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# NDVI, a Proxy for the Associated Millet and Cowpea Growth Stages in the Sahelian Zone

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**ABSTRACT**

**The NDVI PROBA-V 1 kilometer resolution was used to apprehend the associated millet and cowpea growth stages in the Sahelian zone characterized by the presence of these two crops on the same cultivated plots. The ten-day NDVI images values of associated millet and cowpea were used to establish seasonal NDVI profiles which were then crossed at growth stages followed during the cycle. When millet or cowpea sowing dates are spread over several dekads during the season, their growth stages observed per dekad during the cycle remain heterogeneous. When the growing season begins until the end of July, the NDVI index values oscillate between 0.15 and 0.27 with vegetative development marked by tillering for millet and vegetative growth for cowpea. In response to rainfall, the NDVI index value increases to peak between 0.31 and 0.34 in early September when crops are in full growing. During the peak of the NDVI index, the growth stages of millet vary from Boot stage, flowering and grain-filling. The growth stages of cowpea vary from branching, flowering and pod formation in the three locations of the study. In the case of millet and cowpea association on the same cultivated areas, the fluctuation of the NDVI is influenced by the predominant crop, which is millet. The low spatial resolution at 1 kilometer would imply, in addition to millet and cowpea, that the NDVI value also takes into account other crops present such as sorghum or abundant woody species in some Sahelian cultivated areas. The seasonal profile of low spatial resolution NDVI is a tool that can be used to understand the stages of growth of millet and cowpea associated during the cycle over relatively large and homogeneous spaces for these two crops.**

**Key words:** millet, cowpea, growth stages, NDVI.

## INTRODUCTION

The crops under rain in the context of the Sahel are subject to many hazards which often disrupt their growth during the production season. They can suffer from delayed start of the season, dry sequences, pest pressure, flooding or early stopping of rains before the end of the cycle, etc. The period from sowing to harvest remains a time of monitoring crops in the fields. In view of

the contribution of crops under rain to the food security of the populations, most of the Sahel States have put in place early warning systems for monitoring crops during rainfed agricultural seasons. This monitoring makes it possible to determine growth delays during the cycle and to anticipate even before the harvest on the identification of potential areas of production deficit in order to provide appropriate responses.

Traditionally, monitoring crop growth has involved many observers in the field. This requires substantial financial resources which are sometimes difficult to mobilize. To facilitate rapid decision-making thanks to available agricultural information, one of the alternatives is to use satellite image data. Opportunities for monitoring plant cover in general over large areas and at lower cost are available through the use of low-resolution satellite images in the context of the Sahel [1]. One of the much used satellite data is the Normalized Difference Vegetation Index (NDVI). The normalized difference vegetation index is appropriate for assessing the vigor of the vegetation and observing stressful situations during the cycle [2]. Many studies, for example, have used NDVI images to explain the dynamics of vegetation cover change in recent years in the Sahel [ 3-11]. The production of seasonal NDVI profiles also made it possible to better distinguish land use classes in the Sahelian environment and to differentiate between rangelands, cultivated fields, and fallows [12-13]. In the field of crop monitoring in the Sahelian environment, the case of the association of millet and cowpea on the same cultivated plot remains an agricultural practice frequently encountered in relatively large areas. Therefore, monitoring of the growth of associated millet and cowpea crops during the cycle should be considered using low spatial resolution satellite images from PROBA V. Millet and cowpeas present a great interest due to the use of the cereal as a staple food for many Sahelian populations and the use of the market value regard to the legume.

## MATERIAL AND METHODS

### Study zone

The study area is located West of Niger between 11.89 ° - 15.35 ° North latitude and 0.99 ° - 3.066 ° East longitude. It corresponds to the old administrative subdivision before 2012 of the three departments of Kollo, Say and Ouallam. Rainfed agriculture is the main activity of rural populations. The rainy season lasts from June to September [14]. The average annual precipitation varies around 400 to 500 mm. The dry season covers the period from October to May. Temperatures vary between 24 ° C and 45 ° C during the dry season, between 28 ° C and 31 ° C during the rainy season. The classification in bioclimatic zones ranges Kollo and Say in semi-arid zone and Ouallam in arid zone [15]. The cultivated land in the study area is shown in the extract from the land use map in Figure 1 [16]. The study zone is characterized by 3 major geomorphological units, namely the plateaus where forest resources are generally present, the sandy skirts and the shallows which represent the areas of cultivated fields [17]. The soils are predominantly sandy and of low fertility [18-19]. The association of millet and cowpea on the same cultivated area represents more than 73% of the types of association of crops in this environment [20-21]. On average, the areas cultivated in combination with millet and cowpea are 1.32 ha per household [20]. This association of millet and cowpea on the same cultivated plot presents various interests for the Sahelian producer. Agronomic research has always proposed different models of association of millet and cowpea according to the alternation of the lines of the two crops at the time of sowing on the same cultivated plot. In Niger farming

areas and in the association system of millet and cowpea on the same land, the recommended seedling spacing for millet is 1m x 1m, or 10,000 pockets per hectare [22]. The recommended sowing density of cowpea by the Vulgarization Services is 1.50 m x 1.50 m [23]. However, in peasant practices, cowpea is sown between millet rows two to six weeks after millet [24].

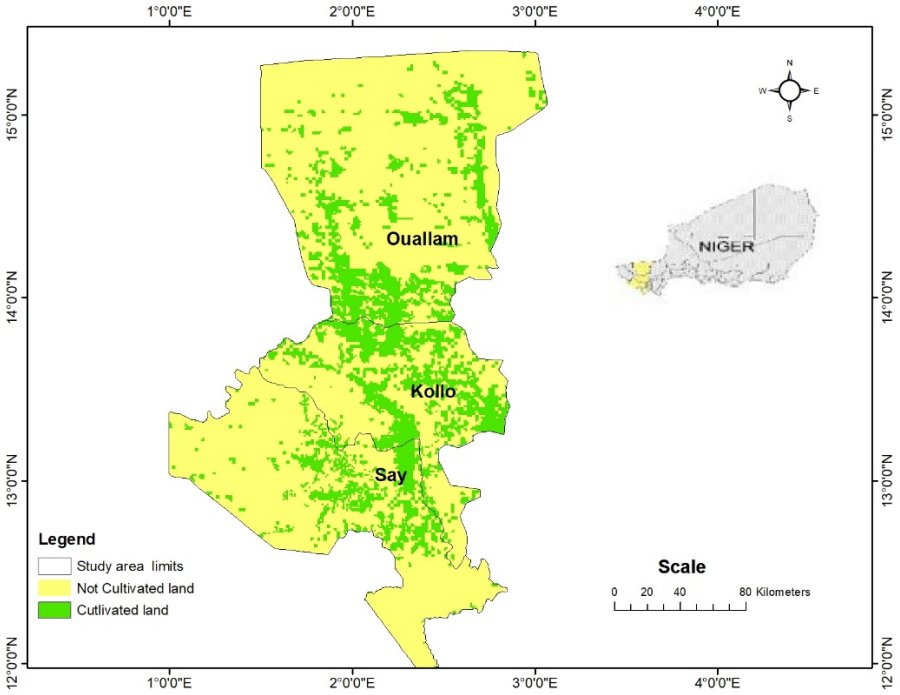



**Fig 1: Presentation of the study zone and extract of occupation cultivated areas [16]**

## Material

Millet crop (Pennisetum glaucum (L.) R. and cowpea crop (Vigna unguiculata (L.) Walp) are cultivated in association during the rainy seasons in the three localities of Kollo, Say and Oualllam. These two crops were monitored on cultivated plots. Ten-day NDVI images of associated millet and cowpeas were collected during the rainfed agricultural campaigns of 2016 and 2017. These images come from the 1 km resolution PROBA V satellite and can be downloaded on the VITO website. But in this study, these images were obtained at the Agrhymet Regional Center in Niamey as part of the MESA (Monitoring for Environment and Security in Africa) project. A layer of administrative boundaries at the department level of the National Geographic Institute of Niger (IGNN) was used as well as a land use map which served as a mask to distinguish between cultivated and non-cultivated areas [16]. The software SPIRIT (Software for the Processing and Interpretation of Remotely sensed Image Time Series) was used to extract the values of NDVI images by decade during the rainy seasons in each of the three localities of Kollo, Say and Ouallam.

## Methods

The growth of millet and cowpea was monitored on cultivated plots. These two crops are present in association on the same cultivated plots. The choice of cultivated plots was based on the sampling technique resulting from the Crop Forecasting and Estimation Survey conducted


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each year by the Statistics Department of the Ministry of Agriculture and Livestock of Niger. In this survey the departments including Kollo, Say and Oualllam were divided into enumeration zones that contain villages. Sampling consisted of first-degree selection of enumeration zones. These enumeration zones are obtained according to a draw proportional to their size. The size of each enumeration zones is defined by the number of households inside. At the second- degree selection, agricultural households were chosen by a systematic selection. The declared plots of farm households drawn were then retained for monitoring the stages of growth of the associated millet and cowpea crops. A total of 243 cultivated plots were considered for monitoring the growth stages of millet and cowpea crops during the cropping cycle (figure 2). Ten stages have been defined for the growth of millet crop [25]. Seven stages were adopted for cowpea with reference to the monitoring of the growth of this crop by the Technical Services of the Ministry of Agriculture and Livestock of Niger. The stages of millet and cowpea crops were monitored decade by decade from June to September during the rainfed agricultural seasons of 2016 and 2017 in Kollo and Say; and during the 2017 agricultural campaign in Ouallam. In peasant practice, millet and cowpea sowing operations on cultivated plots are spread over time. Thus, the sowing dates of millet and cowpea crops were noted and grouped by dekad. The frequencies of sowing dates were calculated per dekad for millet and cowpea for the cultivated plots. During monitoring, for each dekad, the dominant growth stages were observed for millet and for cowpea in the plots. The dominant stages are the stages of millet or cowpea most frequently observed in the cultivated plots during a dekad. Monitoring of millet and cowpea crop stages was coupled with monitoring of the Normalized Difference Vegetation Index (NDVI) of these two associated crops on the same cultivated plots. Twelve ten-day NDVI images of PROBA V of 1 KM resolution were collected per rainy season over the period from June to September. NDVI images data were collected during two years 2016 and 2017 in each of the departments of Kollo and Say. Regarding Ouallam, the data were collected during the 2017 agricultural campaign. The values of the ten-day NDVI images were then extracted by locality with SPIRIT 1.3.0 by methods reducing the problem of NDVI mixty linked to the presence of several crops on the same cultivated plot [26]. The 250-meter resolution land use map of the African continent was used as a mask to extract only the NDVI values of millet and cowpea associated on plots cultivated in Kollo, Say and Ouallam [16]. The land use map of cultivated areas was first converted to 1 KM to have the same resolution as the NDVI images. The administrative boundary layer of the three departments of Kollo, Say and Ouallam was also used as a boundary zone for extracting NDVI values. The average of the ten-day NDVI values over two years was calculated by dekad and the seasonal NDVI profiles of millet and associated cowpeas were carried out with EXCEL for the two localities of Kollo and Say. For Ouallam, the seasonal profile was established on the ten-day NDVI monitoring from June to September of the year 2017. The observed frequencies of the stages in the monitored plots were determined by dekad with SPSS (Statistical Packing for Social Science). The two years 2016 and 2017 were considered for Kollo and Say. The dominant growth stages dekad after dekad of millet and cowpea in 2017 were considered for the department of Ouallam. The seasonal profiles of NDVI of millet and cowpea associated were crossed with the dominant stages of growth of millet and cowpea in each department.

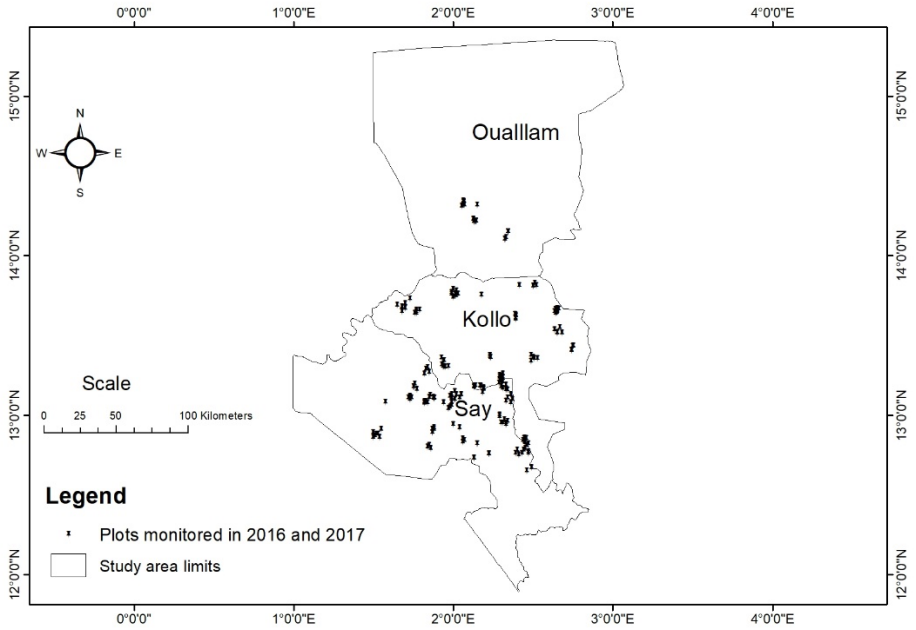



**Fig 2 : distribution of plots monitored in the study zone for years 2016 and 2017**

## RESULTS

The sowing dates of millet and cowpea crops in association in the plots monitored during the 2 seasons 2016 and 2017 in Kollo and Say are spread over time between 4 to 5 dekads depending on the crops and the localities (Figures 3 and 4). The sowing dates of millet and cowpea were also spread over time (3 to 4 decades) during the 2017 season in Ouallam. Sowing dates of millet are concentrated in June in Kollo and was earlier in Say with a concentration in May and June for the two years of observation. Cowpea sowings are grouped in July in Kollo and concentrated in July and late in the 1st dekad of August in Say. In general sowing dates of millet and cowpea were concentrated in June in Ouallam. The seasonal profiles of the Normalized Difference Vegetation Index (NDVI) of millet and cowpea associated crossed with the growth stages observed per dekad from June to September (D16 to D27) were presented for the three departments of Kollo, Say and Ouallam respectively in figures 5, 6 and 7. The NDVI value vary according to the stages of the associated millet and cowpea crops. For a given dekad during the season, the NDVI value is generally explained by one to three dominant stages observed in millet or cowpea crops in the three localities. The NDVI values of associated millet and cowpea are low from June to July (D16 to D21). At this period, the millet is still in the vegetative phase corresponding to a progressive growth at the stages of emergence (L), advanced emergence (LA) then tillering (T). Cowpea passes successively to the emergence (L), advanced emergence (LA) and growth (C) stages at the end of July (D21). NDVI values gradually increase during the season at the end of July to reach a maximum in the 1st dekad of September (D25) in the three localities of Kollo, Say and Ouallam. During this period, millet progressively evolves at the stages of Stem elongation (m), Boot stage (panicle emergence and elongation) (E), then flowering (F) and grain-filling (G). Cowpea crop evolves at the stages of branching (R) then flowering (F) and pod formation (Gs). When the peak of the NDVI value is observed in the 1st dekad of September, the stages of millet vary from Boot stage, flowering and grain-filling


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depending on the 3 localities. At this time of the peak of the vegetation index, the stages of cowpea vary in branching, flowering and pod formation depending on the 3 localities. From the 1st dekad of September, the NDVI value begins to drop at a time of the cycle when the maturation (M) of millet and cowpea crops has started in Kollo and Ouallam. The decline in NDVI is also observed after the 1st dekad of September in Say as soon as the maturation of the millet has started. The comparative seasonal profiles of the three departments show a superiority of the NDVI values of Say compared to those of kollo and Ouallam throughout the cropping season (figure 8).

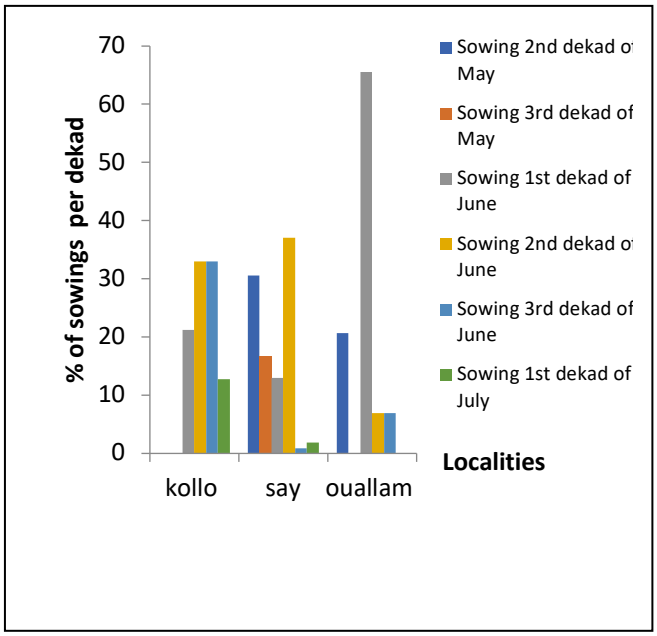



**Figure 3: dekads of millet sowing in Kollo, Say and Ouallam**

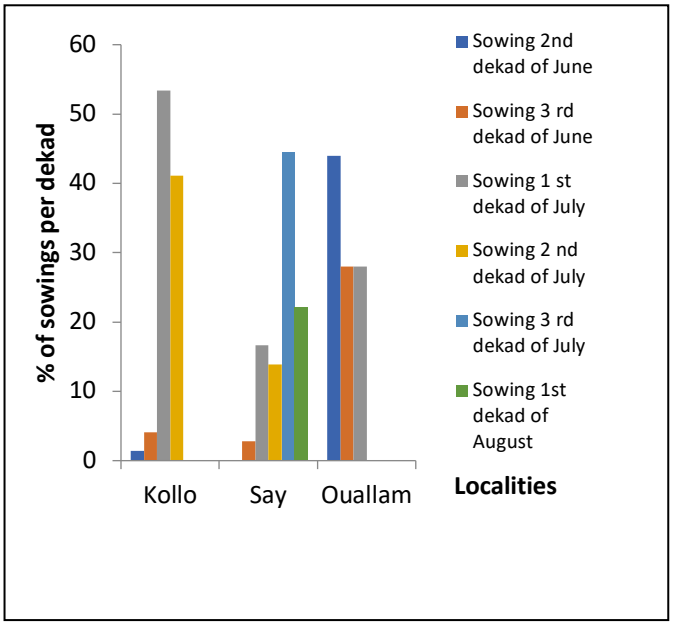



**Figure 4: dekads of cowpea sowing in Kollo, Say and Ouallam**

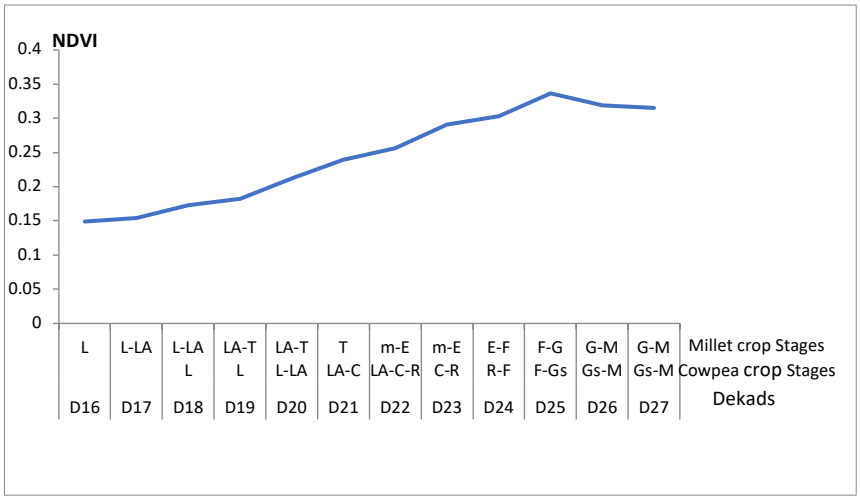



**Figure 5: Seasonal profile NDVI millet and cowpea associated and stages during the cycle in Kollo**

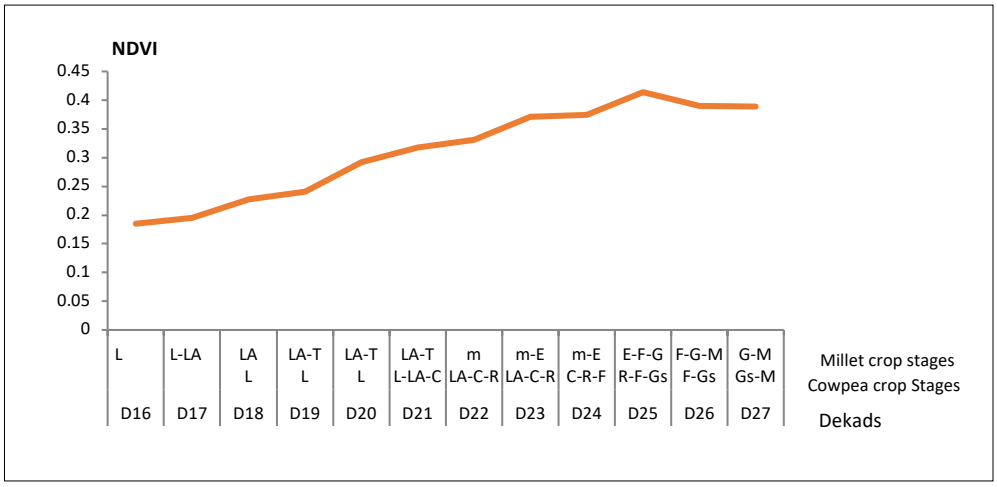



**Figure 6: Seasonal profile NDVI millet and cowpea associated and stages during the cycle in Say**



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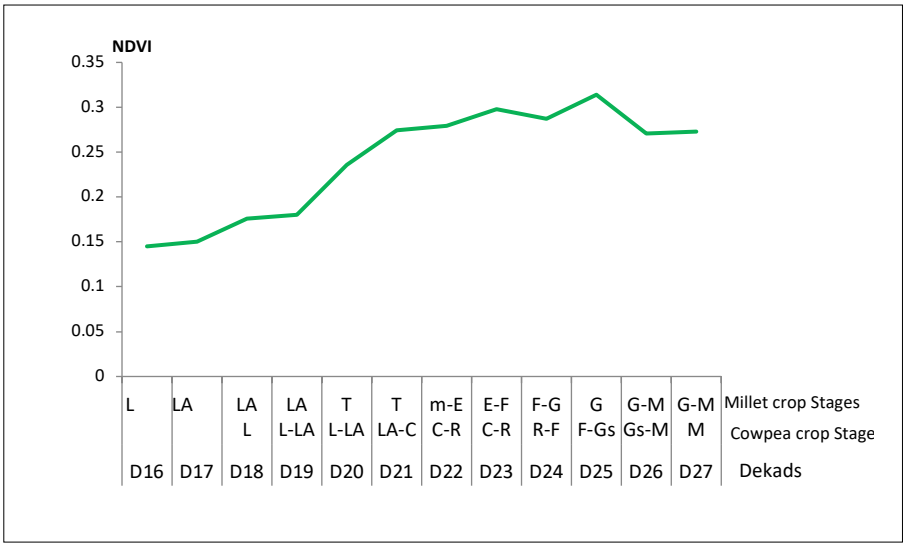



**Figure 7: Seasonal profile NDVI millet and cowpea associated and stages during the cycle in Ouallam**

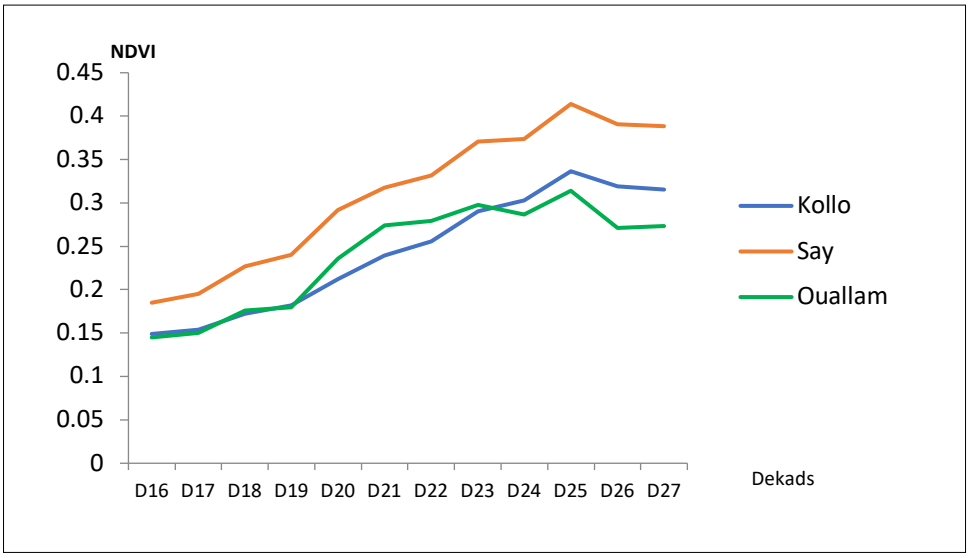



**Figure 8: Seasonal profiles NDVI millet and cowpea associated compared during the cycle in Kollo, Say and Ouallam**

**D16:1st dekad of June, D19: 1st dekad of July, D22: 1st dekad of August, D25: 1st dekad of September**
**D17:2nd dekad of June, D20: 2nd dekad of July, D23: 2nd dekad of August, D26: 2nd dekad of September**
**D18: 3rd dedak of June, D21: 3rd dekad of July, D24: 3rd dekad of August, D27: 3rd dekad of September**

## DISCUSSION

The sowing dates spread over time explain the heterogeneous nature of the growth stages of millet and cowpea per dekad during the cycle in a given locality. One to three dominant growth stages were generally observed per dekad during the cycle for millet or cowpea crop. The time between sowing millet and sowing cowpea is shorter in Ouallam than in kollo or Say. Following the North-South gradient, Ouallam is less watered than Kollo and Say with more frequent rain stops before the end of the rainy season. This would explain the sowing of cowpea almost immediately after that of millet in Ouallam so that the two crops complete their cycle before the end of the rainy season. This would also correspond to an agricultural practice of climate risk management in more arid zones. The problem of the NDVI mixty linked to the presence of both several crops and woody species on the same cultivated plots in the context of the Sahel can be overcome by choosing an NDVI extraction method that uses a mask [26]. In this way only the NDVI values of the cultivated species can be isolated. In addition, agricultural practices such as weeding generally eliminate weeds and especially improve the growth of associated millet and cowpea crops during the cycle on cultivated plots. This practice of weeding, which contributes to reducing the problem of the NDVI mixity, is regularly present in the three localities of the study environment. The low densities of woody species have little influence on NDVI in the rainy season. In the Sahel, the density of trees encountered in cereal production systems associated with legumes is less than 20 plants /hectare [27]. This case is encountered in the production systems of Kollo and Ouallam. In some parts of kollo area such as Fakara, trees and shrubs are scattered in production systems and their ground cover represents less than 5% [19]. On the other hand, the presence of woody species next to crops is stronger in Say. The tree cover represents 37% and the shrub cover 20% in Say against respectively 17% and 18% in Kollo and 11% and 12% in Ouallam [28]. Particularly in Tamou, which is a large commune in Say, the density of the woody species can reach 122 plants / hectare in the agroforestry systems [29]. In addition to the presence of woody species in Say, there is in this locality a relatively strong presence of sorghum crop cultivated in pure alongside plots of associated millet and cowpea crops. The area of sorghum in Say represents 23% of that of associated millet and cowpeas [20]. The presence of sorghum and significant woody cover (in addition to the associated millet and cowpea) would contribute to influence the NDVI values in Say during the cycle. This would explain the superiority of the NDVI seasonal profile of Say compared to those of Kollo and Ouallam during the cropping season. The low NDVI values from 0.15 to 0.24 in Kollo and from 0.15 to 0.27 in Ouallam obtained at the start of the season from June to July can be explained by the still juvenile stages of millet and cowpea at the onset of the season. Added to this, the low sowing densities practiced in rural areas for these two crops and the practice of weeding which eliminates weeds, make the soil bare in some places in the fields. The NDVI values from 0.19 to 0.32 obtained between June to July in Say could be explained by the juvenile stages of millet, cowpea and sorghum crops and by the scarce foliage of the woody species at the start of the season. In response to the relative abundance of rains in August, millet and cowpea crops are growing rapidly. The NDVI gradually increases to peak at the beginning of September with values of around 0.34 and 0.31 respectively for Kollo and Ouallam. The maximum NDVI in early September is 0.41 in Say. In full season, millet colonizes the height while cowpea covers the ground. The growth of millet and cowpea crops is advanced at this time. In Say, where the presence of woody species is relatively more important, the latter's response to abundant rainfall results in abundant foliage with maximum photosynthetic


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activity. This relationship between rainfall and biomass production in the context of the Sahel has been highlighted by several authors [30-32]. The decline in NDVI began with the entry into senescence of millet and cowpea crops in Kollo and Ouallam. Towards the end of the cycle, millet leaves begin to turn yellow [12]. The decline in NDVI started in Say as soon as millet began to mature in this locality, which could explain the importance of the contribution of millet in NDVI ahead of cowpeas and other woody species present on the same cultivated plots. This also confirms the idea that in the Sahel, the value of NDVI in the rainy season remains mainly linked to the herbaceous and not the woody species [11]. The results of seasonal NDVI profiles for millet and cowpea obtained in Kollo and Ouallam are close to those found in cultivated fields in the Sahelian zone [13, 9]. The seasonal profile of NDVI obtained in Say is comparable to that found in cultivated areas with a peak in the value of the vegetative index reaching 0.5 in August [12]. This result was obtained in Dallol Bosso, which resembles to Say in terms of cultivated species and the presence of woody species in cultivated areas. These relatively high NDVI values found in cultivated areas can also be explained by the position of the cultivated lands in the Dallol Bosso area. Dallol Bosso is a fossil valley dominated by millet, sorghum and cowpeas crops.

## CONCLUSION

In areas where the association of millet with cowpea on the same cultivated plots is a predominant agricultural practice and when other crops such as sorghum are less important, NDVI seasonal profiles can help to determine the growth stages of the two crops associated during the cycle. This knowledge of the stages of crop growth is important especially at critical moments such as the start of the season when good growing conditions are difficult to achieve in the context of the Sahel and towards the end of the season, most often marked by early stops of rains. Ultimately, high spatial resolution NDVI images coupled with more detailed land cover maps can help improve remote sensing crop monitoring in the Sahel.

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