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Modelling sowing window effects on grain yield of cowpea varieties: An application of DSSAT CROPGRO-cowpea model in Burkina Faso

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Abstract

Crop simulation models are part of the modern tools used for improving agricultural production performance. An application exercise of the DSSAT CROPGRO-cowpea model was carried out at two locations in Burkina Faso with the aim of contributing in enhancing agricultural practices for better yield of cowpea, through a seasonal analysis of the grain yield over 33-year period. The objectives were to (i) determining the optimum sowing window of cowpea varieties through a seasonal analysis of the grain yield at Kamboinsin and at Kouare, (ii) analysing the performance of Plant Production Department, Institute of the Environment and Agricultural Research of the DSSAT model in yield simulation in various environment. Simulations of the grain yield were performed using ten (10) sowing windows during the 33-years of experiment. The results showed that sowing period and the location affect the grain yield. For all the varieties (Gorom local, KVx396-4-5-2D, Moussa local and Tiligre), the highest grain yield was registered when sowing was done in early May. Mid-May to early June sowings lead to acceptable yields. Irrespective to the variety, late sowing (late June to late July) result in the lowest yields ranging between 980-327 kg ha^{-1} at Kamboinsin and 554-443 kg ha^{-1} at Kouare. The best optimum recommendable sowing window in cowpea production is early May, followed by mid-May to mid-June. Producing cowpea at Kamboinsin results in higher average grain yields than at Kouare. The DSSAT model can be considered as an efficient tool for simulating cowpea grain yield in various environments at different planting periods.

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Introduction

The outputs of agronomical researches on a large spectrum are reliable when they are multi-locations-experiments based or from timely repeated experiment. Thus, experiments are usually carried out on different locations over a specific season or a period of time. This process makes experiments results usually site and season dependent, time consuming and expensive (Jones *et al.*, 2003). The shortening of the required time for a conventional research and the reduction of the research cost require the use of tools such as crops simulation models. A simulation model is a descriptive or representational imitation of a system aiming at improving the best understanding of the system components and their responses to changing conditions (Elgadi, 2020). Crop simulation models (CSMs) are part of the modern tools that can contribute in improving the agricultural productions (Elgadi, 2020). They are mathematical representations of a given-crop able to predict its production potentialities in various environments. According to (Hoogenboom *et al.*, 2019), simulation models are of a great importance for scientists, engineers, managers, decision-makers, and growers that are involved in improving management and the control of agricultural systems. Crop models enable researchers to speculate on long-term consequences of changes in agricultural practices and production systems at an agro-ecosystem scale. Simulation models are increasingly being used to improve cropping techniques and systems (Uehera and Tsuji, 1993). They are successfully used in a large spectrum of climatic conditions (Archontoulis and Miguez, 2014).

The most used simulation models in Sub-saharan Africa are APSIM (Agricultural Production System Simulator) and DSSAT (Decision Support System for Agrotechmology Transfert) (Jones *et al.*, 2003; Keating *et al.*, 2003). The DSSAT suite, developped by researchers cooperating at the International Benchmark Sites Network for Agrotechnology Transfer (IBSNAT) to alleviate the application of crop simulation models in agronomic research (ISBNAT, 1990), incorporates different models for crops (42 crops), soil, climate and water simulation as well as the management system for improving decision-making and production technology transfert from an environnent to another not-similar (Jones and Czerniewic, 2010). CROPGRO-cowpea model is the specific model for cowpea in DSSAT. Cowpea being one of the major food legume crops in tropics and sub-tropics countries, improving the agricultural practices in cowpea production, through the use of modelling is important as it can substantially increase growers productions and subsequently the level of food availabilty.

The calibration or parameterization of a model is the adjustment of some parameters and functions of the model so that simulated values are matched well or at least very closed to observed values from field experiment (Penning de Vries *et al.*, 1989). This is the preliminary required step that precedes an eventual application of a model that should lead to a decision-making. Using the outputs of a well-calibrated and evaluated dynamic crop simulation model is one of the strategies of studying the long term effects of climatic and edaphic variability, while reducing the research time and cost (Holzworth *et al.*, 2014; Rezzoug *et al.*, 2008). In addition, a delay of the onset of the rainy season is reported for many regions of Sub-saharan african countries and dry spells are frequently observed during the beginning, mid and end of rainy season even in the wettest areas (Graef and Haigis, 2001; Marteau *et al.*, 2011). Uncertainties due to changing climate patterns, such as create a huge variability for rainfed agricultural production, which is risky to farmers (Adnan *et al.*, 2017). Sowing date is usually recommended for many years irrespectively to the location and varietal differences. The choice of the appropriate sowing period is the most costless crop management practices able to guarantee better yield at harvest (Amaral *et al.*, 2011), while finding the optimum sowing window between early and late sowing remains a challenge for farmers in savannah zones (Sallah *et al.*, 1997). In Burkina Faso, few researches using modelling was carried out to evaluate the effect of sowing date in cowpea production. Therefore, the application of DSSAT CROPGRO-cowpea model for seasonal yield analysis of different cowpea varieties depending on the sowing period and the location is necessary and right, since a good calibration and validation of the model were achieved for the involved cowpea varieties (Thiombiano *et al*., 2022). This study aimed at contributing to the cowpea agricultural practices enhancement for increasing yield in Burkina Faso. The objectives were: ((i) determining the optimum sowing window of cowpea varieties through a seasonal analysis of the grain yield at Kamboinsin and at Kouare, (ii) analysing the performance of the DSSAT model in yield simulation under various environments.

Materials and methods

Experimental locations

The application of the DSSAT model was carried out in Burkina Faso during thirty-three (33) year-period (1989-2021) in two locations. The first experimental site was in the Centre of environmental and Agricultural Research and Training (CREAF) at Kamboinsin, located at 12°28' N and 01°33' E at 300 m above sea level and the second was at Kouare, located at 12'03'36 N and 00'21'55 E. The annual rainfall varies between 500 and 900 mm at Kamboinsin and between 600 and 900 at Kouare.

Factors and treatments

The application of the DSSAT model involved three factors, the variety at four levels of treatments (Gorom local, Moussa local, KVx396-4-5-2D, Tiligre), the sowing date at ten levels of treatment (late April, early May, mid-May, late May, early June, mid-June, late June, early July, mid-July and late July) and the location at two levels (Kamboinsin and Kouare).

Data collection

Soil data

Information on soil characteristics are one of the important data set required for running DSSAT model. Consequently, chemical and physical characteristics of the different profiles of the soil of the two experimental sites were collected (Table 1) and entered in DSSAT.

Table 1. Soil informations at Kamboinin and at Kouare

Soil properties	Kamboinsin				Kouare			
	Depth (cm)							
	0-14	14-40	40-93	93-120	0-6	6-30	30-87	87-150
Clay	22	17.75	31	33.24	2.6	6.20	11.4	27.4
Silt	36.3	23.73	32.42	30.21	18	18.4	18.2	14.8
Sand	41.7	58.52	36.58	36.55	79.4.	75.4	70.4	57.7
Texture	loamy	sandy-loam	loamy-clay	loamy-clay	sandy-loam	sandy-loam	loamy-clay	loamy-clay
O.C.	1.08	0.2	0.13	0.08	0.22	0.18	0.16	0.22
T.N.	0.06	0.02	0.02	0.01	0.04	0.029	0.09	0.032
pH-water	6	6	5.7	5.7	6.7	5.8	6.8	6.7
Na++	0.02	0.04	0.04	0.05	-	-	-	-
K+	0.26	0.1	0.09	0.06	0.21	0.05	0.02	0.07
Mg++	1.12	0.49	1.05	1.35	0.26	0.20	0.31	0.53
Ca++	3.76	1.55	2.51	2.61	1.02	0.47	0.58	1.08
S.E.B.	5.15	2.18	3.69	4.07	1.49	0.72	0.91	1.68
C.E.C	5.92	2.65	4.08	4.49	1.96	1.96	2.43	3.81
Conductivity	0.09	0.02	0.01	0.02	0.08	0.02	0.01	0.01
Iron	1	0.84	1.25	1.31	180	124	122	120
Phosphorus	0.095	0.01	0.001	0.001	965	772	1158	1255
Total Potassium	965	772	1158	1255	2.6	6.20	11.4	27.4

Source: Institute of Environment and Agricultural Research (INERA), Burkina Faso.

Weather data

The DSSAT model application likewise requires long-term data on weather conditions for a specific environment representing the cropping area, in order that the simulations are reliable. Thirty-three-year (33) weather data including temperature (maximum and minimum), rainfall and solar radiation of the two experimental locations were collected from the Nasa-power site (https://power-larc.nasa.gov/data-access-viewer) and incorporated in the model. Fig. 1 and 2 show the average annual values of the weather variables in the respective sites.

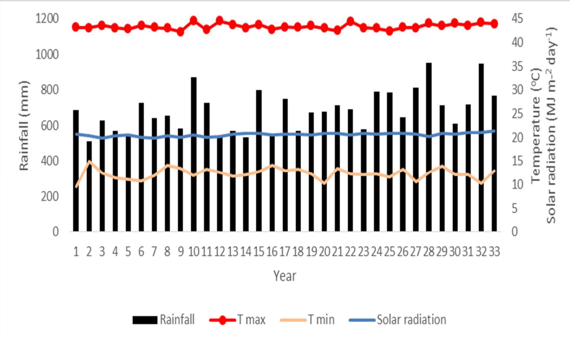

Fig. 1. Thirty three years (1989-2021) annual rainfall (mm), temperature (° C) and solar radiation (MJ m^{-2} day^{-1}) at Kamboinsin (https://power-larc.nasa.gov/data-access-viewer)

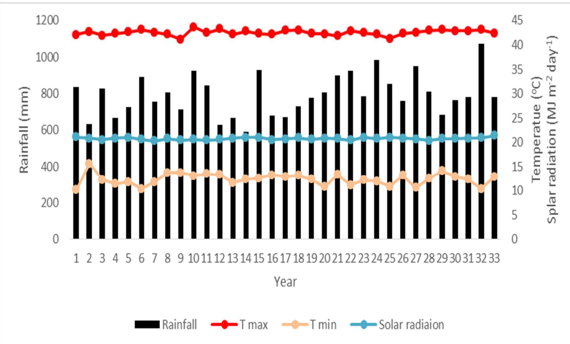

Fig. 2. Thirty three years (1989-2021) annual rainfall (mm), temperature (o C) and solar radiation (MJ m-2 day-1) at Kouare (https://power-larc.nasa.gov/data-access-viewer)

Management and crop data

The experiment management data considered and entered in DSSAT included sowing depth (3 cm), inter-row spacing (80 cm), inter-hills spacing (40 cm), crop variety, fertilizer (NPK (14-23-14) a 100 kg ha^{-1}) and the date of sowing (10 sowing dates). The simulated crop data was essentially the grain yield.

Model application for determining the optimum sowing windows of cowpea varieties

The application of DSSAT model requires a calibration and an evaluation of the model to ensure of its goodness before an eventual application for a given environment. The calibration or parameterization is the adjustment of some parameters and functions of the model so that simulated values are matched or at least very close to observed ones from a field experiment (Penning de Vries *et al.*, 1989). The CROPGRO-cowpea model that is specific for cowpea within DSSAT was therefore previously calibrated and validated for all the involved varieties for the parameters number of days to 50% flowering, days to 95% maturity, grain yield and plant above ground biomass.

Information related to the model calibration and evaluation for the studied cowpea varieties

The calibration and validation experiment was carried out in Burkina Faso during the dry season of 2020 and 2021 at Kamboinsin, in the Centre of Environmental and Agricultural Research and Training (CREAF), located at 12 °28' N and 01 °33' E. The experiment consisted of two factors: drought stress at three levels (control; drought at seedling stage; drought at flowering stage) and the variety at four (04) levels of treatments (Gorom local, Moussa local, KVx396-4-5-2D, Tiligre). Soil data, essentially soil profile content in clay, sand, and silt, and weather information including daily temperatures (maximum and minimum values), rainfall, and solar radiations were recorded. Crop data collected from the control (treatment without water and fertilizer stress) was used for the calibration, while those from the drought stress treatments were used for the model validation. The genetic coefficients of the varieties were estimated by running several times the model using the Genotype Coefficient Calculator (GenCalc).

The model excellently simulated the days to flowering of all the varieties during the calibration exercise with a normalized root means square error value less than ten percent (nRMSE < 10) and a high degree of agreement (d-$_{index}$); the prediction of the days to maturity was excellent for Gorom local and KV×396-4-5-2D (nRMSE=9.642 and 9.62% and d-$_{index}$= 0.84 and 0.746) and good for Tiligre and Moussa local (Table 2) (Thiombiano *et al.*, 2022). The above ground biomass of all the varieties was poorly simulated (nRMSE > 30%) except for Moussa local for which fair agreement was attained. The simulation of the grain yield was excellent for the variety Tiligre (nRMSE=4.564%; and d-$_{index}$=0.741) and good for the others.

Table 2. Simulated and observed data and model calibration statistics for days to flowering, days to maturity, above ground biomass and grain yield as calculated using GenCalc calculator

Parameter	Variety	Observed	Simulated	RMSE	nRMSE	d-index
Days to flowering	Tiligre	50	50	0.707	1.414	0.923
	Gorom local	52	51	0.707	1.359	0.923
	Moussa local	60	62	2.915	4.858	0.673
	KVx396-4-5-2D	50	49	0.707	1.414	0.923
Days to maturity	Tiligre	104	116	12.981	12.482	0.404
	Gorom local	110	118	10.607	9.642	0.004
	Moussa local	119	132	13.509	11.352	0.562
	KVx396-4-5-2D	106	116	10.198	9.62	0.746
Above ground biomass	Tiligre	3672	6130	2666.4	72.614	0.125
	Gorom local	5134	6190	1541.6	30.026	0.111
	Moussa local	5096	6202	1302.3	25.556	0.43
	KVx396-4-5-2D	3828	6115	254.3	66.587	0.058
Grain yield	Tiligre	1329	1294	101.54	7.64	0.741
	Gorom local	1482	1283	202.59	13.67	0.523
	Moussa local	1342	1158	204.6	15.246	0.394
	KVx396-4-5-2D	1456	1302	185.96	12.772	0.255

RMSE: Root mean square error' nRMSE: Normalised root mean square

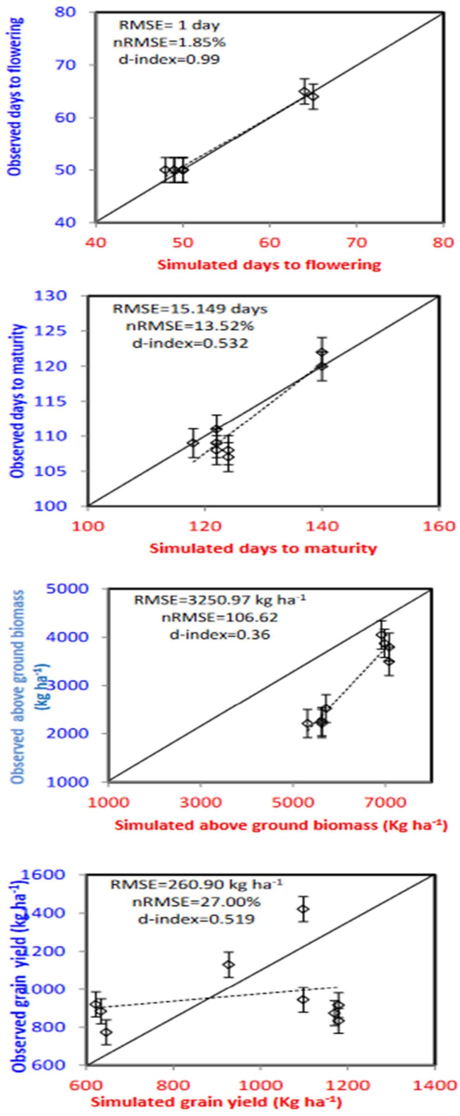

Fig. 3. Comparison of observed and simulated days to 50% flowering, days to maturity, above ground biomass and grain yield for model validation (solid line: 1:1 relationship between observed and simulated values; dashed lined: linear regression. (Source: (Thiombiano *et al.*, 2022)

During the model evaluation or validation, an excellent agreement was reached between the observed and simulated days to flowering (nRMSE=1.85%; d-index=0.99), the prediction was good and fair respectively for days to maturity and grain yield, while poor simulation was consistently observed for the above ground biomass (Fig. 3) (Thiombiano *et al.*, 2022).

The accuracy of the simulation of the days to flowering and maturity durig both calibration and validation of the model is essential. According to (Robertson *et al.*, 2002), an accurate prediction of the grain yield is expected when the phenology is well-simulated.

Model application process

The application of the model for determining the optimum sowing windows of each variety was done through a seasonal analysis of the grain yield using the long term (33 years) weather data, including rainfall, temperature (minimum and maximum) and solar radiations of two locations (Kamboinsin and Kouare) that were collected and entered in DSSAT.

The sowing started at 30th of April and was repeated each ten day up to the end of July. A total of 10 sowing windows were simulated (late April, early May, mid-May, late May, early June, mid-June, late June, early July, mid-July and late July). The cumulative probability plots served to determine the optimum sowing windows.

Results

Statistics from the seasonal analysis of the grain yield over 33-year period experiment at different sowing windows

The results of the seasonal analysis of the grain yield of the studied varieties over the 33-years of simulations at different sowing windows at the two experimental sites (Kamboinsin and Kouare) are shown in Table 3 and 4. The results present the mean, minimum, maximum and standard deviation for grain yield. For all the varieties (Gorom local, Moussa local, KVx396-4-5-2D and Tiligre), at both locations, the highest mean, maximum and standard deviation for the grain yield per hectare was consistently registered when sowing was done in early May.

At Kamboinsin, the best sowing window (early May), was followed by the window mid-May to late May for Gorom local and Tiligre and by mid-May to early June for KVx396-4-5-2D, with mean yield above 1300 kg ha^{-1} for all these varieties. Sowing Moussa local from mid-May to late May gives average yield close that from early May sowing as well (>1100 kg ha^{-1}).

At Kouare, the second best sowing period was mid-May for Gorom local, KVx396-4-5-2D and Tiligre, with an average grain yield ranging between 805 to 821 kg ha^{-1} and a maximum yield slightly above 1600 kg ha^{-1}. Late April sowing of Moussa local led to average yield above 700 kg ha^{-1}, slightly above that from mid-May to early June sowings (<700 kg ha^{-1}).

Except for Moussa local, sowing in late April of all the varieties gave average yield similar to that from early to mid-June sowing at Kamboinsin and that from late May to early June at Kouare. However, delayed sowings (from late June to late July), progressively and remarkably results in reduced simulated grain yield of the varieties, comparatively to sowing in early May. The lowest minimum simulated grain yield for all the varieties at both experimental locations was obtained from late sowings periods, especially late July sowing window, followed by mid-July and early-July. Grain yield decrease of Gorom local and KVx396-4-5-2D for late June to late July sowing windows ranged from 30% to 75% at Kamboinsin compared to early May sowings. At Kouare, the yield decrease was between 45 to 85% and 29 to 86% for the respective varieties. Yields of Moussa local significantly decreased from 20% to 68% at Kamboinsin and from 22% to 81% at Kouare. Similarly, sowing Tiligre from late June to late July consistently resulted in increasing losses of model simulated yield varying between 30% to 75% at Kamboinsin and 45% to 85% at Kouare, compared to early May sowings.

Cumulative distribution functions for the grain yield of the varieties over the 33-year period experiment at different sowing windows

The cumulative distribution function (CDF) plots for the grain yield over the 33-year of simulations at Kamboinsin shows that at the lowest probability, sowing Gorom local from early May to late May resulted in simulated grain yield above 1000 kg ha^{-1} (Fig. 4A). Similar trends were observed for early June, late April and mid-June sowings for respectively 26, 29 and 28 of the 33 years of simulations. At 50% probability, mean yields ranging between 1200 and 1350 kg ha^{-1} were recorded when sowing was done from late April to mid-June. Yields above 1500 kg ha^{-1} were simulated for 9, 6, 4 and 3 of the years of simulations respectively for early May, late April, late May and mid-May windows. Yields below 1000 kg ha^{-1} were reached at 50% and 75% probability respectively for late June and early July sowings. At 50% probability, delayed sowing of Gorom local, from mid-July to late July progressively resulted in simulated yields of less than 500 kg ha^{-1}at Kamboinisin. At Kouare, for 50% of the years, sowing Gorom local in early-May consistently resulted in the highest grain yield (825 kg ha^{-1}) (Fig. 4B), and was followed by late April and from mid-May to mid-June sowing windows, with yields between 600 to 800 kg ha^{-1}.

Table 3. Statistics of the grain yield in kg ha^{-1} of Gorom local and KVx396-4-5- 2D at different sowing windows from the seasonal analysis over 33 years (1989-2021) at Kamboinsin and Kouare

Sowing windows	Kamboinsin				Kouare			
	Mean	Standard deviation	Minimum	Maximum	Mean	Standard deviation	Minimum	Maximum
				Gorom local				
Late April	1269.5	313.2	714	1920	779.1	259.2	225	1426
Early May	1398.7	393.0	912	2182	968.9	435.3	462	2072
Mid-May	1302.9	333.1	971	2078	805.7	329.2	447	1642
Late May	1323.5	250.6	931	2074	773.1	269.2	416	1486
Early June	1272.5	174.1	818	1623	747.0	251.0	367	1298
Mid-June	1159.6	237.9	595	1515	662.9	228.4	318	1198
Late June	974.1	297.0	358	1540	541.4	266.5	144	1066
Early July	744.1	338.4	157	1312	367.9	285.7	36	972
Mid-July	512.5	342.2	40	1145	233.9	234.4	7	727
Late July	337.6	262.3	26	805	143.3	166.1	3	500
				KVx396-4-5-2D				
Late April	1276.2	304	726	1902	774.8	254.7	224	1407
Early May	1411.5	378.3	996	2203	967.5	429.4	486	2021
Mid-May	1315.3	322.7	981	2072	821.8	324.1	459	1645
Late May	1359.4	228.5	943	2037	789.1	274.6	414	1500
Early June	1328.8	179.0	848	1669	770.4	251.9	398	1316
Mid-June	1185.4	239.4	621	1513	692.8	230	339	1221
Late June	974.1	298.8	348	1556	553	263.2	134	1073
Early July	740.6	342.1	149	1319	371.3	286.4	37	978
Mid-July	505.2	343.1	38	1152	735.5	237.5	7	772
Late July	327	257.6	25	212	143.7	168.5	3	489

Table 4. Statistics of the grain yield in kg ha^{-1} of Moussa local and Tiligre at different sowing windows from the seasonal analysis over 33 years (1989-2021) at Kamboinsin and Kouare

Sowing windows	Kamboinsin				Kouare			
	Mean	Standard deviation	Minimum	Maximum	Mean	Standard deviation	Minimum	Maximum
				Moussa local				
Late April	950	372.1	240	1656	729.9	283.4	87	1236
Early May	1289.6	452.5	933	2205	879.9	410.4	407	1841
Mid-May	1145.3	401.5	823	2232	686.2	276.9	365	1398
Late May	1131.7	289.3	835	2211	667.4	226.5	345	1277
Early June	1081.8	191.7	711	1650	618.8	198.8	286	1084
Mid-June	1013.8	2213	578	1500	577.4	203.9	242	1134
Late June	907.7	290.6	410	1422	471.8	235.3	122	1077
Early July	752.5	345.8	187	1387	345.3	252.3	29	924
Mid-July	569.5	328.6	76	1190	234.9	219.1	5	659
Late July	412.7	258.2	40	887	163	173.7	2	501
				Tiligre				
Late April	1267.9	315.8	713	1921	779.7	259.3	225	1425
Early May	1400.4	389.7	912	2184	970.7	433.4	492	2071
Mid-May	1302.4	332.8	973	2076	806.9	328.8	447	1642
Late May	1324.8	250.2	932	2073	774.0	268.5	416	1491
Early June	1273.7	174.7	818	1623	746.9	251.3	367	1292
Mid-June	1161.2	237.8	595	1515	662.7	228.3	308	1197
Late June	973.6	297.4	358	1540	541.2	266.4	144	1060
Early July	742.5	335.9	157	1311	367.5	285.2	36	972
Mid-July	511.7	342.1	39	1144	233.8	234.3	7	727
Late July	337.1	261.9	26	805	143.3	166.4	3	505

Moreover, sowing in early May presented more number of years (12), for which, simulated yield was above 1000 kg ha^{-1}. Late sowings (late June to late July) progressively led to substantial decreases of grain yield (<300 kg ha^{-1}). For the variety KVx396-4-5-2D, at Kamboinsin, a minimum grain yield of 1000 kg ha^{-1} was simulated for early to late May sowing windows, except for one out of the 33 years of simulations (Fig. 4C).

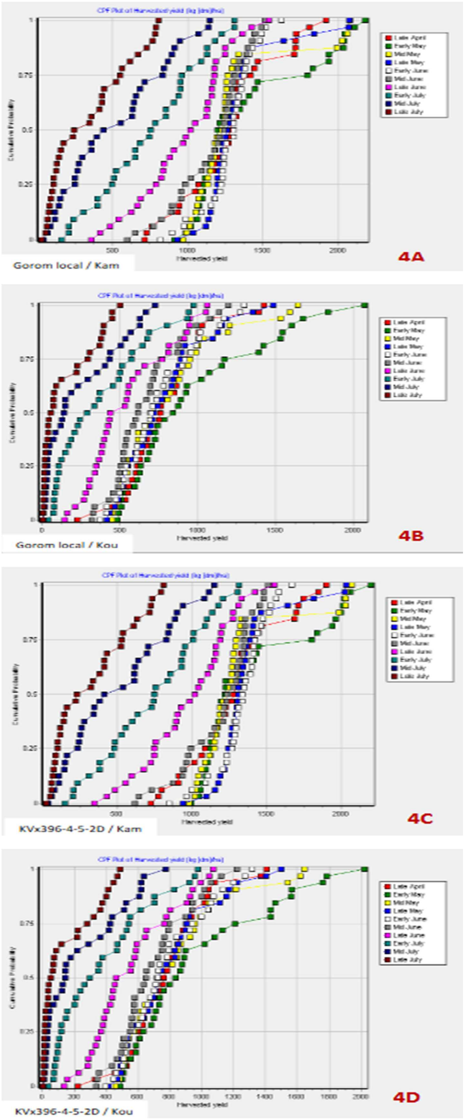

Fig. 4. Cumulative Distribution Function Plots of the cowpea varieties Gorom local (A, B) and KVx396-4-5-2D (C, D) under Different Sowing Windows at Kamboinsin (Kam) and Kouare (Kou)

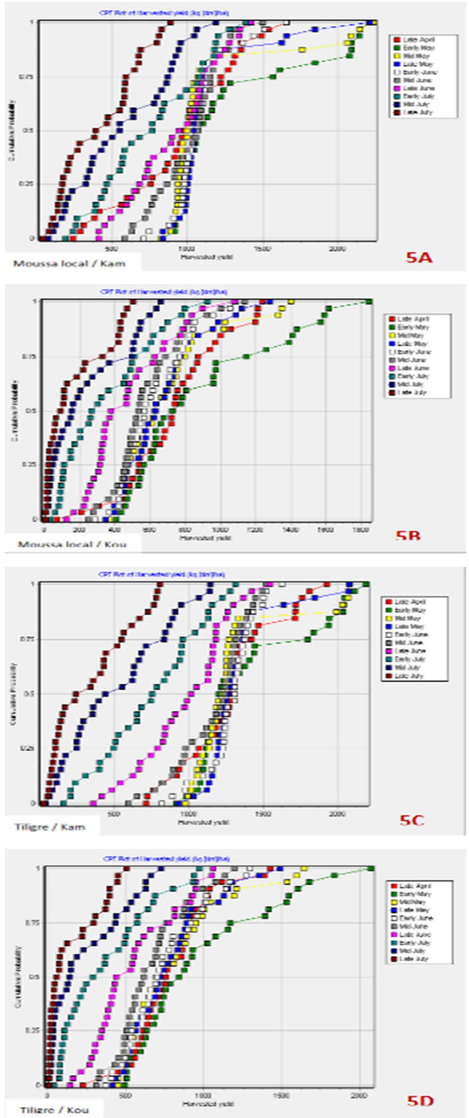

Fig. 5. Cumulative Distribution Function Plots of the cowpea varieties Moussa local (A, B) and Tiligre (C, D) under Different Sowing Windows Kamboinsin (Kam) and Kouare (Kou)

Sowing in early June, late April and mid-June resulted in similar yield, except for 3, 5 and 9 of the years, where yield below 1000 kg ha^{-1} were simulated respectively for the mentioned windows. At 50% probability, yields varying between 1200 to 1350 kg ha^{-1} were attained when sowing was done from late April to mid-June. Yields above 1500 kg ha^{-1} were registered for 9 and 6 out the 33 years of simulations for early May and late April respectively and for 4 years for mid-May and early June sowings. Delaying sowing of KVx396-4-5-2D from mid-June to mid-June resulted to yields below 1300 kg ha^{-1}. Late-June and early July sowings result in simulated grain yield below 750 and 1000 kg ha^{-1} respectively for 50% of the years.

At Kouare, at 50% probability, the highest minimum grain yield was recorded from early sowing window (>830 kg ha^{-1}), followed by sowing in late April and from mid-May to mid-June (Fig. 4D). Similarly to Gorom local, for 50% of the years, late June and early July sowings of KVx396-4-5-2D result in simulated yields lower than 450 and 250 kg ha^{-1} respectively, while those from mid-July to late July leads toyield below 200 kg ha^{-1}.

At Kamboinsin, for Moussa local, at 50% probability, all the sowing windows resulted in yields below 1000 kg ha^{-1}, except for early May and late May sowing periods, for which yield above 1000 kg ha^{-1} were observed (Fig. 5A). Early and mid-May sowings resulted in the greatest number of years (7 and 5) during which, simulated yield was more than 1500 kg ha^{-1}. The simulated mean yield was increasingly reduced when sown from late June to late July, with yield less than 500 kg ha^{-1} for late July sowings. At Kouare, for 50% of the years of simulations, only sowings in late April and early May resulted in minimum grain yield of 750 kg ha^{-1} (Fig. 5B). Yields above 800 kg ha^{-1} were registered from early May and late April sowings at 60% and 65% probability respectively. When Moussa local was sown from mid-May to late May, the yield was slightly above 600 kg ha^{-1}. However, sowings from early June to late July resulted in a progressive decrease of simulated grain yields (585 to 100 kg ha^{-1}).

The cumulative distribution function plots of the 33 years for grain yield of Tiligre at Kamboinsin (Fig. 5C and 5D), show that a minimum yield of 1000 kg ha^{-1} was attained for May sowing windows, except for one of the 33 years, during which yield slightly below 1000 kg ha^{-1} was recorded. These windows were followed by early June, late April and mid-June registered sowings windows. At 50% probability, the grain yield was above 1200 kg ha^{-1} when sowing was done from late April to mid-June. July sowings, constantly and progressively result in important decrease of yields ranging between 750 to 250 kg ha^{-1}. Similarly to the other varieties, early May sowings recorded greater number of years where simulated yield was above 1500 kg ha^{-1} at Kamboinsin. At Kouare, at 50% probability, simulated yields of the variety Tiligre were below 750 kg ha^{-1}, except for sowing in early May, which resulted in at least 800 kg ha^{-1}. Yields ranging from 500 to 125 kg ha^{-1} were observed from late June to late July sowings, either a decrease of 37.5 to 84.4%, comparatively to yields recorded from early May sowings at 50% threshold.

Discussion

These results from the model application showed that irrespective to the variety, the model simulated the period early May to late May as the optimum sowing window for cowpea at both experimental locations as it constantly leads to higher grain yield. This window is therefore the most recommendable to cowpea growers in both locations. The similarity between obtainable yields for late April compared with early to mid-June sowings at Kamboinsin and those from late May to early June at Kouare, shows that there is no need for farmers to precipitate cowpea sowings in late April. No matter how reasonable is the simulated grain yield, late April corresponds to the first rains establishment, and sowing crops during this period is risky, as (Adnan *et al.*, 2017), reported that planting at the onset of rainy season can lead to plants failure as early rains are usually followed by drought spells. Therefore, sowings can be delayed from early May to early June. However, at both locations, the higher guaranteed yield was recorded from early May sowings for all the varieties. Yields were reduced as sowing was delayed within this mentioned period (early May to early June). The results of the cumulative distribution plots, showed that early May presented greater number of years for which yields were exceptionally high. This means that early May should definitely be recommended as the most optimum sowing date for cowpea, followed by mid-May, late May, early June and mid-June, in contrary to late April period. The highest grain yield obtained from May sowing windows could be explained by the fact that at the month of May, soil water content and the relative humidity are low, which is favourable to plants as Thiombiano *et al.* (2023) reported that at early stage of development, less water is required for cowpea plants optimum growth and development leading to higher yields. However, this sowing period can be risky for early maturing cowpea varieties likewise. By sowing in early May, pods maturation may be reached at the period corresponding to the pic of rainfall (mid-July/August). This is in line with (Abdullahi *et al.*, 2020) who suggested that sowing at the onset of rainy season is risky as crop might mature in humid and cloudy weather favourable to cob/grain rot. Thus, when sowing is done in early May (revealed as the best sowing date), adequate measures should be taken to avoid grain rot due to high moisture content during the harvesting period.

Late June to late July sowings windows led to significant reduction of simulated yield. Comparatively to early May sowing, the decrease ranged between 30-75% for Gorom local and KVx396-4-5-2D at both locations and for Tiligre at Kamboinsin and from 20-68% and 22-81% for Moussa local respectively at Kamboinsin and Kouare. These results show that irrespectively to the variety, the more the sowing is delayed; the higher is the cowpea gran yield reduction. This decrease of grain yield could be particularly explained on one hand by an excessive aerial development of plants to the detriment of grain production following the increase of rainfall. On the other hand, the drastic decreases of yields for these sowing windows (late July and above) could also be attributed to an abnormal filling of pods and plants failure before the completion of the cycle due to the lack of water following the decrease of rainfall at the end of production seasons (Adnan *et al.*, 2017; Jibrin *et al.*, 2012).The window late June to late July is definitely not advisable to farmers for sowing cowpea at both agro-ecological zones.

Elsewhere, the lowest simulated grain yields for delayed sowings could be attributed to low solar radiation and soil temperature due to cloudy weather, high rainfall and water logging affecting negatively yields of C4 plants. Alberta (2019) indicated that when sufficient moisture is maintained, decrease in soil temperature leads to decrease in nutrients and water uptake by plants. From the findings of (TNAU, 2016) in maize, very high or very low relative humidity is not conducive for higher grain yield. According to (Oke, 2016), the increase in relative humidity is positively correlated with decline in grain yield.

Grain yield of the cowpea varieties significantly varied among the two locations. This could due to variability in soil characteristics and climatic conditions, especially solar radiation, rainfall and temperature between locations. According to (Lin *et al.*, 2017), crop production is widely influenced by soil physical and chemical properties, climate conditions as well as crop variety. For all the varieties, higher average simulated grain yield was consistently recorded from Kamboinsin, while lower yield was registered at Kouare. Kamboinsin is therefore, the most advisable site for cowpea production compared to Kouare. The choice of the location plays an important role in cowpea production.

Conclusion

The model application resulted in important variability of the grain yield depending on the sowing period and the experimental location. Long-term simulations (33 years) showed that the optimum sowing window is from early May to late May at both locations for all the varieties (Gorom local, Moussa local, KVx396-4-5-2D and Tiligre), and the highest yield was consistently registered when sowing was done in early May. Late April sowings give reasonable yields comparable to yields resulting from early to mid-June sowings at Kamboinsin and that from late May to early June at Kouare. Late sowings of cowpea varieties (late June to late July) at both locations leads to progressive and drastic reduction of grain yield and is to be avoided as sowing period in cowpea production. The most recommendable sowing period of cowpea is early May, followed by mid-May to mid-June. Kamboinsin is the most adapted agro-ecological zone for cowpea production than Kouare.

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