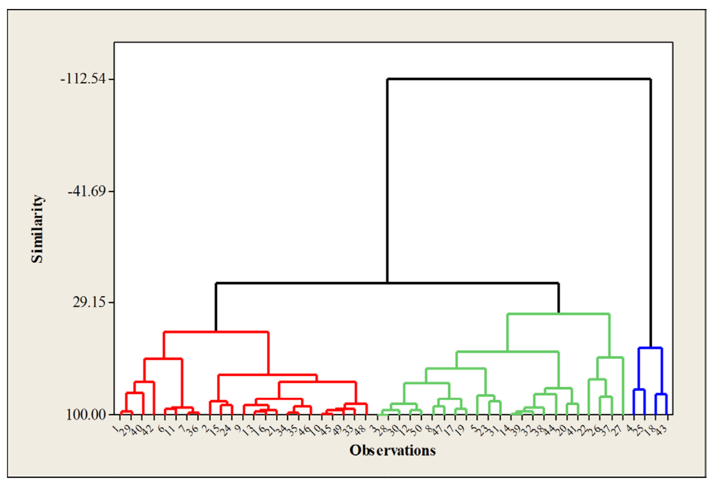

Figure 1. Dendrogram of livestock production unit typologies.

Social characteristics

The producer's age and the number of children in their families were quite similar for the three clusters: farmers were under 60 years old and had between two and three children. C1 producers were the oldest on average, while C2 and C3 producers were the youngest, with an averaging 54 years. The producers interviewed are relatively young and may be more receptive to the use of new technologies. Regarding the distance from the production unit to the municipality, Cluster 1 is 12.5 km away, Cluster 2 is 23.6 km away and Cluster 3 is 30 km away (table 2).

Table 2. Social variables in the identified typologies (mean ± sd).

Clúster	Age (year)	Children (number)	Distance (km)
C1	57.0 ± 7.0	2.8 ± 2.4	12.5 ± 13.9
C2	54.4 ± 12.8	2.8 ± 1.2	23.8 ± 21.2
C3	54.0 ± 17.9	3.0 ± 1.6	30.0 ± 21.6

Source: own elaboration

In this sense, a study on CC adaptation practices indicates that young producers with more education and economic resources are more likely to use CC adaptation practices (Ali and Erenstein, 2017).

Land use and forage shortage

C1 has a smaller total area (36.8 ha average), less sown area and less grazing land than the other clusters. C2 has an average total area of 53.5 ha for forage production, while C2 has 17.4 ha and 30.8 ha of average sown and rangeland, respectively. In contrast, C3 shows an average of 52 ha of total agricultural area, 52.5 ha for sowing and 90.2 ha of rangeland (table 3).

Table 3. Availability, land use and scarcity of forage (mean±de).

Clúster	Total área (ha)	Sown area (ha)	Rangeland (ha)	Forrage shortage (months)
C1	36.8±29.4	12.5±11.1	13.9±12.2	3.3±1.5
C2	53.5±33.1	17.4±11.0	30.8±35.5	3.9±1.7
C3	152.7±48.1	52.5±20.6	90.2±70.8	3.7±1.7

Source: own elaboration.

The planted area uses mainly dual-purpose (grain and forage) sorghum Gavatero-203 and corn (*Zea mays*) to a lesser extent. The sorghum variety (*Sorghum bicolor* L. Moench) Gavatero-203 has an average yield of 2,849 kg.ha^{-1} of grain and 35,367 kg.ha^{-1} of green forage (Hernández *et al*., 2010). The herbaceous stratum plays an important role in livestock feeding during the rainy season, with species of the Acanthaceae family, commonly known as bull grass because of its forage importance, and species like *Carlowrightia arizonica* and *Dicliptera resupinata*, among others standing out in the rangelands (Guízar *et al*., 1994).

This land utilization does not produce enough forage, so there is a pasture shortage of 3.3 (C1), 3.9 (C2) and 3.7 (C3) months per year, so producers are forced to buy forage in the dry season. Rojas-Downing *et al*. (2017), point out that, the lack of forage produced by environmental stress caused by events such as droughts, directly affects pasture productivity as well as the physiological well-being of animals and their reproductive health.

Total cattle in the production units

On average, C1 has 46.1 heads of total cattle (herd), C2 has 60, and C3 has 165 heads of total cattle. Of all livestock heads, C1 and C2 each have 18.8 and 20 adult cows on average, while C3 has 59 adult cows. The number of sires is relatively similar for C1 and C2, while C3 has 3 on average (table 4). These values coincide with those reported by Bautista-Martínez *et al.* (2021) who found three strata and one of the main differentiating characteristics was herd size and structure. However, in our study, it has been found that in Cluster 3, the total number of sires can negatively influence reproductive parameters due to an inadequate sire-cow ratio.

Table 4. Heads of cattle in production units (mean ± de).

Clúster	Herd (number of head)	Cows (number)	Sires (number)
C1	46.1 ± 29.0	20.0 ± 12.3	1.3 ± 0.7
C2	60.0 ± 37.8	18.8 ± 11.3	1.5 ± 0.8
C3	165.2 ± 49.1	59.0 ± 19.7	3.0 ± 0.8

Source: own elaboration.

Livestock productivity

Livestock productivity by groups is presented in table 5, it is observed that C1 shows a daily milk production of 10.3 L, C2 produces 76.7 L and C3 has a production of 232.5 L.day^{-1}; with this information and the average number of milking cows, it is obtain a daily average production per cow of 4.6 for C1, 6.0 for C2 and 7.0 for C3. In Clusters C2 and C3, cows are milked for more than 9 months a year (270 days a year), while in C1 only about one month a year is milked (table 5).

Table 5. Livestock productivity in the identified groups (mean ± de).

Clúster	Milking cows (number)	Milk production (L.day^{-1})	length of milking period (days)	Calves produced annually (Number)
C1	2.2 ± 4.3	10.3 ± 22.4	33.7 ± 85.2	8.9 ± 7.3
C2	12.7 ± 9.1	76.7 ± 66.4	293.6 ± 118.8	13.0 ± 12.5
C3	33.2 ± 11.6	232.5 ±78.8	272.5 ± 109.5	22.7 ± 7.8

Source: own elaboration.

The number of calves produced ranged from 8.9 for C1 to 22.7 for C3. Milk production per cow (4 to 7 L.day^{-1}) agrees with Juarez-Barrientos *et al*. (2015) in a study conducted in dual-purpose systems in Veracruz, Mexico.

Milking days are carried out during a certain time of the year (one to five months), however, the PUs that have fewer cows (such as C1), leave the calf to consume the milk in order to sell it in a shorter time (six months), with an average weight of 220 kg.

Livestock drought adaptation technologies

Adaptation of extensive livestock farming refers to the set of measures and adjustments needed in production practices to reduce the negative effects of climate change (CC) (Villavicencio *et al*., 2023). Five drought adaptation measures or technologies used by the cattle ranching groups in the study region are analyzed in table 6: paddock shading (PS), stocking rate adjustment (SRA), species diversification (SD), forage conservation (FC) and silvopastoral systems (SPS).

Table 6. Livestock drought adaptation technologies (%).

Clúster	PS	SRA	SD	FC	SPS
C1	34.8	39.1	21.7	26.1	21.7
C2	34.8	47.8	43.5	47.8	34.8
C3	0	75.0	25.0	75.0	25.0

Source: own elaboration.

Pasture shade

The benefit of having trees dispersed in the paddocks is reflected in obtaining various products such as wood, food, shade and fruit for livestock (Esquivel-Mimenza *et al.,* 2011). The use of SP was reported by 34.8 % of the production units in C1 and C2; however, producers of C3 do not use this practice. This measure uses the resources available in the pasture in the state of Sinaloa, for cattle feeding during the rainy season; the shrub layer and low trees, smaller than five meters (Guízar *et al*., 1994), which are found in the BTC rangeland. According to Esqueda *et al*. (2011), the most representative trees of the BTC in Mexico are copales (*Bursera* spp.), pochotes (*Ceiba* spp.) and tepeguaje (*Lysiloma* sp.), as well as several columnar cacti.

Adjustment of stocking rate

In Mexico, the number of cattle in at least 24 states is estimated to be higher than the carrying capacity, depending on forage production (Enríquez *et al*., 2021). The SRA is carried out to a greater extent (75 %) by producers in C3 (this cluster shows the largest herd size), followed by C2 (47.8 %) and finally 39.1 % in C1 production units. It is important to mention that this activity is not carried out to seek less overexploitation of forage resources, but as a subsistence strategy, since the producers sell part of their herd (young animals or adult cows) in order to purchase fodder for the dry season (Cuevas-Reyes and Rosales-Nieto, 2018).

Species diversification

Biodiversity is essential for the functioning of ecosystems and human well-being through the provision of environmental services (Pimm *et al*., 2014). 43.5 % of C2 producers indicated having conducted SD, followed by C3 producers with 25 % and in last place with 21.7 %, were C1 producers. In the study area, local research centers have focused on the diversification of forage species adaptable to drought, such as pearl millet (*Pennisetum americanum* L. Leeke), which has a higher efficiency in the use of rainwater compared to traditional crops such as corn or sorghum (Reyes *et al*., 2022). In addition, several varieties of sorghum and grasses such as Pretoria (*Dichanthium annulatum* (Forssk.) Stapf), Callie (*Cynodon dactylon* (L.) Pers.), llanero grass (*Andropogon gayanus* Kunth) and buffel grass (*Cenchrus ciliaris* L.) are used (Loaiza, 2011).

Forage conservation

The practice of FC is performed by the three types of producers (in C1 it is performed by 26.1 %; 47.8 % in C2 and 75 % in C3), this activity requires having agricultural implements such as tractors, trailers and silos to store forage. It is an activity that allows having good quality forage for the dry season, however, it is mainly carried out by producers owning the largest agricultural area (Cuevas-Reyes, 2019).

Silvopastoral systems

The establishment of SPS contributes to sustainable livestock production because it reduces the impact on natural resources and increases the efficiency and profitability of an area; in addition, sanitary and phytosanitary measures improve food safety and animal welfare (Chará *et al*., 2019). In 34.8 % of the production units of C2 there are SPS, 25 % in C3 and 21.7 % in C1, as mentioned by producers who implemented this technology. Generally speaking, it was identified that two of the five practices used (load adjustment and species diversity) coincide with studies carried out in other research projects. Abazinab *et al*. (2022) found that reduction of the population size of livestock and diversification of the species for cattle are measures of adaptation to CC applied by the ranchers.

Conclusions

Three typologies of livestock production units were identified. Cluster one (C1) could be defined as subsistence, since its productive results are very low, it was observed very few animals and the smallest available total area (both sowing and rangeland); these producers are the oldest of the three groups and use paddock shading and stocking rate adjustment as drought mitigation practices.

Cluster two (C2), performed the medium behavior, it is formed by youngest producers, whose cows showed an adequate length of milking period and productive results (per milking cow) in the tipical range reported for these production systems. This Cluster showed a larger total area, with more planting and pasture available area; it stands out due to adopting the most effective drought mitigation practices: stocking rate adjustment, forage conservation and species diversification.

Group three (C3) comprises the youngest producers, who have the largest average livestock area and inventory. These are economically active production units given their levels of productivity characteristic of dual-purpose grazing systems of the Latin American tropics. The drought mitigation decisions of these producers are focused on stocking rate adjustment and forage conservation.

The study made it possible to identify, in the selected sample, drought mitigation practices related to land use from the producers' point of view. These results can serve as a reference to carry out studies in similar environments to improve the use of technologies and scale adaptation measures from the local level and by type of producer to mitigate drought problems in pastoral livestock in tropical areas that use tropical deciduous forest vegetation.

It is recommended that a probabilistic sampling and longitudinal approach be used for future work to validate the results of this study in relation to the use of adaptation measures throughout a production cycle.

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