Unmanned aerial vehicle outputs and associated field measurements of the herbaceous and tree layers of the Senegalese savannah

Simon Taugourdeau, Cofélas Fassinou, Marina Bossoukpe, Ousmane Diatta, Ousmane Ndiaye, Antoine Diehdiou, Ange-Jokébed Adjoua N'Goran, Alain Audebert, Emile Faye

Received: 19 July 2022 | Revised: 17 January 2023 | Accepted: 17 January 2023

DOI: 10.1111/aje.13123

African Journal of Ecology WILEY

TECHNICAL NOTE

Unmanned aerial vehicle outputs and associated field measurements of the herbaceous and tree layers of the Senegalese savannah

Simon Taugourdeau[1,2] | Fassinou Cofélas[3,4] | Marina Bossoukpe[3] | Ousmane Diatta[3,4] | Ousmane Ndiaye[4] | Antoine Diehdiou[3] | Ange N'Goran[3,4] | Alain Audebert[5,6] | Emile Faye[7,8]

[1]CIRAD UMR SELMET-PPZS, Dakar, Senegal

[2]UMR SELMET, CIRAD, INRA Institut Agro, University of Montpellier, Montpellier, France

[3]Département de Biologie Végétale – PPZS, UCAD, Dakar, Senegal

[4]ISRA, CRZ Dahra-PPZS, Dahra Djoloff, Senegal

[5]UMR AGAP Institut, CIRAD, Montpellier, France

[6]UMR AGAP Institut, CIRAD, INRAE, Institut Agro, University of Montpellier, Montpellier, France

[7]UPR Hortsys, CIRAD, Montpellier, France

[8]UPR Hortsys, CIRAD, Univiversity of Montpellier, Montpellier, France

Correspondence
Simon Taugourdeau, CIRAD UMR SELMET-PPZS, Dakar, Senegal.
Email: simon.taugourdeau@cirad.fr

Funding information
Agence Nationale de la Recherche, Grant/Award Number: ANR-16-CONV-0004; Directorate-General for International Cooperation and Development

Abstract

Unmanned aerial vehicles (UAVs) are widely used to assess the vegetation of an ecosystem. This report presents three data sets from UAVs used on a savannah-type ecosystem in Senegal. Two data sets contain an orthomosaic and a surface and terrain digital model (UAV outputs), along with associated field measurements on the tree and herbaceous layers, while the third data set contains an orthomosaic and digital surface model, along with field measurements on the herbaceous layers. One data set was compiled over the entire rainy season on the same plot (plot dataset). One was compiled across a landscape at the 7000 ha Dahra Djoloff research center (CRZ-dahra *Centre de recherche zootechnique de Dahra*). The third data set was compiled across Senegal from the North to the Southeast of the country with wide variability in climate and soil conditions. All the data sets are in Open Access in the Zenodo repository. These data sets could be used in many different studies: calibration between field measurements and UAV outputs on a large scale, or used as an intermediate step between field and satellite images.

KEYWORDS
savannah, Senegal, tree, Uav

Résumé

Les véhicules aériens sans pilote (UAV) sont largement utilisés pour évaluer la végétation d'un écosystème. Ce rapport présente trois ensembles de données provenant d'UAV utilisés sur un écosystème de type savane au Sénégal. Deux ensembles de données contiennent un modèle orthomosaïque et un modèle numérique de surface et de terrain (sorties UAV), ainsi que des mesures de terrain associées sur les couches arborées et herbacées, tandis que le troisième ensemble de données contient un modèle de surface orthomosaïque et numérique, avec des mesures de terrain sur les couches herbacées. Un ensemble de données a été compilé pendant toute la saison pluvieuse sur la même parcelle (ensemble de données de la parcelle). L'un a été compilé à travers un paysage dans le centre de recherches Dahra Djoloff de 7 000 ha (CRZ-dahra *Centre de recherche zootechnique de Dahra*). Le troisième ensemble de données a été compilé à travers le Sénégal du nord au sud-est du pays avec une grande variabilité des conditions climatiques et pédologiques. Tous les ensembles de données sont en Open Access dans le référentiel Zenodo. Ces ensembles de données pourraient être utilisés dans de nombreuses études différentes : étalonnage entre les mesures de terrain et les sorties UAV à grande échelle, ou utilisés comme étape intermédiaire entre les images de terrain et les images satellites.

1 | INTRODUCTION

Unmanned aerial vehicles (UAVs) are now widely available for the general public and also for research purposes, especially for ecosystems. They can be used to take a set of aerial photographs of the ecosystem. Images taken by UAVs can be processed using the Structure from Motion methodology (Frey et al., 2018). It produces a very high-resolution mosaic (with the resolutions ranging from around 1 to 10 cm depending on the flight parameters and the camera), but it also produces a 3D model of the ecosystem. The 3D model, and the surface model produced from it using photogrammetric methods, can be used to assess volumetric measurements of trees and woody communities (Anifantis et al., 2019; Bossoukpe, Ndiaye, et al., 2021; Bourgoin et al., 2020; dos Santos et al., 2020; Oldeland et al., 2017). UAVs can also be used for herbaceous layers using the surface model, but also vegetation indexes based on colour reflectance (only in RGB or with multispectral images; Bendig et al., 2014; Possoch et al., 2016; Wijesingha et al., 2020).

Senegal is a country in the western Sahel. A rainfall gradient occurs from North (around 200 mm of annual rainfall) to the South (around 1200 mm). The soils are sandier in the western part of the country and more ferralitic in the eastern part. The vegetation of most of the ecosystem comprises either cultivated (crops) or spontaneous herbaceous layers in rangelands and a sparse woody community. The UAV is also a good tool for analysing both layers simultaneously.

Here we present three open access data sets from UAV outputs (orthomosaic, surface model, terrain model) and associated field measurements (tree and herbaceous layers). The data sets are available in Zenodo (https://doi.org/10.5281/zenodo.5145395; https://doi.org/10.5281/zenodo.5148336 and https://doi.org/10.5281/zenodo.6421543).

2 | MATERIEL AND METHODS

We acquired three different data sets: two within a landscape (a research station of 7000 ha) in northern Senegal, and one across the country.

2.1 | Sites

2.1.1 | Plot data set

The first data set contains vegetation-monitoring measurements in a 1 ha plot at the Dahra Research Station (Centre de recherche zootechnie de Dahra Djoloff CRZ-Dahra) during the 2020 rainy season (from 19 July 2020, to 17 September 2020) taken every 2 days. The vegetation in the field was a herbaceous savannah, where *Vachellia tortilis* and *Balanites aegyptiaca* were the dominant trees.

2.1.2 | Landscape dataset

The second data set within a landscape was compiled from landscape gradient sites that were 38 ha^{-1} plots across the research centre (Centre de recherche zootechnie de Dahra Djoloff CRZ-Dahra; Figure 1). The UAV images were collected in October 2018 (end of the wet season and maximum of biomass). The sites involved were the sites of previous studies (Bossoukpe, Faye, et al., 2021; Bossoukpe, Ndiaye, et al., 2021). The plots were chosen based on several studies of vegetation dynamics, and these plots were judged to be representative of the diversity of vegetation types within the research centre.

2.1.3 | National gradient measurements

For the national gradients, the measurements were taken on 45 different plots of around 1 ha each in two different field campaigns (Figure 1): one in the northern part at the end of September 2020 and the other in the southeastern part of Senegal in the middle of October. The selection of the sites was a combination of accessibility (not far from the road) and diversity of vegetation. The average rainfall for the 1981–2018 period ranged from 221 to 468 mm/year for the northern part and from 759 to 1246 mm/year for the southeastern part.

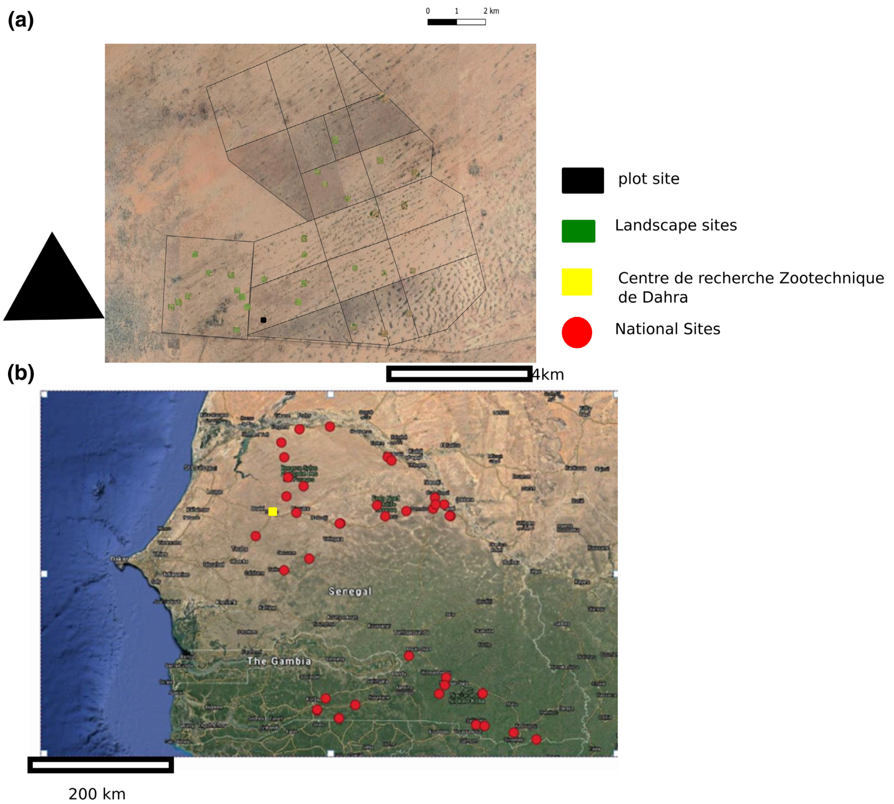

FIGURE 1 Position of the different data sets. (a) Position of the different 1-ha plots within the structure of CRZ Dahra (@google). In green, the position of the landscape plots and, in black, the plot site. (b) Position of CRZ Dahra and the national sites

2.2 | UAV flight plan

For the plot data set, flights were carried out using two different drones: Parrot Bluegrass and Anafi. The Parrot Bluegrass was used from 19/07/2020 to 04/08/2020. The Parrot Anafi was used for the rest of the season. The flights took place at a height of 60m, with a speed of 2 m/s and a 90% overlap (front and side) rate between images, on a double 100m × 100m grid. For the Anafi, the angle of inclination of the camera was fixed at 80°. The flights took place with a PIX4D capture application early in the day every 2 days.

For the landscape data set, the plots were mapped using a Dji Spark UAV with the litchi application (https://flylitchi.com/) for the automatic flight. The flight plan was six 100m transects, each separated by 20m, at a height of 80m and at a speed of 5 m/s. The approximate time flight was around 10 min. Images were acquired in autofocus mode (ISO exposures were automatically adjusted) at 2-s intervals throughout the flight. The angle of view was 80°. The frontal overlap was about 90% and the side overlap about 80% with an 80° angle.

For the national data set, the UAV was a Parrot Anafi with a PIX4D capture application (https://www.pix4d.com/product/pix4dcapture) using the double grid flight plan in a square generally measuring 100m*100m. The height of the flight was 80m with an overlap (front and side) of 80% at low speed and an 80° angle. The flights took place at any time during the day.

2.3 | Field measurements

2.3.1 | Herbaceous biomass

In the plot data set, measurements were focused on herbaceous parameter dynamics. Every 2 days, after the drone flight, herbaceous measurements were carried out in three 1 m^2 squares distributed, respectively, under the crown of a tree, at the edge of the crown, and at a distance from the edge of the crown equal to the height of the tree. These plots were rotated among the trees in the field until all four azimuths of the trees were covered. We recorded the leafing rate, flowering rate, herbaceous cover, senescence rate, fresh aboveground mass, dry mass, and the height of ten individual plants in each quadrat.

For the Landscape data set, 10 squares of 1 m^2 were sampled outside the tree cover at the end of wet season of 2018. All the aboveground biomass was cut at ground level and weighed fresh. A composite sample was made up for each site and weighed dry to evaluate the dry matter content (DMC), hence the dry matter of each sample.

For the national data set, one too three 1 m^2 squares were sampled at the end of the wet season of 2020. All the aboveground biomass was cut and weighed fresh. A composite sample was made up for each site and weighed dry to evaluate the DMC, hence the dry matter of each sample. The heights of five randomly selected herbaceous individuals were measured. We recorded the species composition with the percentage of cover of each species. We collected an herbarium sample each time we had a new species. The samples were used for identification of the species by the IFAN herbarium team.

For the different data sets, the positions of the squares were marked with a wooden triangle painted in white, or with a plastic bag on the ground.

2.3.2 | Tree measurements

Tree measurements were only carried out in the landscape data set and the national data set.

For the landscape, we selected 10 trees on the UAV maps. The measurements were taken after image analysis in January 2019 and January 2020. The trees were not measured at all the sites.

The measured variables were the maximum height of the tree (using a clinometer), the diameter of the tree crown in the North–South direction and in the West–East direction. The tree crown area was calculated assuming that the crown was a circle. The trunk diameters were measured at 0.30 cm in both directions and the circumferences were calculated. All woody species were identified at the species and genus levels.

For the national data set, four trees were measured in the field. They were the four woody individuals closest to the first square of the herbaceous measurements made in each direction (Northwest, Northeast, and Southwest, Southeast).

The distances from the first square of each tree were measured using a telemeter. The height was also measured with a laser telemeter. The circumferences at 0.30 and 1.3 cm were measured. The diameter of the tree crown in the North–South direction and in the West–East direction was measured and the crown area calculated assuming that the crown was a circle.

The species were recorded. We collected an herbarium sample each time we had a new species. The samples were used for identification of the species by the IFAN herbarium team.

2.4 | Image analysis

The images taken during each flight were processed using a PiX4D mapper (Pix4D SA). 3D mapping is the basic parameter proposed in the software. For each plot, an orthomosaic, a digital surface model and a digital elevation model were computed and exported in GeoTIFF format. The x accuracy was around 0.02 m, the y around—0.035 m and the z around the 0.001 m.

3 | DATA ORGANISATION

The data are organised in two separate folders for each data set. The Table 1 presented the synthetic information for the three data sets.

The plot data set is available here https://doi.org/10.5281/zenodo.6421543

The landscape data set is available here https://doi.org/10.5281/zenodo.5145395

The national data set is available here https://doi.org/10.5281/zenodo.5148336

Each data set folder contains four subfolders:

- DSM containing the surface model in tiff
- DTM containing the terrain model in tiff (only for the landscape and national data set)
- Mosaic containing the orthomosaic in tiff
- Data containing the shapefile with the position of the square and table with the field measurements

For the plot, the biomass monitoring data are in a zip file containing the shapefile with the position of the square and table with the field measurements. The shapefile "Subplots.shp" contains the positions of the square sample and its equivalent measurements in the field. The Excel file "En ligne.xlsx" contains the measurements of aboveground biomass. "Biomasse fraîche" is fresh biomass and "Biomasse sèche" is dry biomass. Both are in kg (kg/m^2)." % de recouvrement du quadrat" is grass cover, "% feuillaison" is leafing rate, "% floraison" is flowering rate, "% senescence" is senescence rate, "Individu" is the height of individual plants. The measurements are available for 93 quadrats.

For the landscape data set, the shapefile "Herbaceous.shp" contains the positions of the square sample but also of squares that contained only soil (square cut before the flight).

The file "Herbaceous-landscape.csv" contains the measurements of aboveground biomass (FM (fresh mass) and DM (dry mass)). Both are in g (g/m^2). The biomass is available for 346 square samples.

The shapefile "tree.shp" contains the positions of the trees. Here the shapefile contains the positions of all the trees preselected on the map. Only a selection of these trees was measured in the field.

The file "Tree-landscape.csv" contains the tree measurements with the species, the height (in m), the trunk circumference (TC) in cm and the area of the crown (area) in m^2. The tree measurements are available for 239 trees.

For the national data set, the shapefile" national-shape.shp" contains the positions of both the tree and herbaceous samples. In some

TABLE 1 Synthetic information on the three data sets (number of measurement and information on the flight plan)

	Number of site measurement	UAV model	Flight altitude	Front overlap	Side overlap	Herbaceous measures	Tree measures
Plot	32 (dates)	Anafi	60	90	90	94	0
Landscape	38	Dji Spark	80	90	80	346	239
National	45	Anafi	80	80	80	104	159

cases, it was hard to position the square or the tree. The position and the shape of the object were not well defined.

The file "tree-national.xlsx" contains information on the tree measurements. The ID that contains the site and the positions of the trees, the distance from the square in m that indicates the distance of the tree from the biomass square, the height H (in m), the TC at 1.30 m (TC1.3) and at 0.3 m (TC0.3) in cm and the area of the crown (Area). The species is also described.

The file "herbaceous_national.xlsx" contains information on the herbaceous layer.

For each square, the height of the herbaceous layer (H), FM, DMC and DM are presented. The last columns of the file are the different species with the percentage of cover in each case.

4 | POTENTIAL USES OF THESES DATA SETS

UAVs could be used to evaluate interactions between tree and herbaceous layers. Earlier studies were undertaken in an agroforestry system in central Senegal (Roupsard et al., 2020).

New flights could be carried out in a few years to see the evolution of the vegetation at the different sites and study vegetation dynamics. It may be possible to see a change in tree morphology and possibly tree regeneration and mortality. For the herbaceous biomass, it could be interesting to monitor the biomass with respect to rainfall.

These data could be used to develop calibrations between field measurements and UAV outputs. One part of the data (the tree from the landscape data set) has already been used to develop calibrations (Bossoukpe, Faye, et al., 2021; Bossoukpe, Ndiaye, et al., 2021; Taugourdeau et al., 2022). One possible interest could be to carry out a meta-analysis to develop calibrations on a larger scale across different types of vegetation, but also between different UAVs and flight plans.

The data could be used to upscale vegetation variables from the field variable to a larger scale using satellite images. Indeed, it is possible to use very high spatial resolution images to produce intermediate vegetation maps, and thus calibrate these maps to satellite images with a lower resolution (Taugourdeau et al., 2014).

The goal of many studies has been to evaluate aboveground biomass across the Sahel region (Diouf et al., 2015; Fensholt et al., 2009; Fensholt & Rasmussen, 2011; Zhang et al., 2018). This remote sensing approach is used by several countries to assess the quantity of feed available for livestock. Other studies have focused on tree communities (Brandt et al., 2020; Brandt, Hiernaux, Rasmussen, et al., 2016; Brandt, Hiernaux, Tagesson, et al., 2016; Zhang et al., 2019). UAVs could be used to validate or to calibrate such types of approaches (Kattenborn et al., 2019; Navarro et al., 2019).

ACKNOWLEDGEMENTS

This research was financed by the Carbon Sequestration and Green-house Gas Emissions in (Agro) Sylvopastoral Ecosystems in the Sahelian CILSS States (CaSSECS) project, supported by the European Union under the Development Smart Innovation through Research in Agriculture (DeSIRA) Initiative. The opinions expressed in this article are not necessarily those of the European Union. This work was supported by the French National Research Agency under the Investments for the Future Programme #DigitAg, referred to as ANR-16-CONV-0004.

CONFLICT OF INTEREST

The author declares no conflict of interest.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are openly available in Zenodo at https://doi.org/10.5281/zenodo.6421543, https://doi.org/10.5281/zenodo.5145395 and https://doi.org/10.5281/zenodo.5148336.

ORCID

Simon Taugourdeau https://orcid.org/0000-0001-6561-3228

REFERENCES

Anifantis, A. S., Camposeo, S., Vivaldi, G. A., Santoro, F., & Pascuzzi, S. (2019). Comparison of UAV photogrammetry and 3D modeling techniques with other currently used methods for estimation of the tree row volume of a super-high-density olive orchard. *Agriculture*, *9*, 233.

Bendig, J., Bolten, A., Bennertz, S., Broscheit, J., Eichfuss, S., & Bareth, G. (2014). Estimating biomass of barley using crop surface models (CSMs) derived from UAV-based RGB imaging. *Remote Sensing*, *6*, 10395–10412.

Bossoukpe, M., Faye, E., Ndiaye, O., Diatta, S., Diatta, O., Diouf, A., Dendoncker, M., Assouma, M. H., & Taugourdeau, S. (2021). Low-cost drones help measure tree characteristics in the Sahelian savanna. *Journal of Arid Environments*, *187*, 104449.

Bossoukpe, M., Ndiaye, O., Diatta, O., Diatta, S., Audebert, A., Couteron, P., Leroux, L., Diouf, A. A., Dendoncker, M., & Faye, E. (2021). Unmanned aerial vehicle for the assessment of woody and herbaceous phytomass in Sahelian savanna. *Revue d'Elevage et de Médecine Vétérinaire Des Pays Tropicaux*, *74*, 199–205.

Bourgoin, C., Betbeder, J., Couteron, P., Blanc, L., Dessard, H., Oszwald, J., Le Roux, R., Cornu, G., Reymondin, L., & Mazzei, L. (2020). UAV-based canopy textures assess changes in forest structure from long-term degradation. *Ecological Indicators*, *115*, 106386.

Brandt, M., Hiernaux, P., Rasmussen, K., Mbow, C., Kergoat, L., Tagesson, T., Ibrahim, Y. Z., Wélé, A., Tucker, C. J., & Fensholt, R. (2016). Assessing woody vegetation trends in Sahelian drylands using MODIS based seasonal metrics. *Remote Sensing of Environment*, *183*, 215–225.

Brandt, M., Hiernaux, P., Tagesson, T., Verger, A., Rasmussen, K., Diouf, A. A., Mbow, C., Mougin, E., & Fensholt, R. (2016). Woody plant cover estimation in drylands from earth observation based seasonal metrics. *Remote Sensing of Environment*, *172*, 28–38.

Brandt, M., Tucker, C. J., Kariryaa, A., Rasmussen, K., Abel, C., Small, J., Chave, J., Rasmussen, L. V., Hiernaux, P., & Diouf, A. A. (2020). An unexpectedly large count of trees in the west African Sahara and Sahel. *Nature*, *587*, 78-82.

Diouf, A. A., Brandt, M., Verger, A., El Jarroudi, M., Djaby, B., Fensholt, R., Ndione, J. A., & Tychon, B. (2015). Fodder biomass monitoring in Sahelian rangelands using phenological metrics from FAPAR time series. *Remote Sensing*, *7*, 9122–9148.

dos Santos, L. M., Ferraz, G. A. S., Barbosa, B. D. S., Diotto, A. V., Maciel, D. T., & Xavier, L. A. G. (2020). Biophysical parameters of coffee crop estimated by UAV RGB images. *Precision Agriculture*, *21*, 1227-1241.

Fensholt, R., & Rasmussen, K. (2011). Analysis of trends in the Sahelian 'rain-use efficiency' using GIMMS NDVI, RFE and GPCP rainfall data. *Remote Sensing of Environment*, *115*, 438–451.

Fensholt, R., Rasmussen, K., Nielsen, T. T., & Mbow, C. (2009). Evaluation of earth observation based long term vegetation trends—Intercomparing NDVI time series trend analysis consistency of Sahel from AVHRR GIMMS, Terra MODIS and SPOT VGT data. *Remote Sensing of Environment*, *113*, 1886–1898.

Frey, J., Kovach, K., Stemmler, S., & Koch, B. (2018). UAV photogrammetry of forests as a vulnerable process. A sensitivity analysis for a structure from motion RGB-image pipeline. *Remote Sensing*, *10*, 912.

Kattenborn, T., Lopatin, J., Förster, M., Braun, A. C., & Fassnacht, F. E. (2019). UAV data as alternative to field sampling to map woody invasive species based on combined Sentinel-1 and Sentinel-2 data. *Remote Sensing of Environment*, *227*, 61–73.

Navarro, J. A., Algeet, N., Fernández-Landa, A., Esteban, J., Rodríguez-Noriega, P., & Guillén-Climent, M. L. (2019). Integration of UAV, Sentinel-1, and Sentinel-2 data for mangrove plantation aboveground biomass monitoring in Senegal. *Remote Sensing*, *11*, 77.

Oldeland, J., Große-Stoltenberg, A., Naftal, L., & Strohbach, B. (2017). The potential of UAV derived image features for discriminating savannah tree species. In *The roles of remote sensing in nature conservation* (pp. 183–201). Springer.

Possoch, M., Bieker, S., Hoffmeister, D., Bolten, A., Schellberg, J., & Bareth, G. (2016). Multi-temporal crop surface models combined with the RGB vegetation index from UAV-based images for forage monitoring in grassland. *The International Archives of Photogrammetry, Remote Sensing and Spatial Information Sciences*, *41*, 991.

Roupsard, O., Audebert, A., Ndour, A., Clermont-Dauphin, C., Agbohessou, Y. F. U., Sanou, J., Koala, J., Faye, E., Leroux, L., Sambakhe, D., Jourdan, C., Le Maire, G., Sanogo, D., Seghieri, J., & Cournac, L. (2020). How far does the tree affect the crop in agroforestry? New spatial analysis methods in a Faidherbia parkland. *Agriculture, Ecosystem and Environment*, *296*, 106928.

Taugourdeau, S., Diedhiou, A., Fassinou, C., Bossoukpe, M., Diatta, O., N'goran, A., Auderbert, A., Ndiaye, O., Diouf, A. A., & Tagesson, T. (2022). Estimating herbaceous aboveground biomass in Sahelian rangelands using structure from motion data collected on the ground and by UAV. *Ecology and Evolution*, *12*, e8867.

Taugourdeau, S., Le Maire, G., Avelino, J., Jones, J. R., Ramirez, L. G., Quesada, M. J., Charbonnier, F., Gomez Delgado, F., Harmand, J. M., Rapidel, B., Vaast, P., & Roupsard, O. (2014). Leaf area index as an indicator of ecosystem services and management practices: An application for coffee agroforestry. *Agriculture Ecosystems & Environment*, *192*, 19–37.

Wijesingha, J., Astor, T., Schulze-Brüninghoff, D., Wengert, M., & Wachendorf, M. (2020). Predicting forage quality of grasslands using UAV-borne imaging spectroscopy. *Remote Sensing*, *12*, 126.

Zhang, W., Brandt, M., Tong, X., Tian, Q., & Fensholt, R. (2018). Impacts of the seasonal distribution of rainfall on vegetation productivity across the Sahel. *Biogeosciences*, *15*, 319–330.

Zhang, W., Brandt, M., Wang, Q., Prishchepov, A. V., Tucker, C. J., Li, Y., Lyu, H., & Fensholt, R. (2019). From woody cover to woody canopies: How Sentinel-1 and Sentinel-2 data advance the mapping of woody plants in savannas. *Remote Sensing of Environment*, *234*, 111465.

How to cite this article: Taugourdeau, S., Cofélas, F., Bossoukpe, M., Diatta, O., Ndiaye, O., Diehdiou, A., N'Goran, A., Audebert, A., & Faye, E. (2023). Unmanned aerial vehicle outputs and associated field measurements of the herbaceous and tree layers of the Senegalese savannah. *African Journal of Ecology*, *00*, 1–6. https://doi.org/10.1111/aje.13123