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Geographic information system and unmanned aerial vehicles for soil and pastures evaluation

Sistemas de información geográficos y vehículos aéreos no tripulados para la evaluación de suelos y pastos

Sistemas de informação geográfica e veículos aéreos não tripulados para avaliação de solos e pastagens

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Abstract

The objective of this review is to present soil and pasture evaluation studies using georeferenced aerial photographs captured by sensors on board drones and analyzed using the Geographic Information System (GIS) to develop strategies for use in the management of pastures and farm potential. The use of intensive grazing systems requires advanced knowledge for efficient management, and smart and precision agriculture represents a strategy to reduce costs. Using GIS and drones, an immediate comprehensive diagnosis is obtained, such as quantification of the degradation of a pasture or farm, distribution of botanical composition, and variability of soil and pasture nutrients to generate fertilization plans by specific area (precision agriculture).

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Resumen

La presente revisión tiene como objetivo mostrar estudios de evaluación de suelos y pastos, utilizando fotografías aéreas georreferenciadas capturadas por sensores a bordo de drones y analizadas mediante el sistema de información geográfico (SIG), para desarrollar estrategias de uso en el manejo de los pastos y el potencial de la finca. Hoy día con el uso de sistemas intensivos de pastoreo, se requieren conocimientos avanzados para un manejo eficiente, donde la agricultura inteligente y de precisión, representen una estrategia para disminuir costos. A través de los SIG y drones se puede obtener un diagnóstico integral inmediato, tales como: cuantificación de la degradación de la pastura o finca, distribución de la composición botánica, variabilidad de los nutrientes del suelo y de la pastura. Además, se generan planes de fertilización por área específica (agricultura de precisión), entre otros.

Palabras clave: SIG, dron, agricultura inteligente y de precisión, fertilización.

Resumo

O objetivo desta revisão é mostrar estudos de avaliação de solos e pastagens, utilizando fotografias aéreas georreferenciada capturadas por sensores a bordo de drones e analisadas por meio do Sistema de Informações Geográficas (SIG) para desenvolver estratégias de uso no manejo de pastagens e o potencial da fazenda. Hoje, a utilização de sistemas intensivos de pastoreio requer conhecimento avançado para um manejo eficiente, onde a agricultura inteligente e a de precisão representam uma estratégia para redução de custos. Por meio de SIG e drones, se obtem um diagnóstico abrangente imediato, como: quantificação da degradação de pastagens ou fazendas, distribuição de composição botânica, variabilidade de solo e nutrientes de pastagens para gerar planos de fertilização por área específica (agricultura de precisão), entre outros.

Palavras-chave: GIS, drone, agricultura inteligente e de precisão, fertilização.

Introduction

Nowadays, the use of intensive grazing systems, either the so-called Voissin grazing, ultra-dense grazing, cellular grazing, strip grazing, among others, require advanced knowledge for their efficient management. For this, it is necessary to know the amount of nutrients extracted by animals and plants, in order to replenish them in time and avoid the weeding of paddocks and the degradation of pastures and soils. In addition, Animal Production Systems have advanced considerably. In this sense, the use of techniques to improve Reproduction, Nutrition, Genetics and Health have led to great advances in obtaining more productive animals. However, for animals to respond to these improvement techniques, it is necessary to provide them with good quality pasture and forage that will last over time.

Official figures from 1950 to 2007 indicated that the pasture area in Venezuela had regressed for 57 years, with pasture degradation being one of the reasons for this delay, as a consequence of inadequate management (Espinoza *et al*., 2012). On the other hand, average production costs in 2022, for the liter of milk at the feedlot gate, have ranged between 0.32 and 0.46 $\$.kg^{-1}$ and the standing meat between 1.27 and 1.66 $\$.kg^{-1}$ (Instituto Venezolano de la Leche y la Carne [Invelecar], 2022; Observatorio Lácteo [OCLac], 2022). These costs make us rethink the economic efficiency of the system and implement techniques to be profitable and sustainable, where pastures play a decisive role. Therefore, today it is essential to focus on precision agriculture or livestock farming, using remote sensors on board unmanned drones, supported by global positioning systems (GPS) and spatial analysis using Geographic Information Systems (GIS) technology, which would allow determining the best strategy to optimize the use of available resources.

GIS are used in precision agriculture to collect, store and analyze data in order to increase crop efficiency through the understanding and variation observed in soils, their association with crops, yields and the use of fertilization practices, which are of interest for decision making (Cantos *et al*., 2022). In Venezuela, they have been used mostly in cartographic and cadastral studies, watershed characterizations and in certain agricultural crops (Alberdi and Erba, 2022; Cabeza *et al*., 2021; Figueredo *et al*., 2018; Olivares *et al*., 2021; Rey-Brina *et al*., 2020; Sevilla *et al*., 2009), but there are no works cited in pasture evaluation.

The objective of this article was to show soil and pasture evaluation studies, using georeferenced aerial photographs, captured by drone-borne sensors, and analyzed with GIS techniques to develop strategies for pasture management use and farm potential.

Methods

Maps and data, product of unpublished field reports, developed in Venezuela and Costa Rica, between 2017 and 2021, were used. In this sense, two farms were diagnosed in Venezuela, located in the states of Bolivar (Agropecuaria J & M, C.A., UTM coordinates 623215 E and 823321 N) and Tachira (La Coromoto, 806899 E and 917100 N); and a third farm in Heredia, Costa Rica (Espinos, UTM 815515 E and 1112271 N).

Each farm was geographically located and climatic and edaphic data, relief, hydrology, vegetation cover variability and the use of satellite images were recorded. In addition, historical data and digitized, geo-referenced and vectorized plans were obtained, which were superimposed on the geospatial information subsequently collected on the farm lands, in order to previously select the points geolocated by geographic coordinates for soil and pasture sampling. Then, in the field, photographic scenes were taken by flying with a quadcopter drone equipped with a sensor (CMOS of ½.3'') and effective pixels of 12.4 M, with a flight altitude between 80 and 120 meters above sea level and longitudinal and transversal overlap of 80%. To do so, the following steps were followed: Definition of the study area, generation of flight plans (height, time and flight lines, longitudinal and transversal overlap of the photographic scenes), positioning and GPS measurement of ground control points, calibration of the drone (compass, GPS and camera), flight and taking aerial photographs. This procedure allowed, through photogrammetric processes, the obtaining of fiducial points of each photographic scene with east and north coordinates, the orientation of the aerial shot and the design of the point cloud to generate an orthophotomap of the farm, as well as a digital model of the farm's surface, at detailed spatial resolutions of 5 to 10 cm. To achieve this procedure and the products generated, computer applications were used, such as: GNSS Solution Version 10.1, MapSource and Sokkia Link Version 2.0 (for post processing of ground control points that support the cartographic accuracy of the orthophotomap), Arc-Gis Version 10.1 (for information overlay and spatial analysis) and Agisoft Version 1.2.5 (for photogrammetric processing of the point cloud and orthophotomap).

Geolocated sampling of soil and plant tissue (foliar sampling)

Using GPS, the points previously geo-referenced for the evaluation of soils and grasses were located in the field. For the soil study, a general characterization of the environment was made, highlighting climatic, geological, physiographic, vegetation and current use aspects, such as: precipitation, temperature, slope, stoniness, micro-relief, cover and agricultural use. Then, the soil profile was described to a depth of one meter, detailing elements such as textural class, color, structure, hardness, friability, drainage, presence of roots and biological activity. Finally, soil samples were taken at each geo-referenced point for subsequent laboratory analysis of physical-chemical properties (texture, CEC, MO, macro and micronutrients).

In the case of pastures, the Relative Importance Value (RIV) method described by Espinoza *et al*. (2000) was used, which reflects the percentage ratio of the species present in the pastures. The total biomass production was also estimated and samples were taken to determine the chemical composition (macro and microelements).

Homogeneous management units for suitability and potential of the farm

In order to standardize the areas, homogeneous management units were delimited based on a cluster analysis of the different soil property maps, the digital surface model, the slope map and the description of the soil profile at the sampling sites. For this purpose, greater weight was given to the delimitation of the units to physical properties, such as slope and the distribution of clays and sands, because they are more stable over time. In this sense, for the evaluation of land suitability for the sustainability of the farm, the methodology of the Food and Agriculture Organization of the United Nations ([FAO], 1997) was used, for the classification for fertility purposes, the methodology of Sánchez *et al*. (1982) and for the classification of land according to its capacity for agricultural use, the system proposed by Comerma and Arias (1971).

Predictive maps of soil and pasture nutritive value studies

With the information from samples sent to the soil and pasture laboratories, continuous maps of physicochemical properties were generated, using mathematical interpolation and geostatistical models, such as spline, topogrid and cokriging (Castro *et al*., 2017), which allowed to adequately adjust the levels of natural fertility and nutritive content of pastures.

Pasture health index

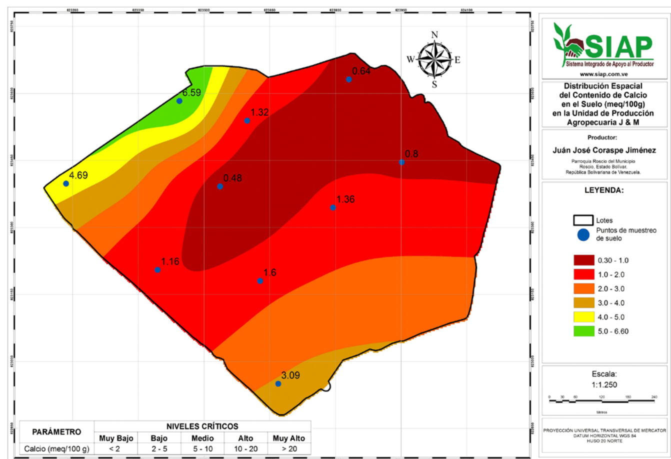
This work raises the possibility of using, not replacing, estimated spectral indices, from the visible bands place index significance (RGB), as an alternative, given the difficulty of using traditional indices such as place index significance (NDVI), given the high cost of multispectral sensors; from the orthophotomap of images obtained by RGB sensors on board drones. Then, using map algebra, the normalized green red difference index (NGRDI) was calculated, which is linearly related to the normalized difference of the reflectances of both bands, using equation 1 (Gitelson, *et al*., 2002).

$$\text{NGRDI} = (\text{DN green} - \text{DN red}) / (\text{DN green} + \text{DN red}) \qquad \text{(Eq. 1)}$$

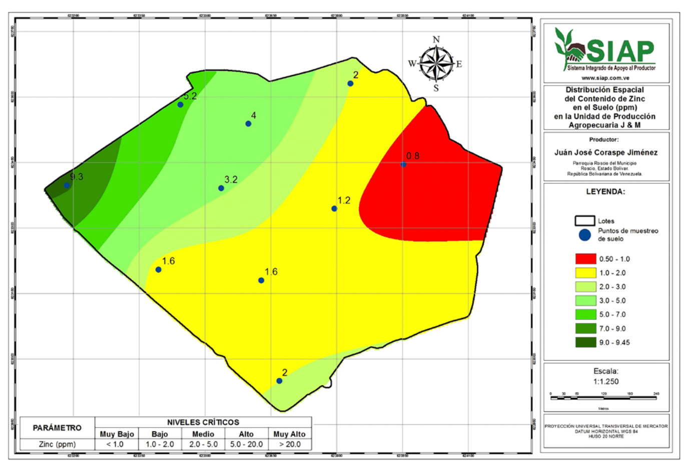
This index allowed inferring the state of health of the pastures, through the nutritional state of the vegetation, ground cover density, pest and disease attack. For the calibration, a statistical and geostatistical analysis was carried out between the value of the index and the bands with the measurement of the variables, both in the laboratory and in the field, in order to adjust the limits of the equation with respect to the classes obtained in the field.

Results and discussion

Figure 1 shows two maps of physical-chemical properties of the soils of a 50 ha farm, located in the south of Venezuela in Bolivar State, where it is evident that the soils are deficient in calcium in more than 85 % of the farm (red shades), sufficient in a very low proportion in the north (green shades), but with critical levels in the northwest (yellow color); while zinc was deficient only in a part of the eastern part of the farm. According to the concept of precision agriculture, this indicated that the application of the micro element would be only on the basis of that sector, which represents 15% of the surface, while Ca should be applied almost in its totality. Pinargote and Pacheco (2021) considered that precision agriculture, in addition to participating in the sustainability and profitability of the agricultural system, brings great benefits by reducing the environmental impact of agriculture. This aspect is important, considering that the application of high levels of agrochemicals is considered today as an environmental problem in the carbon footprint, even more so in livestock systems.



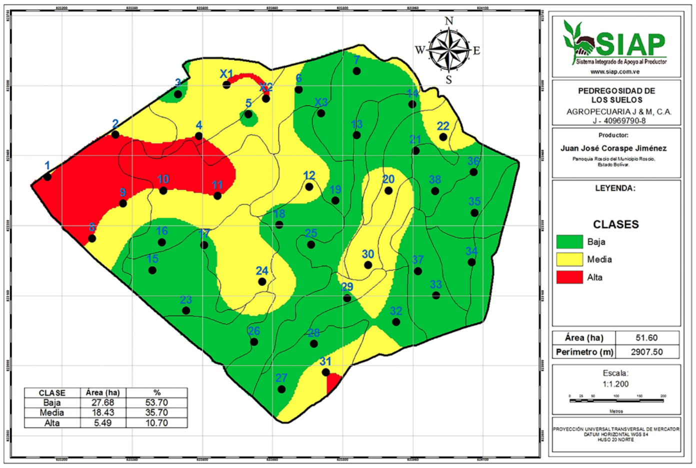
1a. *Distribución espacial del contenido de calcio en el suelo (meq/100g) en la unidad de producción Agropecuaria J & M:* Spatial distribution map of soil exchangeable calcium in the farm J&M. *Leyenda*: Legend. *Lotes*: Lots. *Puntos de muestreo de suelo*: Soil sampling points. *meq/100 g*: meq.100 g^{-1}. *Parámetro*: Parameter. *Niveles críticos*: Critical levels. *Calcio (meq/100 g)*: Calcium (meq.100 g^{-1}). *Muy bajo*: Very low. *Bajo*: Low. *Medio*: Medium. *Alto*: High. *Muy alto*: Very high.



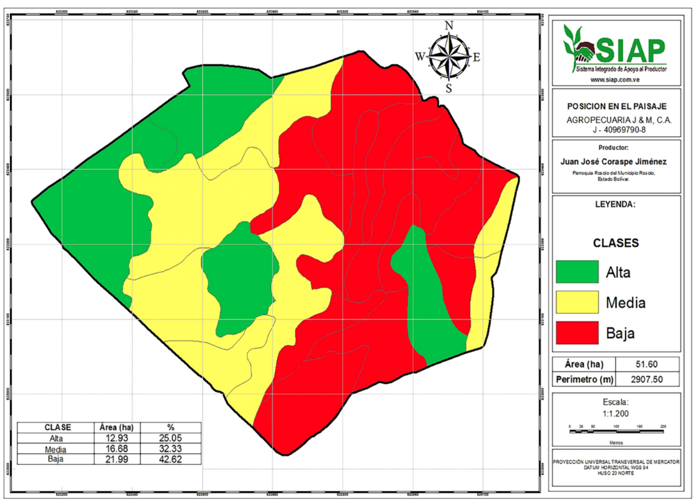
1b. *Distribución espacial del contenido de Zinc en el suelo (ppm) en la unidad de producción Agropecuaria J &* M: Spatial distribution of zinc content in agricultural soils of the J&M farm. *Leyenda*: Legend. *Lotes*: Lots. *Puntos de muestreo de suelo*: Soil sampling points. *Parámetro*: Parameter. *Niveles críticos*: Critical levels. *Zinc (ppm)*: Zinc (ppm). *Muy bajo*: Very low. *Bajo*: Low. *Medio*: Medium. *Alto*: High. *Muy alto*: Very high.

Figure 1. Maps of soil properties at the J & M Agropecuaria farm, El Callao, Bolivar State, Venezuela. 1a) Calcium distribution. 1b) Zinc distribution.

The following is the morphological evaluation and position of the landscape at Agropecuaria J & M, El Callao, Bolivar state, Venezuela (figure 2).



2a. *Pedregosidad de los suelos Agropecuaria J & M*: Surface stoniness of the soils of the J & M farm. *Leyenda*: Legend. *Clases*: Classes. *Baja*: Low. *Media*: Medium. *Alta*: High. *Área* (*ha*): Area (ha).



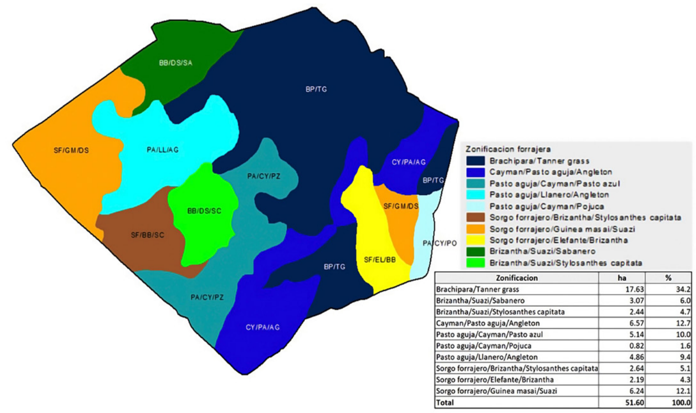
2b. *Posición en el paisaje*: Position in the landscape. *Leyenda*: Legend. *Clases*: Classes. *Baja*: Low. *Media*: Medium. *Alta*: High. *Área* (*ha*): Area (ha).

Figure 2. Morphological evaluation and position of the landscape at Agropecuaria J & M, El Callao, Bolivar State, Venezuela. 2a) Stoniness. 2b) Landscape.

Based on the characterization data (figure 2) and the results of the physical-chemical analysis of the soils, and using the technique of homogeneous management units for suitability and potential of the farm, the possible pasture and forage species to be established in the production unit were recommended, generating an adaptation map by sector (figure 3).

Predictive maps allow visualizing the spatial distribution of the nutrient content of pasture tissue, such is the case of a study carried out in Costa Rica, at the beginning of the dry period and the beginning of the rainy season in a dairy and equine farm (figure 4).

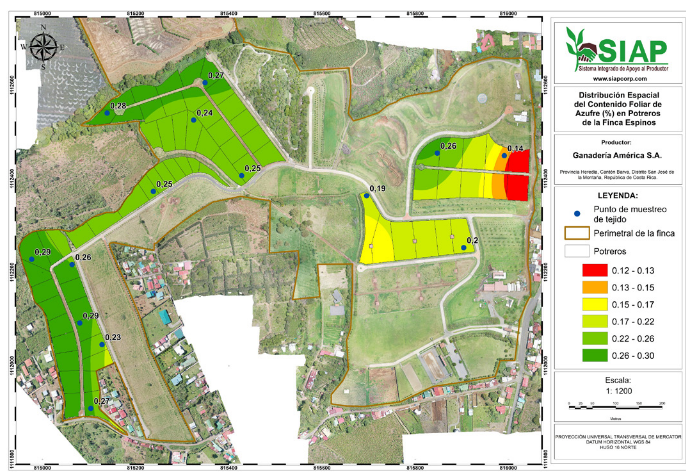
Figure 4 shows adequate sulfur values in the dairy cow and heifer modules with star grass (*Cynodon plectostachyus*), located to the north and west of the farm; while in the equine sector to the east, critical and deficient levels of this nutrient are observed in transvala grass (*Digitaria decumbens*). The Figure clearly shows that the sulfur content in the aforementioned pastures is decreasing from the northwest and southwest to the west, reaching deficient levels in the hybrid transvala grass (red color). This information can be important for the knowledge of nutritionists and the elaboration of diets for precision cattle breeding. However, for greater precision it is likely that a greater number of samples would be required, but also the costs of the study would rise. Barnetson, *et al*. (2020), stated that when remote sensors are used they are not exempt from sampling errors, suggesting further research in this regard.



Zonificacion	ha	%
Brachipara/Tanner grass	17.63	34.2
Brizantha/Suazi/Sabanero	3.07	6.0
Brizantha/Suazi/Stylosanthes capitata	2.44	4.7
Cayman/Pasto aguja/Angleton	6.57	12.7
Pasto aguja/Cayman/Pasto azul	5.14	10.0
Pasto aguja/Cayman/Pojuca	0.82	1.6
Pasto aguja/Llanero/Angleton	4.86	9.4
Sorgo forrajero/Brizantha/Stylosanthes capitata	2.64	5.1
Sorgo forrajero/Elefante/Brizantha	2.19	4.3
Sorgo forrajero/Guinea masai/Suazi	6.24	12.1
Total	51.60	100.0

Zonificación forrajera: Forage zoning.

Figure 3. Species adaptable to the Agropecuaria J & M farm, El Callao, Bolivar State, Venezuela.

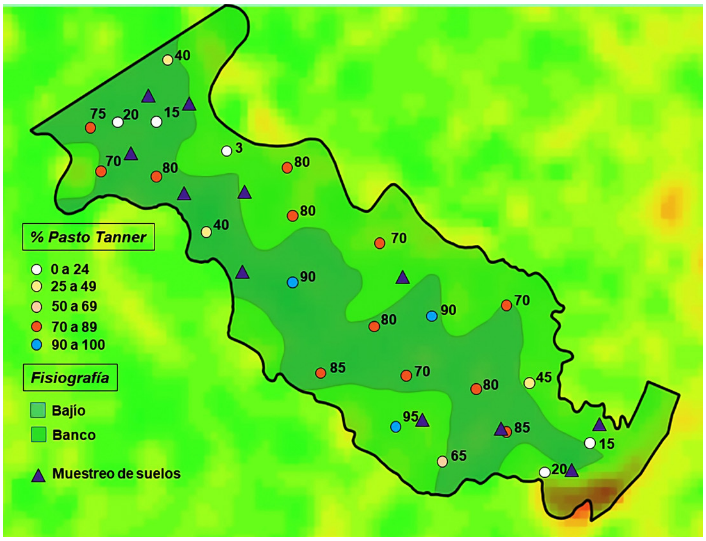


Distribución espacial del contenido foliar de azufre (%) en potreros de la finca Espinos: Spatial distribution of foliar sulfur content (%) in paddocks of the Espinos farm. *Punto de muestreo de tejido*: Tissue sampling spot. *Perimetral de la finca*: Farm perimeter. *Potreros*: Paddocks.

Figure 4. Spatial distribution of sulfur content in star grass and switchgrass tissue on a Costa Rican farm. Evaluation April 2021.

One of the aspects to consider in pasture management is to accurately determine flooded and upland areas. The digital elevation model (DEM) is a tool to separate these areas and define aspects of pasture management. DEMs are geomatic products that allow characterizing the area, such as terrain elevation, surface, slope, aspect, curvature and zones of influence (Mena *et al*., 2011).

Figure 5 shows the DEM of the "La Coromoto" farm over an area of 170 ha, where the physiographic units of banco and bajío are separated, in addition to presenting the proportion of the *Urochloa radicans* species. The study also showed a high proportion of weeds (37.5%).



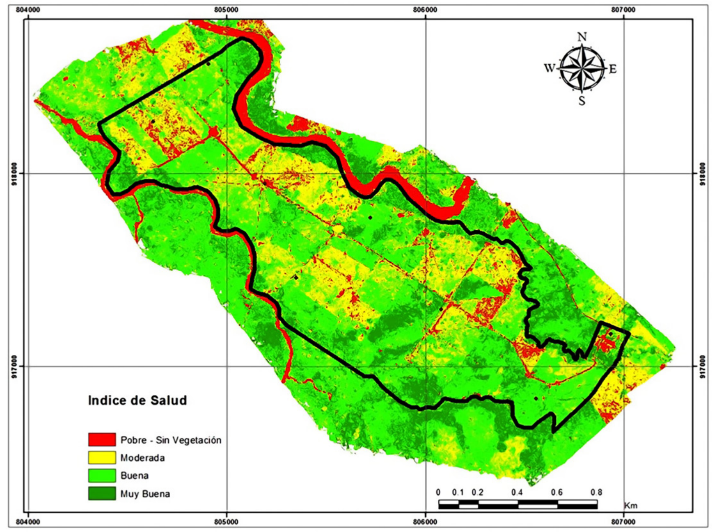
% Pasto Tanner: Tanner grass %. *Fisiografía*: Physiography. *Bajío*: Lowland. *Banco*: Bank. *Muestreo de suelos*: Soil sampling.

Figure 5. Physiography and distribution of Tanner Grass (Urochloa radicans) at La Coromoto farm, Táchira State, Venezuela.

This aspect, together with the observation of tatucos (figure 6) and the health index (figure 7), suggest management practices to be recommended, among which are the use of harrowing, fertilization and animal load adjustments, among others. Tatucos are the product of reticular erosion, and are very common in the 500,000 hectares of southern Lake of Maracaibo (Comerma, 2009).

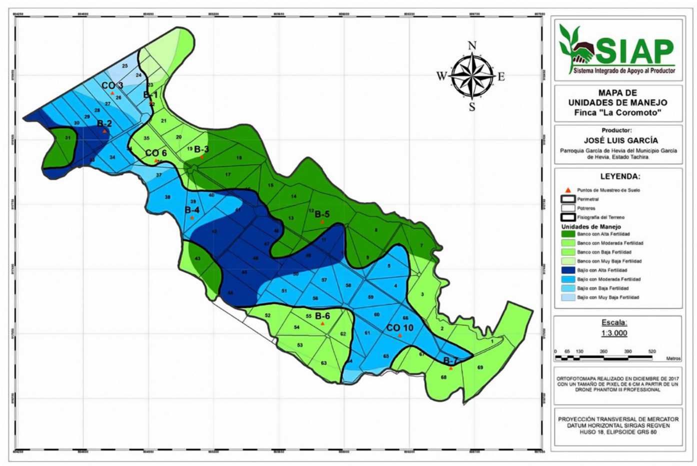
Mena *et al*. (2007), consider that the data processed by GIS determine homogeneous sectors, allowing an integrated analysis of spatially expressed territorial variables. Based on the methodologies for land classification and suitability, after defining the homogeneous management units, a detailed orthophotomap was obtained (figure 8). General recommendations were also obtained through a menu of options (tables 1 and 2), where 13 management units were classified according to the intrinsic characteristics of the farm (bank and bajio units, classified according to soil acidity and fertility, classified as Typic Hapludalfs (bancos) and Aeric Epiaquepts (bajios), recommending a fertilization and pasture management plan.

Figure 6. Drone view of the area where the presence of tatucos in the paddocks can be seen.



Índice de salud: Health index. *Pobre-Sin vegetación:* Poor-No vegetation. *Moderada*: Moderate. *Buena*: Good. *Muy buena*: Very good.

Figure 7. State of health of paddocks in La Coromoto farm, Táchira state, Venezuela.



Mapa de unidades de manejo Finca "La Coromoto": Map of management units "La Coromoto" farm. *Leyenda*: Legend. *Puntos de muestreo de suelo*: Soil sampling points. *Perimetral*: Perimeter. *Potreros*: Paddocks. *Fisiografía del terreno*: Physiography of the terrain. *Unidades de manejo*: Management units. *Banco con alta fertilidad*: Bank with high fertility. *Banco con moderada fertilidad*: Bank with moderate fertility. *Banco con baja fertilidad*: Bank with low fertility. *Banco con muy baja fertilidad*: Bank with very low fertility. *Bajío con alta fertilidad*: Lowlands with high fertility. *Bajío con moderada fertilidad*: Lowland with moderate fertility. *Bajío con baja fertilidad*: Lowland with low fertility. *Bajío con muy baja fertilidad*: Lowland with very low fertility.

Figure 8. Homogeneous management units in La Coromoto farm, Táchira, Venezuela.

Conclusions

Geographic information systems and unmanned aerial vehicles are a valuable tool for the evaluation of pasture and agri-food resources, generating a rapid diagnosis of the entire farm and management plans, making it possible to propose strategic fertilization by specific area (precision agriculture). Using the methodology employed with GIS, it is feasible to recommend potential maps to improve livestock production units, through a menu of options.

Table 1. Menu of options to strengthen the La Coromoto Production Unit, Táchira State, Venezuela.

Units	System	Option	Crop	Use	Description	Paddock	Observations
BN-MF-SA	Pastoralism and Agriculture	Pasture for Grazing Agricultural Crops Legume	Decumbens Ruziziensis Legume Tanner Guinea-grass Passion fruit	Grazing Hay Protein in association Self-consumption and sale	Establishment of new pastures by over-seeding Follow fertilization recommendations	1-2-3-52-53-54-55-62-63-68-69	Maintain the species present in the paddock.
BJ-LF-EA	Pastoril	Pasture for grazing	Tanner	Grazing	Follow fertilization plan	26-27-37	Handling animal loads and days of rest and occupation.

BN: Bancos; BJ: Bajios, MF: Moderate fertility, LF: Low fertility, SA: Strong acidity, EA: Extreme acidity (Not published).

Table 2. Fertilization levels (kg.ha^{-1}.yr^{-1}) in the different physiographic units. La Coromoto Farm, Táchira State.

Fertilizante	BN-HF	BN-MF	BN-LF	BN-MB	BJ-HF	BJ-MF	BJ-LF	BJ-VLF
Phosfate rock from Riecito	350	350	400	400	200	300	350	350
Phosfate rock from Monte Fresco	400	400	450	450	250	400	400	400
Pearl urea (U)	0	0	0	0	250	250	250	250
Potasium chloride (KCl)	25	0	25	0	50	0	50	50

BN: Bancos; BJ: Bajios, HF: High fertility, MF: Moderate fertility, LF: Low fertility, VLF: Very low fertility

With the use of GIS and drones it is possible to obtain quantifiable products such as: the quantification of the degree of degradation of a pasture or farm, the distribution of botanical composition, the determination of the variability of soil and pasture nutrients, the separation of physiographic areas through the MDE to define management plans, such as irrigation and the adequate management of forage species.

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