Description of Four Dual-Purpose River Buffalo (*Bubalus bubalis*) Farms in Tropical Wetlands in Mexico. Part 1: Social Aspects, Herd Distribution, Feeding, Reproductive, and Genetic Management

Aldo Bertoni[1,2], Adolfo Álvarez-Macías[2], Diego Armando Morales[2,3], José Luis Dávalos[4] and Daniel Mota-Rojas[2,*]

[1]Master's Program in Agricultural and Livestock Sciences [Maestría en Ciencias Agropecuarias], Universidad Autónoma Metropolitana (UAM), Xochimilco Campus, 04960, Mexico City, Mexico

[2]Neurophysiology, Behavior, and Animal Welfare Assessment, Department of Animal Production and Agriculture (DPAA), Universidad Autónoma Metropolitana (UAM) Xochimilco Campus, 04960, Mexico City, Mexico

[3]Holistic management, Savory Institute, Agriculture Science, Universidad EARTH, Guácimo, 70602, Costa Rica

[4]Department of Economics, Administration and Rural Development, Universidad Nacional Autónoma de Mexico (UNAM), Mexico City 04510, Mexico

Abstract: This article characterizes four dual-purpose river buffalo farms (DPBPS) in south-southeastern Mexico. The objectives were to obtain a broader profile of this system and capture values related to buffalo breeding in that area. The study identified a group of producers with high levels of education (17 ± 1.15 years) and years of experience in agricultural systems (28.75 ± 10.81), especially with buffaloes (9 ± 1.83 years). Land tenure is private, and the average surface area of ranches is 428.75 ± 245.57 hectares, located mainly (92%) in flatlands and floodplains with an average number of animals per hectare 2.03 ± 0.69 AU/h. The area has various vegetable strata (grasses, bushes, trees). Feeding is based on the consumption of vegetable species like Camalote grass (*Paspalum fasciculatum*), West Indian Azuche grass (*Hymenachne amplexicaulis*), and Aleman grass (*Echinochloa polystachya*), complemented with minerals. Production units (PU) 2 and 3 add a low proportion of balanced feed. The average number of animals per PU is 611 ± 50. Dams and calves represent the largest proportions in the herds. The main breed raised in these buffalo production systems is Buffalypso (58% ± 21%), followed by Italian Mediterranean (24% ± 5%) and Murrah (10% ± 14%). The data collected show that the reproduction methods most often utilized, in order of frequency, are fixed-time artificial insemination (FTAI), direct mounting (DM), and estrus-detected artificial insemination (EDAI). Proportions are 61% ± 18%, 24% ± 25% and 14% ± 17%, respectively. The DPBPS studied are distinguished by the presence of owners and managers with high levels of education, extensive experience in agricultural systems, and the capacity and willingness to implement new technologies that permit continuous improvement. However, their experience in buffalo production is still limited, so there is ample room for improvement.

Keywords: River buffalo, production system, tropical wetlands, Bubalus bubalis.

INTRODUCTION

The river buffalo is a species recognized especially for milk production, but buffalo meat also has outstanding nutritional characteristics compared to beef from conventional cattle [1-5]. In 2019, river buffaloes produced 132,959,000 tons of milk, representing 15% of worldwide production. River buffalo production systems in Latin America usually obtain milk and meat products simultaneously on ranches that organize dual-purpose production systems. These production systems have had a mean annual growth of 4% over the past five years [6]. India is the principal buffalo milk-producing country on the planet, as it accounts for 80% of the world's population [2].

Though concentrated in Asia, this species has been introduced, gradually, into tropical zones in the Americas, especially in wetter regions that are susceptible to flooding [7,8] as a function of certain favorable characteristics compared to bovines that include prolificacy, longevity, disease resistance, precocity, adaptiveness to swampy areas, and the capacity to exploit natural environments where fodder is abundant but is of low-to-medium quality [5,7]. Bio-conditions in south-southeastern Mexico are characterized by the high temperatures and humidity [9,10] typical of tropical wetlands; There are broad extensions of land with a high potential for grazing by herds of river buffalo [11].

Buffalo-raising is of great economic importance in Asia and Europe, and interest in this activity is growing in Latin American countries that have ample tropical wetlands. To date, however, few studies have been

*Address correspondence to this author at the Neurophysiology, Behavior and Animal Welfare Assessment, Universidad Autónoma Metropolitana (UAM), Calzada del Hueso 1100, Del, Coyoacan, 04960, Mexico City, Mexico; E-mail: dmota@correo.xoc.uam.mx

conducted to evaluate the characteristics of dual-purpose river buffalo production systems (DPBPS) in economic, social, organizational, ecological, technical, technological, productive, and commercial terms. Research of this kind is required to identify features where a potential for improvement exists. In light of these circumstances, the objectives of this work were to characterize some DPBPS that are currently operating in tropical regions of Mexico. Due to the vast amounts of data collected, results will be presented in two complementary publications. This first article reports on the following components: the social aspect, land tenure, feeding, and nutritional management, animal inventories, and the management of reproduction and genetics.

MATERIALS AND METHODS

This is a retrospective analysis based on data from the year 2019. It consists in characterizing dual-purpose river buffalo production systems (DPBPS) in south-southeastern Mexico. The principal goals were to determine the configuration and functioning of several production units (PU). To capture the complexity of these DPBPS, general systems theory was utilized as the conceptual framework because it facilitated an integral comprehension of the diverse dimensions, interactions, and feedback that participate in agricultural systems [12]. The following section describes the methodological strategy adopted.

Selection and Description of the Sample

Requests for information were sent to the *Asociación Mexicana de Criadores de Búfalo* (Mexican Association of Buffalo Breeders, AMEXBU) to compile a range of samples. We registered 37 buffalo production units in the country, distributed mainly in the south-southeastern region. We selected seven of those units devoted exclusively to dual-purpose exploitation. Then, using a non-probabilistic method, we chose four of the seven for intensive study. In the logic of this sampling method, the researcher is responsible for choosing the sample. In this case, the selection was performed with a convenience method [13]. The locations of the four PU chosen were: PU1, Hidalgotitlán, southern Veracruz; PU2, Pinotepa Nacional, Oaxaca; and PUs3 and 4, Macuspana, Tabasco.

Selection of Variables and Design of the Data Collection Instrument

In order to define variables potentially relevant to social aspects, land tenure, animal inventories, reproductive, sanitary, and genetic management, periodic meetings were held with key actors in buffalo production, including the owners and managers of the four DPBPS. To complement this, we visited all four DPBPS [12-15], where we collected 41 variables, some qualitative, others quantitative (Table **1**), and constructed an index for the dimension of reproductive management. The indices are based on dichotomic variables representing the presence, or absence, of the technologies implemented or those with which each PU is equipped. The elements present were codified with a 1; if absent, the score assigned was 0. Each index was calculated using the following equation:

$$NT_j = \frac{\sum_{i=1}^{n_j} x_{ij}}{n_j} \times 100$$

NT_j: technological level of dimension j

x_{ij}: technologies selected from area j

n_j: total number of technologies selected in area j

The methods for compiling potentially important data that have been used most often in characterization studies like this one include questionnaires and/or direct observation [9,16]. For this reason, we elaborated a semi-structured survey format with 83 questions.

Data Collection and Processing

Once the four experimental units were identified and the data collection instrument defined, the next step was to collect the information of interest. Data collection at the PUs was conducted in person using the questionnaire mentioned above and through direct observation by one of the authors of the study [9,12,17]. Upon finalizing this phase, the data obtained were captured in Microsoft Office 365® for later review and information processing, using a pre-designed model.

Review of the Information and Selection of the Variables

The field data gathered through the questionnaire were recorded in a database elaborated in an Excel spreadsheet. The database was then thoroughly cleansed to eliminate incongruences and equal values in all the PUs and out-of-range values for some variables. When that procedure was completed, we performed a basic descriptive statistical analysis.

Table 1: The Qualitative and Quantitative Variables Analyzed

Dimension	Variable
Social	Age
	Education Level (years)
	Livestock systems experience (years)
	Water buffalo systems experience (years)
	Annual training
Land tenure	Total hectares
	Various plant strata on flat surface (ha)
	Various plant strata on a flat floodable surface (ha)
	Various plant strata on hillock surface (ha)
	Type of trees used
	Type of shrubs used
	Type of fodder used
	Type of grazing system used
Feeding	Type of animal feed
	Type of food supplement
	Average number of animals per hectare (AU/ha)
	Maximum number of animals per hectare (AU/ha)
Animal inventory	Buffalo cow (number of animals)
	Buffalo pregnant heifer (number of animals)
	Buffalo heifer (number of animals)
	Female buffalo calves (number of animals)
	Bulls (number of animals)
	Buffalo Steers (number of animals)
	Male buffalo calves (number of animals)
	Total inventory (number of animals)
	Animal Unit Equivalents (AUE)
Reproductive management	Heat detection method
	Directing Mounting (DM) (%)
	Fixed-time artificial insemination (FTAI) (%)
	Estrous-Detected artificial insemination (EDAI)
	Sexed semen (%)
	Embryo transfer (ET) (%)
Genetic	Buffalypso (%)
	Mediterranean (%)
	Murrah (%)
	Jafarabadi (%)

ha Hectares. **AU** Animal Unit. **AU/ha** Animal Unit Per Hectares. **DM** Directing Mounting. **FTAI** Fixed-Time Artificial Insemination. **EDAI** Estrous-Detected Artificial Insemination. **ET**. Embryo Transfer.

Application of Techniques of Statistical Analysis

As with the database, this stage was conducted in Microsoft Office 365®, utilizing formulae integrated with that software for basic calculations of descriptive statistics (mean, standard deviation) regarding the series of original variables and the indices mentioned above. Fully aware of the implications of performing these operations (mean, standard deviation) for such a small number of experimental units, the procedure began with the first approach to values that could provide highly-reliable estimates for future studies with a larger number of units.

Description of the Production Systems

The data from each PU were presented individually with the key trend and dispersion measures to describe the DPBPS as a group, accompanied by a discussion of each one. The aim was to obtain a broader panorama of each variable from a comparative and argumentative perspective. To generate a discussion based on the aforementioned criteria, some references to conventional cattle are included since, at least in Latin America, these species have traditionally been raised in dual-purpose production systems.

RESULTS AND DISCUSSION

Social Aspects

The study found that the producers had an average age of 47 ± 17.45 years regarding the social variables. PU3 had the youngest rancher (29 years) due to a recent generational change. The oldest producer was from PU2 and was 68 years of age. With respect to education, we identified two PU owners with 16 years of education, while the other proprietors had at least 18 years. The average years of education of the four owners were 17 ± 1.15 (Table **2**), which means that they all had reached at least the undergraduate level of studies. The survey also found that all four had studied programs related to fields of animal production. That datum means that this group is among the 4.6% of ranchers with the most years of education at the national level [18].

Their average years of experience in buffalo production units was 9 ± 1.83 years, but these ranchers had previous experience in livestock production before deciding to incorporate river buffaloes into their operations. This raised their average years of experience to 28.75 ± 10.81 in related activities, especially in dual-purpose systems that raised cattle

Table 2: Social Characteristics of the Dual-Purpose River Buffalo Production Units

PU	Ages	Education Level (years)	Livestock systems experience (years)	Water buffalo systems experience (years)	Annual training (Frequency)
1	54	16	36	10	4
2	68	18	40	8	0
3	29	16	19	7	1
4	37	18	20	11	1
Average	47	17	28.75	9	1.5
SD	17.45	1.15	10.81	1.83	1.73

PU Production Unit. **SD** Standard Deviation.

(genus *Bos*). While that experience may give a significant advantage, it means that their buffalo herds have been handled in ways that are quite similar to cattle, an approach to management that has not always produced positive results.

Three of the four producers received some form of training at least once a year, so the average value for the annual frequency of training was 1.5 ± 1.73. Training generally focuses on key topics for buffalo production, such as assisted reproduction techniques and regenerative grazing systems.

On the aspect of record-keeping, all four PUs maintain production registers on cards and in ledgers and manage their data in electronic systems. It is important to mention that PU1 and PU3 were in the process of migrating their production data to computer packages designed specially to compile and analyze zootechnical data. This facilitates decision-making related to developing and improving PUs [17]. Producers who calculate various production indicators have a higher capacity to elaborate and implement enhancement plans in the short, medium, and long term [19], including programs for genetic improvement and to determine selection criteria as a function of the data recorded.

The high level of education, frequent training, detailed recording of productive and accounting data, and experience of these producers constitute a substantial human capital that augments their capacity to adopt more efficient technologies and management strategies at their PUs [9,20,21]. These factors help explain why they decided to incorporate an emerging species such as the river buffalo into their operations and integrate a certain technology level to potentiate their capacities. We found that one of these PUs recently went through a generational change that favored the continuity of these activities and facilitated continuous improvement in its buffalo-raising activity [22,23].

Land Tenure and the Surface Area Available

All four PUs are privately-owned. Their surface areas are 600, 590, 450, and 75 hectares, respectively for PUs 1, 2, 3, and 4, giving an average of 428.75 ± 245 h. These values differ significantly from those reported in characterization studies of dual-purpose bovine production systems in tropical areas in Mexico by Orantes *et al*. (26.7 ± 29.52 h) [17], Juárez-Barrientos (40.2 ± 37.9 h) [24], and Granados-Rivera *et al*. [9]. The latter work reported values from three groups: 19 ± 3.49, 32 ± 11.17, and 128 ± 79.59 h. Similarly, analyses of buffalo production systems in Turkey also show smaller average extensions [16]. According to these figures, the DPBPS form a specific stratum within the framework of dual-purpose production units in Mexico's tropical wetlands. The larger production scale also reflects the producers' high socioeconomic level, increasing the probability that their operations will be viable financially and technically [20,23].

In three of the PUs, the agricultural surface area is predominantly flat or of the floodplain type. This is especially true in PU1, where this kind of terrain represents over 60% of the total extension. On average, these units have 166.25 ± 180.71 h of this type of land, which means that it covers 25% of the total surface area. Only PU2 has hills (Table **3**). Therefore, these PUs are very large and contain a range of natural resources and biodiversity, including diverse strata of vegetation that combine trees, shrubs, and grasses in distinct proportions. These conditions increase the potential for successful buffalo-breeding because they allow buffaloes to express their thermoregulation mechanisms (wallowing in mud) while also offering shade trees to protect them from solar

Table 3: Distribution of the Surface Area Occupied by these DPBPS

PU	Various plant strata on a flat floodable surface (ha)	Various plant strata on flat surface (ha)	Various plant strata on hillock surface (ha)	Total hectares
	ha.			
1	420	180	0	600
2	0	50	25	75
3	155	295	0	450
4	90	500	0	590
Average	166.25	256.25	6.25	428.75
SD	180.71	190.85	12.50	245.57
	Percentage (%)			
1	70%	30%	0%	100%
2	0%	67%	33%	100%
3	34%	66%	0%	100%
4	15%	85%	0%	100%
Average	30%	62%	8%	100%
SD	30%	23%	17%	

PU Production Unit. **SD** Standard Deviation. **ha** hectares.

radiation [23,25-27]. Finally, the vegetable cover helps preserve the favorable features of the soil; that is, the existing level of vegetable biodiversity is beneficial for both the buffaloes and the ecosystem [28].

Herd Distribution

The number of animals had a mean of 611 ± 50. The smallest unit was PU2 with 124, and the largest was PU1 with 980. The herds consist primarily of females, with an average of 272 ± 163.78 buffalo cows per PU, representing 44.9% of the total population. Pregnant buffalo heifers averaged 29 ± 8.30 animals, or 4.8% of the total, while the percentage of buffalo heifers was 5.4% (33 ± 39.48), and female calves (120 ± 76.16) represented 19.8% of the total. Females are, of course, fundamental in PUs because they are responsible for multiplying the herd and producing replacement animals for the ones destined for sale or milk production. This may explain why the replacement females and buffalo cows at these PUs account for 74.9% of the herds (Table **4**).

Turning to the male buffaloes, the number of bulls at these PUs averaged 13.80 ± 11.50, while the numbers for steers and male calves were 25 ± 43.59 and 113.5 ± 68.18 respectively. These figures correspond to 2.3, 4.1, and 18.7% of the total, respectively (Table **4**). Male buffalo calves are usually sold at around one year of age. However, at PU3 and PU4, we identified older steers because the abundant fodder available allowed those ranchers to keep the animals for another year, so they could gain more weight and be sold at the market for higher prices. This demonstrates the flexibility of these production systems, for they can prioritize either meat or milk production as a function of the fodder available and the relative behavior of market prices [29,30].

In general, these dual-purpose production systems show a strong inclination towards milk production but do not marginalize the production of animals for meat, as suggested by the high proportion of females compared to the very low proportion of adult male animals.

Feeding and Nutritional Management

The principal source of feeding consists of native grasses based on rotating grazing systems that limit or eliminate the need for chemical fertilizers altogether by promoting the utilization of organic fertilization through the reintegration of the animals' own excreta. The main fodder species are native grasses like Camalote grass (*Paspalum fasciculatum),* Azuche grass (*Hymenachne amplexicaulis*), and Aleman grass (*Echinochloa polystachya*) [23]. These plants are not very palatable for bovines of the genus *Bos*, but the anatomical and physiological characteristics of the river buffalo's digestive system allow them to digest this fodder

Table 4: Herd Distribution Per Buffalo Category

PU	Buffalo cow	Buffalo pregnant heifer	Buffalo heifer	Female buffalo calves	Bulls	Buffalo Steers	Male buffalo calves	Total inventory	Animal Unit Equivalents (AUE)
Number of animals									
1	430	40	80	200	30	0	180	960	711.5
2	50	27	0	20	3	0	24	124	95.65
3	350	30	0	150	12	90	150	782	593
4	260	20	50	110	10	10	100	560	418.5
Average	272.50	29.25	32.50	120.00	13.75	25.00	113.50	606.50	454.66
SD	163.78	8.30	39.48	76.16	11.50	43.59	68.18	360.89	267.89
Percentage (%)									
1	45%	4%	8%	21%	3%	0%	19%	100%	
2	40%	22%	0%	16%	2%	0%	19%	100%	
3	45%	4%	0%	19%	2%	12%	19%	100%	
4	46%	4%	9%	20%	2%	2%	18%	100%	
Average	44%	8%	4%	19%	2%	3%	19%	100%	
SD	3%	9%	5%	2%	1%	6%	1%		

PU Production Unit. **SD** Standard Deviation. **AUE** Animal Unit Equivalents.

efficiently [27,31,32]. All four PUs base their feeding on these grasses but add mineral complements. PU2 and PU3 supplement their herds' diet with silage and balanced feed, though providing these sources does not necessarily ensure improved productive indicators. PU3 administers a 1-kg portion of the balanced feed to milking cows and 0.5 kg to male calves up to the age of 7 months. The latter measure significantly reduces the percentage of milk that calves consume. At PU2, the diet of milking cows is supplemented with corn silage in the dry season due to specific climatic conditions (Table **5**).

The relatively low level of supplementation in these PUs is a significant finding, especially for the units in tropical zones where seasonal oscillations of humidity and temperature are smaller. This contrasts with the report on dual-purpose bovine production systems by Cuevas-Reyes [33], which observed a high degree of dependence on balanced feed for the animals destined to be sold for meat, especially on larger PUs. While both cattle and buffaloes are classified as large ruminants, the latter have higher food conversion values. This may account, in part, for the low level of supplementation they require compared to bovines raised and developed under similar conditions [34].

The average number of animals calculated per hectare in this study was1.12± 0.28 AU/h. The maximum number of animals per hectare was 2.03 ±

Table 5: Feeding Management

PU	Type of animal feed	Type of food supplement	Animal Unit Equivalents (AUE)	Total hectares	Average number of animals per hectare (AU/ha)	Maximum number of animals per hectare (AU/ha)
1	Native fodder / minerals	Minerals	711.5	600	1.19	1.70
2	Native fodder	Silage / Minerals	95.65	75	1.28	1.40
3	Native fodder	Balanced feed / Minerals	593	450	1.32	3.00
4	Native fodder / Cultivate fodder	Minerals	418.5	590	0.71	2.00
		Average	454.66	428.75	1.12	2.03
		SD	267.89	245.57	0.28	0.69

PU Production Unit. **SD** Standard Deviation. **AUE** Animal Unit Equivalents. **AU/ha** Animal Unit per Hectares.

0.69 AU/h which is lower than the 2.20 ± 1.87 AU/h reported by Juárez-Barrientos *et al*. (24). PU3 had the highest value with an annual average as high as 3 AU/h, though this number could be increased by relying more on the supplementation with balanced feed and/or improving rotational grazing management (Table **5**).

Another important aspect of these PUs refers to the nutritional requirements of river buffaloes [35]. On this topic, Paul [36] argued that these animals consume a lower percentage of dry matter than bovines in proportion to their live weight due to their greater efficiency in converting fodder, even native grasses of low-to-medium quality that have a high content of structural carbohydrates. Therefore, grazing areas should be adjusted as a function of the characteristics of this species. Iglesias *et al*.'s comparative study [37] of buffaloes and cattle of similar age and weight in silvopastoral systems showed that the former achieved significantly greater daily and final weight gain ($p< 0.05$), even though calculations of daily food ingestion revealed that the buffaloes spent less time-consuming food than the cattle ($p< 0.05$). These findings might suggest that buffaloes consume less food, though we need more reliable measurements of the amounts of dry matter consumed per day before reaching this conclusion. We do know, however, that the river buffalo has the capacity to efficiently exploit areas where cattle-raising could be pursued only with great difficulty.

This suggests that existing conditions could support larger animal loads, especially during some seasons of the year, and that this could bring improvements in the average annual production levels. Efficient management and exploitation of the region's natural resources have the potential to reduce per-unit production costs in systems based on the exploitation of vegetable cover. This benefit could be quite notable in comparison to stable-based systems [9,10].

As described above, efficient management of natural resources is a key aspect of DPBPS; however, a determining factor that complements the expression of certain desirable qualitative and quantitative characteristics is the genetic management implemented at PUs. The next section examines the breeds utilized and the selection criteria that producers consider.

Genetic Management

The main breed raised on these buffalo production systems is Buffalypso (58% ± 21%), followed by Italian Mediterranean (24% ± 5%) and Murrah (10% ± 14%) (Figure **1**). In the strict sense, the predominant breed is a mixed one. Although all breeds are deemed apt for dual-purpose systems, Murrah and Mediterranean buffaloes have outstanding characteristics for milk production. Indeed, the latter has often been included in programs of genetic improvement because it has specific, advantageous characteristics for the dairy industry (e.g., volume of milk, fat, protein, and the qualitative characteristics of protein composition) that are reflected in objective indicators determined by tests of progeny and pedigree. Unfortunately, the lack of established norms in Mexico impaired the importation of germplasm for many years, so the utilization of this material simultaneously with techniques of assisted reproduction did not begin until 2017 after the norms were modified and Mexico opened its sanitary borders to countries like Italy, where notable advances have been made in selecting animals that can transmit desirable milk production characteristics [35].

In the case of the genetic selection of dams, the criteria most often applied at all four DPBPS are the volume of milk production and docility; that is, features both qualitative and quantitative are assessed when evaluating milk production and behavioral aspects. The features that need to be evaluated in this regard are associated with high productivity, such as an adequate corporal structure that optimizes the ingestion and transformation of food. A second key feature is developing an ample mammary system capable of synthesizing large amounts of milk. Other desirable traits include the location and size of the teats to prevent problems with the milking process, especially if automated equipment is utilized. The characteristics of the animals' hooves and legs are also closely related to their permanence in production units [23,38]. This is particularly important in grazing PUs where buffalo have to move to paddocks to ingest their food. However, it might also be important to consider such features as the morphological characteristics associated with long-term permanence in the PU; for example, high productivity and fertility.

In summary, while the selection criteria that these ranchers consider are transcendental, there is room for improvement in their selection of both the dams and sires that remain in their respective PUs. The latter are selected through catalogs of mating bulls that have the genetic values that breeders wish to transmit to the descendants of their herds. This genetic material is sometimes employed through estrus-detected artificial insemination (EDAI), but more frequently with fixed-

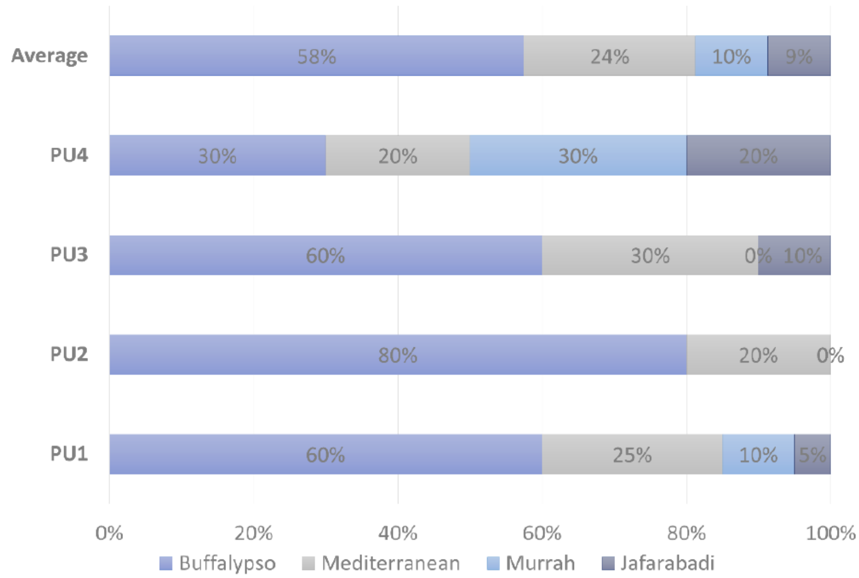


Figure 1: Principal breeds utilized.

time artificial insemination (FTAI). The assisted reproduction technologies used in these PUs are described in the following section.

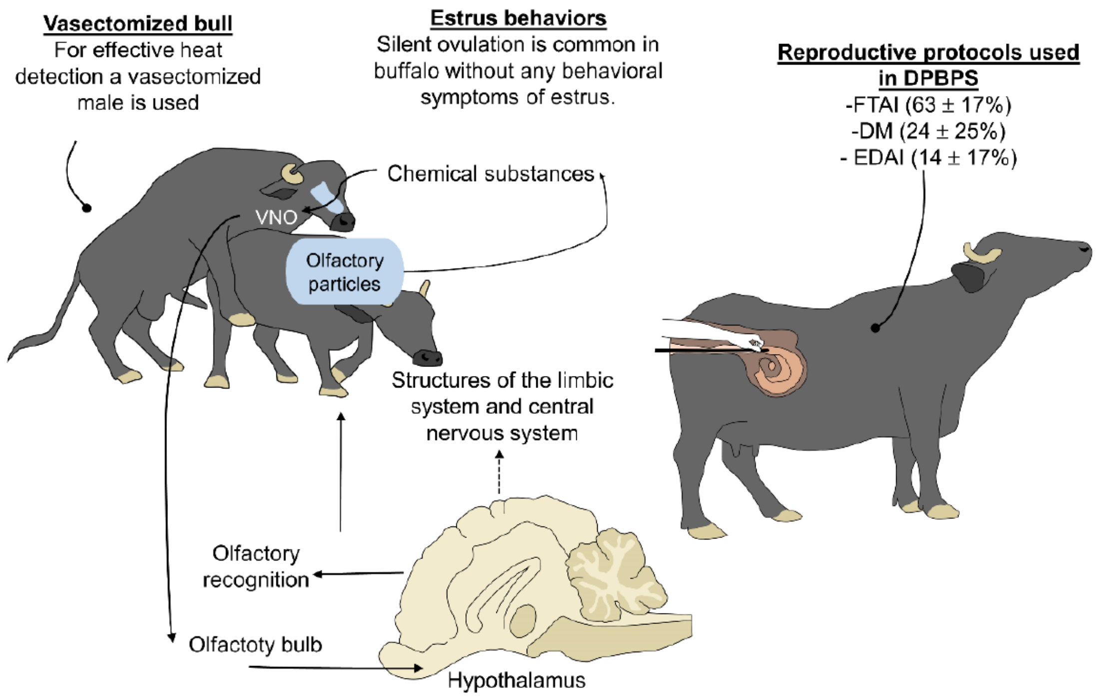
Reproductive Management

The management of reproduction in these PUs is performed as a function of the anatomical and physiological characteristics of the buffalo cow and the zootechnical objectives of each operation. In this case, the main methods utilized are those of assisted reproduction that is congruent with the reproductive specificities of this species and permit genetic improvement. According to the data gathered, the method of reproduction most often employed is fixed-time artificial insemination, followed by direct mounting (DM). Both are more common than estrus-detected artificial insemination. Calculations showed the following proportions: 61% ± 18%, 24% ± 25%, and 14% ± 17%, respectively (Table **6**). In contrast, various studies of conventional dual-purpose cattle (genus *Bos*) production systems in tropical environments report low or null utilization of these technological tools of assisted reproduction [9,21,30] (Figure **2**).

No cases of embryo transfer (ET) or the use of sexed semen were detected, though the importation of those technologies is now allowed and could begin to accelerate genetic progress in DPBPS in Mexico [29].

The group of producers studied displays clear evidence of initiatives to acquire improved genetic resources and assisted reproduction technologies that consider the seasonal reproductive cycle of the buffalo cow and the difficulty involved in detecting estrus. This is shown by the relatively frequent utilization of FTAI and –though to a lesser extent– EDAI, which require a vasectomized bull to identify females that are viable for the utilization of these technologies since the typical signs of estrus –vulvar edema, frequent urination, vaginal secretion– are shown at low intensities in buffalo cows, making visual detection difficult and impairing the identification of optimal times for applying the EDAI technique. Moreover, buffalo cows have low estradiol concentrations [40,41], and studies have found that only 3.4% of these animals show homosexual behavior, while over 60% experience silent estrus [33,37]. Therefore, the joint implementation of reproductive biotechnologies contributes to genetic advancement towards the objectives of improving productive indices and controlling the estrus cycles of buffalo cows.

Production units in countries like Colombia, Argentina, and Venezuela have successfully implemented more complex methods of assisted reproduction, such as embryo transfer, the use of sexed semen, thermal monitoring to better understand changes during estrus, and technologies that allow the detection of sick animals without clinical signs [42,43]. There are even cases where genomic testing is applied to identify the animals with the greatest genetic potential. By integrating all these tools, those PUs have improved important characteristics for both the dairy and meat industries [39-41]. Producers in Mexico have been advancing towards the adoption of new reproductive techniques, but the absence of norms has



DM Directing Mounting. **FTAI** Fixed-Time Artificial Insemination. **EDAI** Estrous-Detected Artificial Insemination. **VNO.**Vomeronasal Organ.

Figure 2: Reproduction methods utilized on the DPBPS. This figure illustrates the assisted reproduction techniques utilized at these four DPBPS. They include fixed-time (FTAI) and estrus-detected (EDAI) artificial insemination. The goals are to achieve genetic improvement of stocks and identify optimal times for serving females. EDAI requires a vasectomized bull because buffalo cows present low frequencies of homosexual behaviors, vulvar edema, and frequent urination, so it is difficult to visually identify the onset of estrus. However, the vomeronasal organ (VNO) of male buffaloes allows them to perceive chemical substances that project signals towards the olfactory bulb and diverse structures of the limbic and autonomous nervous systems that trigger recognition of the female's estrus condition [39].

Table 7: Reproductive Management and Assisted Reproduction Techniques

PU	Estrous detection method	FTAI	DM	EDAI	Total	Reproductive management index
1	Vasectomized bull	60%	5%	35%	100%	60%
2	Vasectomized bull	70%	10%	20%	100%	60%
3	no detection	80%	20%	0%	100%	60%
4	no detection	40%	60%	0%	100%	40%
	Average	**63%**	**24%**	**13%**	100.00%	55%
	SD	17%	25%	17%		10%

PU Production Unit. **SD** Standard Deviation. **DM** Directing Mounting. **FTAI** Fixed-Time Artificial Insemination. **EDAI** Estrous-Detected Artificial Insemination.

blocked the implementation of certain technologies – like importing embryos– that require zoosanitary permits [28,40,44].

CONCLUSION

The DPBPS studied are distinguished by the presence of owners and managers with high levels of education, extensive experience in agricultural systems, and the capacity and willingness to implement new technologies that permit continuous improvement. However, their experience in buffalo production is still limited, so there is ample room for improvement.

It is also clear that the DPBPS occupies a specific stratum in the framework of livestock-breeding in Mexico, one with high levels of management that promote the rational exploitation and regeneration of various vegetable strata, including flood-prone zones and wetlands rarely exploited by conventional cattle ranches or for other agricultural uses. Nevertheless, the adoption of assisted reproduction techniques such as the use of sexed semen and embryo transfer may further increase the productivity of buffalo enterprises in Mexican tropical areas.

REFERENCES

[1] Sabia E, Napolitano F, Claps S, Rosa G De, Lucia V, Braghieri A, *et al*. Environmental impact of dairy buffalo heifers kept on pasture or in confinement 2018; 159: 42-9. https://doi.org/10.1016/j.agsy.2017.10.010

[2] Mota-Rojas D. De Rosa G, Mora-Medina P, Braghieri A, Guerrero-Legarreta I, Napolitano F. Dairy buffalo behaviour and welfare from calving to milking. CAB Rev Perspect Agric Vet Sci Nutr Nat Resour 2019; 14(035): 1-9. https://doi.org/10.1079/PAVSNNR201914035

[3] Nasr MAF. The impact of crossbreeding Egyptian and Italian buffalo on milk yield and composition under subtropical environmental conditions. J Dairy Res 2016; 83(2): 196-201. https://doi.org/10.1017/S0022029916000194

[4] Napolitano F, Mota-Rojas D, Álvarez-Macías A, Braghieri A, Mora-Medina P, Bertoni A, *et al*. Factores productivos y su incidencia en el bienestar de la búfala lechera en sistemas de producción extensivos e intensivos. Soc Rur Prod Med Amb 2020; 20: 155-73.

[5] Bertoni A, Mota-Rojas D, Napolitano F, Sabia E, Álvarez-Macías A, Braghieri A, *et al*. Chapter 6: Aspectos zootécnico y morfológicos: Estudio comparativo entre búfalos de agua y ganado convencional. In: Napolitano F, Mota-Rojas D, Guerrero-Legarreta I, Orihuela A, editors. El búfalo de agua en Latinoamérica: hallazgos recientes. 3rd ed. México: BM Editores; 2020; p 209-55. https://www.lifescienceglobal.com/journals/journal-of-buffalo-science/97-abstract/jbs/4550-el-bufalo-de-agua-en-latinoamerica-hallazgos-

[6] IDF. The World Dairy Situacion Report. Brussels, Belgium: Fédération Internationale du Lait; Bulletin 2020; p. 506.

[7] Crudeli GA, Patiño EM, Maldonado Vargas P, Konrad JL. Pasado, presente y futuro del búfalo en Argentina. Rev Vet 2014; 25(2): 140-5. https://doi.org/10.30972/vet.252513

[8] Cruz-Monterrosa R, Mota-Rojas D, Ramirez-Bribiesca E, Mora-Medina P, Guerrero-Legarreta I. Scientific Findings on the Quality of River Buffalo Meat and Prospects for Future Studies. J Buffalo Sci 2020; 9: 170-80. https://doi.org/10.6000/1927-520X.2019.08.03.18

[9] Granados-Rivera LD, Quiroz-Valiente J, Maldonado-Jáquez JA, Granados-Zurita L, Díaz-Rivera P, Oliva hernandez J. Caracterización y tipificación del sistema doble propósito en la ganadería bovina del Distrito de Desarrollo Rural 151, Tabasco, México. Acta Univ 2019; 28(6): 47-57. https://doi.org/10.15174/au.2018.1916

[10] Magaña-Monforte J, Rios-Arjona G, Martínez-González J. Los sistemas de doble propósito y los desafíos en los climas tropicales de México. Arch Latinoam Prod Anim 2006; 14(3): 105-14.

[11] Ávila HRV, Godoy AV, Severiano HJ, Gallardo HÁ, Sánchez JFDLT, Aguilar CGG, *et al*. Estado del Arte Sobre Investigacion E Innovación Tecnológica en Ganadería Bovina Tropical. In: Estado del arte sobre investigación e innovación tecnológica en ganadería bovina tropical. Segunda ed. Ciudad de México: REDGATRO; 2018; p. 44-66.

[12] Arroniz JV, Rivera PD. Caracterización socioeconómica y tecnologica de los sistemas ganaderos en siete municipios del estado de Veracruz, Mexico. Zootec Trop 2010; 27(4): 427-36.

[13] Abascal E, Grande E. Análisis de encuestas. Madrid: ESIC editorial; 2005; p. 289.

[14] Rangel J, Rivas J, Torres Y, Perea J, De-Pablos CH, Barba C, *et al*. Efecto del tamaño del rebaño y la zona ecológica en el nivel tecnológico del sistema de doble propósito del trópico Ecuatoriano. Rev Cient la Fac Ciencias Vet la Univ del Zulia 2016; 26(3): 164-72.

[15] García A, Valdés Y, Vargas J. Determinación de los costos energéticos y económicos para producir un buey apto para las labores agrícolas. Rev Ciencias Técnicas Agropecu [Internet] 2014 [cited 2020 Oct 4]; 23(4): 51-8. Available from: http://scielo.sld.cu/scielo.php?script=sci_arttext&pid=S2071-00542014000400009

[16] Işik M, Gül M. Economic and social structures of water buffalo farming in Muş province of. Rev Bras Zootec 2016; 45(7): 400-8. https://doi.org/10.1590/S1806-92902016000700007

[17] Orantes-Zebadua M, Platas-Rosado D, Córdova-Avalos V, De los Santos-Lara M, Córdova-Avalos A. Caracterización de la ganadería de doble propósito en una región de Chiapas, México. Ecosistemas y Recur Agropecu 2014; 1(1): 49-58.

[18] INEGI-ENA. La Encuesta Porcentajes de productores por rangos de edad Porcentaje de productores por nivel de estudios. Secr Agricutura y Desarro Rural [Internet] 2019; 2. Available from: https://www.inegi.org.mx/contenidos/programas/ena/2017/doc/mini_ena17.pdf

[19] Cortés Mora J, Cotes Torres A, Cotes Torres J. Revista Colombiana de Ciencias Pecuarias Structural features of dual-purpose cattle production system. Rev Colomb Ciencias Pecu 2012; 25(2): 229-39.

[20] González JMS, Rodríguez JAL, Sagarnaga Villegas M, Zavala-Pineda MJ. Adopción de tecnologías por productores beneficiarios del programa de estímulos a la productividad ganadera (PROGAN) en México. Rev Mex Ciencias Pecu 2013; 4(2): 243-54.

[21] Cuevas RV, Baca Del Moral J, Cervantes EF, Espinosa GJA, Aguilar ÁJ, Loaiza MA. Factores que determinan el uso de innovaciones tecnológicas en la ganadería de doble propósito en Sinaloa, Mexico. Rev Mex Ciencias Pecu 2013; 4(1): 31-46.

[22] Valdovinos-Terán EM, Espinoza-García JA, Velez-Izquierdo A. Innovación Y Eficiencia De Unidades Bovinas De Doble Propósito En Veracruz. Rev Mex Agronegocios 2015; XIX(36): 1306-14.

[23] Rodríguez-Gonzalez D, Minervino AH, Orihuela A, Bertoni A, Morales-Canela A, Álvarez-Macías A, Mota-Rojas D, *et al*. Handling and neurophysiological aspects of the dual-purpuse water buffalo system in the Mexican humic tropics. Animals 2022; 12: 608. https://doi.org/10.3390/ani12050608

[24] Juárez-Barrientos JM, Herman-Lara E, Soto-Estrada A, Ávalos-de la Cruz DA, Vilaboa-Arroniz J, Díaz-Rivera P. Tipificación de sistemas de doble propósito para producción de leche en el distrito de desarrollo rural 008, Veracruz, México. Rev Cient la Fac Ciencias Vet la Univ del Zulia 2015; 25(4): 317-23.

[25] Marai IFM, Haeeb AAM. Buffalo's biological functions as affected by heat stress - A review. Livest Sci 2010; 127: 89-109. https://doi.org/10.1016/j.livsci.2009.08.001

[26] Mota-Rojas D, Napolitano F, Bradhieri A, Guerrero-Legarreta I, Bertoni A, Martínez-Burnes J, *et al*. Thermal biology in river buffalo in the humid tropics : neurophysiological and behavioral responses assessed by infrared thermographic. J Anim Behav Biometeorol 2020; 9(2103): 1-11. https://doi.org/10.31893/jabb.21003

[27] Galloso-Hernández MA, Rodríguez-Estévez V, Alvarez-Díaz CA, Soca-Pérez M, Dublin D, Iglesias-Gómez J, *et al*. Effect of Silvopastoral Systems in the Thermoregulatory and

Feeding Behaviors of Water Buffaloes Under Different Conditions of Heat Stress. Front Vet Sci 2020; 7: 1-8. https://doi.org/10.3389/fvets.2020.00393

[28] Galloso-Hernández MA, Rodríguez-Estévez V, Alvarez-Díaz CA, Soca-Perez M, Dublin DR, Iglesias-Gómez J, *et al*. Selectivity of Leguminous Trees by Water Buffaloes in Semi-intensive Systems. Front Vet Sci 2020; 7: 1-9. https://doi.org/10.3389/fvets.2020.542338

[29] Bertoni A, Álvarez A, Mota-Rojas D. Desempeño productivo de los búfalos y sus opciones de desarrollo en las regiones tropicales. Soc Rural Prod y Medio Ambient 2019; 19(38): 59-80.

[30] Vilaboa-Arroniz J, Díaz-Rivera P, Ruiz-Rosado O, Juárez-Lagunes F. Socioeconomical and technological characterization of afroecosystems with dual purpose cattle in the Papaloapan Region, Veracruz, México. Trop Subtrop Agroecosystems 2008; 10(1): 53-62.

[31] Prusty S, Kundu SS, Kumar Sharma V. Nutrient utilization and methane emissions in Murrah buffalo calves fed on diets with different methanogenic potential. Livest Sci 2017; 202: 89-95. https://doi.org/10.1016/j.livsci.2017.05.023

[32] Bertoni A, Álvarez-Macías A, Mota-Rojas D, Dávalos JL, Minervino Hamad AH. Dual-purpose water buffalo production systems in tropical Latin Lmerica: Bases for a sustainable model. Animals 2021; 11(10): 1-16. https://doi.org/10.3390/ani11102910

[33] Cuevas-Reyes V, Rosales-Nieto C. Characterization of the dual-purpose bovine system in northwest Mexico: Producers, resources and problematic. Rev MVZ Cordoba 2018; 23(1): 6448-60. https://doi.org/10.21897/rmvz.1240

[34] Bertoni A, Napolitano F, Mota-Rojas D, Sabia E, Álvarez-Macías A, Mora-Medina P, *et al*. Similarities and Differences between River Buffaloes and Cattle : Health, Physiological, Behavioral and Productivity Aspects. J Buffalo Sci 2020; 9: 92-109. https://doi.org/10.6000/1927-520X.2020.09.12

[35] Napolitano F, Mota-Rojas D, Guerrero-Legarreta I, Orihuela A. The Latin American River Buffalo, Recent Findings [In spanish]. 3rd ed. Mexico City: BM Editores; 2020. 1544 p. Available from: https://www.lifescienceglobal.com/journals/journal-of-buffalo-science/97-abstract/jbs/4550-el-bufalo-de-agua-en-latinoamerica-hallazgos-

[36] Paul SS. Requirements of buffaloes. Rev Bras Zootec Nutr 2011; 2011: 93-7.

[37] Iglesias JM, Galloso M, Toral OC, Aguilar A. Comportamiento productivo y conducta de búfalos de río y toros Cebú en silvopastoreo. Pastos y Forrajes 2019; 42(3): 223-9.

[38] ANASB. Indice di Selezione aggregato per la Bufala Mediterranea Italiana [Internet]. Associazione Nazionale Allevatori Specie Bufalina 2021 [cited 2021 Aug 12]. Available from: https://www.anasb.it/attivita-anasb/indice-di-selezione-ibmi/

[39] Neglia G, De Nicola D, Esposito L, Salzano A, D'Occhio MJ, Fatone G. Reproductive management in buffalo by artificial insemination. Theriogenology 2020; 150: 166-72. https://doi.org/10.1016/j.theriogenology.2020.01.016

[40] Bertoni A, Mota-Rojas D, Mora-Medina P, Álvarez-Macias A, Guerrero-Legarreta I, Morales-Canela A, *et al*. Scientific findings related to changes in vascular microcirculation using infrared thermography in the river buffalo. J Anim Behav Biometeorol 2020; 8: 288-97. https://doi.org/10.31893/jabb.20038

[41] Zicarelli L. Ciclo estral. In: Crudeli G, Konrad JL, María-Patiño E, editors. Reproducción en búfalas. Primera ed. Argentina: Moglia ediciones; 2016; pp. 57-69.

[42] Mota-Rojas D, Wang D, Titto CG, Gómez-Prado J, Carvajal-de la Fuente V, Ghezzi M, *et al*. Pathophysiology of Fever and Application of Infrared Thermography (IRT) in the Detection of Sick Domestic Animals: Recent Advances. Animals 2021; 11: 2316. https://doi.org/10.3390/ani11082316

[43] Mota-Rojas D, Pereira AMF, Wang D, Martínez-Burnes J, Ghezzi M, Hernández-Avalos I, *et al*. Clinical Applications and Factors Involved in Validating Thermal Windows Used in Infrared Thermography in Cattle and River Buffalo to Assess Health and Productivity. Animals 2021; 11: 2247. https://doi.org/10.3390/ani11082247

[44] Guerrero Legarreta I, Napolitano F, Mota-Rojas D, Orihuela A. El búfalo de agua en las Américas, enfoques prácticos y experimentales. Segunda edición. México, Editorial BM Editores. Enero, Ciudad de México 2019; pp. 1-881. https://bmeditores.mx/entorno-pecuario/descargas/el-bufalo-de-agua-en-las-americas-2a-edicion/

Received on 17-01-2022 Accepted on 09-03-2022 Published on 11-03-2022

https://doi.org/10.6000/1927-520X.2022.11.02