USING SENTINEL 2 IMAGES TO QUANTIFY AGRICULTURAL ENCROACHMENT IN BURKINA FASO'S PROTECTED LIVESTOCK RESERVES

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ABSTRACT:

Tensions around land use between agricultural and livestock-herding communities remain contentious in Burkina Faso. As such, land use patterns and interactions between grazing land and cropland are important to the dynamics of these tensions and conflicts. This study uses Sentinel 2 satellite imagery to evaluate the expansion and encroachment of cropland in two protected livestock reserves in Southern Burkina Faso: the Niassa and Sondré-Est Pastoral Zones. This study specifically looks at cropland expansion within the borders of the protected reserves. The method used, the 3 Period Timescan, creates a temporal NDVI profile across three key periods of the growing season (the start/planting period, middle and end/harvest). Cropland is easily identified against other land use types due to its unique NDVI profile, which shows a significant increase between the planting and pre-harvest period and stands out significantly against the smoother profile of natural vegetation. The NDVI profile is then made into a Red-Green-Blue composite image which allows for easy identification between cultivated and non-cultivated areas. This study found a significant expansion of cropland in both protected zones between the period of 2016 and 2021.

1. INTRODUCTION

Beginning with the droughts of the 1970s and 1980s, pastoralist herding communities in Burkina Faso began to migrate from the semi-arid northern region of the country, to its sub-humid southern region. This shift in the dynamics of land use, alongside growing demand for agricultural land has led to increased tensions and often conflicts between farming and herding communities (Nouhoun et al, 2019). Allocating land for farming or grazing is increasingly perceived as a zero-sum calculation among these communities. As a response, the government of Burkina Faso created "Pastoral Zones" across the country as reserves for livestock herders where animals could graze without the risk of entering cropland. In many instances, herding communities were moved into these zones, often in the more humid parts of the country. Farming in these areas is typically prohibited unless done by herders residing within the reserve, so as to protect the herder's access to fodder. However, cultivation in and around pastoral areas by neighboring agricultural communities has increased significantly since the creation of the pastoral areas, exacerbating already fraught tensions between herding and farming communities (Elodie, 2010, N'Doh, 1992). These zones have increasingly become sites of conflict between farming and herding communities, which in many cases have become deadly (Nébie et al 2020, Ouattara, 2016, Abroulaye et al, 2015). Burkina Faso's trend towards creating additional livestock reserves has been met, in many cases with agricultural encroachment in these areas, further limiting the access of herders to grazing areas (Gonin and Gautier 2015).

As a result, tracking the year to year changes in cropland around these zones is critically important. However, monitoring agricultural growth in such zones is difficult as it requires expensive field work in remote areas. Publicly available land-cover datasets are updated too infrequently to be used for this kind of monitoring and are generally far too inaccurate in identifying crop land in the Sahel (Samasse et al 2018).

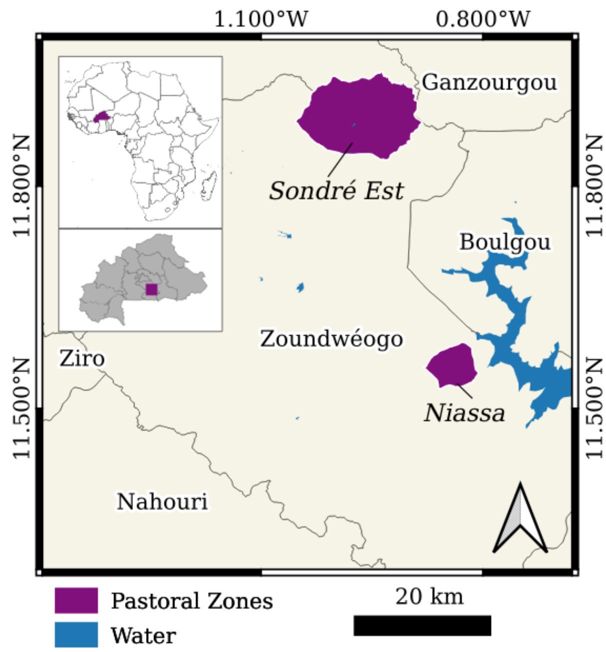

Figure 1: Location of the the pastoral zones studied, EPSG:4326

This study uses Sentinel 2 satellite images to track agricultural growth in pastoral zones in a cost-effective manner (avoiding the need for costly field visits), focusing on the pastoral zones of Sondre Est and Niassa.

Both pastoral zones are broadly within the confines of Zoundweogo province (though Sondre Est is on the border of Zoundweogo and Bazega). Zoundweogo averages between 800 and 900mm

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of rainfall per year with a rainy season from May until October. It benefits from the Bagré Barrage and several streams as water sources. As a result, it is considerably more wet than traditional pastoral homelands in the North and East of the country (from where many pastoralists inhabiting the zones originate) and offers attractive opportunities for the growth of not only staple crops but also fodder for animals. Nébié et al (2020) estimate the population of Sondre Est to include 8,500 pastoralists and between 10,000 and 11,000 large and small ruminants. Unfortunately, no population data or similar studies could be found for Niassa.

2. METHODOLOGY

In order to map agricultural growth, Sentinel 2 imagery was used in Google Earth Engine (GEE). Reproducibility and accessibility were prioritised, and as such, GEE was selected as an accessible cloud platform to easily access the imagery and run the analysis from a browser (Gorelick et al, 2017). To visualise agricultural areas, the "3 Period TimeScan" method was employed. This method uses a series of Normalized Difference Vegetation Index (NDVI) Images from the Sentinel 2 satellite throughout a growing season to isolate areas of active cultivation.

Any single NDVI product can provide an indication of vegetation presence on a given date, but one snapshot is not sufficient to distinguish croplands from other types of vegetation. For such a distinction, a time-series of images is needed to create the profile of vegetation across the growing season to compare between land use or vegetation types. Responding to this need, the "3-Period Timescan" (3PTS) method offers a solution. 3PTS creates a seasonal time-series profile of NDVI in which the maximum NDVI values for three separate subperiods of the agricultural season are separated into Red-Green-Blue (RGB) bands which form an RGB color composite. The red band represents the maximum NDVI value during the first period of the growing season (P1), the green the maximum NDVI in the middle (P2), and the blue the maximum NDVI at the end (P3). The 3PTS composite of these bands reflects the vegetation's temporal evolution during the agricultural period. 3PTS is implemented in GEE using Sentinel 2 imagery at 10m resolution (Boudinaud and Orenstein, 2021). Figure 2 provides an illustration of cropland visualized against natural vegetation, where the shape of cropland can be easily distinguished.

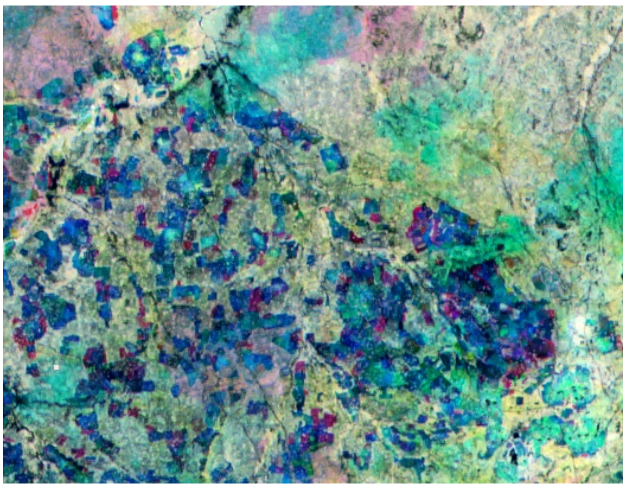

Figure 2: Example of cropland visualised by 3 Period Timescan in the Niassa Pastoral Zone

Figure 3 offers a 3PTS visualization of the entire Niassa Pastoral Zone. Several sample sites are marked on the figure, each of a different land cover type. Their NDVI profiles across the three periods of the growing season are plotted on figure 4.

Croplands are thus identified by their temporal evolution of NDVI values throughout the different phases of the agricultural season compared to other landcover types. For West Africa's single rainy season, this corresponds to the period between June and October. During the sowing period (P1:"beginning of the season", approximated by 15th June to 1st August), croplands show low photosynthetic activity. This activity increases significantly during the growing phase (P2: "middle", 2nd August to 1st September), until reaching a maximum value right before the harvest (P3: "end of season", 2nd September to 15th October). By contrast, the dominant type of land cover (reserves and pastureland with mixed woody cover) has a smoother temporal profile. Grassland with mixed woody cover peak in P1 with the rainy season, and slowly decline over time. Forests, maintain high NDVI values throughout the entire growing season, while bare soil (sparse vegetation) and water maintain low NDVI values.

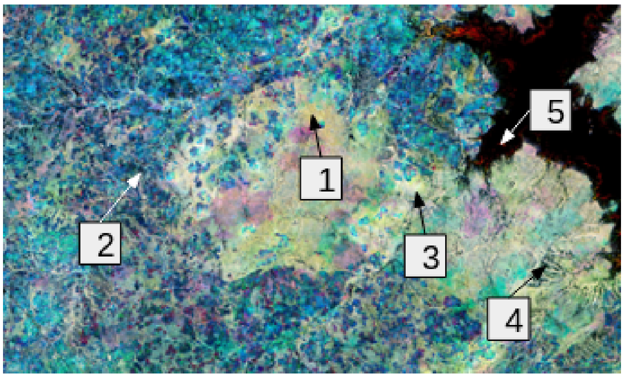

Figure 3: Sample sites of different landcover types from a 3 Period Timescan image of the Niassa Pastoral Zone

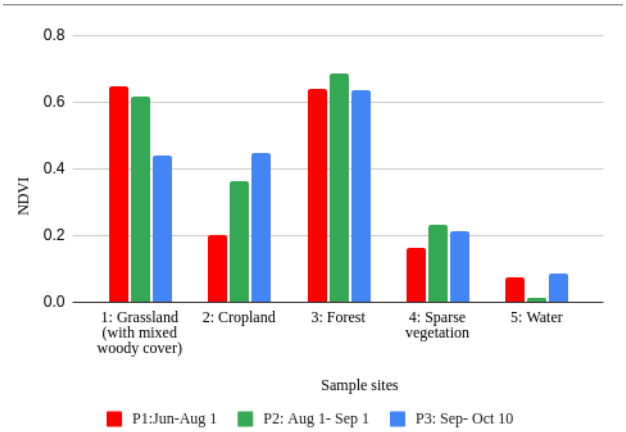

Figure 4: NDVI values for the different sample sites

The 3PTS RGB composite of the images allow for a user-friendly method to visually identify cropland in a single image. Cropland pixels in the RGB composite appear in a dark blue due the noticeable peak right before harvest in P3, thus creating a dominance of blue between the three colours. Grassland with mixed woody cover typically appear in a variety of lighter shades due to the higher NDVI values in the first two periods. Forests appear in white, due to the saturation of all 3 bands throughout the temporal period. Bare soil and water appear as nearly black pixels with their low NDVI values throughout all three periods.

Rather than machine learning, visual identification was the preferred method of identification due to the relatively small size of each pastoral zone. The time needed to prepare training data and clean the results of a supervised classification would have exceeded the time to manually identify each area of cropland. As a result, once the images were treated by GEE, they were manually traced within QGIS. The 3PTS script, originally made for GEE was then translated to run in PyQGIS. Once run, the script created a raster image for each year's growing season in the archive (2016-2021) and polygons were traced over each visualised cluster of cropland. The total surface area of all polygons in hectares was then calculated for each year. A github repository contains both the PyQGIS and GEE code and can be run with no prerequisites (Appendix 1).

The borders of the pastoral zones were provided to the authors by Burkina Faso's General Directorate for Development of Pastoral Perimeters (DGEAP). These boundaries are available in a Github repository (Appendix 2). While this study used DGEAP data to mark the borders, recognition of the borders of the zones remain a contentious issue among local communities in the province (Nébié 2020)

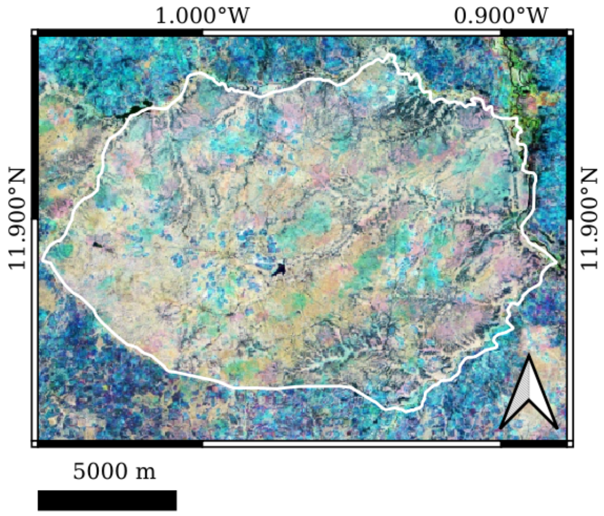

Figure 5: 3PTS image of the Sondre Est Pastoral Zone from 2017, with the zone's borders in white. EPSG 4326

Figures 5 and 6 offer 3PTS images of the zones from 2017 (the year the clearest imagery was available). The stark division between the pastoral zone and agricultural production can be seen as cropland seems at the very limit of the zone's borders as defined by the DGEAP dataset.

3. RESULTS

The results of the study indicate a significant expansion of cropland within the boundaries of both protected livestock reserves between 2016 and 2021, as seen in Figure 7. For Sondré Est, cropland expanded by 40 percent and 160 percent for Niassa. Indeed, cropland has increased with each passing year until the present year of 2021. A number of these fields are suspected to be encroachments, given their proximity to the border of the zone and that many are contiguous with the agricultural fields outside of the zones' borders. However, it is estimated that a number of the fields are the result of the zones' resident herders planting fodder or other cereals for their own consumption. The latter assumption is made based on the location of the fields in question (far from the borders of the reserves) and their proximity to

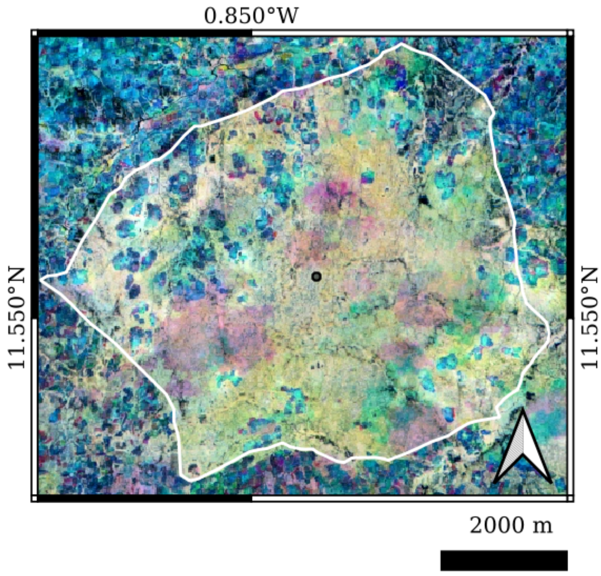

Figure 6: 3PTS image of the Niassa Pastoral Zone from 2017, with the zone's borders in white. EPSG 4326

permanent structures in the reserves (habitations, wells or park buildings).

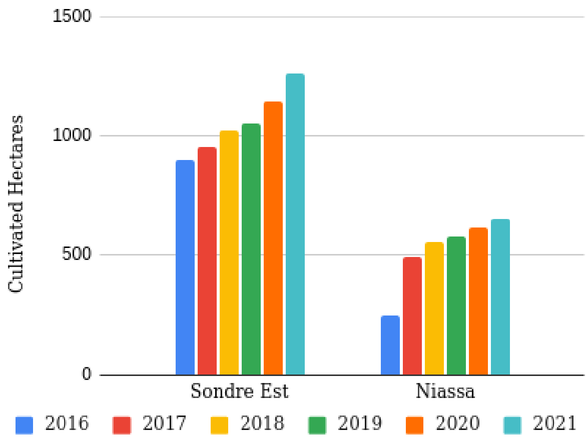

Figure 7: Total cropland within the boundaries of each reserve from 2016 to 2021

Figure 8 identifies cropland expansion in Sondre Est. The light blue polygons are fields that were already present in 2016 (and continuously cultivated to the present) whereas the dark blue are fields seen in a 2021 3PTS image. These dark blue fields thus appeared between 2017 and 2021, as they were not seen at the end of the 2016 growing season. In the case of Sondré Est, noticeable clusters of cultivated surfaces can be identified. One on the south-east portion of the zone, One at the northern frontier and several in the centre, surrounding an inhabited settlement within the zone. This last cluster appears to be cultivated by the residents of the zone itself (as crops for human consumption or animal fodder). Those on the frontiers, given their proximity to the agricultural frontier, are more likely to be encroachments cultivated by agriculturalists living outside the zone. These encroachments are particularly acute in the South-Eastern quadrant of the zone and the Northern border. (Figure 8).

Figure 9 shows an aerial image of a settlement surrounded by

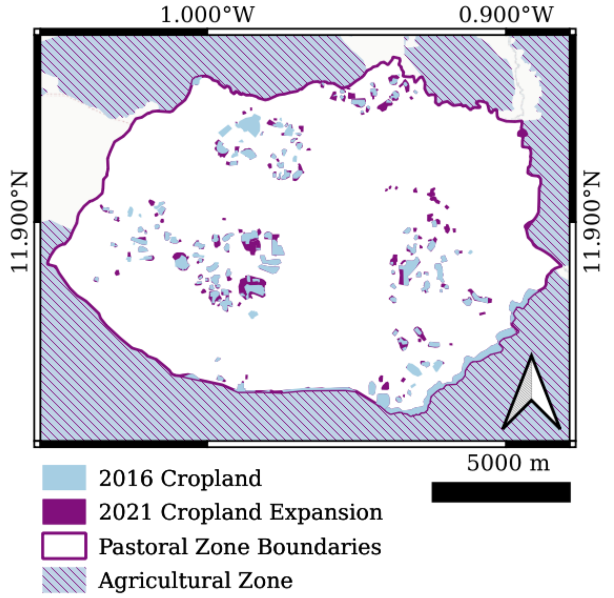

Figure 8: Cropland changes in the Sondre-Est Pastoral Zone between 2016 and 2021 , EPSG 4326

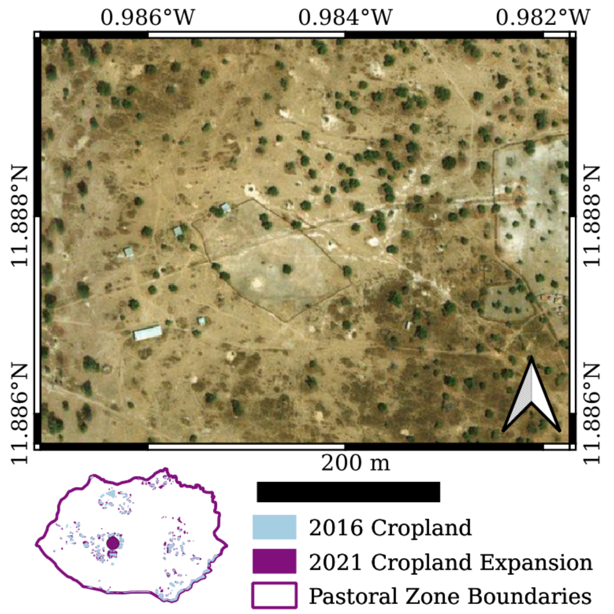

Figure 9: Aerial image of a settlement near a cluster of cropland in Sondre Est (source: Bing Aerial), EPSG 4326

one of the larger clusters of cropland in Sondre Est (seen on the overview map, south east of the centre of the zone). The presence of permanent buildings, well-within the interior of the zone can be clearly seen on the aerial image. The proximity of these fields to these structures indicates a significant likelihood that the fields within this cluster are cultivated by the herders, the inhabitants of the zone.

For Niassa, the sown areas have almost tripled, going from 248 to an alarming 650 ha between 2016 and 2021 (Figure 5). While the cumulative total of cropland in Niassa is inferior to that of Sondré Est, the proportional increase is far greater. The pattern of cropland in Niassa differs strongly from Sondre Est. Unlike Sondre Est, the concentration of cropland in Niassa can be found

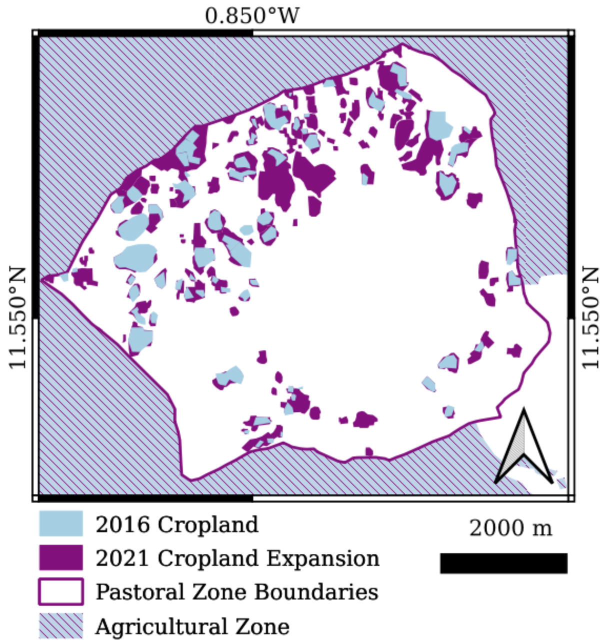

Figure 10: Cropland changes in the Niassa Pastoral Zone between 2016 and 2021,EPSG 4326

on the zone's border.

Figure 11 shows a zoomed-in portion of a 3PTS image of the northern border of the Niassa zone from 2018 (the year which had the clearest imagery for this area). The fields to the south of the border are quite close to those on the other side of the border in teh agricultural zone. Some of the fields are even contiguous with fields on the other side of the border. This proximity to the border and to existing cultivations indicates a strong likelihood that these fields are encroachments and constitute a defacto extension of the agricultural zone surrounding the Niassa Pastoral Zone.

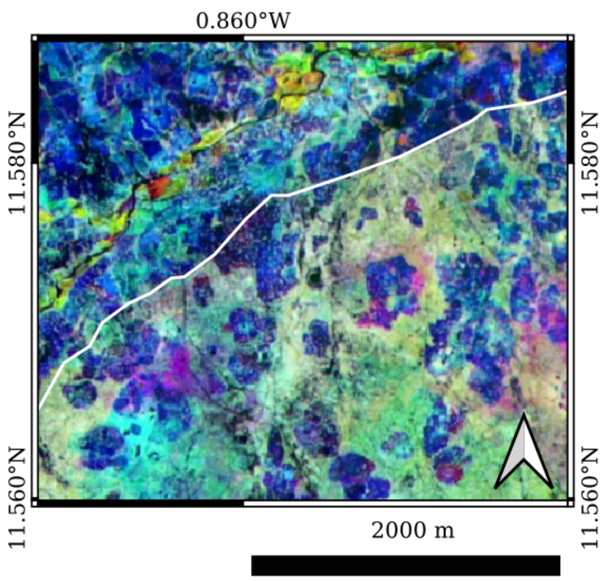

Figure 11: A 2018 3PTS image Cropland in Niassa on the northern border of zone (border in white),EPSG 4326

4. DISCUSSION

Regarding the methodology and choices of tools, the authors acknowledge that while GEE is free to access, it is by no means open source. However, at the time of this writing, GEE offered the most user-friendly option to create these images at zero cost. In the interest of reproducing this study elsewhere, this factor is highly important. As a result, the ease and accessibility of this tool make GEE the most appropriate option for this kind of analysis.

Furthermore, the use of Sentinel-2 images was deliberate. While Sentinel-2 images lack the archive length of other satellites, such as Landsat, the 10m resolution is so far unparalleled among openly accessible sensors. Given the small size of farms (typically under 1 ha) in the area, such resolution is critical to visualise cultivation.

One of the key limitations of this study is the lack of ground-truth data. This study was performed as a case study for a cost-effective means to understand agricultural changes without field work. That said, the lack of ground-truth data from field work reduces the dimensions of the results. Indeed, such data would have provided a greater understanding of the social underpinnings of cultivation in the zone and the identification of who was responsible for planting the fields (herders resident in the zone or farmers from the bordering communities).

While the 3PTS method has already been used in numerous studies across the Sahel to map cropland changes (Boudinaud and Orenstein, 2021), there are some methodological limitations to consider when discussing the potential for scaling up this kind of study. One is that 3PTS is very well suited to identifying rainfed cropland as the three periods can be easily aligned to the rainy season. No attempts thusfar have been made to test the method for irrigated cropland that is often active outside of the traditional growing season. Likewise, the agro-ecological heterogeneity of the Sahel makes scaling a single study across the region difficult. Relatively small distances can encompass vast changes in land use, habitation and rainfall patterns. This variation means that NDVI values can vary greatly across the subregion, even for similar land cover types. This heightens the requirement for highly localised studies, which may not always be possible to generalise into a machine learning algorithm. The need for highly localised studies likewise favours visual identification over machine learning or supervised classification, given the time needed to collect training data and clean the results of the classification. That said, continued exploration of machine learning possibilities with 3PTS data are still needed.

These findings are important in the contemporary context of Sahelian land use conflicts. Farmer-Herder conflicts in the Sahel are often framed as incidents of aggression or encroachment on the part of herders. Indeed, the narrative of the ”mobile” herder intruding on the ”sedentary” farmer when herds graze on private fields seems intuitive. While insufficient to explain complicated landuse dynamics, this simplified narrative has fed into a widely accepted discourse on a “herder invasion” at all levels of international organisations and media (Moritz and Mbacke 2021). Such discourse however lacks nuance and neglects the clear cases, as demonstrated by this study, of when “sedentary” farming can encroach upon grazing lands. This finding on encroachment is in line with numerous field studies conducted on pastoral resources in Burkina Faso, notably that of Gonin and Gautier (2015).

5. CONCLUSION

Using temporal profiles of Sentinel-2 NDVI images across the growing season, this study was able to identify significant agricultural encroachment in two pastoral areas in Burkina Faso. The method, employed on Google Earth Engine, allows for open-access imagery to effectively quantify changes in agricultural cultivation from one year to the next.

ACKNOWLEDGEMENTS

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APPENDIX

1) A Github repository for the 3 Period Timescan code (for GEE or PyQGIS)
https://github.com/oren-sa/3PTS.

2) A Github repository containing pastoral boundaries as defined by the Burkina Faso General Directorate for Development of Pastoral Perimeters (DGEAP)
https://github.com/oren-sa/BFpasto

3) A Google Earth Engine App of the 3 Period Timescan which can be run without executing code
https://ogis.users.earthengine.app/view/timescanviz