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Projecting potential impact of COVID-19 on major cereal crops in Senegal and Burkina Faso using crop simulation models

P.K. Jha, A. Araya, Z.P. Stewart, A. Faye, H. Traore, B.J. Middendorf, P.V. Prasad

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ABSTRACT

Context: The rapid emergence of COVID-19 could have direct and indirect impacts on food production systems and livelihoods of farmers. From the farming perspective, disruption of critical input availability, supply chains and labor, influence crop management. Disruptions to food systems can affect (a) planting area; and (b) crop yields.

Objectives: To quantify the impacts of COVID-19 on major cereal crop’s production and their cascading impact on national economy and related policies.

Methods: We used the calibrated crop simulation model (DSSAT suite) to project the impact of potential changes in planting area and grain yield of four major cereal crops (i.e., rice, maize, sorghum, and millet) in Senegal and Burkina Faso in terms of yield, total production, crop value and contribution to agricultural gross domestic product (GDP). Appropriate data (i.e., weather, soil, crop, and management practices) for the specific agro-ecological zones were used as an input in the model.

Results and conclusions: The simulated yields for 2020 were then used to estimate crop production at country scale for the matrix of different scenarios of planting area and yield change (−15, −10, −5, 0, +5, +10%). Depending on the scenario, changes in total production of four cereals combined at country levels varied from 1.47 M tons to 2.47 M tons in Senegal and 4.51 M tons to 7.52 M tons in Burkina Faso. The economic value of all four cereals under different scenarios ranged from $771 Million (M) to $1292 M in Senegal and from $1251 M to $2098 M in Burkina Faso. These estimated total crop values under different scenarios were compared with total agricultural GDP of the country (in 2019 terms which was $3995 M in Senegal and $3957 M in Burkina Faso) to assess the economic impact of the pandemic on major cereal grain production. Based on the scenarios, the impact on total agricultural GDP can change −7% to +6% in Senegal and −8% to +9% in Burkina Faso.

Significance: Results obtained from this modeling exercise will be valuable to policymakers and end-to-end value chain practitioners to prepare and develop appropriate policies to cope or manage the impact of COVID-19 on food systems.

1. Introduction

The coronavirus disease 2019 (COVID-19) has proven to be both highly infectious and highly virulent making this pandemic much more disruptive than those of the past (Shereen et al., 2020). The rapid emergence of COVID-19 has indirectly strained global food systems and the livelihoods of farmers globally due to disruption of chains from farm to plate (Siche, 2020). While there has been tremendous progress in tracking COVID-19 incidence and mortality rates, little quantification has occurred on the potential adverse effects COVID-19 or the mitigation methods, may have on food production systems. Such efforts are critical to guide decision-making that effectively mitigates both, the adverse direct impacts of COVID-19 and the indirect impacts of mitigation efforts. Necessary practices designed to slow the spread of COVID-19 have significant impacts on agriculture with cascading short- and long-term implications. These impacts can be assessed by estimating risks and...
systemic shift to determine the resilience of food systems.

The immediate impacts which determine the resilience of the food system can be analyzed through the lens of food security (Torero, 2020), food production and supply chains for inputs and outputs (Stephens et al., 2020). Food system resilience not only accounts for all elements (e.g., inputs, processes, people, and institutions) but also considers the dynamic cohesion and inter-dependent nature of these elements, including feedbacks (Ericksen, 2008). Health of farmers, disruption of shipping and transportation due to border closure and restrictive mobility, inaccessibility of loans to the smallholder farmers due to closure of financial institutions, fragmented labor availability and closure of markets are some of the key factors, which have potential ripple effects on the entire food system (Béné, 2020). Developing countries and smallholder farmers may face an even greater challenge as they are often much less resilient to shocks and there are often fewer supporting mechanisms to reduce the impact of such volatility (Tittonell, 2014).

Disruption of supply chains and availability of labor among other critical inputs influences crop management in many Western African countries which is already reeling under threat of price volatility, outbreak of pests and diseases (e.g., fall army worm, locusts, wheat rust and cassava mosaic virus), and occurrence of abiotic stresses (e.g., prolonged drought and high temperature stress). To cushion the shock of the pandemic on vulnerable segments, African governments have implemented several collective relief measures to strengthen the resilience of food systems (World Bank, 2020). The return or influx of migrant labor from cities due to job losses to their own villages and unavailability of off-farm jobs in rural areas may lead to increase in farm activities including planting area, particularly if they have access to land and inputs. The COVID-19 has significantly affected the labor market in sub-Saharan Africa, including in Senegal and Burkina Faso (Balde et al., 2020). At the farm scale, disruptions can affect planting area, and crop yields and these impacts are less meaningful at the scale of national economy. However, the accumulated and cascading impact at the country scale would be more meaningful, when it comes to the socioeconomic empowerment of the farmers, a key element of the food system. Food system resilience at shorter spatiotemporal scale (e.g., farm productivity) and at larger spatiotemporal scale (e.g., agricultural gross domestic product-GDP), are both interconnected and vulnerable to strain and shocks imposed by COVID-19. It is difficult to estimate and analyze the exposure, sensitivity, and adaptive capacity of farm, individually at the country scale. Crop simulation models help to extrapolate the farm-scale crop yields from different representative agroecological locations to the country scale.

Crop simulation models have been used to study crops responses under different environments (Heslot et al., 2014; Boote et al., 2018), in identifying the potential impact of climate change (Rosenzweig et al., 2014; Reynolds et al., 2016; Araya et al., 2020a, 2020b), to strategize crop management practices (Folberth et al., 2019; Jha et al., 2018, 2021; Araya et al., 2021a, 2021b, 2021c), and assessing impacts of pests and diseases on agricultural systems (Donatelli et al., 2017; Jha, 2019). Crop models simulate crop growth and development using soil, weather, crop management practices and crop specific parameters (Hoogenboom et al., 2017). Moreover, the information from the field scale can be extrapolated to a large spatiotemporal scale and hence reduces time and resource constraints in analyzing the impacts of short- and long-term abiotic and biotic shocks (Corbeels et al., 2018; Sinclair et al., 2020). The immediate impacts of supply chain disruptions on the planting area and crop yield can be studied using well calibrated crop simulation model (Béné, 2020; Deveroux et al., 2020).

In this study, we have projected how potential disruptions to the input supply chain may impact national crop production and agricultural GDP of Senegal and Burkina Faso, by generating scenario matrices of change in planting area and crop yields. With a high incidence of extreme poverty, Western Africa frequently faces food deficits due to low crop productivity constrained by low fertility and erratic climatic shocks and survives largely on global food relief measures during crises. The agriculture sector is a key economic driver in Senegal and Burkina Faso employing ~75% and ~80% of working population, respectively. The agriculture sector also contributes ~17% and ~25% of the respective country’s GDP (World Bank, 2020). With an objective to project the potential impact of COVID-19 related disruptions, scenario analyses have been conducted to project how changes to farmer’s ability to plant and secure inputs and their application may impact overall crop productivity and national agricultural GDP. These scenario analyses have been conducted for Senegal and Burkina Faso with reported confirmed cases and deaths of 26,927/638 and 10,682/120 respectively as of February 01, 2021 (https://coronavirus.jhu.edu/map.html). These confirmed cases were 0.6% of the total people employed in agriculture for Senegal (29% of country’s population) and 0.2% of the total people employed in agriculture for Burkina Faso (25% of country’s population) (World Bank, 2020).

The objectives of this study are: (i) to project the impacts of changes in land area and yield due to lack of availability of labor and disruption of input supply chain on key major cereals crops using a crop simulation model, (ii) to quantify the value of the crop under different scenarios of planting area and yield change, and (iii) to analyze the changes in proportion of GDP (i.e., share of selected cereal crops to total agricultural GDP) contributions under different scenarios. The goal of this study is to provide scientific evidence to policymakers and end-to-end value chain practitioners which may help in reducing the overall adverse impacts of COVID-19 and the related mitigation strategies on smallholder farmer production systems.

2. Material and methods

2.1. Study sites

The study was conducted in Senegal and Burkina Faso. The point simulations were performed at three different locations which represent different agroecological zones- northern arid and semi-arid, central sub humid, and southern humid in Senegal- based on low to high rainfall distributions respectively (Sow et al., 2016; Fig. 1a, 2a). The major farming system in the northern arid region is agropastoral livestock production with groundnut (Arachis hypogaea L.) and pearl millet (Pennisetum glaucum L.) as the major crops; in the central sub humid region cotton (Gossypium hirsutum L.), pearl millet (Pennisetum glaucum L. (R.) Br.), sorghum (Sorghum bicolor L. Moench) and maize (Zea mays L.); and in the southern humid region rice (Oryza sativa L.), pearl millet and maize. Across the country the major cereals crops grown are pearl millet, rice, maize, and sorghum (Leippert et al., 2020). Therefore, these four major cereal crops were chosen for the impact assessment. The locations were Yang Yang (northern arid; 15.66° N latitude, 15.42° W longitude, and elevation of 40 m above mean sea level), Tambacounda (central sub humid; 13.77° N latitude, 13.67° W longitude, and elevation of 24 m above mean sea level) and Guiragor (southern humid; 13.01° N latitude, 16.07° W longitude, and elevation of 17 m above mean sea level) (Fig. 1a).

Similarly, in Burkina Faso, the point simulations were performed at four different locations which represent different agroecological zones- Northern Sahel, Southern Sahel, North Sudan, and South Sudan - based on rainfall distributions and vegetation pattern (Fontes and Guinko, 1995; Fig. 1b, 2b). The predominant rainfed farming system in the Northern Sahel consists of pearl millet and sorghum; in Southern Sahel pearl millet, groundnut, and sorghum; in North Sudan maize, pearl millet, sorghum, and rice; and in South Sudan maize, rice, and cotton (Stoofers, 2016). Sorghum, pearl millet, maize and rice are the major staple crops, which are grown on ~80% of the country’s arable land. Therefore, these four major cereal crops were chosen for the impact assessment. The locations were Dori (North Sahel; 14.03° N latitude, 0.09° W longitude, and elevation of 289 m above mean sea level), Sanmatenga (South Sahel; 13.40° N latitude, 1.15° W longitude, and...
The elevation of 317 m above mean sea level, Komki (North Sudan; 12.10° N latitude, 1.74° W longitude, and elevation of 316 m above mean sea level) and Peni (South Sudan; 10.93° N latitude, 4.22° W longitude, and elevation of 340 m above mean sea level) (Fig. 1b).

2.2. Data sources

2.2.1. Actual area and yields

Large-scale studies on crop yield variability requires long-term regional or national data to validate any simulation studies (Grassini et al., 2015; Van Wart et al., 2015). Aggregated country level data on actual harvested area, production, and yield for major cereal crops (i.e., rice, maize, sorghum, and pearl millet) were retrieved from the FAO-STAT database (FAO, 2020) (Tables S1, S2). This is a global database of annual crops and livestock production, consumption of input and market values of produce, environmental and food security indicators, and associated economy and trade. In this study, data on area, production, and yield of major crops for thirty years (1989–2018) in Senegal and Burkina Faso was retrieved, to compare actual yields with the simulated yields. It was assumed that aggregated country scale yield data is likely to underestimate actual field scale variability in yield. The national average yields were compared with the average simulated yield at the representative locations of different agroecological zones in the country. The yields at point simulation were averaged as national average simulated yields, which were later multiplied with total observed area under the respective crop to get total simulated production.

2.2.2. Weather data

For simulation studies, availability of weather data for each location is scarce, especially for sub-Saharan Africa. The gridded weather databases, derived from interpolated data from weather stations, remotely sensed data from satellites, and global circulation models, meet the regional scale crop simulation’s requirement. The weather data for this study were obtained from the Prediction of Worldwide Energy Resource (POWER) Project of National Aeronautics and Space Administration’s (NASA), produced by the NASA Langley Research Center. NASA-POWER provides data on a global grid with a spatial resolution of 0.5° latitude by 0.5° longitude (https://power.larc.nasa.gov/data-access-viewer/).

The gridded daily weather data from NASA-POWER are derived from remotely sensed satellite observations coupled with the land surface model, which is supported by data from ground stations and satellites. These reanalyzed gridded weather datasets have been used for yield simulations at regional scale (Bai et al., 2010; Lobell et al., 2010; Aboelkhair et al., 2019; Parkes et al., 2019). Thirty-year (1989–2018) weather parameters such as daily solar radiation, maximum and minimum temperature, and rainfall at each of the locations in Senegal and

Fig. 1. Study sites and market locations in (a) Senegal and (b) Burkina Faso.

Fig. 2. Average annual precipitation (mm) for 1950–2000 in (a) Senegal and (b) Burkina Faso (Source: WorldClim 2; Fick and Hijmans, 2017).
Burkina Faso (Fig. 2a, b), were downloaded from NASA-POWER. The long-term rainfall trend remains same which supports vegetation distribution in both countries till date (Ilboudo et al., 2020). The weather data were ingested to the Decision Support System for Agro-technology Transfer (DSSAT v4.7; Hoogenboom et al., 2017) crop model using WeatherMan, which converts raw data to DSSAT weather format (Pickering et al., 1994). For 2020, average daily weather data for 30 years (1990–2019) were considered as hypothetical normal weather data at all the locations for the simulation purpose.

2.2.3. Soil data

In this study, we used 10-km resolution gridded global soil profile datasets (Han et al., 2019), which are synthesized using SoilGrids1km datasets (Hengl et al., 2014) and HarvestChoice soil profile: HC27; (Koo et al., 2019). The soil fertility factor (SLPF) value was adjusted (Pickering et al., 1994). For 2020, average daily weather data for 30 years (1990–2019) were considered as hypothetical normal weather data at all the locations for the simulation purpose.

2.2.4. Crop and management information

Most of Senegal and Burkina Faso lies in the arid and semi-arid tropics with variable spatiotemporal rainfall distribution and low soil fertility, which leads to poor agricultural productivity in these low input rainfed systems. Management practices such as planting dates, plant population density, fertilizer timing and application for each crop were retrieved from reported literature in Senegal (Khairwal et al., 2007; Ekeleme et al., 2008; Sommer et al., 2013; Okuyama et al., 2017) and Burkina Faso (Barro et al., 2017; Ouedraogo et al., 2018; Serme et al., 2018; Theriault et al., 2018). To simulate yields of the four major cereal crops (rice, maize, sorghum, and pearl millet) under rainfed conditions, the planting date was considered as 15 June, which is an average date for the onset of the rainy season in Senegal (Sane et al., 2018) and Burkina Faso (de Longueville et al., 2016). For uniformity, the fertilizer application rate (NPK-68:22:37 kg ha$^{-1}$) with split dose of nitrogen at sowing and 40 Days After Sowing (DAS), phosphorus and potassium at sowing, was kept constant for all crops for both countries (Tabo et al., 2007). The row spacing was kept constant for maize (MacCarthy et al., 2015); sorghum (Hayford, 2018); and pearl millet (Mason et al., 2015) at 75 cm and for rice at 30 cm (Tabot, 2015), for all locations in both countries. The sowing rates were kept constant at 25 kg ha$^{-1}$, 10 kg ha$^{-1}$, 5 kg ha$^{-1}$, and 80 kg ha$^{-1}$ respectively for maize (Olayoye et al., 2009), sorghum (Kpong, 2007), pearl millet (Ajiegbu et al., 2019) and rice (Sall et al., 1998) for all locations in both countries.

2.2.5. Food prices and agricultural GDP

The local retail prices for the crops were retrieved from the database of global food prices under the auspices of the World Food Program (WFP, 2020). It covers major crops for 76 countries and more than 1500 local markets, which are updated every week. The retail prices at the local market were retrieved on June 15, 2020. In this study, retail prices at 60 (Senegal) and 18 (Burkina Faso) local market locations were retrieved from the WFP database and converted from XOF (West African CFA) currency to USD per ton. The market locations are shown in Fig. 1 and are listed with crop retail prices in Supplementary Tables S3 and S4 respectively for Senegal and Burkina Faso. Total gross domestic product (GDP) in 2019 was $23.58 Billion (B) for Senegal and $15.75 B for Burkina Faso, of which $3995 M and $3957 M comes from agricultural and allied sectors respectively for Senegal (2020) and Burkina Faso, (2020). The average market price of all local markets was used as a national average crop price.

2.3. Model calibration and evaluation

Crop simulation models have been used to study growth and development of crops under different environments (Araya et al., 2017; Jha et al., 2018, 2021). The crop model used for this study was DSSAT version 4.7, which simulates crop growth and development based on the interaction among genotype, environment, and management practices (Elias et al., 2016; Hoogenboom et al., 2017) using daily weather data and soil inputs. Crop genetic coefficients are the parameters which determine cultivar growth and development under different environment. The cultivars which were already calibrated and evaluated for Western African regions were selected for this study. The cultivar coefficients for rice (Modified IR 64) (de Vries et al., 2012), maize (Msongo) (Worou et al., 2018), sorghum (CSM-335) (Singh et al., 2014), and pearl millet (CIVT) (Singh et al., 2017) were used for simulation (Supplementary Tables S5-S8). The observed yield for 2018 (FAO, 2020) was considered as the target to evaluate the model. The models were calibrated by adjusting SLPF in the soil input file to improve model performance. For calibration, best available conditions (Southern Humid locations) were preferred for both countries (Lobell et al., 2009). The model was first calibrated for 2018 using weather data for 2018 and observed yield from FAO as the target yield and then evaluated for long-term observed yield data from FAO.

The calibrated model was used to simulate long-term crop yield (1989–2018) for all locations in Senegal and Burkina Faso. Soil characteristics, crop genotype and management practices at the individual locations were used. Crop yields were simulated using different daily weather data corresponding to the specific year. The national simulated average annual yield (1989–2018) under two different scenarios; with and without fertilizer application, were compared with the national observed yield from FAO (FAO, 2020) (Figs. 4 and 5). After model evaluation for 1989–2018, the yields were simulated for 2020 at different locations and converted to the national average yields. The country level simulated production was estimated through a simple approach of multiplying different scenarios of national average simulated yields with the different scenarios of change in cultivated area from a reference value. The reference value of cultivated area of different crops were retrieved from the latest total cultivated area of the crops in 2018 for both countries (FAO, 2020) and the reference value for yield was a national average 2020 simulated yield.

2.4. Scenarios of change in area and yield due to COVID-19

There is widespread unconfirmed speculation about the potential impact of the COVID-19 on input availability due to the disruption of supply chains in Africa (Ehi, 2020). However, there has not been any scientific evidence that quantifies how such disruptions in the supply chain may impact crop production and agricultural GDP. Disruptions of input supply chains (e.g., seeds, fertilizers and nutrients, pesticides, availability of credit) can influence farm operations and crop management decisions that can decrease crop yields. In addition, the movement of migrant labor from cities to villages and unavailability of off-farm jobs in rural areas led to reduced earnings in Senegal and Burkina Faso (Balde et al., 2020). Several may engage in farming, especially those who can or have access to land. Consequently, it could lead to an increase in the overall crop planting area. Due to lack of scientific evidence, it is difficult to quantify how much these disruptions in the supply chain and return of people to villages may impact crop production and overall agricultural GDP. Based on these assumptions, six different types of hypothetical scenarios of percentage change in the planting area and crop yield were designed and classified as −15, −10, −5, 0, +5, +10% leading to 36 scenario matrices. The simulation production and value of all four crops, and their combined estimated crop values were compared with total agricultural GDP of the country under different scenarios.
2.5. Assumptions and limitations

The simulations were performed under rainfed conditions assuming there were no surface water storage and soil saturation. The soil characteristics were kept static as in SoilGrids1km datasets and there were no biotic and abiotic constraint to the simulated yield, though these conditions are prevalent in African conditions (Stewart et al., 2020; Saito et al., 2019; Ouedraogo and Ayantunde, 2019). Following the model validation for 2020, long-term simulations were performed using the same cultivars irrespective of decadal change of varietal improvement (Walker et al., 2015) and the same fertilizer rates irrespective of change in recommendation (Rware et al., 2014).

2.6. Evaluation and statistical analysis

We compared predicted and observed yield and used the coefficient of determination ($R^2$, Eq. 1), and Root Mean Square Error (RMSE; Eq. 2) (Willmott, 1982) to measure the performances of the calibrated model.

$$R^2 = \frac{\sum_{i=0}^{n}(O - \bar{O})(S - \bar{S})^2}{\sum_{i=0}^{n}(O - \bar{O})^2\sum_{i=0}^{n}(S - \bar{S})^2}$$  

(1)

$$\text{Root Mean Square Error} = \sqrt{\frac{\sum_{i=0}^{n}(S - O)^2}{n}}$$  

(2)

where S and O are simulated and observed yields, respectively; $\bar{S}$ and $\bar{O}$ are mean simulated and observed yields respectively; i is variable; n is number of variables; and $\Sigma$ is symbol used for summation of all variables.

3. Results and discussion

3.1. Model calibration and validation

Initially, the Crop Environment REsource Synthesis (CERES) sub model in DSSAT was calibrated for all the grain cereals in both countries. The model was calibrated for 2018 at Southern humid locations, considering best optimal conditions among all other locations (Fig. 3a). The calibrated model was used to evaluate for the years 1989–2018 and to simulate yield for 2020 at all other locations. For Senegal, yields of all crops were found to be lowest in the northern arid locations as they have the least annual rainfall availability (Figs. 2a and 3a), followed by the central sub humid location and yields were the highest in the southern humid location. Likewise, the same yield gradient was found in the simulation for Burkina Faso, where the Northern Sahel location had the lowest yields, followed by Southern Sahel, Northern Sudan, and Southern Sudan having the highest yields (Fig. 3b). The yield gradient follows the annual rainfall availability pattern across the locations in Senegal (Djaman et al., 2017) and Burkina Faso (Zampiligré et al., 2014) (Fig. 2a, b).

In Senegal maize and rice, simulated yield could not capture the long-term observed yield pattern (Fig. 4a and b). Database of the observed yield from FAO (FAO, 2020) showed that there was 1.6 times increase in cultivated area for maize from 108,114 ha in 2002 to 175,575 ha in 2003 and declined to 130,461 ha in 2006 (Fig. 4b), which correlates with the yield variation during this period as reported by Shi and Tao (2014). Similarly, for rice, the cultivated area increment was reported from 80,312 ha in 2007 to 125,329 ha in 2008. This 1.6 times increase in rice yield after 2008 (Fig. 4a) is speculated to be attributed to improved management practices and varietal improvements as government policies for rice production changed after 2003 with collective efforts on soil fertility and weed management along with timely harvest (Tollens et al., 2013). Crop yield variability can be attributed either to the expansion of cropland area and/or to the improved cultivar and optimized management practices and were reported by Okuyama et al. (2017), with reference to technical efficiency of production potential of cereal crops in Senegal. The variability in rice yield is far more affected by environmental variables (e.g., rainfall) than the other crops, such as upland rice, whereas lowland rice in humid conditions is relatively less variable (Okuyama et al., 2017). However, simulated yields of sorghum and millet were consistent with the long-term yield pattern. The simulated yield pattern for sorghum could capture long-term yield trends with RMSE of 176 and 271 kg ha$^{-1}$ for fertilized and no fertilized scenarios, respectively (Fig. 4c). Similarly, in the case of pearl millet, a RMSE of 183 and 288 kg ha$^{-1}$ for fertilized and no-fertilized scenarios captured long-term yield trends (Fig. 4d), respectively.

In Burkina Faso, yield simulations for all crops were consistent with the national observed yield (Fig. 5a-d). However, there were interannual variability in the yields of maize and rice, which can be attributed to change in cultivated area, and/or optimized and improved management practices in Burkina Faso (Waongo, 2015) rather than varietal yield improvement (Henao and Baanante, 2006). This stagnation in yield pattern has been exacerbated by depletion of soil nutrients and erratic rainfall patterns (Stewart et al., 2020; Zougmoré, 2018).

3.2. Simulated production

For Senegal, total production varied from 0.55 M tons to 0.92 M tons for rice, 0.23 M tons to 0.39 tons for maize, 0.13 M tons to 0.22 M tons for sorghum, and 0.56 M tons to 0.94 M tons for millet (Fig. 6a-d), depending on the matrix of worst possible scenarios (−15% change in area and yield) to best possible scenario (−10% change in area and yield). Depending on the scenario, the changes in total production of four cereals combined at country level varied from 1.47 M tons to 2.47 M tons.

For Burkina Faso, total production varied from 0.32 M tons to 0.53 M tons for rice, 1.50 M tons to 2.48 tons for maize, 1.68 tons to 2.81 M tons.

![Fig. 3. Simulated yield of major cereal crops in (a) Senegal and (b) Burkina Faso for 2020.](image-url)
for sorghum, and 1.01 M tons to 1.70 M tons for pearl millet (Fig. 7 a-d), depending on the matrix of worst possible scenario (i.e., −15% change in area and yield) to best possible scenario (i.e., +10% change in area and yield). Depending on the scenario, the changes in total production of four cereals combined at country level varied from 4.51 M tons to 7.52 M tons. For both the countries (Senegal and Burkina Faso), at every 5% change in area and yield together, the production level declined by approximately 4–5% for all crops.

3.3. Estimation of crop values

The retail prices of each of the crop at local markets (XOF per kg) were converted into global prices ($ per ton). Retail price of crops at 60 and 18 local markets respectively in Senegal and Burkina Faso representing all agroecological zones was determined (Fig. 1 and Supplementary Tables S7 and S8). The average of all local markets was considered as the national average price. For Senegal, total crop value varied from $407 M to $682 M for rice, $85 M to $143 M for maize, $56
M to $94 M for sorghum, and $223 M to $373 M for millet (Fig. 8 a-d), depending on the matrix of worst possible scenario (i.e., −15% change in area and yield) to best possible scenario (i.e., +10% change in area and yield). Depending on the scenario, the changes in total value of four cereals combined at country level varied from $771 M to $1292 M in Senegal.

For Burkina Faso, total crop value varied from $188 M to $319 M for rice, $371 M to $622 M for maize, $369 M to $617 M for sorghum, and $323 M to $540 M for millet (Fig. 9 a-d), depending on the matrix of worst possible scenario (i.e., −15% change in area and yield) to best possible scenario (i.e., +10% change in area and yield). Depending on the scenario, the changes in total value of the four cereals combined at country level varied from $1251 M to $2098 M.
3.4. Crop cumulative share to country’s agricultural GDP

The economies of Senegal and Burkina Faso are largely based on agriculture with 17% and 25% share of agriculture to total GDP respectively (World Bank, 2020). This sector is also the most vulnerable to abiotic and biotic stresses during the cropping season. The current pandemic has witnessed severe disruption of supply chains due to closure of international borders and domestic social distancing. According to IMF forecasts, the pandemic will have severe impact on GDP in 2020. GDP growth in 2020 is expected to slow down to 1.1% as compared to 6.3% in 2019 for Senegal and 2% as compared to 5.7% in 2019 for Burkina Faso (IMF (International Monetary Fund), 2020, Fig. 8. Estimate value of major cereal crops (a) rice, (b) maize, (c) sorghum, and (d) pearl millet for 2020 in Senegal.

Fig. 9. Estimate value of major cereal crops (a) rice, (b) maize, (c) sorghum, and (d) pearl millet for 2020 in Burkina Faso.
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The total GDP contribution from agriculture were compared with the combined estimated value of all cereal crops to analyze the potential impact of these crops on the economy. These estimated total crop values, under different scenarios, were compared with the total agricultural GDP of the country (in 2019 terms which was $3995 M in Senegal and $3957 M in Burkina Faso; World Bank, 2020) to assess the economic impact of the pandemic due to changes in major cereal grain production (Figs. 10 and 11).

For Senegal, the total contribution of these four crops is estimated to contribute 26% to the total agricultural GDP in the scenario of no change in area and yield. As planting area or yield changed in the scenario matrix, the estimated contribution of the four crops varied from 19% to 32% in terms of the contribution to total agricultural GDP (Fig. 10). For Burkina Faso, the contribution of total estimated values for these four crops contributes 44% to the total agricultural GDP in the scenario of no change in area and yield. As planting area or yield changed in the scenario matrix, the estimated contribution of the four crops varied from 32% to 53% in terms of contribution to total agricultural GDP (Fig. 11). Based on the scenarios, the impact on total agricultural GDP can change –7% to +6% in Senegal and –8% to +9% in Burkina Faso as dependent on the impact of COVID-19 on changes in planting area and yield (Figs. 10 and 11).

Overall, the economies of Senegal and Burkina Faso have been struggling due to decrease importation of Chinese goods, plummeting crude oil prices, alienating investors, and shifting of budgets from other sectors to health sectors due to COVID-19 (World Bank, 2020). All these factors had pressurized the government to formulate adaptive and mitigative measures during post COVID crisis and deescalate the long-term ongoing process under Sustainable Development Goals (SDG). These countries will have to alter their development agendas and change the discourse of development around COVID-19. The possible negative impact on major cereal crops may not only influence economic growth but it could also influence funding allocation to agricultural development and government’s subsidy program to farmers, thus significantly impacting farmer’s resilience in the near- or medium-term future. At the end of the cropping season, the net impact on cereal crop production, if it remains neutral or positive, would open a debate on resilience of farm sizes. Smallholder farms, that are primarily family owned are more resilient than the large farms which depend on hiring laborers (Stephens et al., 2020). Whereas smallholder farms are more vulnerable to lack of inputs and lack of availability of credit to purchase or transport products to structured markets. Some of the smallholder farmers may not be resilient if they do not get support from the government either in terms of protection programs to get credit from banks or subsidies for inputs (particularly seeds and fertilizers).

Using participatory approaches to understand the needs of farmers, researchers and other stakeholders and setting research and development priorities, portfolio and design is essential for impact (Middendorf et al., 2020). Our recent survey of large set of smallholder farmers (n = 872) in 14 different regions of Senegal showed that majority of the

Fig. 10. Estimated total crop values and their share of agricultural gross domestic product (GDP) under different scenarios for 2020 in Senegal. The green color in the center represents share (in %) of four cereal crops to total agricultural GDP. Colors on the donut represent estimated crop values (in million USD). The representation of colors are light blue is for the value of rice, orange is for maize, grey is for sorghum, and yellow is for millet.
respondents (82.5%) expressed concern that COVID-19 would make it difficult to get enough food on a regular basis for their households (Middendorf et al., 2021). The key questions which need extensive investigation are, how the farming efficiency due to technology could improve farm resiliency during the pandemic and how inequality among farms to access those tools, has affected agricultural productivity at different spatial scale from farm to country? This study of projection of impact on cereal crops would also help in reimagining the role of agricultural policy in strengthening the resilience and overall functioning of smallholder farming system at local scale and global food-trade per se.

4. Conclusions

As of now, with increasing mortality, COVID-19 is spreading globally and affecting a large part of the vulnerable populations in Western Africa directly and indirectly due to weak healthcare system and poor socioeconomic conditions. The necessary, swift mitigating measures imposed by governments exacerbate the supply chain disruptions for the food systems. These disruptions in the supply chain could have direct and indirect impacts on food production systems and livelihoods of farmers through change in planting area and/or crop productivity. Major cereal production in Senegal and Burkina Faso has an important contribution in these countries’ agricultural GDP and could impact their economies. In this study, using a crop simulation model, we have projected potential impacts of COVID-19 on major cereal crops through different scenarios. Scenario analyses of planting area changes and yield show significant changes in production, value, and subsequent contribution to GDP. Based on the scenarios, the impact on total agricultural GDP can change −7% to +6% in Senegal and −8% to +9% in Burkina Faso. The magnitude of the change in total agricultural GDP can be extrapolated in term of resiliency and resource mobilization in the food system. The more impact on the economy could be interpreted as farming being less resilient system and vice versa. The results obtained from this modeling exercise will be valuable to policymakers and end-to-end value chain practitioners to prepare and develop appropriate policies to cope or manage the impact of COVID-19 on food systems.

Declaration of Competing Interest

The authors declare that they have no competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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